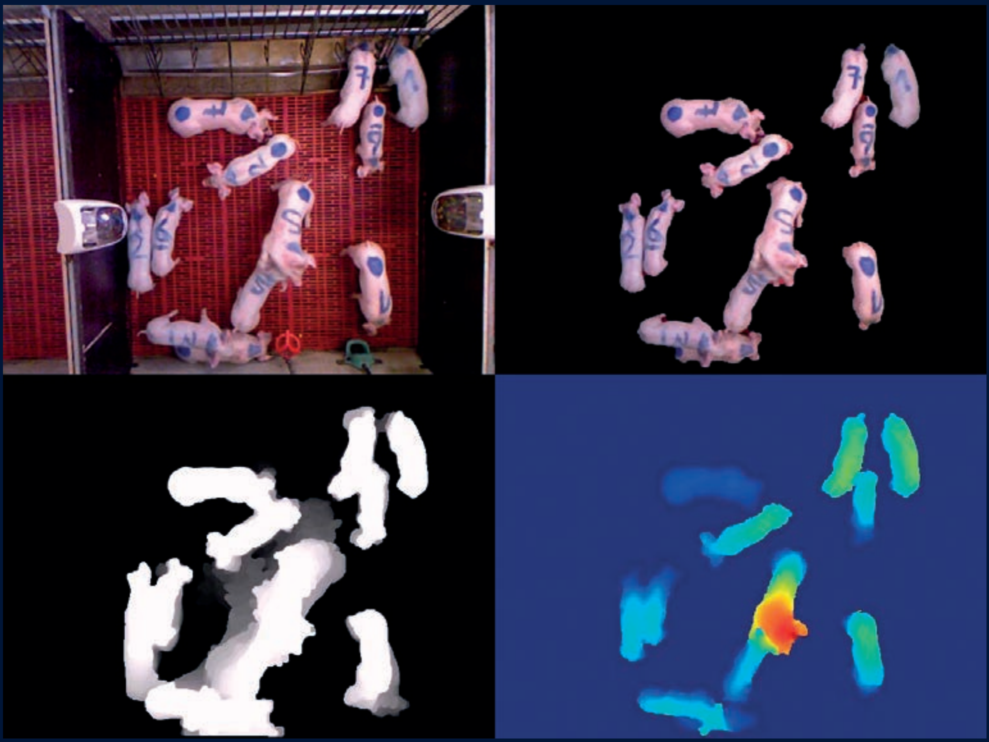

# Precision Livestock Farming '13

Edited by D. Berckmans and J. Vandermeulen

PRECISION LIVESTOCK FARMING ‘13

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Edited by D. Berckmans
and J. Vandermeulen

Papers presented at the 6th European Conference on Precision Livestock Farming

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10-12 September ‘13

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## Table of contents

## Editorial

This 6th European Conference on Precision Livestock Farming, ECPLF 2013, is the first independent conference which is not combined with other fields of science, as was the case until 2011. However it is still a joint conference as it combines the ECPLF conference with the final conference and workshops of several ongoing EU projects: the BioBusiness project, the ALL-Smart-Pigs project and the EU-PLF project.

The decision to hold a specific PLF conference seems to be a good one: the number of participants has more than doubled compared to the previous conferences, more papers than ever have been submitted from more countries, and people from more disciplines are participating.

We all know that worldwide livestock production is facing serious problems: animal health must be safeguarded in order to preserve human health and guarantee safe food products, animal welfare must be improved while the number of animals per farmer is increasing, environmental impact must be significantly reduced and, finally, production must be economically viable otherwise livestock production will move to regions of the world where these objectives and regulations are not applied. The last five ECPLF conferences have generated more than 650 papers discussing the results of research into monitoring of several variables on cows, pigs, chickens and sheep for indoor and outdoor applications. Many solutions have been reported, based on sensors, contactless sensing with image analysis or sound analysis, wireless data transmission, traceability techniques, etc. We have created the expectation that PLF can support and improve techniques to make smart farming a reality and create added value for many stakeholders: animals, farmers, veterinarians, feed and product suppliers, health services, policy makers, the media and of course the consumer.

All this research is good and necessary but we have now reached a point where we must achieve and demonstrate developments which create real added value in the field through the use of PLF technology. The most important stakeholder in terms of guaranteeing healthy livestock production is the farmer, who is closest to the animal and makes his living from working with his animals. Animals need a high quality of life and PLF can support this through real-time monitoring and management. We now need to make the technology work in field conditions. This requires collaboration between a number of scientific disciplines and we are very pleased to see that this is happening. However, we also need strong engagement from the industry, including SMEs, in order to implement innovative technology in the livestock field.

The organisers’ aim for this conference is that it will contribute to the exchange of knowledge and experience through productive discussions and help to further progress in the PLF field where technology meets biology. We have attempted to define homogeneous sessions which will generate high-quality discussion. We wish you a very successful conference.

Daniel Berckmans

# Session 1

# PLF: Basic Principles

## Basic principles of PLF: gold standard, labelling and field data

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### Abstract

PLF systems aim to offer a real time monitoring and managing system for the farmer. This is fundamentally different from all approaches that aim to offer a monitoring tool without improving the life of the animal under consideration. It is nice to detect a problem after an animal has arrived at the slaughterhouse. It is better to detect a problem while the animal is being reared and to take immediate management action. The idea of PLF is to provide a real-time warning when something goes wrong so that immediate action can be taken by the farmer.

This requires real-time algorithms that are able to detect or predict problems while the rearing process is ongoing. To successfully develop such algorithms in an efficient way, some basic principles must be respected. This paper aims to explain the interaction between taking field data, applying a gold standard and using labelling techniques to develop real-time algorithms that allow real time monitoring and management of living organisms.

**Keywords:** principles of PLF, gold standard, labelling

### Objectives

The first objective of this paper is to describe some basic principles which make the development of algorithms for monitoring and managing livestock much more efficient. The use of field data to develop real-time algorithms involves some basic steps that must be properly understood if they are to be successful.

PLF is a multidisciplinary science which requires collaboration between animal scientists, physiologists, veterinarians, ethologists, engineers, ICT experts, etc. The second objective is to achieve some agreement in the terminology used by these different disciplines in order to improve communication between specialists from different disciplines.

## Method

<u>A living organism is a CITD system</u>

Since we are aiming to create an early warning system, it is wise to focus on the first signs that can be monitored in a non-invasive and contactless way in a group of animals. When the animal experiences less than ideal conditions it will exhibit an initial response in terms of behavioural changes and these first signs should be picked up by the PLF sensing technology, such as image and/or sound analysis.

As stated in the first EC PLF conference in 2003 (Berlin), a living organism is a so called "*CITD system*": this stands for Complex, Individually Different, Time-Varying and Dynamic (Berckmans and Aerts, 2006; Quanten *et al*., 2006). It is obvious that a living organism is much *more complex* than any mechanical, electronic or ICT system. The complexity of information transmission in a single cell of a living organism is much higher than most other systems that may be considered. In biological research and the management of biological process (e.g. medical world, livestock world) in industry and society, the general trend is still to compare groups of living organisms by looking for statistical differences in experiments. Statistical methods have been developed primarily to find significant differences between the averages of groups. However, there is not a single living organism that lives or acts as the purely theoretical average of a group since all living organisms are *individually different* in their responses. This raises serious questions about the way a lot of research is carried out on animals and humans. The *time varying* character of a living organism means that a living organism's response to a (environmental) stimulus or stressor might be different each time it happens. A living organism is constantly looking for a good energy balance and as a consequence is continuously changing its physical condition and mental status. Of course living organisms are dynamic systems.

The CITD nature of living organisms has an important impact on the type of algorithms we need to develop. It implies that algorithms to monitor these time-varying individuals must continuously adapt to the individual and/or use principles that can be used in real time in the field application.

*The method of this paper is to explain some basic principles by taking an example. In this case the example is the real-time monitoring of infection in pigs by using real-time sound analysis.*

<u>Field data or bio-signals</u>

The basic methods used in PLF involve continuously measuring responses directly on the animal rather than in the environment surrounding the living organism. Since animal responses can be very fast, it is useless to carry out a survey once a year, once a month or week, or even twice a day. We need a continuous monitoring/management tool. Today the word continuous might mean every second or up to fractions of seconds

as it is possible to achieve this level of detail using affordable technology.
The general approach to collecting real-time field data, known as bio-signals, on the animal is to use sensors (e.g. temperature measurement, GPS position, accelerometer data), real-time image analysis or sound analysis. The last two techniques have some advantages such as: no need for physical contact, no risk of infection or disease transfer, no risk of influencing the animal response while making the measurement, no need to recover sensors from living animals, reduced costs since one camera or microphone can monitor a group of animals.

The *field data* consist of a lot of numbers originating from the sensors (e.g. 240 samples per second for an accelerometer), images (e.g. 25 images per second) or sound signals (e.g. 20,000 samples per second).

The result is a huge amount of data and the transmission of so much data takes time, energy and money. Sending data wirelessly involves energy and costs; we should therefore avoid transmitting too much data and develop real-time algorithms which calculate information from the data at the lowest possible level, enabling us to transmit information rather than data. We therefore need real time algorithms which can calculate relevant information from the data.

<u>Linking field data, target variable, gold standard, feature variable and labelling</u>

*Target Variable*
In each of the processes involved in developing a real-time PLF algorithm we have to take some steps in which we combine different types of variables in order to produce a generic method for developing an algorithm. In the example case, we aim to develop a real-time infection monitoring system for pigs by using real-time sound analysis of the sound produced by the animals. This means that in this example the ***target variable*** is the infection status of the pigs. The target variable directly relates to the final objective of the algorithm. In the example of an infection monitoring system, this means that the variable is a Yes/No status as to whether an animal is infected or not.

*Gold Standard*
The first question is whether we have a reliable ***gold standard*** to quantify the real health status of pigs. Do we have a generally accepted way of measuring the infection status of a pig? A *gold standard* or reference point can be defined as a state-of-the-art scientific measurement or method which enables us to draw a conclusion relating to the final objective of the algorithm or the status of the target variable, in this case the yes/no infection status of a pig. A gold standard of this kind might be an expensive and complex method but the most important point is that this gold standard should be accepted by scientists as the state-of-the-art measurement or method which will quantify the target variable in a reliable way. In the case of infection in pigs, a gold standard might be blood analysis of the pig to quantify whether the animal is infected or not.

In most cases the gold standard is cannot easily be applied to real time measurements and consequently has a much lower sampling frequency than the real-time solution that we are looking for. In the case of blood analysis, it is technically unrealistic to consider continuous blood sampling and blood analysis. This can be done once every hour, for example, which is already an ideal case, for an individually housed pig in a cage (see Figure 1) (Moreaux *et al*., 1999; Van Hirtum *et al*, 1999, 2002, 2003). If the animal is individually housed in a cage the catheter can remain in place. However, this is not possible for pigs housed in a group, such as 15 pigs in a pen, because in that case blood sampling would take a lot of time and induce stress in the animals. Having worked on the development of this approach since 1991 (Aerts J.M., 1991) we can say that, in most cases, establishing an accurate gold standard is one of the most difficult elements of developing PLF algorithms.

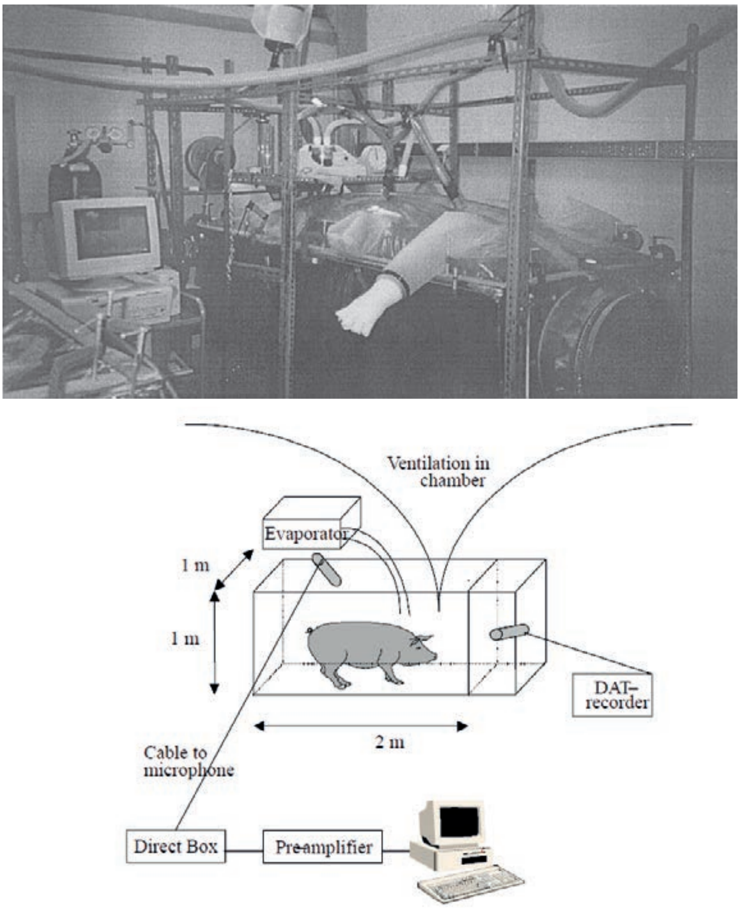


Figure 1: Laboratory installation to perform repetitive experiments on an individual pig with gold standard (blood sampling)(top)  Laboratory test installation to induce coughs and to infect the pig (bottom)

*Feature Variable*
The idea of the real time monitoring system assumes that we can find another variable that can give an early warning of infection; this variable is called the ***feature variable***. In the example of infection monitoring, the idea was to use the number of coughs as the feature variable that would indicate the infection. The *hypothesis* was that a respiratory disease infection would generate a response by the cells in the wall of the airway. As a result, the characteristics of the wall would be different and this would generate a different energy content in the sound signal from the coughs, as is also found with humans.

The *feature variable* is the variable that is calculated from the field measurements on the animal which are captured by sensor signals, image or sound information. The idea is that the feature variable can be measured or calculated at a high sampling frequency or continuously in relation to the dynamics of the process, in this case infection of the pig. The PLF algorithm aims for real-time calculation of the target variable so that there is no need to store all the field data, or in this case all the sound signals measured at a rate of 20,000 Hz, in the final monitoring system.

This shows that the first *objective of the algorithm* must be to estimate or calculate the value of the feature variable (the number of coughs) from the measured field data (the measured sound signals in the pig house). The *second objective of the algorithm* is to link the value of the feature variable (the number of coughs) to the target variable (the infection status of the pig).

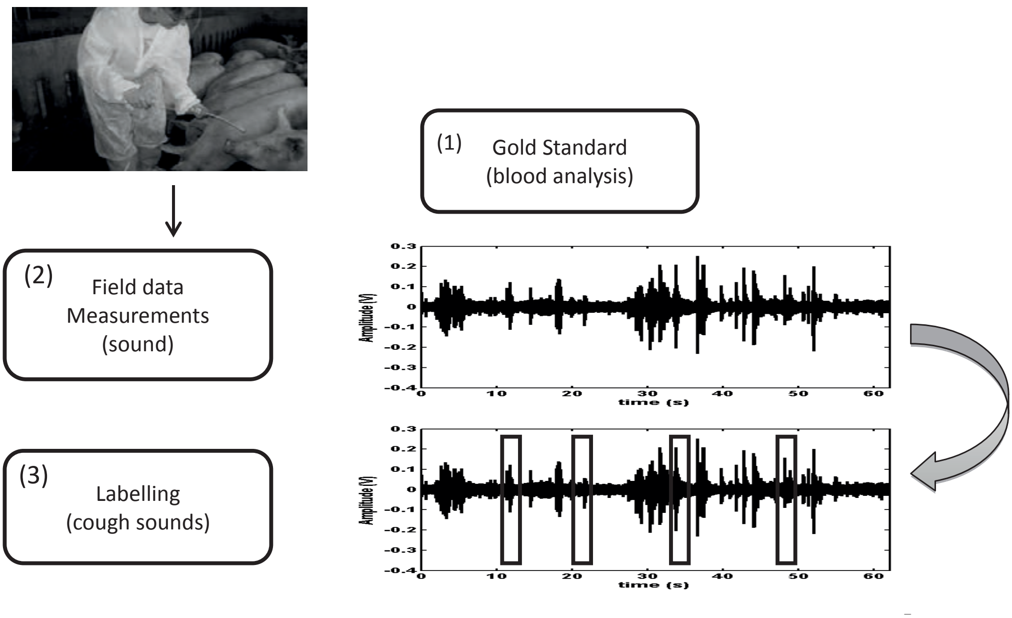


Figure 2: Example sound data collected as a function of time

*Labelling*

In this example, when collecting the **bio-signals or field measurements** on the animal we obtain the sound data produced by the animal (see Figure 2). In order to develop an algorithm that can detect the number of coughs automatically, we again need a reference point which indicates the point in time when the field data contain coughs. To develop an algorithm for cough counting it is not sufficient to know the actual number of coughs in the data; we need to know when exactly a cough starts and when it ends. This information must be obtained by careful audio-visual analysis of the field data using some kind of methodology: for example a human observer on the scene who carries out audio-visual counting of coughs to mark them. Another method is for a human to carry out off-line audio-visual marking of coughs on the measured data. This might be less expensive and easier but is it as accurate as on-the-spot observations (in the livestock house)? This activity is called **labelling**: *detailed manual audio-visual analyses of the feature variable from the measured field data to be used as a reference point for algorithm development* to calculate the feature variable (Figure 3).

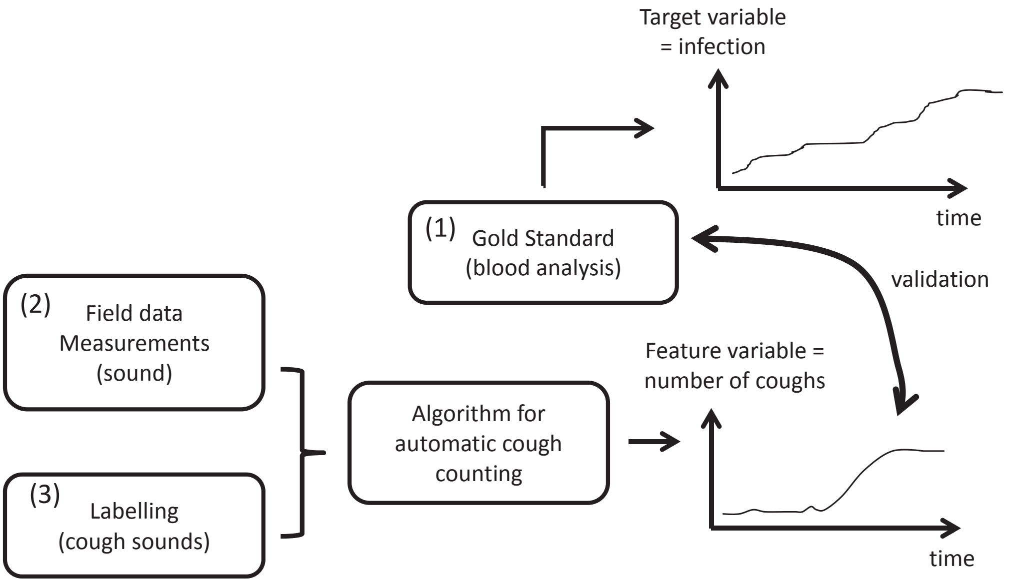


Figure 3: Measurements, labelling and gold standard to develop algorithms.

This accurate labelling of field data is very labour-intensive: manual labelling of a 48-hour video, involving marking start and stop points (e.g. in an image) for only 7 different activities can easily take a few man-months! Each single image or data sample has to be analysed to identify the beginning or end of one of the activities. To label, for example, the beginning and end of each cough, grunt or sneeze among all the other sounds (fans, doors, feeder lines, outside noises, animals moving, etc.) in sound data that were captured at a sample frequency of 20,000 Hz requires a serious investment of man hours. Research teams specialising in labelling have developed tools which enable this time-consuming hard work to be carried out more efficiently (Guarino *et al.*, 2007). It has been demonstrated that audio-visual labelling of pig coughs in a scene is not very straightforward (Aerts *et al.*, 2005; Ismayilova *et al.*, 2013; Ferrari *et al.*, 2010).

It is clear that the accuracy of labelling will be of crucial importance in developing accurate algorithms. If the accuracy of labelling is unknown, a new problem arises with regard to how to develop an accurate algorithm.

Gold standard and labelling activities are two different things which should not be confused; this is evidenced by the fact that the objectives relating to the target variable and feature variable are different, and that these variables vary over time, creating a need for real time calculation of the feature variable.

## Algorithm Development

When data are collected we print them as a function of time and apply labelling in order to obtain reference data for the feature variable. The labeller has now marked exactly where a cough starts and ends in all the field data. We can now develop/run the first part of the algorithm which calculates the values of the feature variable, in this case the coughs as a function of time and finally the number of coughs.

By comparing the labelled coughs with the results of the algorithm, we can develop, improve and compare the number of coughs calculated by the algorithm with the number of coughs as labelled by the human labeller. The algorithm must detect the individual coughs automatically to enable calculation of the feature variable in real time from the field data.

The next step is to develop the second part of the algorithm, namely to compare the feature valuable with the results of the gold standard in order to complete the algorithm for automatic detection of the infection indicator (Figure 3).

## Comparing algorithm results with reference data: validation, sensitivity and specificity

When an algorithm is run with data, the outcome should be compared with the gold standard applied to the target variable in order to **validate the algorithm**. *Validation* means that the algorithm is tested on data that were not used during its development. We already know that the algorithm will work with the data that were used to develop it. The challenge is to make it work with new, independent data. The algorithm may give correct results, which mean that the coughs are recognised correctly, but it may also give false positives, which mean that the algorithm classifies a sound as a cough when in fact it is not a cough. Another problem is that the algorithm might produce false negatives, which means that a no-cough sound is classified as a cough. Two terms are used to quantify the performance of an algorithm: sensitivity and specificity (Genazzani 1991)

**Sensitivity** can be defined as the ratio of real coughs which produce a correct result in the algorithm to the total number of coughs.

$$sensitivity = \frac{number\ of\ true\ positives}{number\ of\ true\ positives + number\ of\ false\ negatives}$$

**Specificity** can be defined as the ratio of other sounds which produce a negative result in the algorithm to the total number of other sounds.

$$specificity = \frac{number\ of\ true\ negatives}{number\ of\ true\ negatives + number\ of\ false\ positives}$$

**Algorithm testing in field situations.**

Whatever type of physical or mathematical simulation we use in the lab, experience shows that the hard work starts when the algorithm is implemented in a real livestock house. The main reason for this is that animal-related processes in a commercial livestock house are much more complex than anything we can simulate in the laboratory.

In the case of real-time cough monitoring, validation of these algorithms in the field, conducted in a piggery in Lombardy (Italy), demonstrated that the algorithms developed were able to classify the cough correctly in 86% of cases (Guarino *et al.*, 2008). The final results in terms of performance of these algorithms can be expressed quantitatively using the criteria discussed above (Exadaktylos *et al.*, 2008).

**Conclusions**

Making algorithms work in real-life conditions is a hard job that all developers will experience before successfully developing a reliable and accurate real-time monitoring system. Producing journal publications and patents is clearly far easier than creating cheap, reliable and accurate PLF tools.

Technology nowadays offers exciting opportunities to develop automatic monitoring and management products to help farmers remain competitive in the face of the many requirements and skills that society imposes on them. Technology, however, is just a tool which supports many others. Development of suitable systems needs much more intensive collaboration between people from different disciplines, which appears to be difficult because each discipline, each team and many individuals are just hunting for more research money instead of focusing on making more progress in their field of research or the sector where their knowledge should be applied.

We hope that this paper and our efforts to define some terms will help to facilitate communication between scientists from the different disciplines that are needed to create useful PLF tools.

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## Precision livestock farming: an overview of image and sound labelling

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### Abstract

The shift in livestock farming methods from extensive to intensive poses a number of significant challenges for animal welfare, environmental sustainability and food security. Automatic animal monitoring may be one method of supporting farmers in achieving farm sustainability. Precision Livestock Farming (PLF) can combine audio and video information into automated tools that serve as early warning systems for the farmer if health or welfare problems are detected.
First, reliable sounds and images that indicate poor animal welfare must be identified by animal experts. Then, through careful labelling of sounds or images, it is possible to create a complete database which is suitable for algorithm development.
Labelling is an activity which precisely defines and interprets detailed variations in measured field signals. This study will describe sound and image labelling with the aim of developing an automated tool.

**Keywords:** Sound, Image, Labelling, Algorithm, Precision Livestock Farming

### Introduction

In recent decades there has been enormous growth in livestock production, driven by population growth and changes in dietary preferences associated mainly with increasing wealth and urbanisation.
The increasing demand for meat, dairy products and eggs has important implications for agricultural production methods; in fact livestock/crop production is becoming increasingly industrialised worldwide, shifting from extensive, small-scale, subsistence production systems towards more intensive, large-scale, geographically-concentrated, specialised and commercially oriented ones.
Intensive or confined livestock production involves thousands of animals of similar genotypes which are raised for one purpose (such as pigs, laying hens, broiler chickens, ducks, turkeys) with a rapid population turnover and under highly controlled conditions, often in constrained housing without adequate space, fed with industrial feeds instead of natural forages.
In the past, livestock management was based on the farmer's experience and simple animal observation. Today, the farmer has to play a completely different, more

entrepreneurial, role which forces him to spend most of the day in the office, losing contact with animals (Guarino, 2005).
Poor housing, crowding and lack of food in intensive farming systems can often cause welfare problems. The increase in the number of animals being reared also leads to a higher likelihood of creating pandemics of zoonotic origin, with several diseases such as Avian Flu (2003) and H1N1 Flu (2009) outbreaks occurring in Europe in recent years. Zoonoses are diseases that are transmissible between animals and humans. Humans can acquire these infections directly from contact with sick or carrier animals, contaminated foodstuffs, or from other environmental sources (Lahuerta *et al.*, 2011). It is important to control the spread of these diseases and the use of medication is becoming very important as a means of avoiding disease transfer from animals to humans. This is especially true in livestock and poultry, where antimicrobials are used to prevent disease and to treat infections. Furthermore, antibiotics are also used to help the animals to grow faster. This over-use of antibiotics leads to the development of antibiotic resistance, which means that some bacteria strains are able to survive exposure to one or more antibiotics. This resistance has several negative aspects both in human and animals, such as increased morbidity and mortality due to inappropriate therapy and the increase in costs for medical treatment (Acar, 1997).
Experience in Europe shows that changing animal husbandry practices and removing growth-promoting antimicrobials from feed results in decreased resistance in animals without loss of productivity or loss of value in food animals (Shea, 2003).
In order to arrest the current global increase in antibiotic resistance and to reduce costs related to diseases and veterinary interventions, the methodology must include the elimination of unnecessary use of medication through the introduction of disease surveillance strategies and by promoting research and development into new approaches to the control and prevention of pathologies.
One potential method of achieving better control of the food production chain is to develop reliable automatic monitoring systems in order to increase food safety, animal health and welfare.

### Precision livestock farming

Information technology (IT) is continuously making remarkable progress in terms of technical efficiency. In particular, production methods and reductions in device size and energy consumption have made the technology cheaper and more accessible.
When recent progress in IT and sensors is combined with the use of internet connections, it is possible to implement new technologies which are complementary to industrial production based on animal biology. These new technologies can provide methods of supporting the farmer, providing him with an early warning system for automatic, non-invasive identification of production, health and welfare problems on farms.
Through the application of process engineering, Precision Livestock Farming (PLF) can combine audio and video information into on-line automated tools that can be used to

control, monitor and model the behaviour of animals and their biological response. The PLF approach can easily be applied to different aspects of management, with a focus on the animals and/or the environment, and at different scales, from the individual to the entire flock/herd (Wathes, 2010). PLF can also be used to aid the management of some complex biological production processes, for example in food strategies, to control the growth rate and to monitor the animal activity (Halachmi *et al*., 2002; Aerts *et al*., 2003a; Aerts *et al*., 2003b; Costa *et al*., 2007).The aim of these technical tools is not to replace, but to support the farmer who always remains the most important element of good animal management (Costa *et al*., 2007).

The definition of PLF is 'the application of the principles and techniques of process engineering to livestock farming to monitor, model and manage animal production' (Wathes, 2010). According to Wathes (2010) PLF relies on four essential elements:

1. The continuous sensing of the process responses at an appropriate frequency and scale with a continuous exchange of information with the process controller;
2. A compact, mathematical model, which predicts the dynamic responses of each process output to variation of the inputs and can be – and is best – estimated online in real time;
3. A target value and/or trajectory for each process output, e.g. a behavioural pattern, pollutant emission or growth rate;
4. Actuators and a model-based predictive controller for the process inputs.

In general, the reliability of PLF is determined primarily by the animal and all the physiological variables that can/must be continuously measured, such as weight, activity, behaviour, food intake, noise produced, body temperature, heart or respiratory rate, etc. Continuous measurement means that, depending on the variable in question, the frequency of measurements must be high/elevated. Other requirements include the capability to provide reliable prediction and, along with on-line measurement, integration of the algorithms that are necessary for automatic animal monitoring in order to implement correct control strategies (Guarino, 2005).

Possible approaches to automatic monitoring systems may be based on sound, images and collection of environmental data.

One of these "monitoring technologies" is bioacoustics. This cross-disciplinary science investigates sound production, dispersion and reception in biological organisms (Fletcher, 2004) and offers several advantages in terms of the detection of relevant sounds linked to the physiological status, activity, health and mental status of reared animals. Bioacoustics has been used to evaluate conditions such as stress and welfare through screams, calls and vocalizations (Moura *et al*., 2008; Ferrari *et al*., 2013), and to assess health by monitoring coughs and sneezes (Aerts *et al*., 2005; Ferrari *et al*., 2008; Silva *et al*., 2009; Ferrari *et al*., 2010). Furthermore it is a simple, cheap and non-invasive technology.

For example, respiratory diseases are one of the most prevailing pathologies in pig farming and veterinarians use cough sounds as a method of diagnosing respiratory diseases.

Cough sounds can only be assessed during a visit to the farm and an automatic monitoring tool for animals' coughs can contribute to improved farm management through opportune treatments (Silva *et al*., 2009).
Another approach to animal status assessment traditionally includes manual and visual scoring, but the large number of man-hours required for these methods involves high costs, and use of a sensor attached to the animals can be invasive and may alter the outcome (Cangar *et al*., 2008). For this reason, the use of automatically collected images to analyse farming systems is becoming more and more common. It is relatively cheap since it requires a small number of cameras and a computer, it is non-invasive and it gives access to more frequent data over long period. In addition to this, large numbers of dependent variables can easily be calculated (Cangar *et al*., 2008).
Image analysis has been widely used in many species to investigate thermal comfort (Shao&Xin, 2008), behaviour (Leroy *et al*., 2006), activity (Costa *et al*., 2009; Aydin *et al*., 2010), growth trends (De Wet *et al*., 2003; Demmers *et al*., 2012), welfare (Leroy *et al*., 2006; Viazzi *et al*., 2011) and health problems (Cangar *et al*., 2008; Song *et al*., 2008).
First of all, reliable standardised indicators of poor animal health and welfare status must be identified by animal experts. Standardising objectively measurable welfare indicators could improve systems for monitoring animal welfare at farm level and help to identify stressful practices so that preventive and corrective action can be taken within the growth cycle of the animals (Candiani *et al*., 2008). These indicators provide the basis for identifying the sounds and images that can be used to develop an analysis algorithm which is capable, on the basis of continuous monitoring, to predict and manage animal health and/or welfare, or take control actions (climate control, feeding strategies, etc.).
Sounds and images which identify behaviours or symptoms related to welfare and health indicators must be recorded. The next step involves the expertise of people who can extract and label the sounds or images that can provide evidence of problems on the farm.

### Sound labelling

Sound labelling involves the extraction and classification of individual animal sounds on the basis of the amplitude or frequency of the sound signal in audio files recorded on the farm. The labellers identify sounds that are of interest on the basis of the key indicators and golden standards provided by veterinarians and ethologists.
Auditory recognition of sounds coming from a noisy environment such as the farm is a demanding task. On farms, sounds from animals are often overlapped by other sounds (feeders, gates, etc.), the acoustic source is not always at the same distance from the microphones, and reverberation can alter sound propagation.
Due to their discontinuity, it is impossible to filter out all these background noises;

audio identification is therefore dependent on the subjectivity of the different labellers and their accuracy and interpretation/understanding.
For this reason it is helpful to support listening with visual information about the energy envelope of the noises recorded, using audio editing software such as Adobe® Audition®. This type of software provides a visual representation of sound waves, displaying waveforms for the evaluation of audio amplitude or the spectrum of the sound, which reveals audio frequency (Figure 1).

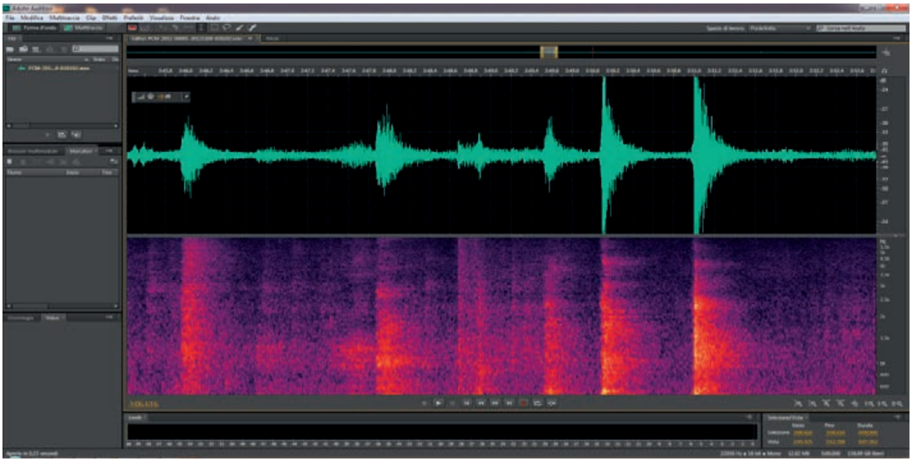

Figure 1. Screenshot of Adobe® Audition®. Waveform (upper part) and spectral display (lower part) of an audio file.

The waveform display (Figure 1, upper part) shows a waveform as a series of positive and negative peaks. The xaxis (horizontal ruler) measures time and the yaxis (vertical ruler) measures the amplitude that is the loudness of the audio signal (Adobe® Systems Incorporated, 2003).
The spectral display (Figure 1, lower part) shows a waveform by its frequency components, where the xaxis (horizontal ruler) measures time and the yaxis (vertical ruler) measures frequency. This view allows the analysis of audio data in which frequencies are most prevalent. Colours range from dark blue, indicating lowamplitude frequencies, to bright yellow, indicating highamplitude frequencies (Adobe® Systems Incorporated, 2003).
While listening to the audio files it is possible to zoom in and out in the two domains (frequency and amplitude) in order to visualize clearly the energy envelope of each sound.


Figure 2. Screenshot of Adobe® Audition®. Spectral display of an audio file with the insertion of labels describing a cough attack (CAT).

When a sound of interest (e.g. a cough, sneeze or vocalisation) is detected, the labeller can mark it and can insert a label describing the sound (Figure 2). For each sound, the start, end and duration is automatically recorded.

### Video labelling

Video labelling is precise detection of the occurrence of behaviours of interest performed by the group of animals or individuals and is performed by manual extraction and classification of individual frames of a video recorded at the farm. This classification is based on key indicators and golden standards provided by veterinarians and ethologists. Depending on the variables (activity, occupation, behaviours, etc.), the video must be calibrated in order to define zones of interest inside the video where behaviours, activity and occupation can be measured and labelled (Figure 3).

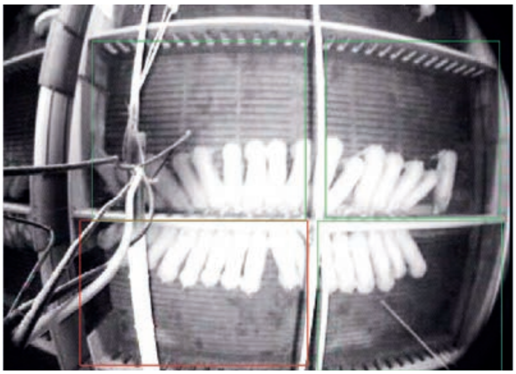

Figure 3. Definition of zones of interest inside the video where behaviours, activity and occupation can be measured and labelled

To estimate activity or occupation, the pen floor area must be converted into pixels in the image and then the pixel intensity is used to evaluate animal activity.
In order to support and speed up visual labelling, a labelling tool (Figure 4) was developed in MATLAB©It is based on the principle that relates changes in pixel intensity to a good estimation of animal activity (*activity index*, *Figure 4b*).

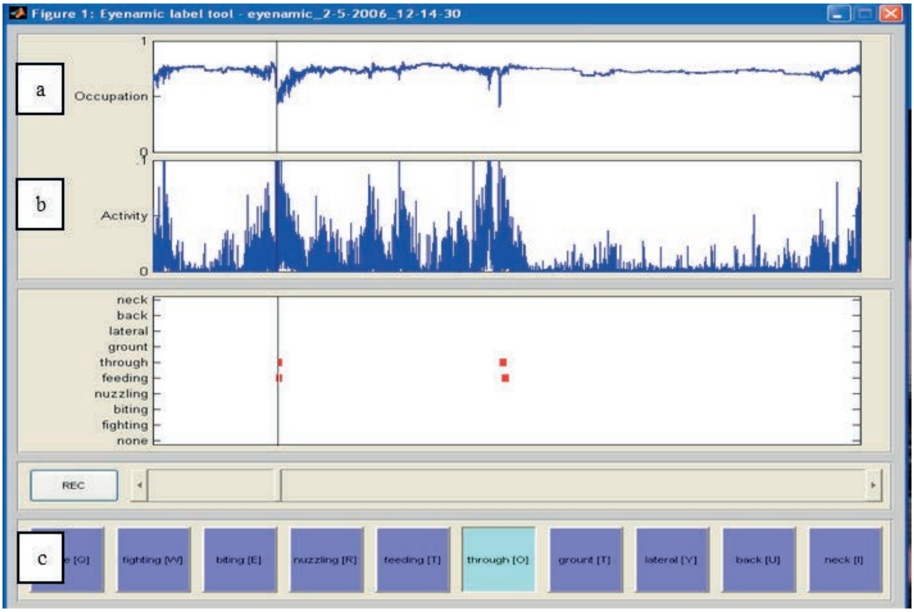


Figure 4. Screenshot of Labelling Tool. a) Occupation index. b) Activity index. c) Customisable buttons

With this information it is possible to identify parts of video with reduced activity (most of the day) and focus attention only on those sequences which contain movement. Another parameter that is considered in the Labelling tool is the *occupation index* (Figure 4*a*); this parameter indicates the ratio between the zone occupied by animals and the total area of the pen. By aassociating those two parameters, the software creates threshold values for animal activity, making it possible to skip those periods of the day when animals move out of necessity (e.g. feeding, drinking time).
This tool is helpful in detecting periods of increased activity and by fast forwarding the video to those periods only, the labellers can record all the information about the behaviour detected. The software interface is customisable, so the labeller can name the buttons identifying the chosen behaviours or events of interest (Figure 4c).
With this tool the labeller can easily classify behaviours by manual sliding of the video, and when a specific behaviour, or multiple behaviours, is/are observed in the image the matching button/buttons is/are selected. Data collected in this way can be

exported in order to create a data set containing all the information that will be useful in developing an algorithm for the automatic detection of behaviours (start/end time, duration, description of the behaviour and animal identification).

## Conclusions

The essential prerequisite for the development of a reliable algorithm for automatic identification of health and welfare problems on farms is the accuracy of the data collected. The automated tool should work on any farm in any conditions, and data standardisation is strongly dependent on manual labelling. This fundamental step, which is necessary for data analysis and model development, takes an enormous amount of time and manpower. For these reasons, an accurate labelling tool should be developed. This goal will be reached through accurate validation of the output from the labelling tool (audio or video) against data collected by means of manual labelling procedures.
In order to achieve highly accurate and useful labelling, key indicators and golden standards must be clear and precise. For this reason, it is desirable to have close cooperation between animal health/welfare experts and labellers. Each labeller must be trained according to key indicators and golden standards; he/she must be competent and skilled in animal physiology, welfare and behaviour in order to understand the importance of the labelling procedure.

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# Uncertainty and error analysis in parameter estimation models

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## Abstract

Uncertainty analysis is essential to draw conclusions from measurement data. This is particularly important in situations with highly uncertain values or where precise evaluations are needed. This paper focuses on how uncertainty in parameter estimation can affect the uncertainty of modelled values. As an example, calibration of a $CO_2$ sensor using a simple linear regression will be used to illustrate this use. A regression analysis using least-squares fitting provides information on the parameter uncertainties. The correlation between model parameters is also required. Since regression parameters are calculated from the same dataset, they normally show a high level of dependence. Therefore, these correlations must be considered. In the case shown in this study, calibration parameters (slope and intercept) were strongly correlated (r=-0.99). The inclusion of correlation in the uncertainty model reduced uncertainty in the results. Finally, an overall standard uncertainty of 20 ppm was found as a result of the calibration and uncertainty analysis.

**Keywords:** uncertainty, error analysis, $CO_2$ balance, propagation

## Introduction

Whatever their degree of complexity, models use and combine a variable number of parameters in order to predict the behaviour of a certain system. Therefore, model parameters must first be estimated and then used to predict the behaviour of a system. All models are subject to a certain degree of uncertainty, partly because of errors in estimating model parameters, but also because models are a simplistic representation of complex systems. Therefore, all models should include an estimation of the uncertainty associated with their predictions. In other words, to understand and draw conclusions from the results of a model, it is necessary to have an estimation of the model error.

Uncertainty is a quantitative value which characterises all the errors in a complete measurement system. In contrast, error is an idealised concept related to a single measurement. Therefore, a measurement system may have a large numerical or percentage uncertainty, yet a particular measurement within that system may have a small error due to random chance.

Two basic steps are essential in determining uncertainties in measurements: formulation and propagation. In the formulation stage all measured variables must be specified in terms of average and uncertainty. The model constitutes a quantitative relationship between them and the model result. Both variables and model parameters will be estimated with a certain degree of error which must be identified and quantified. The propagation stage will propagate the uncertainties from the measured values through the model to obtain the model uncertainty. Both analytical and numerical methods can be used for this purpose. The former are based on the law of the propagation of uncertainty, whereas the latter use Monte Carlo methods to propagate uncertainties.

Both approaches to uncertainty propagation have been widely described in the literature. The law of the propagation of uncertainty is based on the first-order Taylor series and constitutes a linear approach to errors. This approach is valid if the model is linear, the different uncertainty sources contribute in comparable amounts, and the uncertainty of each parameter is relatively low in relative terms compared to the parameter value. To overcome these limitations, numerical models based on probability distributions can be used, although they are computationally more complex (JCGM, 2008).

A sensitivity analysis is essential to identify the most relevant sources of uncertainty, which can be expressed as a percentage of the model uncertainty. In linear models, these contributions can be quantified and assessed easily. However, in complex models this sensitivity analysis becomes crucial. In non-linear models, small variations in certain parameters can be associated with large variations in the model input, and therefore efforts should be directed towards improving its estimation. On the other hand, effort can be spared for parameters with negligible impact on the final uncertainty.

Finally, dealing with dependent variables is always problematic. Theoretically, all dependences between the model variables should be identified and quantified, and then incorporated into the uncertainty model. However, dealing with dependence increases the complexity of uncertainty propagation, and therefore the decision to assume independence between variables must be clearly justified.

After reviewing these basic concepts relating to error and uncertainty analysis, the objective of this work is to present a particular case based on the measurement of carbon dioxide ($CO_2$) using commercial sensors.

## Material and Methods

Sensor selection

The sensors were intended for use in ventilation calculations using the $CO_2$ balance. Other control and management applications (e.g. animal welfare) could also be of interest. The $CO_2$ balance method (CIGR, 2002; Pedersen *et al*, 2008) relates the amount of $CO_2$ released by animals and their manure and the difference in outlet-inlet $CO_2$ concentrations, to the ventilation flow. For accurate measurements, the amounts produced by the animals must be known, as must the distribution of $CO_2$ concentrations. This is particularly important in very open, naturally ventilated livestock buildings.

Commercial sensors were evaluated in terms of their suitability for a wireless sensor network and measurements in a livestock building. In line with these requirements, the sensor CO2S-PPM-1 (SST Sensing Technologies, Lanarkshire, UK) was selected on the basis of the following characteristics:

- Precision of 50 ppm or better so that it could be used in $CO_2$ balances as described by CIGR (2002).
- Very low electricity consumption (<10 mA) to ensure a long autonomous operation time.
- Relatively low cost so that it could be used in commercial farms.
- Suitable for on-farm measurements.

Twelve of these sensors were acquired and mounted in 12 wireless nodes. The measurement system is based on Wireless Sensor Network (WSN) technology. In these networks, a group of nodes cooperate to form a network which allows the transmission of information from the measuring nodes to a receptor. Nodes can behave not only as sensor nodes but also as repeating nodes. A generic WSN was used, based on subGhz wireless communication technology, which provides a good balance between electricity consumption and signal range. Each node was powered by four 1.5V AA batteries and provided measurements of $CO_2$, temperature and relative humidity.

Sensor calibration

The sensor was calibrated in a closed chamber under laboratory conditions. A photoacoustic gas monitor (INNOVA 1412, Lumasense, Denmark) was taken as a reference. Different $CO_2$ concentrations were introduced into the chamber using pure $CO_2$. The sensor response was then compared with the reference analyser and different calibration curves were obtained. The calibration range was from 3000 to 5000 ppm. Measurements were taken every minute.

Uncertainty analysis

Sensor calibration is presented as a simple model for analysing the uncertainty of propagation. This is outlined in Figure 1, which must be considered a simplistic approach to uncertainty propagation for calibration of sensor measurements ($x_i$) according to reference measurements ($y_i$).

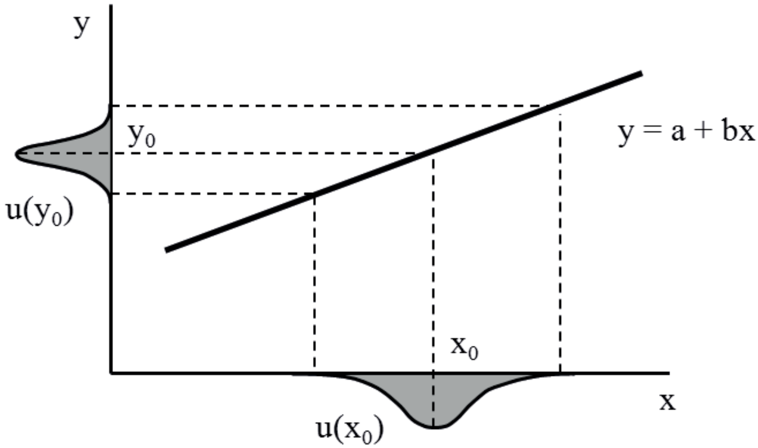



Figure 1: Uncertainty propagation in a simple linear model with known parameters

However, this is a simplistic situation which does not correspond to reality (Ellison *et al.*, 2000). In practice, regression parameters are estimated with some degree of uncertainty due to:

- Random variations of the sensor measurements
- Random effects resulting in errors in the reference values
- The assumption of linearity may not be valid

As a result, the propagation of uncertainty in a calibration model must follow the procedures recommended by the Guide to the Expression of Uncertainty in Measurement (GUM) described by ISO (1995). If a target measurement "y" is determined by the expression "y = a + bx", the uncertainty of the dependent variable u(y) can be calculated as a function of the uncertain variables and parameters involved in its calculation. In this particular case, this expression takes the following form (ISO, 1995):

$$u^2(y) = u^2(a) + x^2u^2(b) + 2x\,u(a)\,u(b)\,r(a,b) \qquad (1)$$

Where:

u(y): uncertainty in the dependent variable

u(a) and u(b): uncertainty in the regression parameters, which is equivalent to the standard error of parameter estimation.

r(a,b) correlation coefficient between the regression parameters, which is calculated as:

$$r(a,b) = -\frac{\sum x_i}{\sqrt{n \sum x_i^2}} \quad (2)$$

Two uncertainty propagation methods were used . Firstly, the law of propagation of uncertainty proposed by ISO (1995); secondly, numerical simulations (Monte Carlo methods) were conducted using the RiskAmp Monte Carlo Add-in Library software (version 2.97) for Excel.

## Results and Discussion

Figure 2 shows the calibration curve obtained for the sensor. It was noted that the calibration changed slightly between different tests. However, it was not possible to relate these changes to any of the environmental conditions registered (temperature, relative humidity or air pressure).

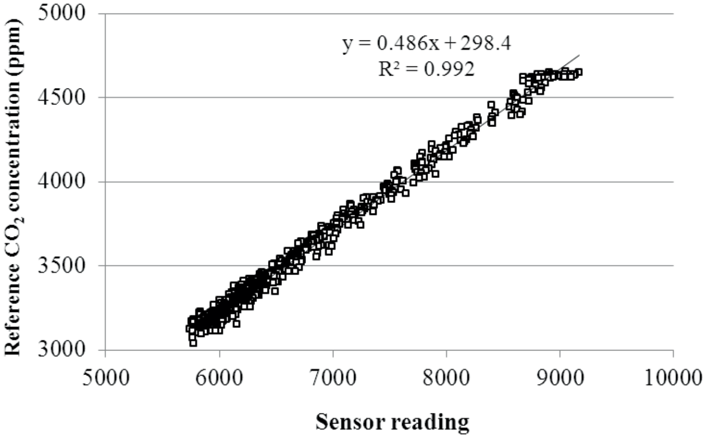



Figure 2: Calibration curve for the $CO_2$ sensor

The statistical results of this calibration are presented in Table 1.

Table 1: Least-square regression parameters of the calibration model

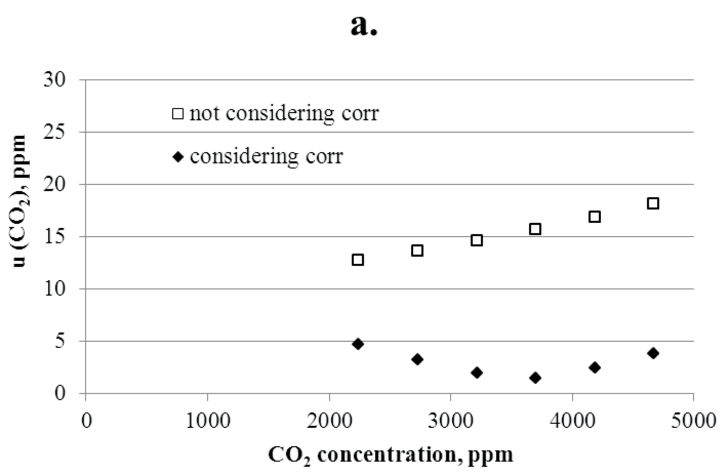
| Parameter | Estimate | Standard error (=uncertainty) | p-value |
|---|---|---|---|
| Intercept (a) | 298 | 11 | <0.001 |
| Slope (b) | 0.4861 | 0.0016 | <0.001 |

Both parameters a and b were strongly correlated (r=-0.99). This correlation arises when the measured points are displaced from the vertical axis. If this displacement is to the right, the correlation between slope and intercept will be negative. This means that any increases in the slope due to random choice involve a decrease in the intercept and vice versa. If the displacement of measurements is to the left of the vertical axis, this relationship would be the opposite.

According to ISO (1995), it is possible to artificially eliminate the correlation between both parameters. This may simplify computation of the standard uncertainty of a predicted correction or calibration. To do this, the x values must be corrected by subtracting the average of all x values. This means that the average of all corrected x values is 0 and therefore equation 2 would show that r=0.

Calculation of the uncertainty in $CO_2$ measurement, depending on the measured value, is represented in Figure 3. The effect of considering or not considering correlation on the final uncertainty is presented. The effect of the calibration model is presented first. It can be observed that not considering correlation leads to an overestimation of the model uncertainty. With this model, uncertainty increases with the concentration measured. However, considering the correlation between model parameters gives a lower uncertainty in the calibration model. Furthermore, a minimum uncertainty value is found to fall at the average value of concentrations used in the calibration curve.

If the sensor uncertainty is also included in the model (Figure 3 b), it can be observed that the global uncertainty increases, but the effect of the correlation is less important in relative terms. In this case, the standard uncertainty associated with the overall calibration was 20 ppm. This level of uncertainty may be sufficient for most $CO_2$ balance situations. As indicated by Blanes and Pedersen (2005), this method should be sufficient to detect differences of 150 ppm between exhaust and inlet $CO_2$ concentrations.



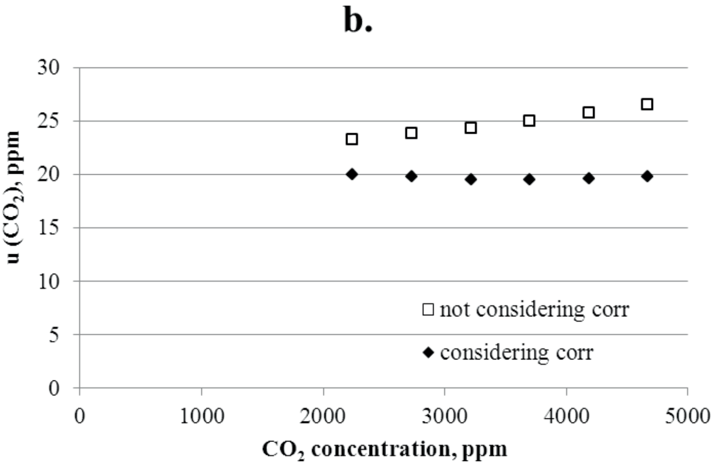



Figure 3: Uncertainty in $CO_2$ measurement depending on the measured value, considering and not considering correlation: a. uncertainty introduced by the regression model; b. global uncertainty of the calibration and sensor uncertainty.

## Conclusions

Model calibrations involve uncertainties which must be accounted for. This study examined the specific case of calibration of a $CO_2$ sensor. The effect of the correlation between the regression parameters was accounted for. Finally, the standard uncertainty for this sensor was established as 20 ppm for the range between 2000 and 5000 ppm

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## Essential steps in the development of PLF systems for the dairy sector

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### Abstract

Recently, many new initiatives are taken in the development of PLF applications for use on dairy farms. New initiatives (sensors or other hardware) that are potentially interesting for application on dairy farms often started by engineers. Only few of these ideas make it into real PLF applications. Decisions on which PLF system needs to be developed further are not made very consequently. This paper gives a background on how to select ideas for PLF applications that are worthy of further development.

The development of hardware is only a first step in the development of a PLF application, which consists of four stages: (1) technique, (2) data interpretation, (3) integration of information and (4) decision making. Data interpretation is a crucial step, because it involves a clear definition of the animal or farm status that needs to be detected and the gold standard associated with that. Algorithms needs to be developed and validated to transform data into information. At the third stage, the information obtained from the hardware is combined with other on or off-farm information (e.g., cow performance and economic data) to support decisions. It is not a necessary step in PLF systems, but it will improve the value of a PLF system. Stage 4 is the actual decision making, either by the herdsman or autonomously by the PLF system.

Knowing the characteristics of a PLF application, the potential value of that application has to be determined. The potential value of a PLF application should be based on three elements: (1) the development costs of the PLF application, (2) the
net economic benefit of the PLF application and (3) the preference of the farmer. The economic value of a PLF system depends on the type of application. Many new developments are aimed to improved disease situations. The costs of disease is then an important first element, because in the costs of disease lies the potential economic value of the PLF system. Other benefits may be present as well: for example improved production efficiency (e.g., concentrate feeder systems) and reduced labour (e.g., automatic milking). Preferences of the farmer are often overlooked. For this type of work, it is necessary to have clear (as SMART as possible) descriptions of the potential PLF applications.

Experiences from the past show that, for instances, mastitis detection systems for conventional milking parlours did not have enough added value and therefore were not successful. Estrus detection systems on the other hand, seem to be successful. This PLF application has well worked out algorithms to link the sensor data to estrus and there is a clear action connected to the detection of estrus (insemination).

To conclude, innovations in the field of PLF often come from engineers, not necessarily involved with dairy farming. That stage often ends with prototype hardware and that is only the first step in PLF development. To explore the final potential of a PLF system economic effects, farmers preferences and expected development costs should be taken into account. When this is done more systematically then was done in the past, the risk of development of an unsuccessful PLF system will become much lower.

## Introduction

The development of PLF applications for dairy farming started in the 1970s with the development of electronic cow identification. The possibility to identify individual animals led to the development of a range of possibilities to manage the individual cow. Besides the development of individual concentrate supplementation, PLF applications were not implemented, although in the 1980's work was carried out into development of PLF applications, as represented in a series of conferences on the automation of dairying that were held in Wageningen, the Netherlands (e.g., Anonymous, 1987). In the 1990's development of PLF applications for dairy farming was centered around automatic milking, this was again represented by a series of scientific meetings that were held in the Netherlands (Ipema *et al*., 1992, Hogeveen *et al*., 2000, Meijering *et al*., 2004). Since the early 2000's development of PLF is reflected in European Conference for Precision Livestock Farming.

Numerous ideas for PLF applications for dairy farming have been suggested and currently are being suggested. Some of these new initiatives are associated with the introduction of automatic milking, where detection of abnormal milk and clinical mastitis could not be done by visual inspection of the milk and/or udder anymore. Many new initiatives, e.g., introduction of automated estrus detection equipment (Løvendahl and Chagunda, 2010) or detection of claw health problems (de Mol *et al*., 2013), are not necessarily associated with automatic milking.

New initiatives (sensors or other hardware) that are potentially interesting for application on dairy farms often started from engineers. The development of hardware is, however, only a first step in the development of a PLF system. Hereafter, a large part of the work still has to be done. This work needs the involvement of data specialists and herd specialists in order to define gold standards and decision support tools. That work is costly and it is not sure whether the final PLF application will be a success. Decisions on which PLF system needs to be developed further are not made very consequently.

In this paper we give an overview of factors that are important for the priorization of PLF applications in dairy farming. We start with a description of the elements that are needed to develop good PLF applications, followed by an overview of the success factors for PLF applications in dairy farming and finally we will provide a few examples.

**Stages in PLF development**

A framework with which the stages in development of PLF applications can be described is given in Figure 1. The framework describes the steps from a sensor to a decision.

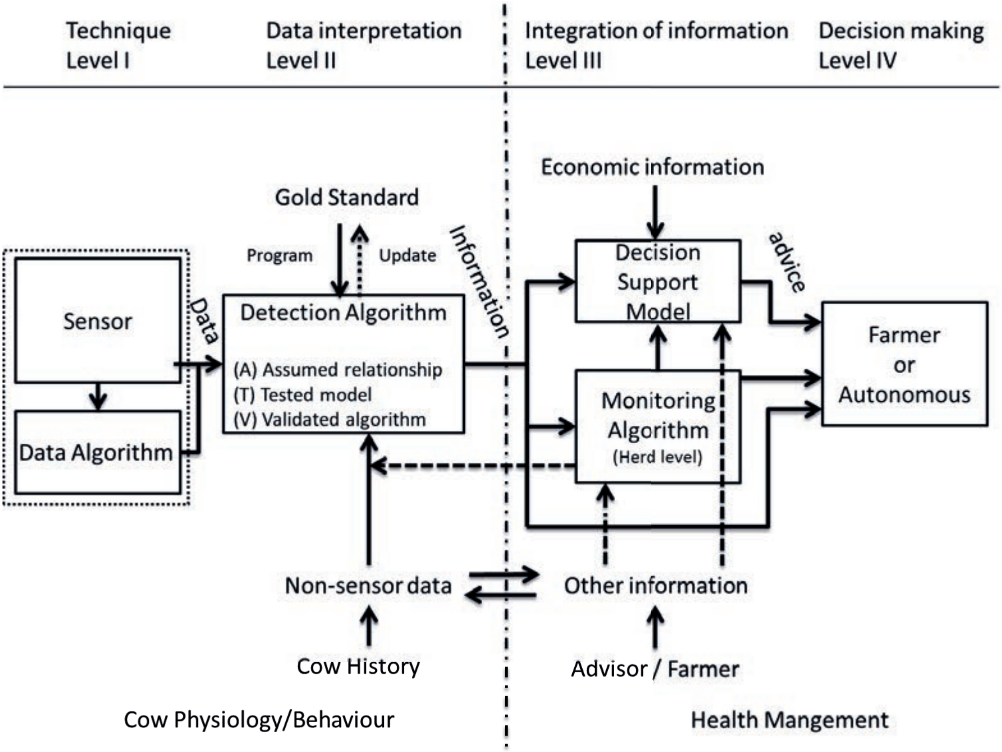


Figure 1. Framework to describe the elements in a PLF application for dairy farms (Rutten *et al.*, 2013).

The first step in PLF development, level I, is the description of the technique and the hardware. In some sensors the produced data is processed by a data algorithm (for example a pedometer records clicks of a mercury switch, the data algorithm produces a step count per time unit from these clicks). The next stage (level II) is called "data interpretation" and measures changes in the sensor data to produce information about the cows' status (e.g., estrus). The three categories identified within this level are an assumed relation, a statistically tested relation, and a validated algorithm. From a statistically tested relation, it is possible to build a predictive model (detection algorithm) that classifies the cows' status (for example, in estrus or not in estrus). For validation, a data set (not the one used to build the detection algorithm) is used to assess the performance by comparing the classification of the algorithm with the gold standard. This stage is a crucial step in development of PLF applications because in this stage, the data from a sensor is related to a physiological state of the animal that has a meaning for the decision maker. Moreover, this data interpretation can be very tedious as has been shown for PLF applications on detection of mastitis (Hogeveen *et al*., 2010). Moreover, the description of the performance of a PLF application should be done in such a way that it is useful for farmers and that the performance of different PLF applications can be compared (Kamphuis *et al*., 2013). Level III integrates the sensor information with other information (such as economic information), to produce advice for the farmer (e.g., Steeneveld *et al*., 2010). Furthermore, information of individual cows can be aggregated by a monitoring algorithm at the herd level. The output of this algorithm can be seen as either general information on the herds health for the farmer or additional data input for the detection algorithm. The decision is eventually made either by the farmer or autonomously by the sensor system (level IV, known as "decision making").

## Value of PLF applications

The potential value of a PLF application for commercial dairy farms can be based on three topics: (1) development costs of the PLF application, (2) net economic benefit of the PLF application and (3) preference of the farmer.

### Costs of development

The first aspect that needs to be looked at is the costs for development of the PLF application. These costs are often under estimated. Because, dependent on the complexity of the problem, these costs can be high. Ideally these costs will become part of the price of the PLF system. However, many times public money is involved in this development and these costs are left out of the price of the final PLF system. Realistic estimations of the needed steps in development of the PLF application are needed in order to be able to estimate the costs of development (and thus the cost price of the final product).

### Economic value

The economic value of a PLF system depends on the type of application. Many new developments are aimed to improved disease situations. The costs of disease is then an important first element, because in the costs of disease lies the potential economic value of the PLF system. Costs of production diseases are often known (e.g., Bruijnis *et al*., 2010, Hogeveen *et al*., 2011, Inchaisri *et al*., 2010). If a PLF application is expected to reduce the incidence of one or more diseases, the costs can be expected to be reduced proportionally with the reduced incidence or prevalence. So it is relatively straightforward to calculate the benefits of reduced diseases. The difficult part is to make an estimation of reduction in disease situation. For instance, in the case of estrus detection, we might have data on an improved estrus detection ate, but it is unclear how this estrus detection rate is related to the final success rate of conception and the final calving interval.

Other benefits may be present as well: for example improved production efficiency (e.g., concentrate feeder systems) and reduced labour (e.g., automatic milking). The benefits of improved disease levels, reduced labour, reduced feed costs per kg milk should be weighed against the investment costs of the system as the farmer has to pay it. There are only a limited number of cost estimations known (e.g., Ostergaard *et al.*, 2005).

For some PLF systems, economic advantages in the dairy production chain are envisaged. Because the way that milk is produced is becoming more and more important, transparency in the dairy chain on items such as animal welfare and grazing is gaining in value. Dairy processors might want to use information from sensors for this purpose. Moreover, information from sensors can also be interesting for breeding purposes and therefore for breeding organizations. Because the farmer is the one investing, these benefits should be taken out of the equation unless chain partners motivate farmers to invest in PLF systems that benefit the entire chain.

<u>Farmers preferences</u>
Even if a PLF application is cost-effective, adoption of the technology is dependent on other factors. A large heterogeneity exists among farmers (micro-level behavior) with regard to the adoption of technology. Economic factors such as size effects, risk preference and variation in the availability of labor and/or capital are factors for adoption of new technology. Also timing and investment irreversibility are important factors for adoption of new technology (Sauer and Zilberman, 2012).

Goals of farmers differ and has shown to have an effect on the farmers entrepreneurial behavior (Bergevoet *et al.*, 2004). It might be that behavior with regard to PDF applications also differs between farmers. Preferences of the farmer are often overlooked. Especially on farms where the family provides a large proportion of the labor, goals of farmers go wider than only profit maximization. With, for instance, conjoint analysis, farmers preference for systems can very well be studied (e.g., Mollenhorst *et al.*, 2012). For this type of work, it is necessary to have clear (as SMART as possible) descriptions of the potential PDF applications.

**Examples of application**

<u>The example of mastitis detection</u>
In the 1980s much research work has been carried out in on-line detection of mastitis (see for an overview Nielen *et al.*, 1992). However, adoption of these systems was low. Partly it was because it was unclear for which purpose these on-line mastitis detection

systems could be used. Algorithm development was not aimed at specific goals but merely at generic detection of mastitis (e.g., Maatje *et al*., 1992). Systems were described as being able to detect clinical mastitis as well as subclinical mastitis. But the associated actions differ between detection of clinical mastitis and subclinical mastitis. The reason to detect clinical mastitis is to treat animals, while the reason for detecting subclinical mastitis is more diffuse. It is partly to have an idea of the herd level of intramammary infections or it might be used for early treatment of mastitis. These differences do require different detection rules (Hogeveen and Ouweltjes, 2003). In order to treat clinical mastitis cases, the alert should be related closely to the onset of clinical mastitis, while for detection of subclinical mastitis cases these requirements are lower. However, even when specifically aimed at the detection of clinical mastitis, detection performance is not great (Hogeveen *et al*., 2010).Moreover, farmers were already able to detect clinical mastitis. It was and is part of standard milking procedures. For subclinical mastitis, farmers received information through somatic cell count measurements as part of the milk production recording system. In either case, the added value of mastitis detection is unclear.

No economic calculations on the use of mastitis detection systems are available. Automated mastitis detection is not expected to replace labor. The economic value should come from better detection and decision making around treatment of mastitis. The total failure costs of mastitis are approximately € 80 per cow per year (Hogeveen *et al*., 2011) and improved detection and treatment is not expected to reduce these costs with a large proportion. It has even been shown that cow specific treatment of clinical mastitis does not provide any added economic value (Steeneveld *et al*., 2011). It is, therefore, not surprising that farmers with a conventional milking system did not adopt automated mastitis detection systems.

With the introduction of automatic milking systems, there was a sudden need for on-line detection of mastitis because visual inspection of the cow and her milk became very laborious. Despite the relatively bad predictive value of the on-line mastitis detection systems, they were needed in AMS and are now widely implemented.

The example of estrus detection

In the late 1980's and early 1990's, research into the use of pedometers to detect estrus was carried out (e.g., Holdsworth and Markillie, 1982; Redden *et al*., 1993). More recently, 3D-accelerometers are becoming available and are used to detect estrus (Valenza *et al*., 2012; Lovendahl and Chagunda, 2010). Besides these activity-based automated estrus detection systems, other systems are also available, for instance a progesterone measuring system (Friggens and Chagunda, 2005).

Automated estrus detection systems do have a clear aim: detection of estrus with as associated action the insemination of a cow in estrus. The detection system may be combined with a system to optimize the time of insemination. For some individual cows it can be economically beneficial to extend the time of insemination (Steeneveld *et al.*, 2012). Because of the necessity of timely insemination, the definition of the gold standard in order to evaluate the performance of estrus detection systems is also quite straightforward. Estrus should be detected in time for insemination.

The benefits of automatic estrus detection are twofold. First, automated estrus detection can save labor. Visual estrus detection requires a lot of labor. Dutch recommendations are three times daily 20 minutes of visual inspection of the cows. When this activity is automated, a large proportion of this time is saved. The second benefit lies in an increase in the estrus detection rate. Especially because most farmers do not reach the recommended time of visual inspection. An average estrus detection rate of 50% was assumed (Inchaisri *et al.*, 2010). So when the sensitivity of an automated estrus detection system reaches, for instance, 80%, this can be seen as an improvement of estrus detection. As a consequence the average number of open days and the calving interval will reduce. One study is known on the economic effects of automated estrus detection (Ostergaard *et al.*, 2005). In this normative study it was estimated that the break-even price for an automated estrus detection system, based on in-line progesterone measurements was for an average Danish herd of 120 cows was € 45 per cow per year. The break-even price depended on the differences in the type of estrus detection system and herd reproduction management and varied between € 3 and € 81 per cow per year.

In many countries, farmers are starting to implement automated estrus detection systems. It is estimated that in the US 10 to 15 % of the farmers are utilizing automated estrus detection equipment (Bewley, 2013, personal communication). For the Netherlands this is estimated to be 19-20 % (Knijn, 2013, personal communication). The success of this PLF application can be that for estrus detection systems there is a clear goal of the system and there are clear advantages both in terms of reduction of labor as well as in improved herd productivity.

## Concluding remarks

Development of PLF applications for dairy farms is costly. Not all applications that were marketed were a success. For instance, mastitis detection on farms with normal milking parlors has never been successful, while estrus detection systems are currently being implemented on a large scale. Innovations in the field of PLF often come from engineers, not necessarily involved with dairy farming. That stage often ends with prototype hardware and that is only the first step in PLF development. Large investments have to be made to develop algorithms that translate data collected by sensors in information relevant for the decision maker. Moreover, the PLF applications may need integration with other farm data sources and decision support. Information delivered by PLF application should be clearly linked to useful actions by the farmer. Without this, a PLF application is bound to fail.

Actions that can be supported by PLF applications may differ in value. So before deciding on which PLF application to develop, knowledge on possible actions and the (economic) value of these applications should be known. When this is done more systematically then was done in the past, the risk of development of an unsuccessful PLF system will become much lower.

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# Session 2

# Cattle - Lameness

## Automatic lameness detection based on 3D-video recordings

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### Abstract

Manual locomotion scoring for lameness detection is a time-consuming and subjective procedure. Therefore, the objective of this study is to quantify the classification performance of a computer vision based algorithm for automated lameness scoring.
Cow gait recordings were made during four consecutive night-time milking sessions in an Israeli dairy farm with a 3D-camera. A live on-the-spot assessed 5-point locomotion score was the reference for the automatic lameness score evaluation. A dataset of 1436 cows with automatic lameness scores and live locomotion scores was used for calculating classification performance.
The analysis of the automatic scores as independent observations led to a correct classification rate of 50.4% on a 5-point level scale. When allowing a 1 unit error on the 5-point level scale, a correct classification rate of 87.6% was obtained. The obtained tolerant binary correct classification rate was 88.6%.
The automated lameness detection system obtained a tolerant correct classification rate of 88.6%.

**Keywords:** dairy cow, lameness, computer vision, 3-dimensional, classification

### Introduction

Lameness is a major welfare issue in modern intensive dairy farming (Lievaart and Noordhuizen, 2011; Bruijnis *et al.*, 2012). Prevalence rates depend on housing (Potterton *et al.*, 2011), management (Chapinal *et al.*, 2013), feed (Amory *et al.*, 2006) and breed (Barker *et al.*, 2010). Averaged reported lameness prevalence rates range from 20% to 25% in USA, and 33% to 37% in Europe (Schlageter Tello *et al.*, 2011). Herd locomotion scoring is a common method to obtain a lameness prevalence rate (Flower & Weary, 2009). However, this procedure is time-consuming (Thomsen, 2009) and subjective (Channon *et al.*, 2009). In the scientific community, different approaches were developed to automate locomotion scoring and lameness detection. Two-dimensional (2D) computer vision approaches to analyze the gait focused on the measurement of different gait and posture variables such as back arch curvature (Poursaberi *et al.* 2010),

step overlap (Pluk *et al*., 2010) , hoof release angles (Pluk *et al*., 2012) and the body movement pattern (Poursaberi *et al*., 2011; Viazzi *et al*., 2013a). The challenge to practical application of this method is to accurately identify the location in the image of anatomical body parts such as hooves, limb joints, withers and back contour lines. Until now, this has been performed using manually labelled markers attached to the limbs of the cows (Aoki *et al*., 2006; Song *et al*., 2008; Blackie *et al*., 2011). The manual labelling step inhibits full automation. Video pre-processing provides an alternative for locating the anatomical body parts in the video. During pre-processing, videos are transformed to sequences of binary images in which anatomical parts of cows can be clearly segmented from the background. Van Hertem *et al*. (2013a) showed however that image segmentation in 2D RGB-images was problematic in practice in real farm conditions due to dynamic background restrictions in side view perspective. To overcome these restrictions, a three-dimensional (3D) camera in top down perspective was suggested to obtain the same body movement pattern as with the side view camera. Viazzi *et al*. (2013b) developed an automated lameness scoring algorithm based on 3D imaging of the cow's gait. The algorithm measured the body movement pattern, which was related to the back arch curvature, one of the key indicators of cow lameness (Sprecher *et al*., 1997). The algorithm was validated on a small dataset of 92 cows and reached a sensitivity of 76% and a specificity of 93% (Viazzi *et al*., 2013b).
Therefore, the aim of this study was to quantify the classification performance of the algorithm developed by Viazzi *et al*. (2013b) on a bigger dataset, constructed with data from multiple days.

## Materials and Methods

<u>3D Camera Setup</u>

Data were obtained by the Agricultural Research Organization (ARO) in a commercial dairy farm in kibbutz Yifat, Israel. All cows were housed in separate no-stall fully roofed open cowsheds with dried manure bedding material. The 3D-camera was located behind an after-milking sorting gate. In order to make the cows walk in the camera field of view, a mobile narrow corridor (maximum width = 2.10 m; minimum width = 1.00 m) was built directly after the sorting gate. The sorting gate and the 90 degrees-turn in the corridor provided the necessary time delay between every two successive cows. After a data collection session, the construction can be packed along the walking path, where it did not interfere with the farm routine.
Cow gait was recorded at 30 fps with a Microsoft Kinect Xbox 3D-camera (Kinect™, Microsoft corp., Washington, USA). The camera was positioned in top down perspective, 3.20 m above ground level. A photocell (HRTL 96B™, Leuze electronic GmBH, Owen, Germany) was used to trigger the video recording. This photocell was located 0.5 m before the beginning of the camera field of view, and was linked to a programmable logic controller (NI USB-6501, National Instruments, Austin Texas, USA). The controller was set to record four seconds in order to have only one cow per video. The camera was connected to an operating computer through a USB-port.

After each data collection session, the construction was packed along the walking lane path, where it did not interfere with the farm routine. The recorded videos contained a depth recording (for 3D-reconstruction) and a RGB-recording and were saved as .oni-files to a 1TB hard disk (Western Digital, Irvine California, USA). The OpenNI 1.0 Software Development Kit framework (www.openni.org, last accessed at 24 March 2012) was used to make recordings with the Kinect camera.
Due to the sunlight sensitivity of the cameras, data were collected during four consecutive night milking sessions. External artificial light sources were installed around the video corridor, but not pointing directly to the sensor, to increase cow visibility for locomotion scoring and visual identification.

Locomotion Score Reference

During each data collection period, cows passing the corridor were on-the-spot manually locomotion scored by a trained observer (so called '*locomotion score*', '*LS*' or '*reference*'). The locomotion scoring was based on the discrete 5-point numerical score of Sprecher *et al.* (1997) [1=healthy; 5= severely lame].

3D Video Analysis

All videos were analyzed by a MATLAB Runtime Compiler (Matlab® R2011b, The MathWorks©, Inc, Natick, MA, United States) software package performing the procedures described by Viazzi *et al.* (2013b) and Poursaberi *et al.* (2010). The software analyzed on average 4.9 ± 2.7 frames per video in which a full cow body shape could be segmented from the depth image. The body movement pattern (BMP) was calculated as the median value of all processed frames in the video. The BMP-output ranged from 0.13 to 0.33. The calculation of BMP was described earlier by Viazzi *et al.* (2013b). The software automatically analyzed all videos. The cows in the video were manually identified based on the recorded RGB-video frames.

Data Selection

The last six groups of the milking herd (approximately 500 cows) were followed. These groups consisted of multiparous cows and lameness prevalence was highest in these groups. In four consecutive data collection periods, 1436 complete cow-observations were done. A complete observation consisted of a live locomotion score by the observer and a successfully recorded video. For the further analysis of the data, the four consecutive locomotion scores did not vary more than one numerical unit to reduce human errors in the reference.

Classification Procedures

The algorithm score (AS) was compared to LS. In order to put the BMP-score on the same scale as the LS [classes 1-5], a rescaling of the BMP-values was done with Equation 1, with *min(BMP)* the minimum value of BMP, and *max(BMP)* the maximum value of BMP.

$$AS = 0.5 + 5*[(BMP - min(BMP)) / [max(BMP)-min(BMP)]] \quad (1)$$

The AS-values were transformed to their nearest integer values.
Another approach to put the BMP-score on the same scale as the LS was using four non-equidistant cut-off thresholds. For each combination of cut-off thresholds in the range of [*min(BMP), max(BMP)*], the correct classification rate (CCR) and misclassification rate (MCR) were calculated. The four thresholds that maximized the 5-point CCR were selected as the maximizing CCR-thresholds. The thresholds that minimized the 5-point MCR were selected as the minimizing MCR-thresholds.

<u>Confusion Matrix</u>
A confusion matrix was used to evaluate the classification model output against the LS reference. CCR or accuracy is the proportion of cows that was correctly classified by the model. Sensitivity is defined as the proportion of Lame cows that were classified by the model as Lame. Specificity is defined as the proportion of Not-Lame cows that were classified by the model as Not-Lame.

***5-point Classification.*** In the 5-point confusion matrix, both the reference and the model output are tabulated in 5 levels. The CCR is defined as the sum of the elements on the main diagonal in the confusion matrix.
***Strict Binary Classification.*** The 5-point locomotion score was transformed to a binary score (Lame vs. Not-Lame). Cows that were scored as LS = 1 or LS = 2, were considered to be Not-Lame, and cows that were scored as LS = 3, LS = 4 or LS = 5 were considered to be Lame.

***Tolerant Binary Classification.*** Cows scored as LS = 2 and LS = 3 are the most problematic cases to detect. The strict binary classification hides the 'acceptable' classifications with one unit error in reference groups LS = 2 and LS = 3. For instance a cow scored by the reference as LS = 2 (Not-Lame) and by the algorithm as AS = 3 (Lame) will be classified as a false positive case, while it still falls within the tolerant classification (1 unit error). Therefore, a less strict or tolerant binary transformation was made in order to incorporate these acceptable classifications in the true positives (correctly classified Lame cows) and the true negatives (correctly classified Not-Lame cows). For cows scored by the reference as LS = 1, LS = 4 and LS = 5, a cut-off threshold between 2 and 3 was set. For cows scored by the reference as LS = 3, a cut-off threshold between 1 and 2 was set. This implied that cows with AS = 1, were considered as false negatives, whereas AS $\geq$ 2 were considered as true positives. For cows scored by the reference as LS = 2, a cut-off threshold between 3 and 4 was set, implying that cows with AS = 4 or AS = 5 were considered as false positives, and cows with AS $\leq$ 3 were considered as true negatives.

## Results and Discussion

Strict 5-point classification

- Applying thresholds that maximize 5-point CCR (T1 = 0.17, T2 = 0.21, T3 = 0.25 and T4 = 0.28) resulted in a correct classification rate of 50.4% (Table 1a).
- Applying thresholds that minimize 5-point MCR (T1 = 0.14, T2 = 0.21, T3 = 0.25 and T4 = 0.30) resulted in a correct classification rate of 37.7% (Table 1b).
- Applying equidistant thresholds after rescaling (T1 = 0.17, T2 = 0.21, T3 = 0.25 and T4 = 0.29) resulted in a correct classification rate of 50.1% (Table 1c).

Table 1: Strict 5-point classification. Classification of *n* = 1436 independent cow-observations represented with confusion matrices. The strict and tolerant (Tol.) correct classification rates (CCR) for each confusion matrix are presented below each table.

| | | **(a) Maximizing correct classifications** | | | | | **(b) Minimizing misclassifications** | | | | | **(c) Rescaling** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | | T1 | T2 | T3 | T4 | | T1 | T2 | T3 | T4 | |
| | | 0.17 | 0.21 | 0.25 | 0.28 | | 0.14 | 0.21 | 0.25 | 0.30 | | 0.17 | 0.21 | 0.25 | 0.29 | |
| | | **Reference** | | | | | **Reference** | | | | | **Reference** | | | | |
| | | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **3** | **4** | **5** |
| **Model** | **1** | 440 | 222 | 60 | 13 | 5 | 52 | 13 | 1 | 0 | 0 | 465 | 249 | 69 | 17 | 5 |
| | **2** | 123 | 211 | 95 | 43 | 8 | 511 | 420 | 154 | 56 | 13 | 102 | 186 | 88 | 42 | 10 |
| | **3** | 25 | 46 | 52 | 33 | 18 | 25 | 46 | 52 | 33 | 18 | 21 | 44 | 50 | 30 | 16 |
| | **4** | 1 | 3 | 7 | 14 | 3 | 2 | 4 | 8 | 15 | 6 | 1 | 4 | 7 | 14 | 4 |
| | **5** | 5 | 1 | 1 | 1 | 6 | 4 | 0 | 0 | 0 | 5 | 5 | 0 | 1 | 1 | 5 |
| **Strict CCR** | | 50.4 % | | | | | 37.7% | | | | | 50.1% | | | | |
| **Tol. CCR** | | 87.3% | | | | | 91.4% | | | | | 86.7% | | | | |

**T1, T2, T3 and T4 represent the cut-off threshold values for transforming the continuous algorithm output to a discrete 5-point scale in each categorization. Algorithm output values range from 0.13 to 0.33.**

Tolerant 5-point classification

When allowing a 1 unit error, the 5-point CCR was 87.3% when maximizing correct classifications, CCR was 91.4% when minimizing misclassifications, and CCR was 86.7% when rescaling the BMP-output. In further analysis, the thresholds for maximizing correct classifications were used because it obtained the best strict CCR.

Strict binary classification

Strict binary classification results are presented in Table 2a, and reached a CCR of 78.8%. Sensitivity of strict binary classification was 37.6%, and specificity was 92.5%.

Tolerant binary classification

The tolerant binary classification results are presented in Table 2b. The binary lameness classification led to a CCR of 88.6%, a sensitivity of 64.1% and a specificity of 96.8%.

Table 2: The strict binary (a) and tolerant binary (b) confusion matrix when maximizing correct classifications with $n$ = 1436 cow-observations.

| | | **(a) Strict** | | | **(b) Tolerant** | | |
|---|---|---|---|---|---|---|---|
| | | Reference | | | Reference | | |
| | | **Lame** | **NotLame** | | **Lame** | **NotLame** | |
| **Model** | **Lame** | 135 | 81 | | 230 | 35 | |
| | **NotLame** | 224 | 996 | | 129 | 1042 | |
| **Performance** | | **37.6** | **92.5** | **78.8** | **64.1** | **96.8** | **88.6** |

The results suggest that accurate lameness detection can be done by applying a computer vision algorithm on 3D-camera measurements. Compared to a LS reference, the 3D-algorithm output obtained a CCR of 50.4% on a 5-point level.

Improvement of CCR from 50.4% to 78.8% was achieved when transforming the 5-point scale to a strict binary scale (Lame vs. Not-Lame), a method previously applied by Winckler and Willen (2001), Channon *et al.* (2009) and Main *et al.* (2010). A binary score is simple and easy to understand and it gives an agronomical value to the algorithm output. For practical use, the farmer needs to be informed on which cows are lame and need treatment, and which cows are not lame. On the other hand, a binary classification hides some useful information.

A commonly used cut-off threshold to differentiate between clinical and subclinical lame cows is between LS 2 and 3 (Winckler and Willen, 2001). Cows that were scored as 2 or 3 by the reference or the model had a larger impact on the strict classification, whereas for the tolerant classification these values were still acceptable.

In the presented analysis, cut-off thresholds were determined on a group level. In further research when more consecutive measurements can be available, cow-specific individual cut-off thresholds should be calculated. Viazzi *et al.* (2013a) have shown that using an individual threshold the accuracy of the model can be improved with 10%.

In this study, a 5-point live locomotion scoring (Sprecher *et al.*, 1997) was performed on-the-spot, and served as the reference. This golden standard is known to be subjective and inter- and intra-observer repeatability is low (Flower and Weary, 2009; Schlageter

Tello *et al.*, 2012). Locomotion scoring is however a common used method because it provides an immediate, on-site assessment and it does not require technical equipment (Flower and Weary, 2009). As a tentative to achieve higher reliability in the reference and reduce the subjectivity effect of the scorer, a 1 unit error in the 5-point scale was allowed, and this led to a tolerant CCR of 87.3%.
When allowing a 1 unit error in the binary classification, the tolerant CCR = 88.6%, which is comparable to the study of Viazzi *et al.* (2013b), who achieved a CCR of 90%. Viazzi *et al.* (2013b) however used a strict binary classification and all data were gathered in 1 session.

Poursaberi *et al.* (2010) obtained an accuracy of 96% on a dataset of 184 cows. Their algorithm analyzed the back curvature with the inverse radius variable on 2D side view images. Their side view video recordings however were made in controlled experimental conditions on an experimental dairy farm - not on a commercial dairy farm.
The automatic scoring in our study was only focusing on the arching of the cow's back. Detecting only the back arching as a method to detect lameness was described earlier by Poursaberi *et al.* (2010), Poursaberi *et al.* (2011) and Viazzi *et al.* (2013a). However, when performing a locomotion scoring, the back arching is only one of the indicators (Flower and Weary, 2009; Schlageter Tello *et al.*, 2011). In further research, other parameters such as gait asymmetry and head bob are advised to be included in the 3D-video analysis as well.

Van Hertem *et al.* (2013b) developed an automatic lameness detection model based on behavioural and performance variables that reached 85% model sensitivity and 89% model specificity. Future research should reveal if the combination of both approaches (computer vision and behaviour and performance sensing) increases the classification accuracy of the combined model, and which variables should be included in the combined model.

## Conclusion

A 3D-video based algorithm for lameness detection was validated in real farm conditions and compared with live locomotion scoring.

- Independent cow-observation analysis resulted in a correct classification rate of 50.4%.
- After transforming the algorithm output to a strict binary scale in order to give it a biological meaning, a correct classification rate of 78.8% was obtained.
- When allowing a one unit error as a tentative to reduce observer related errors, a tolerant correct classification rate of 87.3% was obtained.
- By transforming the algorithm output to a tolerant binary scale, a correct classification rate of 88.6% was obtained.

The above-mentioned results should be considered before implementing an automatic lameness detection system in more farms.

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# Sensor data trends are significantly different between Lame and Non-Lame cows

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## Abstract

The hypothesis that sensors available on-farm can detect changes in behaviour and physiology associated with different types of lameness was tested by comparing trends of sensor data from Lame cows with those from Non-Lame cows. Sensor data included data from weighing scales, pedometers and milk meters collected between November 2010 and June 2012 on five pasture-based dairy farms. Data on lameness events were collected by farmers trained in detecting and diagnosing lame cows before the study commenced. For each lameness event (n = 318 events affecting 292 cows), the Lame cow's sensor data for a period of 14 days prior to the day of detection were randomly matched by farm and date to 10 Non-Lame cows. In this period, Lame cows decreased in live-weight, activity, milk yield in the first two minutes of milking, total milk yield and milking duration. Lame cows also entered the milking platform later. In comparison, Non-Lame cows had no change in sensor data trends. These significant differences in sensor data trends imply potential value of sensors available on-farm in detecting lameness. Sensor data patterns of milking order, milk yield in the first two minutes of milking, and total milk yield were significantly different between the different lameness types. Sensor data patterns of live-weight, activity and milking duration were not.

**Keywords:** Dairy cow, Lameness, Sensor data trends, Detection

## Introduction

With New Zealand lameness incidence rates ranging between 16 and 26 new cases per 100 cows per year (Tranter & Morris, 1991; Gibbs, 2010) and with costs estimated at $NZ350 dollars per case (R.N. Chesterton, personal communication), the annual costs for the average New Zealand farm (~400 cows; DairyNZ, 2012) can be estimated at $NZ22,400 to $NZ36,400 (or €14,000 to €23,000). It is, therefore, not surprising that lameness has been grouped with mastitis and infertility as one of the top three cow health issues related to economic losses in the dairy industry (Juarez *et al*., 2003).
Lame cows are usually detected by visual observation of a cow's gait and back posture (Sprecher *et al*., 1997); however, as herd sizes increase along with the number of cows managed per farm labour unit, visual detection of lame cows becomes more challenging. Sensors used for monitoring other aspects of animal health (e.g., pedometers for

automated heat detection and weigh-scales for monitoring body condition) are available on a growing number of farms and are likely to become increasingly popular. It would be worthwhile if this sensor data could also be used for the automated detection of lame cows and in this way better utilise sensor data already available on-farm.
This study hypothesised that sensor data already available on-farm can be used to detect changes in behaviour and physiology associated with cows becoming clinically lame with special emphasis on changes in sensor data patterns related to different types of lameness.

**Materials and Methods**

Ethics approval for this work was obtained through the AgReasearch Ruakura Animal Ethics Committee (AEC 12210) before commencement of the study.

Data collection
A description of data collection and analyses has been provided by Kamphuis *et al.* (2013). In short, data were collected on five pasture-based Waikato dairy farms with a mean herd size of 770 cows, (range 432–1628) between November 2010 and June 2012. All farms had a rotary milking platform (Waikato Milking Systems, Hamilton, New Zealand). All farms except one applied a seasonal spring calving regime; one farm had a split calving herd with cows calving in spring and autumn. Herds comprised predominantly crossbred cows being >75% on three farms. Two farms had a herd comprising 50% Friesian Holstein and 50% crossbred.

Individual cow and sensor data from each milking session were automatically recorded on herd management software (Frontier, Afikim, Kibutz Afikim, Israel) with data files generated daily and remotely transferred via the internet to a central database at DairyNZ (Hamilton, New Zealand). Cow data included cow identification number and days in milk. Sensor data at the cow level included (1) live-weight, (2) activity as the average number of steps per hour between milking sessions, (3) milking order proportional to herd size, (4) milk yield in the first two minutes after teat cup attachment, (5) total milk yield, and (6) milking duration. Participating farmers were trained (Healthy Hoof Programme, DairyNZ Ltd, Hamilton, New Zealand) in detecting and diagnosing lame cows before the study commenced. When a cow was observed as lame, farmers recorded cow identification number, date of observation, affected limb, and type of lameness with categories being (1) Foot rot, (2) Solar damage including Sole Penetration and Bruising, (3) White line disease, and (4) Other, including Interdigital lesion, Overgrowth and Not recorded. Data on other health events (e.g., clinical mastitis events and data on artificial insemination or natural breeding events) that occurred during the collection period were extracted from the herd management software at the end of the data collection period. Sensor data measured at morning and afternoon milkings were averaged to obtain one value per day for each cow. If sensor data were available for one milking only on a particular day, that sensor value was used for that cow for that day.

Definition of Lame and Non-Lame cows

Lame cows were defined as cows with at least one lameness event recorded. To ensure that sensor data were not affected by health events other than lameness or by calving events, any lame events that coincided with a health event recorded from 14 days prior (Day-14) to the date of detection recorded on Day 0 (Day0) till seven days after detection (Day+7) were excluded. Lame events where Day-14 fell within the first 30 days in milk were also excluded. The 22-day time period from Day-14 to Day+7 was considered a Lameness Episode. Lameness Episodes with less than 10 days of sensor data from Day-14 through Day0 were excluded. Each Lameness Episode was randomly matched by farm and date with 10 Non-Lame cows, creating lameness blocks. Non-Lame cows were cows without recorded lameness events during the entire data collection period, without any health event recorded during the matched 22-day time period and with at least 10 days of sensor data from Day-14 through Day0. Each lameness block therefore contained sensor data from one Lame cow and 10 Non-Lame cows. The selection procedure ensured that Lame cows were never eligible to contribute data as a Non-Lame cow and that Non-Lame cows could contribute data to more than one lameness block.

Statistical analyses

Sensor data measured at Day0 through Day+7 were excluded for all cows to prevent sensor data being influenced by management practices after a cow was observed lame. This left a time period running from Day-14 through Day-1 for each cow within each Lameness Episode to be included in the statistical analyses. Differences in sensor data trends for each variable were analysed for Day-14 through Day-1 using a mixed model where the repeated measurements of each cow through time were modelled using an autoregressive first order covariance structure. The mixed model included Day, Lameness and the interaction of these two terms as fixed effects and Lameness Block, Cow within Lameness Block and Day within Cow as random effects. Differences in sensor data trends between Lame and Non-Lame cows are indicated by the interaction term Day within Lame. To test differences in Lameness Type within the Lame group, Lameness Type and the interaction between Day and Lameness Type were added to the first model as fixed effects. Differences in sensor data trends between Lameness Type are indicated by the interaction term Day within Lameness Type. Data preparation was done using SAS (Version 9.2, SAS Institute Inc., Cary, North Carolina, USA). Statistical analyses were conducted using GenStat (Payne *et al.* 2009).

## Results and Discussion

A total of 466 lameness events were recorded during the data collection period. This was much lower than expected based on an annual incidence rate of 16 new cases per 100 cows reported for North Island farms in New Zealand (Tranter & Morris, 1991).

Table 1 The number of cows and the number of Lame cows included in the statistical analyses (total and per farm) and their assigned Lameness Type.

| Farm | Cows (n) | Lame cows (n) | Foot rot | Solar damage[1] | White line | Other[2] |
|---|---|---|---|---|---|---|
| 1 | 914 | 138 | 50 | 31 | 46 | 11 |
| 2 | 539 | 22 | -- | 2 | 13 | 7 |
| 3 | 814 | 54 | 14 | 30 | 7 | 3 |
| 4 | 543 | 57 | 7 | 13 | 27 | 10 |
| 5 | 2094 | 47 | 35 | 1 | 1 | 10 |
| Total | 4904 | 318 | 106 | 77 | 94 | 41 |

[1]Incl. Sole penetration and Bruising. [2]Incl. Interdigital lesion, Overgrowth, and Not recorded

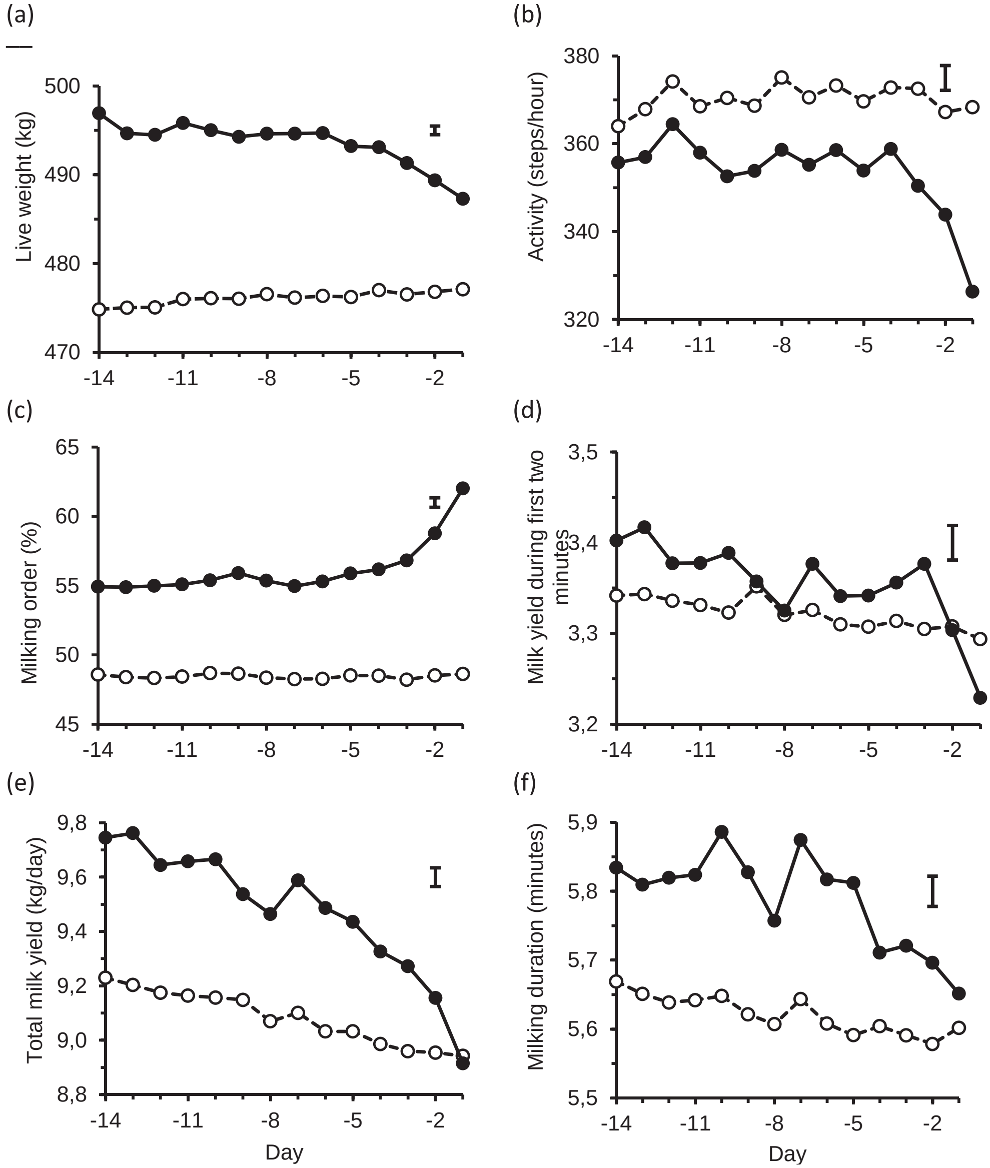


Figure 1 Daily means for Lame (●; n = 318) and Non-Lame (○; n = 3,180) cows for (a) live weight, (b) activity (steps/hour), (c) milking order proportional to herd size, (d) milk yield during the first two minutes, (e) total milk yield and (f) milking duration from Day-14 till Day-1 of lameness event detection. The vertical bars in each plot represent the maximum standard error of the difference for time comparisons within the Lame cow group. Sensor data trends through time of Lame cows differ significantly ($P < 0.05$) from Non-Lame cows for all six sensor-based variables (Source: Kamphuis *et al.*, 2013).

One explanation for the lower incidence found in this study is that farmers have been reported to fail to identify ~75% of lame cows (Whay *et al.*, 2002). The lower incidence could be a result of the farmers having participated in the Healthy Hoof Programme; a programme that assessed farm risk factors, including race conditions and how cows were brought to the milking parlour for milking. These two factors have been identified as major contributors of lameness prevalence (Chesterton *et al.*, 1989). Farmers enrolled in the current study may have reduced lameness risk on their farm based on this Healthy Hoof Programme and as a result lowered the incidence of lame cows. From the 466 events, 318 were included in the statistical analyses; their distribution across farms and their assigned Lameness Type are summarised in Table 1.

Figure 1 plots the daily means for the six sensor-based variables for Lame and Non-Lame cows during the selected time period (Day-14 through Day-1). Over time, Lame cows lost weight, decreased their activity, entered the milking parlour later, had a decreased milk yield in the first two minutes and a decreased total milk yield, and it took less time to milk them. These sensor data trends through time differed significantly ($P<0.05$) between Lame and Non-Lame cows for all six sensor-based variables. These results are in agreement with previous studies reporting that lameness affected a cow's normal behaviour: lame cows have been reported to increase their lying time (Juarez *et al.* 2003), spend less time walking and enter the milking parlour later (Walker *et al.* 2008) than non-lame cows. Lameness has also been reported to reduce milk production (Green *et al.* 2002) and body condition (Walker *et al.* 2008).

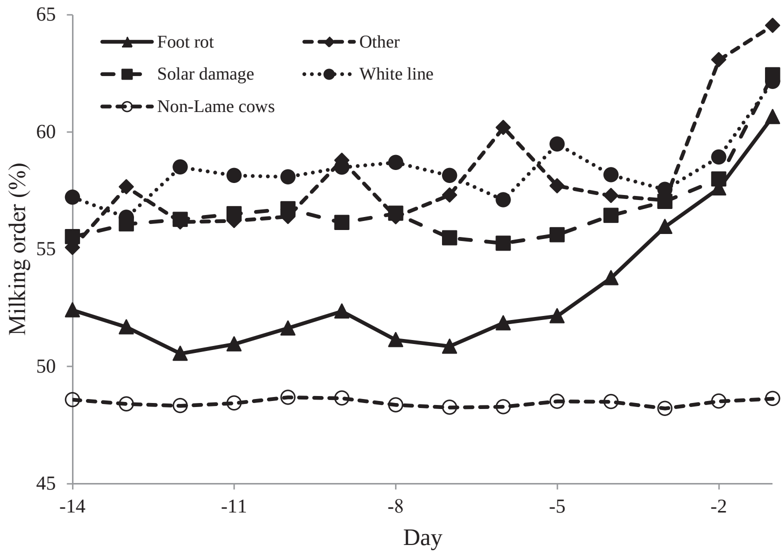


Figure 2 Average daily values for milking order proportional to herd size for Lameness Type and for Non-Lame cows from Day-14 till Day-1 of lameness detection. The sensor data trends through time differs significantly ($P <0.01$) between Lameness Types.

Figure 2 demonstrates that there is a significant difference (P<0.01) in sensor data pattern changes for milking order between the different Lameness Types. Whereas cows diagnosed with Foot rot had a slow but steady increase in milking order, cows diagnosed with Solar damage had a sudden and more pronounced increase in milking order. Sensor data patterns between Lameness Types were also significantly different for milk produced in the first two minutes and total milk yield (both P<0.05) but not for live-weight, activity and milking duration.

There was a large range in sensor data values for all six sensor-based variables within the group of Lame cows, but also between Lame and Non-Lame cows and among farms. Figure 3 shows this variation for milking order where the difference in milking order between Day-1 and Day-5 was calculated for Lame and Non-Lame cows for each farm. Part of this variation could be attributed to the fact that sensors were not calibrated for study purposes. It could be debated whether it was better to use calibrated data from validated sensors. However, this study focussed on the potential of currently commercially available sensors as used on-farm for the automated detection of lameness, regardless of whether these sensors were calibrated often, as a normal maintenance practice, or not at all.

The large variation in sensor data implies that models using a one sensor-based variable are unlikely to be good enough to predict lameness. Predicting the type of lameness will be even more challenging with fewer sensor-based variables significant differences in sensor data trends. The results imply that multiple sensor data have to be combined to improve detection performance, and that the primary focus should be on predicting or detecting lame cows and not on predicting the type of lameness. Combining sensor data

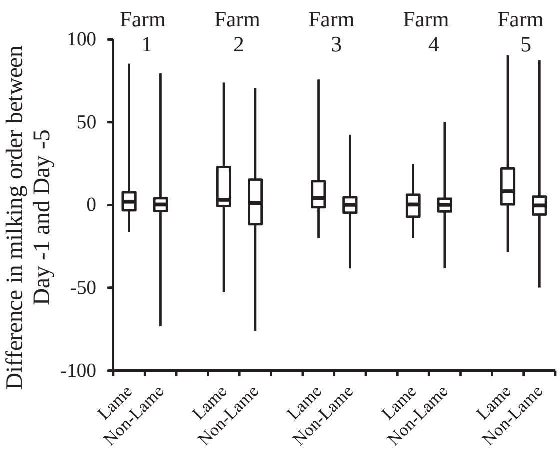


Figure 3 Box plots for the difference in milking order proportional to herd size between Day-5 and Day-1 before lameness detection for Lame and Non-Lame cows on each farm. The length of each box represents the interquartile range (distance between 25th

and 75th percentile) with the group median presented by the horizontal line within the box. Each whisker indicates the range of values on that side of the median.
to improve model performance has proven to be valuable for automated detection of clinical mastitis (Kamphuis *et al*. 2008). Future research should focus on the combinations of variables that show the best potential to develop an automated lameness detection model.

## Conclusions

Lame cows have significantly different behavioural and physiological sensor data trends compared to non-lame cows. Sensor data patterns of milking order, milk yield in the first two minutes, and total milk yield were significantly different between the different types of lameness. These results imply potential value of using sensors currently available on-farm to predict lame cows. However, the large variation in sensor data values suggests that a future detection model is likely to benefit from combining sensor data.

## Acknowledgements

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## Haematology profiles of dairy cows with claw horn disorders

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### Abstract

Claw horn disruption (CHD) in dairy cows weakens the integrity of the hoof, results in lesions ranging in severity from mild haemorrhages to ulcers, and can cause lameness and pain. Haematology profiles of cows with sole ulcers (the most severe pathology associated with CHD), and of cows with moderate and severe haemorrhaging, were examined. Study 1: 12 cows clinically lame due to solar ulceration were identified using locomotion and hoof scoring. These were paired with cows (sound) of similar lactation number, days in milk (DIM). Body condition score (BCS), and liveweight, that had healthy feet. Study 2: Cows (n = 41) were locomotion and hoof scored at 111 ± 23 DIM, then assigned to 3 categories on the basis of haemorrhage score; 1 = no/minimal haemorrhage, 2 = moderate haemorrhage; 3 = severe haemorrhage. Blood samples for both studies were taken via jugular venipuncture on the morning of hoof scoring. Total leukocyte, neutrophil (N), lymphocyte (L), monocyte, eosinophil and basophil counts were determined within 3 hours of blood collection from $K_3$EDTA anti-coagulated blood (6 mL) using an automated haematology analyzer (ADVIA 2120, Bayer Healthcare, Siemens, UK). All data were analysed using PROC MIXED in SAS v9.1. Study 1: Cows with ulcers had higher locomotion scores than sound cows (13.5 ± 0.54 versus 6.7 ± 0.54; $P < 0.001$). There was no difference in total leukocyte counts, neutrophil, lymphocyte, or monocyte count, or of eosinophil or basophil count and percentage. However cows with ulcers had higher neutrophil % ($P<0.05$) and tended to have a lower lymphocyte % ($P=0.1$) than sound cows. Ulcer cows had a higher N:L ratio (1.04 ± 0.1) than sound cows (0.76 ± 0.1; $P = 0.05$). Study 2: There was no effect of haemorrhage category on locomotion score or on any haematology variable. Cows that were clinically lame with sole ulcers had a leukocyte profile indicative of systemic inflammation and stress. A similar pattern was not evident in study 2. It is possible that only CHD severe enough to cause clinical lameness, and thus a sickness response, affects leukocyte profiles.

**Keywords:** Lameness, blood profiles, leukocytes, hoof health

### Introduction

Lameness is a significant economic factor for the dairy industry and an indicator of pain and compromised animal welfare. Several scoring systems that consider posture and

gait have been proposed to allow categorization of lameness by severity. However, these methods are observer dependent and thus lack reliability. The use of objective markers of locomotion abnormalities, immune and neuroendocrine activation for detection of inflammatory foot lesions that cause pain and lameness in dairy cows is warranted.
If lameness is detected accurately and early, lameness prognosis and the overall welfare of the cows may be enhanced. Furthermore, the magnitude of locomotor variability of dairy cattle at walk is unknown and needs to be explored. Locomotion variability dictates the number of trials necessary to have a representative profile of the animal's motion. Although gait changes are useful indicators of hoof discomfort associated with inflammatory and painful lesions these changes might also indicate conditions that are not animal welfare concerns. For example, factors such as physical constraints (e.g, distended udder, conformational abnormalities, and rough flooring surfaces) are known to alter locomotion in otherwise sound cows. Therefore, it is unlikely that gait changes alone will provide accurate detection of lameness caused by painful inflammatory foot lesions.

Physiological markers (biomarkers) amenable of objective measurement may be useful in lameness diagnosis. This alternative dimension of measures encompasses the changes within the immune and neuroendocrine systems in response to tissue injury and infection. For example, cows with behavioral alterations indicative of lameness from painful inflammatory foot lesions have lower serum dehydroepiandrosterone (DHEA) concentrations and higher cortisol:DHEA ratio (Almedia *et al.*, 2007). These hormonal changes are characteristic of pituitary-dependent adrenal response stimulation, and, along with the sickness behaviors, they provide evidence to support the assumption that a sensitization of the central nervous system occurred in the subjects suffering from inflammatory painful foot lesions.

These findings by Almedia *et al.* (2007) characterized a potential dysregulation of the HPA axis and cortisol:DHEA ratio which are known to cause immunological changes that may predispose to pathologies by altering TH1/TH2 balance. DHEA favours a TH1 immune response by increasing IL-2 production, and decrease synthesis of proinflammatory cytokines such as IL-6 and TNF-α, while cortisol favours a TH2 response by suppressing production of IL-12.

Overall, systemic physiological changes detected in blood provide a novel spectrum to be explored in future lameness studies and foster the possibility of having objective measures available for diagnosis of important diseases that debilitate the welfare of animals, such as lameness detection. The objective of the studies were: 1), to compare the leukocyte profiles of cows with sole ulcers (the most severe pathology associated with CHD) and healthy cows (Study 1), and 2), to compare the leukocyte profiles of cows with moderate and severe sole haemorrhaging with healthy cows (Study 2).

## Materials and methods

Care and Use of Animals

All animal procedures performed in this study were conducted under experimental licence from the Irish Department of Health and Children in accordance with the Cruelty to Animals Act 1876 and the European Communities (Amendment of Cruelty to Animals Act 1876) Regulation 2002 and 2005.

Study 1: Cows with ulcers versus sound cows

- Lactating cows locomotion scored weekly, lame cows hoof scored
- Lame cows with ulcers but no other disorders: n =12
- Matched with a healthy cow by days in milk (DIM), liveweight, BCS and diet

Study 2: No to mild, versus moderate versus severe haemorrhages

Cows (n = 41) locomotion and hoof scored at 111 ± 23 DIM

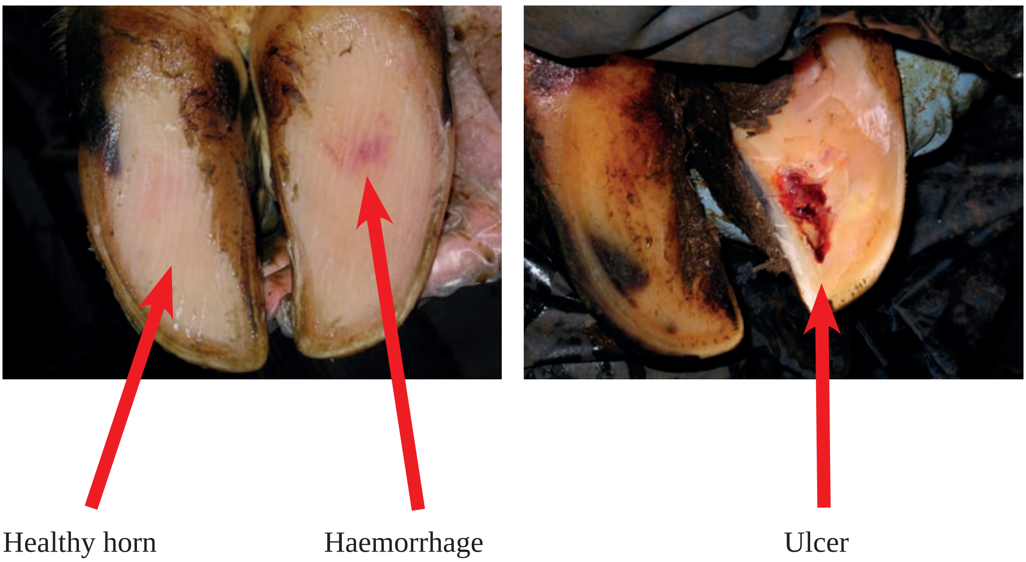
Placed in one of 3 categories: No to mild, moderate or severe haemorrhage

Locomotion scoring

Five aspects of locomotion were scored on a scale from 1 to 5: spine curvature, tracking up, ab/aduction, Speed, and head bob (O'Driscoll *et al*., 2010). These five aspects were summated to give one overall locomotion score per cow.

Hoof scoring

Hind feet lifted, and both claws examined for presence of infections, mechanical or chaemical trauma, and sole ulcers and haemorrhages (O'Driscoll *et al*., 2008).



Haematology profiles

Blood samples for both studies taken on the morning of hoof scoring were collected into 1 × 6 mL $K_3$Ethylenediaminetetraacetic acid ($K_3$EDTA) tube (Vacuette, Cruinn Diagnostics, Ireland) by jugular venipuncture for haematological analysis Jugular venipuncture into 6ml $K_3$EDTA tubes. Total leukocyte, neutrophil, lymphocyte, monocyte, eosinophil and basophil number and percentage (%) were determined using an automated haematology analyzer (ADVIA 2120, Bayer Healthcare, Siemens, UK).

## Results and Discussion

There was no difference ($P>0.05$) in neutrophil number, lymphocyte number, eosinophil percentage or number, basophil percentage or number, monocyte percentage or number, between cows with ulcers and sound cows. The multifactorial nature of lameness, and inappropriate level of understanding of the pathophysiology and etiology of different lameness types impairs the progress with objective biomarkers discovery for this condition and consequently, slows down the development of effective therapies and prevention strategies for this condition. In addition to boosting diagnostic reliability, the prospect of developing such biomarkers of inflammatory and painful related-lameness lesions could help identify animals in need of pain relief and provide appropriate targets for the development and monitoring of novel lameness therapies.

**Study 1:** Cows with ulcers versus sound cows

Cows with ulcers cows had higher ($P<0.05$) locomotion scores than sound. They had a higher percentage of circulating neutrophils (Figure 1), and a tendency for a lower lymphocyte percentage, which resulted in a higher neutrophil lymphocyte ratio (Fig. 2).

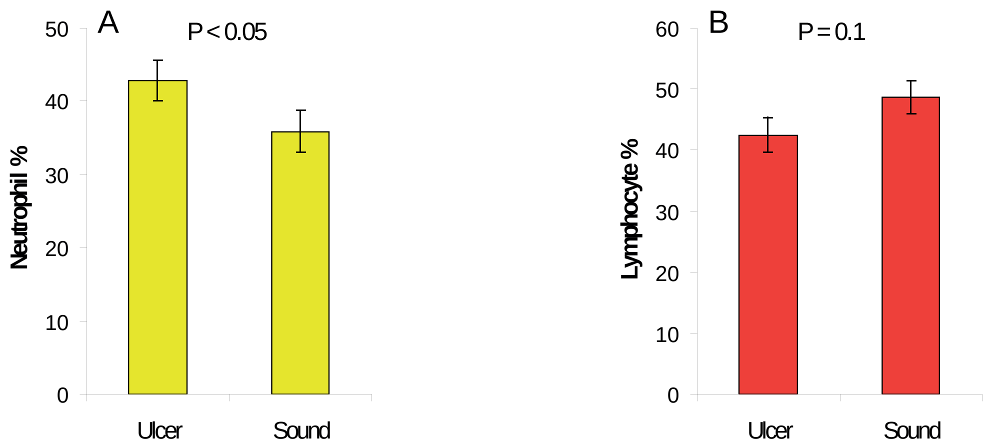



Figure 1. Neutrophil % (A) and lymphocyte % (B) of cows with ulcers and sound cows

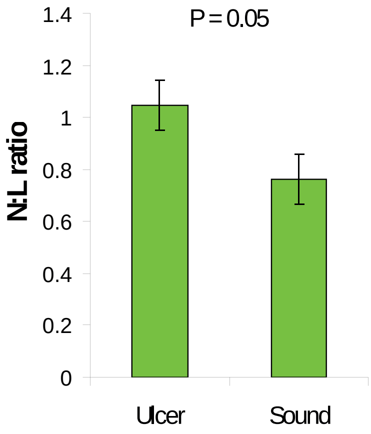



Figure 2. Neutrophil-lymphocyte (N:L) ratio of cows with ulcers and sound cows

In study 2, cows were locomotion and hoof scored at approximately 3 months post partum. They had sole haemorrhages scores ranging from 0 to 91 (higher scores = worse sole damage), but no other hoof pathology, or other health disorder. Blood samples were taken on the same day as hoof and locomotion scoring were carried out.

Sole haemorrhage score was increased (worsened) in cows and there was no difference in locomotion score between groups. There was also a tendency for cows with sole damage to have a higher neutrophil:lymphocyte ratio (Table 1).

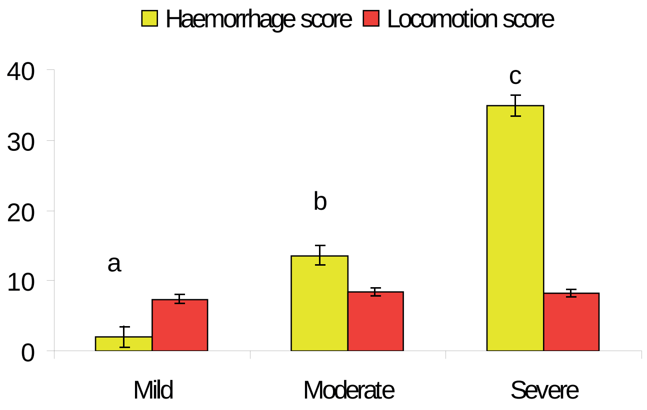



Figure 3: Mild, moderate and severe haemorrhages

Cows were split into 3 groups by haemorrhage score. There was no difference in locomotion score between groups. There was no effect of group on any of the haematological variables.

Table 1: Haematology variables in cows with mild, moderate, and severe haemorrhages.

| **Haemorrhage category** | **Mild (n = 10)** | **Moderate (n = 20)** | **Severe (n = 11)** | ***P*-value** |
|---|---|---|---|---|
| WBC number ($10^3$ cells/µL) | 8.24 ± 0.74 | 9.01 ± 0.52 | 8.40 ± 0.74 | 0.64 |
| Neutrophil (N) number ($10^3$ cells/µL) | 3.09 ± 0.42 | 3.42 ± 0.30 | 3.39 ± 0.42 | 0.80 |
| Neutrophil % | 37.2 ± 2.3 | 37.7 ± 1.6 | 39.0 ± 2.3 | 0.84 |
| Lymphocyte (L) number ($10^3$ cells/µL) | 3.8 ± 0.4 | 4.2 ± 0.3 | 3.8 ± 0.4 | 0.53 |
| Lymphocyte % | 42.6 ± 2.9 | 40.0 ± 2.5 | 42.6 ± 2.7 | 0.65 |
| N:L ratio | 0.87 ± 0.11 | 0.85 ± 0.08 | 0.91 ± 0.11 | 0.91 |

## Conclusions

Cows that were clinically lame with sole ulcers had a leukocyte profile indicative of systemic inflammation and stress, a similar pattern was not evident in study 2. It is possible that that only CHD severe enough to cause clinical lameness, and thus a sickness response, affects leukocyte profiles

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## Automatic back posture evaluation in dairy cows using a 3D camera

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### Abstract

This study tested and evaluated a computer vision technique to automatically detect lameness in dairy cows. A three-dimensional camera system was used to extract the back posture of the animals automatically from a top view perspective. Four parameters to describe the curvature of the cow's back were used in a decision tree to classify cows as lame or not lame. The experiment was conducted at a commercial Israeli dairy farm and a dataset of 273 cows was recorded by the three-dimensional camera. The classification performance of the 3D algorithm was evaluated against the visual locomotion scores awarded by an expert veterinarian. The analysis resulted in a sensitivity of 75.0% and a specificity of 98% on a 2-point level scale (lame or not lame). These results show that it is possible to use a 3D camera in dairy farming in order to develop a fully automatic lameness monitoring tool for dairy farming.

**Keywords:** dairy cow, lameness, computer vision, back posture

### Introduction

Lameness can be defined as the deviation in gait resulting from pain or discomfort from hoof or leg injuries (Flower and Weary, 2009).

Lameness in dairy cows is a painful condition that reduces productivity and animal welfare (Bruijnis *et al*., 2012). Economic losses due to lameness are incurred as a result of treating the animaland decreased milk yield (Green *et al*., 2002; Archer *et al*., 2010), reduced reproductive performance (Sprecher *et al*., 1997; Garbarino *et al*., 2004), increased culling risk (Barkema *et al*., 1994; Booth *et al*., 2004) and increased production costs (Cha *et al*., 2010).

Diagnosis of lameness on dairy farms relies on visual locomotion scoring of different gait and posture parameters such as gait asymmetry, head bopping and back curvature (Schlageter-Tello *et al*., 2011).

However, a visual scoring method is not feasible in today's intensive farming because it is too time-consuming. An automatic lameness monitoring system can therefore

facilitate an increase in welfare and a reduction in losses for the farmer.
Several computer vision applications based on the cow's body shape have been developed in the dairy business (listed by Halachmi et al 2008 JDS) but, as yet, no 3D application has being developed for automatic lameness detection.
The objective of this study is to evaluate the use of a 3D camera to automatically detect lameness in dairy cattle.

## Material and methods

Experimental setup

The experimental data were gathered in May 2012 at a large dairy farm located in Kibbutz Yifat, Israel. The herd size of the farm was 951 lactating Israeli-Holstein cows with an average milk yield of 11,500 kg/year per cow. The cows were divided into 11 groups according to health and production status (group size: 96±12 cows). All cows were milked three times a day in a 2 x 32 side-by-side milking parlour.
A 3D Kinect camera (Microsoft corp., Redmond, WA) was used to record the walking cow after milking. The depth sensor of the 3D camera had a 57° horizontal and 43° vertical angular field of view and a maximum image throughput of 30 frames per second. The camera could provide a depth image size of 640 x 480 pixels with 1 cm resolution at a distance of 2 m from the cow.
The 3D camera was placed 3.15 m above a corridor (width: 0.7-1.1 m) so that the cow flow would be in single file. As the sensor was highly sensitive to sunlight, the experiment was carried out at night, using the last 4 milking groups of cows that comprised 339 cows in total. These groups were chosen because the lameness prevalence was higher in these groups.

Automated lameness detection algorithm

The algorithm for evaluating the back arch using the 3D camera recordings was developed and evaluated in Matlab (R2010b, The MathWorks Inc., MA), using a workstation with a 2.40 GHz dual-core processor and 3 GB of RAM with Windows 7 installed. The algorithm consisted of three steps:

- *Cow segmentation*

The cow was segmented from the background by applying a lower threshold $t1$ ($t1$ = 1400 disparity) and an upper threshold $t2$ ($t2$ = 2200 disparity) to the disparity value of the 2D matrix representing the depth information from the Kinect camera.

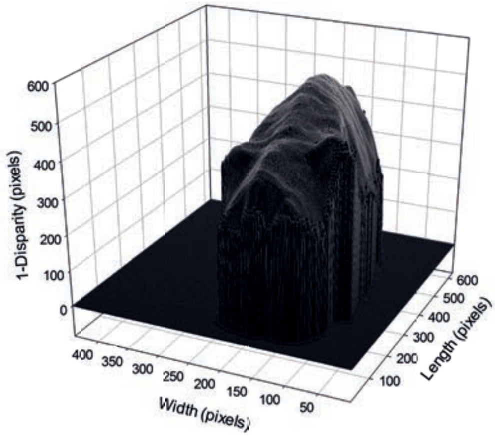

Figure 1. Mesh graph of the segmented cow shown from the rear.

Afterwards, the area of each object detected was calculated. The objects with an area smaller than 8000 pixels (85% of the average area of a cow in pixels) were filtered out. If objects remained after this filtering process, the object with the biggest area was considered to be the segmented cow (Figure 1).

- *Parameter extraction*

After the cow was segmented, the curvature of the back was extracted and four parameters were calculated and used to assess lameness (Figure 2). $\theta_1$ represented the curvature of the front part of the animal's body around the shoulders, $\theta_2$ represented the curvature of the back part around the hip, while $\theta_3$ and $L_1$ contained information relating to the overall curvature.

In order to calculate these parameters, the highest point ($R$) in the total curvature of the animal's back was used as a starting point. Two ellipses were fitted to the left and right side of point $R$ and their orientations $\theta_1$ and $\theta_2$ were calculated. The intersection between the two lateral axes of both ellipses was determined and the resulting anglewas calculated. $L_1$ was the vertical distance between this intersection point and $R$.

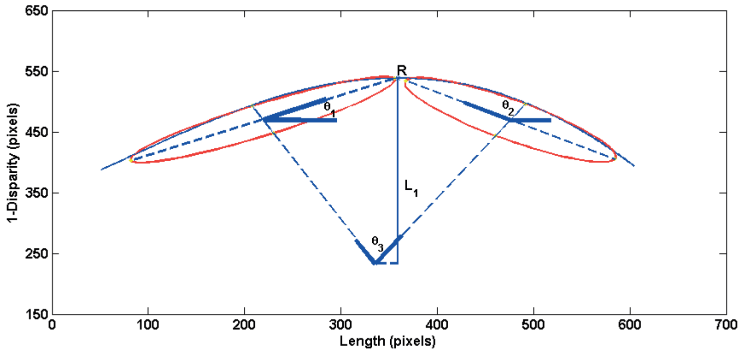

Figure 2. Parameters $\theta_1$, $\theta_2$, $\theta_3$ and $L_1$ extracted from the back curvature of the cow.

- *Lameness classifier*

Decision tree learning (Quinlan, 1986) was chosen to classify the parameters extracted from the back posture into the three different lameness classes “Not Lame”, “Lame” and “Severely Lame” according to the scores awarded.
In these tree structures, each branching node represents a choice between two or more alternatives. Every branching node is part of a path to a leaf node. In this research, the leaf node represented the particular classification of the lameness score, based on the given parameter values. The decision tree learning classifier was applied to the dataset, using a 10-fold cross validation in order to avoid over-fitting of the training dataset. This method partitions the dataset into 10 subsamples: a single subsample is retained as validation data while the remaining samples are used as training data. The cross validation process is repeated 10 times, with each of the subsamples used once as validation data. WEKA 3.6.1 (Hall *et al.*, 2009) was used to evaluate classifier performance by calculating different metrics (Table 1).

Table 1. Performance measure used for the classifier.

| Measure | Formula | Description |
|---|---|---|
| True Positive (TP) Rate | TP/(TP+FN) | The proportion of positive instances that are correctly classified as positive |
| False Positive (FP) Rate | FP/(FP+TN) | The proportion of negative instances that are erroneously classified as positive |
| Accuracy | (TP+TN)/(TP+FP+TN+FN) | The proportion of instances that are correctly classified |
| Precision | TP/(TP+FP) | The proportion of instances classified as positive that are really positive |
| Error rate | (FP+FN)/(TP+FP+TN+FN) | The proportion of instances that are incorrectly classified |

<u>Scoring method</u>

A veterinarian with expertise in lameness scored all the cows visually using the five-point Flower and Weary locomotion score (2006). Scores varied from 1 (normal walking) to 5 (severely lame) and were based on observation of 5 gait attributes: flatness of back, steadiness of head carriage, tracking up, asymmetry of gait and reluctance to bear weight.
By the end of the experiment, 273 different cows had been scored by the veterinarian and automatically scored by the system.
To increase the expert’s reliability (Engel *et al.*, 2003, O’Callaghan *et al.*, 2003), the five-point scoring scale was simplified into a three-point score. Scores 1 and 2 referred to cows classified as ‘Not Lame’. Score 3 referred to cows that were ‘Lame’. Scores 4 and 5 referred to cows classified as ‘Severely Lame’.

## Results and discussion

Table 2 and Table 3 illustrate the results of the decision tree classifier applied to the dataset by using 10-fold cross validation.

Table 2. Confusion matrix of the decision tree classifier using 10-fold cross validation.

| | | Classified by the algorithm | | |
|---|---|---|---|---|
| | | 'Not Lame' | 'Lame' | 'Severely Lame' |
| Classified by the expert | 'Not Lame' | 217 | 3 | 2 |
| | 'Lame' | 10 | 17 | 8 |
| | 'Severely Lame' | 3 | 9 | 4 |

As the confusion matrix (Table 2) shows, 217 'Not Lame', 17 'Lame' and 4 'Severely Lame' instances were correctly classified. Overall 87% of the instances were correctly classified with a TP rate of 87%, a FP rate of 22%, an accuracy of 93%, a precision of 86% and an error rate of 7% (Table 3).
However, the results indicate that the TP rate and precision are only high when detecting instances of 'Not Lame' cows. While the TP rate here is 98%, it is only 49% for 'Lame' and 25% for 'Severely Lame'.
However, as demonstrated by Table 2, most of the classification errors were between 'Lame' and 'Severely Lame' cows. When a binary classification ('Lame' and 'Not Lame') is used instead of three classes, 'Severely Lame' and 'Lame' cows are both classified as 'Lame' cows. As expected, the metrics of the classifier improve, as shown in Table 4 and Table 5.
The performance measure of the classifier remains the same for 'Not Lame' cows, while the TP rate and precision of 'Lame' cows increases to 75% and 88%, respectively (Table 5).

Table 3. Result of the decision tree classifier using 10-fold cross validation.

| Classified by the expert | TP Rate | FP Rate | Accuracy | Precision | Error rate |
|---|---|---|---|---|---|
| 'Not Lame' | 0.977 | 0.255 | 0.934 | 0.943 | 0.066 |
| 'Lame' | 0.486 | 0.05 | 0.890 | 0.586 | 0.110 |
| 'Severely Lame' | 0.25 | 0.039 | 0.919 | 0.286 | 0.081 |
| Weighted Average | 0.872 | 0.216 | 0.928 | 0.859 | 0.072 |

Table 4. Confusion matrix of the decision tree classifier using 10-fold cross validation and binary classification.

| | | Classified by the algorithm | |
|---|---|---|---|
| | | ‘Not Lame’ | ‘Lame’ |
| Classified by the expert | ‘Not Lame’ | 217 | 5 |
| | ‘Lame’ | 13 | 38 |

Table 5. Results of the decision tree classifier using 10-fold cross validation and binary classification.

| Classified by the expert | TP Rate | FP Rate | Accuracy | Precision | Error rate |
|---|---|---|---|---|---|
| ‘Not Lame’ | 0.977 | 0.255 | 0.934 | 0.943 | 0.066 |
| ‘Lame’ | 0.745 | 0.023 | 0.934 | 0.884 | 0.066 |
| Weighted Average | 0.962 | 0.240 | 0.934 | 0.940 | 0.066 |

Table 4 shows that 5 ‘Not Lame’ cows were incorrectly classified by the algorithm as ‘Lame’ and 13 ‘Lame’ cows were incorrectly classified as ‘Not Lame’.

The misclassification of ‘Lame’ cows was probably due to the fact that cows presented a natural arched back. In further research, this error can be corrected by using an individual model that considers the natural posture of each cow and detects deviation from the natural posture on an individual level. Cows are, in fact, different from each other, for example in terms of udder size and natural back arch. The back posture of the animals is therefore never identical and the animals are bound to react individually to lameness (Viazzi *et al*., 2013).

The misclassification of ‘Not Lame’ cows was due to the fact that some of the cows did not present a back arch, even if they were lame. The back arch is in fact a valuable variable that can be used to detect lameness in dairy cattle and can be extracted by vision techniques (Poursaberi *et al*., 2010; Pluk *et al*., 2010). As soon as the animal feels pain while standing or walking, it is reluctant to bear weight on the injured leg and consequently shifts the weight towards the contralateral limb (Neveux *et al*., 2006). As a result, the cow tends to increase the curvature of the back and to lower her head.

Lame cows tend to increase the curvature of the back but this is not the only sign that the expert uses to score lameness: steadiness of head carriage, head bopping, tracking up, reluctance to bear weight and asymmetry of gait are further variables to be taken into consideration when detecting lameness visually. The use of only one variable can explain the misclassified instances and the sensitivity of around 75%. However, it can be argued that the back arch proved to be suitable for lameness detection when only one single variable can be used in real farm conditions.

Computer vision techniques have the advantage of providing continuous information without handling the animals or applying sensors to them. Even though computer vision techniques can be used to detect lameness, it is difficult to obtain reliable and fully automated segmentation of walking cows or to extract useful parameters by means of computer vision techniques on commercial dairy farms by means of image segmentation using a 2D side view camera (Van Hertem *et al*., 2013).

The 3D camera method proved to be suitable for an automated lameness detection system. An advantage of using a 3D top view approach compared to a 2D camera is the fact that animals can be classified even if they are walking side by side. Moreover, the back arch extraction could be more precise with the 3D camera than with the 2D camera because the 3D camera can discriminate the spine whereas the 2D camera cannot discriminate the spine from the hipbones, which obstruct the view of the spine. A major advantage of the 3D approach is that it does not need a complex algorithm to segment the cow and can therefore be applied in real time. However, use of a 3D camera also has limitations. The camera currently in use was developed for indoor applications. Although it is not sensitive to artificial light, the camera is very sensitive to natural light. Therefore, the experiment, which was conducted in an outdoor area, had to be carried out at night. Another limitation of this camera is the small field of view, which meant that only a few frames (2.56±0.9) in which the cow's entire back was in the camera view could be extracted and used for lameness classification.

Notwithstanding these limitations, the main objective of this study was to test the feasibility and performance of using a 3D camera for automatic lameness detection. The study demonstrated that the 3D approach is reliable, but further studies should also evaluate the system's performance when applied to a larger number of animals, different breeds and farming conditions that are different from those in Israel.

## Conclusion

The use of an automated algorithm for monitoring lameness in dairy farms, which was based on 3D camera recordings, was tested on 273 cows under farm conditions in Israel. The algorithm did not discriminate between 'Lame' and 'Severely Lame' cows with a satisfactory level of accuracy. However, when the classification was on a 2-point level scale ('Lame' or 'Not Lame'), the analysis produced a sensitivity of 75.0% and a specificity of 98% under 10-fold cross-validation. Due to the very good segmentation features of the 3D camera, a fully automatic image processing algorithm to calculate and assess the back curvature of dairy cows for lameness detection in real time is feasible.

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## Session 3

## PLF: Socio-economics and ethics

# Precision feeding – A developing countries perspective for sustainable ruminant production

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## Abstract

Precision feeding, as understood in developed countries, requires feed resources of high quality and their delivery to animals in a disciplined manner using smart engineering and computerised technologies to maximise productivity. However, it may not be possible to achieve this in extensive, mixed extensive and mixed crop-livestock production systems in developing countries due to a lack of resources and infrastructure as well as a lack of knowledge and technical skills on the part of farmers. A large percentage of milk and meat is produced through these systems in developing countries and these systems contribute substantially to the total world production of animal products. For these diverse systems, an alternative term for *precision feeding* is *balanced feeding* which aims to provide nutrients that match animal nutrient requirements in a manner that fits the production system. There are examples of ration balancing in developing countries, mainly in the mixed crop-livestock systems, that employ a high degree of precision in creating balanced diets using the nutritive value library of feed resources and nutrient requirements based on the physiological stage of animals and the production objective of rearing the animals. The aim in developing countries should be to practise the concept of ration balancing using ‘smart feeding’ approaches (strategic use of available feed resources, preferably local ones) to meet the physiological needs of the animals. A large impact can be elicited using these approaches.

**Keywords:** Ration balancing, Precision feeding, Smart feeding, Feed analysis, Livestock productivity

## Background and context

The future is characterised by a growing world population and increased demand for more and better food due mainly to increasing incomes in developing countries. By 2050 the world will need to feed an additional 2 billion people and will require 70% more meat and milk than current consumption levels (FAO, 2009 a,b). This is amidst growing concerns over land, soil and water scarcity (agriculture accounts for 70% of all freshwater use), on-going global warming and frequent and drastic climatic vagaries. These factors, along with increased competition for arable land and non-renewable resources such as fossil carbon sources, water and minerals (such as phosphorus), pose a great challenge to the sustainability of feed and food production systems. There is a huge shortage of feeds and fodder in developing countries (Makkar, 2012). In addition to broadening the feed resource base by identifying novel feeds, efficient use of available feed resources is a key to the sustainable development of the livestock sector. It is the feed that drives livestock production while animal reproduction and breeding, and animal health and welfare, play supporting albeit important roles. Increasing the efficiency of feed resource use represents a major objective of livestock production both in the developed and developing world, because feed can account for up to 70% of the total cost of production. In addition, feed has an impact on animal productivity, greenhouse gas emission, animal health, product safety and quality and animal welfare. This objective is consistent with approaches aiming to alleviate poverty, increase animal productivity, decrease natural resource degradation and protect the environment.

By 2050, the world will require an estimated additional 1.3 billion tonnes of grain, of which it is estimated that 40% would be used for feeding livestock, mainly pigs and poultry (IAASTD, 2009). Given this scenario, it would be prudent to provide the ruminant sector with an impetus that relies on locally available feed resources and especially forages and agro-industrial by-products. Since a large number of ruminant animals are kept by smallholder resource-poor farmers, such an approach would help lift them out of poverty and could provide growth that is socially equitable, financially cost-effective and ecologically sound. In 2011 the world cattle and buffalo population stood at 1.6 billion while that of small ruminants (sheep and goats) was 1.9 billion, with an overall increase of 8% for large ruminants and 6% for small ruminants since 2000 (FAOSTAT, 2011). Currently, in addition to contributing approximately 14% to total global meat production, the ruminant sector produces 725 million tonnes of milk. It is also interesting to note that the contribution of ruminants can vary considerably between countries and regions. For example in sub-Saharan Africa and the whole of Africa, ruminants make a much higher contribution to total meat production (60 and 57%, respectively) compared with Latin America (39%) and Asia (21%).

According to Powell *et al.* (2013), approximately 37% of global lactating cows have a feed nitrogen use efficiency in milk (NUE-milk) of < 10%. These low efficient cows account for only 10% of the milk production and 33% of the nitrogen excretion globally. A very large proportion (80%) of these lower production cows are found in Africa. For example, Togo, The Gambia, Djibouti and Burundi have the lowest milk production and have NUE-milk of 3.3%, 2.5%, 4.1% and 4.1%, respectively. In contrast, approximately 30% of global lactating cows have NUE-milk between 21% and 25%, and these cows account for 53% of the milk production and 35% of nitrogen excretion globally. Countries such as the USA, Germany, UK and The Netherlands have the highest levels of milk production and have NUE-milk of 25.0, 24.6, 23.1 and 26.8%, respectively. Approximately 3% of the global lactating cows have NUE-milk of > 25% and these cows account for 7% of the global milk production and only 3% of the global nitrogen excretion. The highest levels of NUE-milk (> 30%) are attained in countries such as the Republic of Korea, Thailand, Japan, Canada, Jordan and Cyprus. The partitioning of lactating cows into the NUE milk classes of < 10%, < 20% and < 25% for Africa is 92%, 98% and 100%; for Asia it is 15%, 92% and 97%; and for Central and South America it is 82%, 90% and 100%, respectively. These results suggest that substantial improvement can be achieved in feed management, milk production and NUE-milk. In another FAO global study, most animals in developing countries yield < 2000 kg fat and protein corrected milk (FPCM) per year and the emission intensity (kg carbon dioxide-equivalent produced per kg FPCM) of animals that yield 1000 kg FPCM/year is approximately 5 while that of animals yielding 2000 kg FPCM/year is 3. In contrast, in developed countries that have cows yielding 5000–9000 kg FPCM/year there is a marginal change in the emission intensity, from approximately 1.6 to 1.5 per 1000 kg FPCM/year (Gerber *et al.*, 2011). Thus the increase in NUE-milk and the decrease in the emission intensity of greenhouse gases increase more rapidly at lower than at higher levels of milk production. The situation is the same for meat producing animals (Flachowsky & Kamphues, 2012) and a high proportion of the animals in developing countries are low producers.

Even different farms in one country (developed or developing) have wide variations in the efficiencies of feed conversion, nitrogen excretion and enteric methane emission although the differences in these efficiencies are much larger in developing than in developed countries (Powell *et al.* 2010; Garg *et al.*, 2013; Wang *et al.*, 2013), which could be ascribed to vast differences in feeding practices, animal comfort and other farm management practices in developing countries. Most animals in developing countries perform at 40 to 50% of their genetic potential, mainly because of an inadequate and imbalanced feed supply and poor livestock management conditions. Poor feeding also reduces reproductive efficiency, resulting in a higher age at first calving, higher calving interval and low body weight of newborn calves. Good feeding and management practices generate a higher impact in terms of an increase in conversion of feed nutrients into the animal food chain and a decrease in emission of nitrogen and methane into the environment at lower levels of animal production than at higher levels. In developing countries most animals belong to the lower levels of production and therefore globally more gains can be generated from large numbers of producers catching up through the application of known simple technologies and good management practices rather than from pushing the frontier for the few high producers using the high-tech approaches. A higher impact, , in terms of increasing productivity and decreasing greenhouse gas emissions, could be achieved in developing countries by improving feeding practices so that animals can attain their full potential and also by improving genetic potential by cross breeding and/or selection and concurrently improving feed availability. The focus should evidently be on low output production systems. Against this background the concept of precision feeding is discussed in this paper.

## Precision feeding in the context of developing countries

Ration balancing

The original term *precision agriculture* was coined in relation to plant nutrition, namely the provision of all inputs in the places and at the times they are required by the plant, thereby maximising their use. In animal nutrition, precision feeding may have different dimensions, but from a practical viewpoint on a farm it refers to matching animal requirements with the dietary nutrient supply. Precision feeding, as understood in developed countries and for intensive production systems, requires feed resources of high quality and their delivery to animals in a disciplined manner using smart engineering and computerised technologies to maximise productivity. However, it may be impossible to achieve this in extensive, mixed extensive and mixed crop-livestock production systems in developing countries due to a lack of resources and infrastructure and a lack of knowledge and technical skills on the part of farmers. It is interesting to note that a large percentage of milk and meat is produced through these systems in developing countries, and these systems contribute substantially to the total world production of animal products. For these diverse systems, an alternative term for *precision feeding* is *balanced feeding* which aims to provide nutrients that match animal nutrient requirements in a manner that fits the production system.

For ruminant production, one of the main aims of precision or balanced feeding is to maintain a healthy rumen and maximise microbial protein synthesis, which is vital for maximising feed use efficiency. This will increase productivity and as a spill-over decrease emissions of environmental pollutants (e.g. nitrogen, phosphorus and methane) when expressed per unit of animal product, and increase the profitability of animal production. At high levels of production, precision or balanced feeding should also provide the required supply (after taking into account the supply from the rumen) of rumen undegradable protein, amino acids and fat.

In a cut and carry system where the intake and chemical composition of feed ingredients and ration can be well controlled, the application of balanced feeding is less challenging than in extensive and semi-extensive production systems. The nutrient requirements based on the physiological stage of animals and the production objective of rearing the animals can be obtained from the tabulated values (using for example National Research Council nutrient requirement values; NRC, 2001). It is always advisable to use the nutritional requirement data for the breeds in question; however for most local breeds in developing countries these data are not available. Although the nutritional requirement data available for breeds similar to those in question can be used to prepare balanced rations, for accurate balancing of the ration it is imperative to generate these values for the breed in question. Feeding a balanced ration maximises nutrient use in the animal food chain and minimises the release of environmental pollutants.

In developed countries the concept of ration balancing is being applied in big commercial farms with the assistance of professional animal nutritionists. But application of this approach on smallholders' farms in developing countries is a challenge due to the low level of technical skills and education on the part of farmers as well as small herd sizes and mixed types of animal (different ages, breeds, both sexes). In order to apply this approach effectively, it is essential to develop appropriate institutions, capacity and infrastructure. An example of application of this approach on thousands of small farms exists in India. The National Dairy Development Board (NDDB) of India has developed user-friendly computer software to advise milk producers on their doorstep to balance the rations of their lactating animals with the available feed resources and area-specific mineral mixtures (FAO, 2012a). In order to balance rations in the field, 'Nutrition masters' are created. These 'Nutrition masters' have data on the chemical composition and nutritive value of feed resources (generally in the form of metabolisable energy) for commonly used feed ingredients across various agro-climatic regions, and on the nutrient requirements of lactating cows for milk production and other physiological functions, such as maintenance and pregnancy. Officers from the grass-roots implementing agencies (dairy cooperative unions/federations, Non-Government Organisations, service providers and producer companies) are trained by the NDDB in the preparation of balanced rations, and they are responsible for training the village-based local resource persons. The programme is implemented on the farmers' doorsteps with the help of these resource persons. Data generated so far from approximately 11,500 animals in seven locations indicate that feeding a balanced ration can increase net daily income by 10–15% for those having one-two cows and/or buffaloes. This is through an increase in milk production and a decrease in the cost of feed. The milk production efficiency (fat corrected milk yield/feed dry matter intake) for cows before and after ration balancing were 0.58 and 0.78 kg/kg, respectively and for buffaloes the corresponding values were 0.53 and 0.66 kg/kg, implying that more milk was produced from one kg of feed when using balanced rations. Furthermore, feeding balanced rations reduced enteric methane emissions by 15–20% per kg of milk produced and faecal egg counts of internal parasites significantly ($P < 0.05$); it also increased levels of serum immunoglobulins, suggesting improved animal immunity (FAO, 2012a; Garg *et al*., 2013). A similar approach is being attempted on dairy farms in cooperative areas in the Chiang Mai area in Thailand.

In a mixed extensive system, efforts are made to use supplementation to provide those nutrients that are deficient in the rangelands and are inadequate for meeting the nutrient needs of animals. The deficient nutrients in developing country situations are generally nitrogen and minerals, and generally tree leaves, oil seed cakes, brans, urea-N and mineral mixtures are provided as supplementation to overcome the nutrient deficiency. Providing grazing animals in extensive systems with supplements in the form of urea-molasses multi-nutrient blocks near the watering site , and greens and browses as fodder also aims to meet the nutrient requirements of animals. All of these result in higher animal productivity (Makkar *et al*., 2008, Makkar 2012).

In extensive and mixed extensive ruminant production systems there is a need to apply the ration balancing concept on a sound technical basis (and not by ‘feeling’). The application of a ration balancing approach in these systems requires data on energy requirements for walking in addition to maintenance energy requirements, which for local breeds in developing countries is scanty. These data can possibly be generated through the use of doubly labelled water or $^{13}C$ labelled bicarbonate methodologies (Makkar, 2008). In addition, information on what and how much an animal consumes during grazing is also vital besides the chemical composition and nutritive value of what is being consumed. Data on the latter can be generated in the laboratory once information on what an animal consumes is available. Alkane and isotopic signatures can be used to generate information on what and how much an animal consumes in the rangelands. Recently developed NIRS and satellite image based techniques hold great promise in this regard.

Intensive production systems, both in developed and developing countries, are dependent on global trade in feed ingredients (Makkar, 2012) and therefore the use of feed ingredients grown in different parts of the world makes the use of area-specific mineral mixtures less relevant. However, in extensive and mixed extensive livestock production systems there could be a deficiency of specific minerals in the soil and hence in the plants on which the animals graze. , The use of area-specific minerals, based on mineral deficiency, could be an important component of ‘balanced feeding’ in developing countries. Correction of mineral deficiency in the field has been shown to increase milk production by 10 to 15% in dairy cows. In sheep 60% of anoestrus females came into oestrus within 15 to 21 days and the remaining 40% after 42 days of mineral supplementation (FAO, 2011a).

The ration balancing approach that matches all nutrients, including minerals, to the animal’s requirements aims to optimise rumen function so that the efficiency of microbial protein synthesis in the rumen is optimised . Determination of milk-urea can be taken as a measure of nitrogen supply to the animal. Excretion of urinary purines as an index of microbial protein synthesis has been used extensively to determine the production of microbial protein synthesis in the rumen (Chen *et al*., 1990). Approaches based on the excretion of urinary purines, urinary allantoin to urinary nitrogen ratio, and purine derivative to creatinine ratio in spot urine samples, proposed by Makkar (2004), could be viable field tools to assess the nutrient deficiency and then to take corrective steps. Further simplification of these tools and making them robust for on-site assays (e.g. pen-side tests, biosensors, paper-strip based assays) would make the balanced feeding approach easier and more widely applicable in all systems including extensive (pastoral) systems.

<u>Ration balancing in conjunction with ‘smart feeding’</u>

The aim in developing countries should be to practise the concept of ration balancing using ‘smart feeding’ approaches (strategic use of available feed resources, preferably local ones) to meet the physiological needs of animals. An example of smart feeding is using fodder (by feeding directly or after conservation) when the yields of crude protein and/or digestible organic matter from the fodder per unit of land area are at the maximum, and not just the biomass. This will maximise the nutrient supply to animals from cultivated fodders in cut and carry systems. In developing countries, it calls for increased collaboration between forage breeders, agronomists and animal nutritionists, both when breeding new forages and when optimising agronomic practices. Animal nutritionists have a number of tools available, e.g. to measure crude protein, protein and *in vitro* organic matter digestibility, which could be applied to a small quantity of the forage samples available during the breeding phase. Without animal nutritionists on board, plant breeding and agronomic studies in developing countries are largely restricted to biomass measurement. The concentration of crude protein decreases and that of lignin increases with maturity, resulting in lower forage quality both in terms of crude protein and organic matter digestibility with maturity, while the biomass availability increases. The aim must be to achieve a good understanding of changes in crude protein yields and organic matter digestibility as a function of forage maturity, and to provide farmers with this information in the form of the window (in days) when these parameters are at the maximum; a further aim should be to build up farmers' understanding that use of forages as 'cut and feed', *in situ* feeding, hay or silage, should be based on the yields of crude protein and digestibility units and not on the weight of forage. Days after planting or cutting is a good proxy for forage maturity; however these proxy parameters may not always provide farmers with the information they require as the maturation rate may vary depending on climatic factors. The availability of simple tools that farmers can use will ensure the efficient use of forage nutrients. Portable NIRS is being applied more and more to assess the nutritive value of forages *in situ*; however, currently its high cost makes its routine use prohibitive. Emphasis should be placed on the need to develop simple tools.

Another example of 'smart feeding' is to use larger amounts of fodder resources (preferably available on farm) and smaller amounts of concentrates to prepare the balanced ration because the cost of protein or nutrient supply from fodder resources is generally lower than that from concentrates. Lower costs for protein and energy supply from fodder/forages than from concentrates have been recorded in Vietnam (Salgado *et al*., 2013). Studies on comparative costs of nutrient (crude protein and energy) supply from fodder and concentrate are also in progress in India (M.R. Garg; personal communication). As the cost of feed represents a substantial percentage of the total production cost, reducing the level of concentrates would decrease input costs, resulting in higher profits for farmers. In addition, it will also reduce food-feed competition. Development of the animal industry based on locally available feed resources is also expected to decrease livestock's carbon footprint and reliance on trade. The use of feeds available on-farm, such as fodder, also helps to reduce nutrient imports. This reduces nutrient deposition on the farm which could become a source of pollution if it exceeds the saturation level of the soil. On-farm fodder production also encourages the use of animal manure as fertiliser, thereby reducing nutrient leaching from farms. All these approaches contribute to the economic, environmental and social sustainability of livestock production systems in addition to enhancing food security.

In order to fatten small ruminants, feeding an 'adequate' amount of a balanced diet during the period when feeds are in short supply and expensive (e.g. in the dry season) might not be an economic option for smallholder farmers in developing countries if an adequate market for the animals is not available in the dry season. Compensatory growth of the animals in the wet season that follows the dry season, when availability of fodder and other feed resources is higher and these are available at a lower price, could be more profitable for farmers. On the other hand, storing feed and using it strategically to fatten animals required for sacrifice during the festival season in some countries, when the demand as well as the selling price for animals are high, are some 'smart feeding' options.

In addition to providing a balanced diet in terms of chemical composition, physical factors such as the particle size of the fibre or feeding of ingredients as individual components or as a total mixed ration (TMR) also influence the nutrient use efficiency in the animal. Feeding of TMR has been shown to have several advantages over feeding ingredients separately, such as lower feed loss, higher nutrient availability, lower enteric methane production and higher animal performance (FAO, 2011a, 2012b), this latter system is conventionally practised in many developing countries. Similarly, the technology for making densified total mixed ration blocks (DTMRBs) or densified total mixed ration pellets (DTMRPs) based on straws and oil seed meals provides an opportunity for feed manufacturers and entrepreneurs to supply balanced feeds to dairy and other livestock farmers on a large scale. Feeding these products increases animal productivity and decreases wastage of feed ingredients, including straws (FAO, 2012b). Other simple technologies, such as chopping forages, increase animal productivity and reduce forage waste. Animals use a considerable amount of energy in chewing forages and chaffing makes it possible to save this energy and divert it for productive purposes. Both intake and rumen microbial digestion of chopped forage are higher compared with un-chopped forage (FAO, 2011a). The rumen needs to be operating at maximal efficiency in terms of mixing, rumination and emptying. Continuous mixing of rumen contents improves the intimacy between ingested feed particles and the microbial population, which is essential for optimal fibre digestion (Beever & Drackley, 2013). Small amounts of cereal straw (< 0.5 kg/day) as a source of structural fibre, when fed at a suitable length (4 to 8 cm) and structure and fully incorporated into mixed rations, resulted in higher animal performance (Beauchemin *et al*., 2008). In contrast, feeding ryegrass straw as a ground pelleted or coarse chopped cubed feed to cows grazing high quality pasture showed no positive effects on milk production and milk composition (Wales *et al*., 2001). These results demonstrate the importance of including forage in the ration to achieve optimal rumen function. When suitable forage is correctly processed and incorporated into well mixed rations, minimisation of feed selection ensures more consistent ration consumption and the appropriate fibre length assures optimum rumen health and function.

Quality control systems for feed analysis and balanced feeding

Precision or balanced feeding goes hand in hand with accurate determination of the nutritive value of feed resources. The author's personal experiences and those of international experts demonstrate that such data originating from many laboratories in developing countries are not reliable since quality control systems and good laboratory practices are not integrated in the feed analysis. There is therefore a need to integrate quality control systems into animal feed analysis laboratories in developing countries. Manuals to address these issues have been produced by FAO (FAO, 2011b, 2013). It is proposed that a *World Association of Animal Feed Laboratory Analysts* should be established to promote the application of precision/balanced feeding based on sound data and to improve animal and human health by enhancing the quality and safety of animal feeds.

## Future research

The impact of balanced feeding in developing countries can be further enhanced by generating information and developing tools that assist in the application of balanced and smart feeding options. Some examples of this are: determination of nutritional requirements of local breeds at different physiological stages such as maintenance, growth, milk production, walking, pregnancy, etc.; development and use of tools to generate information on what and how much an animal consumes while grazing and use of the information in the development of a simple ration balancing software; generation of information on when to plant and cut forages in order to obtain high yields of crude protein and organic matter digestibility units, and its dissemination to farmers; development of simple tools to assess the nutritional value of forages *in situ* and to evaluate rumen health and status for optimum microbial protein synthesis; and identification of smart feeding options using locally available resources. It is equally important to integrate quality control systems into the conducting of analyses in animal feed analysis laboratories, without which the full impact of ration balancing and smart feeding cannot be realised.

## Conclusions

In developing countries extensive, mixed extensive and mixed crop-livestock production systems are widespread; and in this context application of the concept of 'ration balancing' coupled with 'smart feeding' approaches to meet the physiological needs of animals is precision feeding. Large-scale implementation of such programmes can help to improve the productivity of livestock in developing countries. In developing countries a large percentage of milk and meat is produced in extensive, mixed extensive and mixed crop-livestock production systems and these systems contribute substantially to the total world production of animal products. Precision feeding, as understood in developed countries, using computerised feeding supported by high-cost engineered infrastructure might only be applicable in intensive industrialised production systems in developing countries, although its sustainability under this system is also questionable due to overall poor infrastructure, including irregular and highly-fluctuating power supplies and lack of maintenance support for the high-tech infrastructure. Large impacts in terms of increases in livestock productivity and decreases in environmental pollutants could be achieved by using balanced feeding integrated with smart feeding – precision feeding is a misfit and misnomer under the existing ruminant production systems in developing countries.

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## Does Precision Livestock Farming turn animals into objects?

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### Abstract

Fostering sustainable food security is a major challenge for the livestock production sector worldwide. As a consequence, the process of intensification is gaining momentum. An animal protest group, Dutch Compassion for Animals, claims that automation, and thus also Precision Livestock Farming (PLF), strengthens the trend towards objectifying livestock production animals in this intensification process. This paper describes, analyses and evaluates this claim from an animal ethics perspective. The protest group argues that automation fuels mechanisation and increases in scale, which ultimately results in the transformation of cows from sentient animals into objects. The framework they use to assess this issue from the ethical point of view is problematic. The first problem is that this framework only provides a minimal, negative definition of animal welfare. The second problem is that their conclusion does not belong to a consequentialist framework but to a rival deontological framework. The claim that PLF objectifies animals seems to be unsubstantiated, because it depends on ignoring those PLF capacities that allow a non-stressing focus on individual animals and support increasing levels of animal welfare. Steering PLF in an ethically acceptable direction will be a major task for its developers.

**Keywords**: Objectification, Animal ethics, Production system, Animal integrity

### Introduction

Current trends in livestock farming predict a doubling of the global demand for animal products by 2050. Sustainable food security is a major challenge for the livestock production sector (FAO, 2009; 2013). Intensification is gaining momentum as one means of generating this food security. However, the way animals are kept is debated in Europe and, increasingly, in other regions of the world. Worldwide, livestock production systems are changing and will have to change further in order to meet future demands (Rabbinge and Bindraban, 2012). Precision Livestock Farming (PLF), a set of technological tools that enable farmers to better manage their livestock system (Berckmans, 2008), is one recent innovative trend. Its developers are aware that PLF may lead to further instumentalisation of animals (Wathes *et al,* 2008). An animal protest group, Dutch Compassion for Animals, and more recently Dutch citizens, claim that automation, like PLF, is harmful for animals because it further objectifies animals in livestock production.

This paper evaluates the claim that PLF further instrumentalises animals from an animal ethics perspective. Data were collected through a desk study of research reports and public sources. Although the scientific term ‘Precision Livestock Farming’ or its abbreviation ‘PLF’ can be traced back to the late 1990s, the number of public references is relatively low. Almost no societal groups or media refer directly to PLF. When we switch to the term ‘automation’ many more references are available. We start from the perspective of automation and use the Dutch dairy sector as a case study. Next, we interpret PLF as a second stage in automation. Subsequently, we describe and analyse the claim that PLF is harmful for animals because it objectifies them.

**PLF as a perspective on automation in livestock farming**

PLF relies upon automatic monitoring of livestock and related physical processes. It treats livestock production as a set of interlinked processes, which act together in a complex network. Processes suitable for the PLF approach include animal growth, milk and egg production, endemic disease management, and some aspects of animal behaviour. It is also suitable for managing aspects of animals’ physical environment, such as the thermal micro-environment and emissions of gaseous pollutants, such as ammonia. The potential for PLF to aid the livestock farmer parallels that in crop production where precision farming has been used successfully since the mid-1980s. While some of the techniques are common to the two applications, animals’ sentience and their ability to suffer make livestock production more complex (Wathes *et al,* 2008).

PLF technologies can help livestock farmers to routinely gather information on their animals as a means of supporting assessment of their health, welfare and productivity. Animals can be assessed on either an individual or a group basis. For example, low-cost cameras in combination with image analysis can be used to quantify an animal’s behaviour, size, shape and weight, even in large flocks or herds. These tools make it possible to collect a great deal of information without the stress associated with animal handling. Sensors may be used to optimise production and provide early detection of poor welfare in individuals. They are attached directly to the animal, thus placing the animal at the centre of PLF (Wathes *et al,* 2008). Since the late 1990s, an international group of agricultural scientists have been involved in PLF. Research and development are still on-going (see e.g. Banhazi *et al,* 2012; Lokhorst *et al,* 2011). Conferences, such as the EC-PLF (see Cox, 2003; 2005; 2007; Lokhorst and Groot Koerkamp, 2009) highlight the attractions of PLF for agricultural engineers in the research phase.

However, few researchers have tackled PLF as a fully engineered system of sensors, models, controllers and process targets working automatically. The most pressing needs for such fully engineered systems are data-based models of the key biological and physical processes with meaningful parameters, and control systems that can manage two or more interacting physical and/or biological processes. The process target, which is normally set by the livestock farmer, is based on economic, quality and environmental criteria. Optimising the different processes to meet one overall target can have implications for another target as it may lead to rigidities between, for instance, the farmers' income level versus the level of animal welfare (Wathes *et al,* 2008).

## Two stages of automation in the dairy sector

After World War II, livestock farmers regarded the process of specialisation, scaling up of activities and higher milk yields as an opportunity to produce more food at a lower price. The process was successful: farming systems became efficient through the application of technology and automation, and high levels of human control that rationalised and optimised production (Bos *et al,* 2003). However, until recently, Dutch citizens still had a positive, romantic image of the dairy sector in which cows are thought to graze outside in the meadow, are well taken care of, and reared on small-scale farms (Boone *et al,* 2007). Disrupting this romantic picture, Dutch citizens also became familiar with the negative aspects of industrialised dairy farming systems, such as a crowded housing and the reduced life expectancy of dairy cows (De Jonge and Goewie, 2000).

In order to influence public perception, an animal protest group, Dutch Compassion for Animals, published a paper (Wakker Dier, 2010) in which they claim that 'we are running out of time' to change course in the dairy sector. They argue that cows have become objects. The argument presented consists of eight parts. First, the livestock sector cannot be judged as a whole, because the pig and poultry sector are quite different from the dairy sector. The first two sectors have been and are known to be industrialised, while the latter still has a positive image. Second, they argue that, contrary to popular perception, the dairy sector has also become industrialised and that this causes significant animal welfare problems. Third, mechanisation and increases in scale drive industrialisation. Fourth, mechanisation and increases in scale are made possible by increasing automation. Fifth, the desire for profit drives mechanisation and increases in scale. Sixth, farming activities such as the milking, feeding and monitoring of cows are almost fully automated and this automation leads to fewer people working in the dairy sector and the work they do becomes easier. Seventh, as a result of further automation (e.g. the milking robot), farmers devote less time and attention to caring for the health and welfare of individual cows. This is harmful for the animals. Eighth, and last, automation results in the transformation of cows from sentient animals into objects (Wakker Dier, 2010).

Dutch Compassion for Animals considers the milking robot to be the most important example of further automation (Wakker Dier, 2010). They argue that farmers who invest in new housing also introduce fully automatic milking robots. These robots lead to better control of feed intake and increased milk yields (Hogeveen *et al,* 2004 In: Wakker Dier, 2010). At the same time, fully automatic milking systems do not rely upon the monitoring of animal diseases, like mastitis. That is why new technological tools, like sensors, have been introduced to monitor the individual animal (Hillerton *et al*, 2004 In: Wakker Dier, 2010). In this paper, the use of sensors is characterised as the second stage of automation, which may also be characterised as digitalisation (Ypma, 2012). In order to manage processes in dairy farming, digital output from all kinds of instruments is used to support decisions (see e.g. Blue4Green, 2013). Other examples are automatic feeding robots, and cow calendars to determine cycles for breeding and milk yields (Top and Jagtenberg, 1999; de Mol *et al*, 2006).

Dutch Compassion for Animals claims that the second stage of automation will transform cows even more into objects (Wakker Dier, 2010). Is this claim valid? Animal scientists from Wageningen University who are involved in developing Smart Farming (another term for PLF) deny this claim. From their viewpoint, PLF pertains to 'real time management of biological variation in livestock production systems in which the individual animal has a central focus' (Lokhorst *et al,* 2010). Despite the growing intensification of livestock production, PLF increases the farmer's ability to keep in touch with individual animals (Lokhorst *et al,* 2011). PLF is essentially an enabling toolbox, in other words, farmers can use PLF technologies, such as sensors, to monitor animal health and welfare in order to ensure that individual animals live well and are free of diseases (Lokhorst *et al,* 2010; Lokhorst and Ipema, 2010). In the next section, we assess and evaluate the competing claims relating to objectification made by the animal protest group and the developers of PLF.

## Ethical assessment of the objectification claim

PLF is an approach with great potential to transform livestock farming in positive but also in negative ways. For this reason, Wathes *et al* (2008) performed a bioethical analysis in their review of PLF. They used the ethical framework of Mepham (2000) and applied the principle of 'respect for justice' to a broiler chicken example. In this example, it was assumed that the behavioural repertoire is actively managed by manipulation of light intensity using the PLF approach. The outcome was infringement of the 'respect of justice' principle because of the instrumental use of animals (Wathes *et al*, 2008). This example shows that PLF might be viewed unfavourably by consumers or citizens as a technology that strengthens the objectification of animals.
The animal protest group also associates PLF with objectification when it describes the process of further automation as a process of further objectification.

They ask whether animals should be considered as 'sentient beings' or objects. They use the 'Five Freedoms' framework (Brambell, 1965) to assess this issue, and conclude that automation reduces animal welfare because it turns animals into objects. Seen from an ethical perspective, the framework is consequentialist, just like the first seven steps in the argumentation in the last section. There are two main problems, described below, in using the Brambell (1965) framework in their line of argumentation.

The first problem with the Brambell framework is that in a consequentialist animal ethics approach, the animal welfare argument is often used in discussions about animal production. However, it only provides a minimal, negative definition of animal welfare. A positive definition of animal welfare that covers all situations has to be based, on the one hand, on the interaction between biological information on the status of the animal, and on the other, on normative viewpoints. In this paper, we define animal welfare as the different and overlapping aspects of functioning and health, the feeling of the animal and the aspect of naturalness. Societal organisations, such as Dutch Compassion for Animals or the World Society for the Protection of Animals (see e.g. WSPA, 2013; van Dongen, 2013), focus on the robotics and automation aspects of PLF that can give rise to animal welfare problems. They selectively criticise technology that is not used in a manner that benefits the animal. On the other hand, they downplay PLF tools that routinely gather information from animals, as long as these tools collect information without stress or bodily intervention. Existing ethical assessments recognise PLF as a collection of tools. Nevertheless, before any ethical assessment is possible, these tools have to be implemented as a fully engineered system of sensors, models, controllers and process targets in a specific production system.

The second problem concerns the line of argumentation taken by the animal protest group. The first seven steps of their argument belong to a consequentialist framework. However, their conclusion, that automation turns animals into objects, belongs to a rival deontological framework and thus does not follow from the previous seven steps. In the deontological framework of animal ethics, two principles are central: the intrinsic value of animals and the integrity of animals. Could the animal protest group use these two principles to conclude that automation turns animals into objects?
Intrinsic value is defined as the value animals have on their own, apart from the instrumental values (e.g. economic, ecological, aesthetic) that humans give to animals (Verhoog, 1992). People differ in how they value animals, how important the different aspects valued are, and what these different aspects entail. In a recent survey of views on animals, Dutch citizens were negative about future developments of automation and robotisation because these would lead to instrumentalisation (de Cock Buning et. al, 2012). From an ethical perspective, this means that citizens expect a shift from an acceptable intrinsic valuation of animals to an unacceptable instrumental valuation of animals. Does this claim coincide with the objectification claim of the animal protest

group? Yes, but in both cases earlier automation has already transformed animals into objects. Further automation via PLF may solve animal welfare problems, as created by the first stage of automation, by concentrating on the individual animal.

Next, we turn to the aspect of integrity. This could be a more appropriate ethical perspective for assessing the claim that PLF objectifies animals insofar as it may be interpreted as violating the integrity of animals. Animal integrity can be described as 'the wholeness and completeness of the animal and the species-specific balance of the creature, as well as the animal's capacity to maintain itself independently in an environment suitable to the species' (Rutgers and Heeger, 1999). PLF could violate the wholeness of the animal by installing a series of sensors in the body. On the other hand, PLF could make the environment more suitable for the animals by monitoring and adjusting for uncomfortable conditions.

## Conclusion

The claim that PLF is harmful to animals because it objectifies animals seems to be unsubstantiated, because this claim depends on a partial recognition of PLF. When it is seen as an extension of on-going automation, the objectification of animals will continue because the intrinsic value of farm animals is already violated by automation. In contrast, when PLF is considered as digitalisation, the next stage in automation, it could potentially increase the intrinsic value of the individual animal because the context of a production system determines how PLF is applied. In order to steer PLF in an ethically acceptable direction, its developers must do more than develop state-of-the-art sensing and control systems. These systems are not neutral tools but incorporate values and norms. Steering PLF in an ethically acceptable direction will be a major task for its developers. PLF must, in a pro-active way, link digitalisation not only with animal health and welfare, but also with societal values such as sustainability and biodiversity.

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## Traceability in the feed-animal-food chain

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### Abstract

Most efforts in the area of traceability related to animals concentrate on the animal lifecycle (birth, death and movements in between) without utilising the full range of opportunities that the bidirectional transport of information along the supply chain of feed-animal-food offers. The optimisation of feed quantities and composition, as well as feedback on the effect of management practices is of great value to farmers, feed producers and slaughterhouses. The EU-funded project ALL-SMART-PIGS will deploy a set of SmartFarming technologies on two farms in Spain and two farms in Hungary and attempt to evaluate the economic desirability of these SmartFarming technologies on pig farms. In addition, the project will attempt to evaluate the economics of information transport on the feed-animal-food chain. For this purpose slaughterhouses and feed producers have been chosen as participants in the project LivingLab. In Hungary, the pig farmers produce feed mostly independently, whereas in Spain feed is purchased. In this contribution we will present first results from the LivingLab, in particular on information elements that are economically interesting in the chain as well as the willingness to actually share such information elements.

**Keywords:** Traceability, feed producer, farmer, slaughterhouse

### Introduction

Feed constitutes the single most important cost factor in animal production. Depending on the particulars, questioned producers have reported up to 80% of production cost coming from feed especially for pigs and poultry holdings. In addition, feed is in many places imported, increasing thus the dependency on external trade, currency fluctuations etc. As such there are good reasons to try to optimise feed both on the micro (i.e. farm) as well as on the macro (i.e. country) level.

The EU funded project ALL-SMART-PIGS (www.all-smart-pigs.com) has set out to implement and evaluate five base SmartFarming (Smith and Lehr, 2011) technologies on four European pig farms (two in Spain, two in Hungary):

- Contactless weight measurement

- Dispensed feed per pen
- Cough index as indicator for pulmonary health
- Activity and occupation index (distribution of animals within the pen and movements therein)
- Environmental parameters, such as ammonia concentration, temperature, humidity etc

However, the ALL-SMART-PIGS project wishes to go one step beyond simple data capture and on-farm visualisation for more efficient management that normally is considered the focus of Precision Livestock Farming (Banhazi *et al*, 2012, Cox, 2003, Cox, 2005, Cox, 2007, Cox, 2009, Lockhorst and Berckmans, 2011). The project will exchange data using traceability between supply chain partners (see Figure 1), in particular between:

- Feed providers
- Farms
- Slaughterhouses/cutting rooms

Due to the lack of access to real data, feed manufacturers have to rely on test or research farms, farmers have to rely on experience and the offering of the feed industry and slaughterhouses have little influence on the meat quality, with exception of fines for off-spec animals. Given that even slight decreases of feed need make huge differences on micro and macro level, the current approach is not optimal.

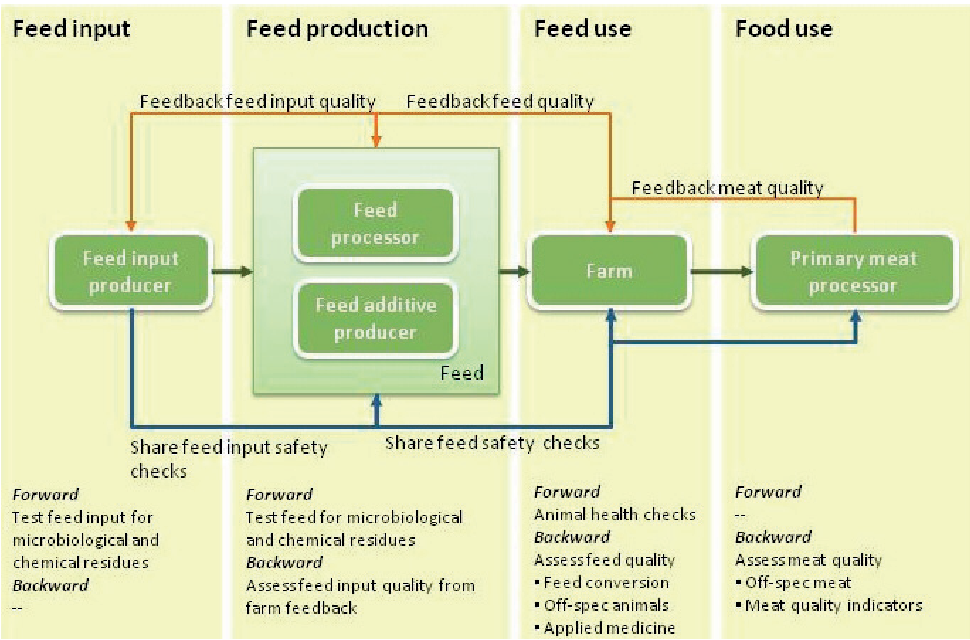


Figure 1: Feed(back) on the feed-animal-food chain

The starting point was our suggestion for a privately run system where carcass composition data is made available to farmers for their individual animals. Farmers would then (via an electronic system) make averaged data available to the respective feed producers who can aggregate this data with that from other farms to judge the performance of their feed compositions (Lehr, 2011, Lehr, 2013). Based on real and massive data, feed producers can on one hand optimise their products and on the other hand offer better products to individual farms.
Given the availability of continuously measured data from the farms, we suggested to measure the impact of management practices along the chain based on such data.

The Danish Catellae System is an example where such an approach has been used, in this case for poultry. After some initial resistance, the system is now used by 100% of the Danish poultry farmers thanks to pressure by larger buyers, but also due to the optimisation potential that such a system allows (Bunkenborg, 2013).

Given that in most countries large buyers do not exercise pressure on the supply chain to exchange electronic data and due to the fact that the exchange of electronic data between food business is still in its early days, we decided to employ an open co-creation method for the design of the traceability system, to guarantee the buy-in of the supply chain partners.

## Materials and Methods

<u>Stakeholder co-creation through LivingLabs</u>

The current challenge for SmartFarming is to penetrate the market (mainly farmers) with a set of new technologies and services. There are at least four key dimensions in industrial marketing (Webster, 1992):

1. Identifying customer needs, which requires understanding the economics of the customer's operations, the structure of the industry within which they operate, and how they compete.
2. Selecting customer groups for emphasis, the classic problem of market segmentation, which takes on special meaning in industrial markets because of the high degree of buyer-seller interdependence after the sale.
3. Designing the product/service package, where there is seldom a standard product, the accompanying bundle of services is often more important than the product itself.

Industrial marketing aims for improved profit performance, where sales volume and market share per se is not as important as in consumer marketing.

In ALL-SMARTPIGS we find the Living Lab (LL) methodology useful for accomplishing the needs for risk reduction and user acceptance in the efforts of bringing research and technology developments within PLF to a specific market – in this case European pig farmers. Each LL farm will act as an open innovation milieu, where innovations are developed by adopting a research intense and stakeholder-driven approach. The focus lies on co-creation of innovations on the basis of users' real needs and by involving the whole value chain.

Living Labs (LL) are currently heavily discussed in the European research community. Most of the discussions focus on open and publically available infrastructures to test and implement new products and services. Partners in the European Network of Open LivingLabs (ENOLL) claim that there are a number of different models that can be used for LL collaborations. However, most LLs summarized in the ENOLL community depend on government and public funding and there is a clear lack of suitable alternative business models. In addition to European level harmonization and definitions, there is now an emerging movement to tailor a LL concept for various user groups and application sectors.

The focus of each LL is:

- Continuous and open co-operation among different involved stakeholders
- Development of innovations based on user needs, desire and preference

This can only be obtained by:

- Engaging and empowering users to take an active part in the creation of valuable innovations
- Interacting with users in their real-world context (i.e. on real farms)
- Correlating user involvement activities with ongoing research and social trends

The ALL-SMART-PIGS Living Lab process can be seen as a spiral in which the focus and shape of the design become clearer, while the attention of the evaluation broadens from a focus on concept and usability aspects to a holistic view on the use of the system. There are four iterative cycles that each consist of a repetition of three phases, see Figure 2.

The three repetitive phases in the ALL-SMART-PIGS Living Lab concept are:

- Appreciating Opportunities (co-creation with users)
- Design (exploration and experimentation)
- Evaluation

These three phases (a-c) are repeated in four iterative cycles (1-4):

- Concept design
- Prototype design
- Final System design
- System Demonstration

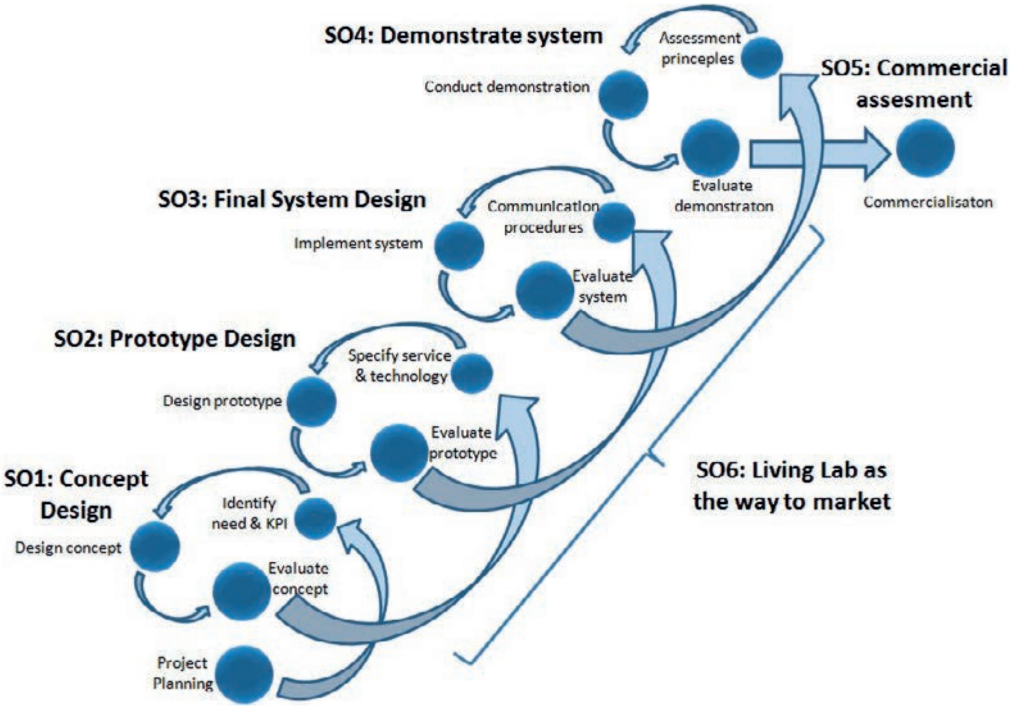


Figure 2: The iterative LivingLab process used in ALL-SMART-PIGS

The application of the LivingLab process to data exchange along the supply chain

In ALL-SMART-PIGS the above iterative process is used (i) to design a technology product/service package that appeals to European pig farmers and provides them with a clear value proposition and (ii) to design and trial a traceability system with the purpose of preparing the development of a commercial offering at a subsequent stage. Given that the development of a commercial system for the exchange of data depends heavily on the acceptability, within the project we only attempt to collect first experiences with a limited number of players in order to better identify areas of value creation.

ALL-SMART-PIGS has organised for this purpose two rounds of LivingLab sessions with three different stakeholder types: (i) feed providers (Spain only, since the Hungarian farmers in the project produce their own feed), (ii) farmers (Spain and Hungary) and (iii) slaughterhouses (Spain only). In a first round we brainstormed with each group individually to capture an ideal view of what data would be most useful. There was also an in-depth discussion of the factors that influence economic results or determine the quality of the end-product.

Based on these discussions the team then developed a first concept for a traceability system. This concept was subsequently presented in follow-up LivingLab session in

June 2013, now with all stakeholders present. The purpose of this session was two-fold: (i) assess and improve the concept and (ii) get the buy-in from the stakeholders to participate in a trial starting in January 2014.

After the feedback from the LivingLab, the team will now prepare the third iteration cycle where the LivingLab participants will be presented with the actual system for validation. Based on the feedback from that round, the final trial system will be prepared. The trial will start in January 2014 and is expected to run for 8 months.

**Results and recommendations**

Table 1: Validated concept for information exchange along the feed - animal - food chain

| | |
|---|---|
| **Feed provider to farmer** | |
| Purpose | • Historic cost of feed per kg of meat<br>• Target growth curve for service agreement<br>• Service level (e.g. % protein, minimum % corn etc) |
| Main data elements | • Historic cost of feed per kg of meat<br>• At beginning of fattening period growth curve (set of data points, potentially in function of target start and end weights)<br>• Updated nutritional profile per delivery |
| Other data | Feed identification (Feed type, delivery identifier/date and a farm/silo) |
| **Farmer to feed provider** | |
| Purpose | Manage changes in composition with respect to farm indicators such as weight gain and feed consumption |
| Main data elements | Per feed identifier (may require a link between pen and silo; for project we can assume one feed per farm) and per day<br>• Avg. weight (kg)<br>• Avg. feed dispensed per animal (kg)<br>• Avg. activity index<br>• Avg. cough index<br>• Avg. effective temperature<br>• Change in ammonia concentration with respect to 1-2 days before |
| Other data | Number of pigs per pen over time |

| | |
|---|---|
| **Farmer to farmer** | |
| Purpose | Understand the performance of the farm relative to peers (weight gain at a particular age, incidences of respiratory diseases, variability of pig weight and lean meat %, activity indexes (under certain environmental conditions and/or feed composition), mortality |
| Main data elements | • Deliver to the system: weight gain at day of production, weight variance, cough index, activity index, variance in lean meat % at end of cycle, mortality<br>• Receive from system: offset from average of the above indicators |
| **Farmer to slaughterhouse/cutting room** | |
| Purpose | • Quality control (and risk control)<br>• Being able to offer differentiated products |
| Main data elements | • Transport date, time and duration<br>• Transport type (smooth road or unpaved path, ventilated/non-ventilated lorry)<br>• Time of last feeding<br>• Genetics<br>• Feed type<br>• Cough index<br>• Treatments |
| **Slaughterhouse/cutting room to farmer** | |
| Purpose | • Weight and composition data to optimise the feeding process<br>• Understanding non-compliances |
| Main data elements | • Per pig: live weight, carcass weight, carcass classification and lean meat %<br>• Observations meat quality<br>• Vet report/quality department report |
| **Slaughterhouse/cutting room to feed provider** | |
| Purpose | Weight and composition data to optimise the feeding process (on average over farms) |
| Main data elements | Via farm: Avg. pig weight, carcass classification and lean meat % |
| Other data | • Environmental conditions<br>• Farm age<br>• Type of production systems<br>• Health problems before fattening (e.g. diarrhoea in piglet) |

Table 1 summarises the different traceability or information exchange subsystems grouped by business partner pairs. The availability of up to date data on weight gain, feed conversion and environmental conditions through the SmartFarming technologies adds a lot of value, in particular for feed producers. Feed producers change the composition of their feed very regularly based on raw material prices. Some feed producers have reported to change their feed composition at times twice daily. Also, one of the feed providers in the LivingLab “personalises” the feed for farmers based on how fast they want the pigs to grow, how concerned they are regarding cost, how much nitrogen they are allowed to produce and other factors.

Slaughterhouses or cutting rooms on the other end are very interested to improve the management of meat quality. Without the data from the farm they are very exposed to changes in meat quality, in particular with respect to retained water. Given the sudden and unexplainable changes in meat quality, slaughterhouses do not offer specialised products, such as drier meat for sausage production. Such a diversified offering would improve their market standing, but currently the associated risk of delivering an off-spec product is simply too high. The value of the information exchange is therefore the ability to manage product risk much better. The LivingLab participants saw little or no value in predicting volumes to be delivered to the slaughterhouses, since the farmers already have standing, volume-based contracts with them.

For farmers the value proposition is increased control over feed, animal growth and delivered weight. Since farmers have little control over carcass weight, they feel very exposed to the slaughterhouse. Having data on animal live weight from the slaughterhouse and being able to compare that to own measurements will reduce the risk of weight manipulation.

Data privacy

Data ownership and privacy is a major concern for all businesses; this is a major issue in food traceability (Lehr, 2013). In our case, the LivingLab participants have decided to allow direct business partners to see the above data, but visibility to peers was excluded. In a larger trial, farmers would be very interested to compare key indicators to sector averages, but with only two farms per country such a comparison is not possible. All participants will retain ownership of their data and will have direct control over their visibility.

## Conclusions

Table 2: Main value creation potential in function of the supply chain step

| Stakeholder | *Main value creation* |
|---|---|
| Feed provider | • Increase in feed quality<br>• Defence against quality claims |
| Farmer | • Increased control of the growth process<br>• Peer comparison<br>• Increased control of delivered material |
| Slaughterhouse | • Reduced meat quality risk |

The LivingLab methodology for identifying stakeholder needs and validating concepts derived from those needs has been very successful in ALL-SMART-PIGS. The project has been able to identify potential areas of value creation for all three stakeholder groups. ALL-SMART-PIGS does not extend its work to secondary processing or even retail, so within this project we are looking for value creation that does not require external funding of the process, e.g. by obtaining premium prices from secondary processing or retail for the additional information coming with the meat.

Table 2 summarises the main value creation areas. After the practical trial in 2014, we expect to be able to provide a qualitative/quantitative cost-benefit estimation to further qualify the value creation potential.

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## Analysis of investment in an oestrus detection system for dairy farms

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### Abstract

Activity meters have been studied and are used for the automated detection of oestrus in dairy farming. However, information on the economic consequences of using activity meters for automated detection of oestrus is lacking. The current study analyses the economic benefits of a sensor system for detecting oestrus, discusses its financial feasibility and appraises the investment in such a system. A herd-level stochastic-dynamic Monte Carlo simulation model was used to simulate reproductive performance of a dairy herd. Results show that an oestrus detection rate of 50% results in an average calving interval of 419 days and an average yearly milk production of 1,032,278 kg. For activity meters, the results show that an oestrus detection rate of 80% result in an average calving interval of 403 days, and an average yearly milk production of 1,043,751kg. For a herd of 130 cows, the estimated investment for activity meters is €14,731. The increase average annual net cash flow due to a higher oestrus detection rate was estimated to be € 3,151. In the investment analysis all the calculated profitability indicators indicated that the investment in activity meters is profitable.

**Keywords:** Investment, Oestrus Detection, Activity Meters, Dairy Farming, Economics

### Introduction

The financial losses of non-optimal reproductive performance of dairy cows have been studied (Groenendaal *et al.*, 2004, Inchaisri *et al.*, 2010). Compared to an average calving interval of 362 days, average calving intervals of 407 and 507 days caused mean net economic losses of 34 and 231 € per cow per year, respectively (Inchaisri *et al.*, 2010). The longer calving intervals caused lower milk production, less calves and lower costs of calving management. As economic losses are associated with a prolonged calving interval, optimizing reproduction management at dairy farms may be profitable. Part of reproduction management is oestrus detection. Studies on the efficiency of visual oestrus detection have reported values around 55% (Firk *et al.*, 2002), but also around

40% (Roelofs *et al.*, 2010). This efficiency might be increased to a value in the range of 60-90% (Firk *et al.*, 2002, Roelofs *et al.*, 2010). However this increase in efficiency, required extra labour input varying from 1-3 periods of 30 minutes per day. So, when a farmer relies on visual oestrus detection either the detection rate is low or the labour input is high.

An option to improve the oestrus detection rate without increasing labour is the use of automated oestrus detection. For automated detection of oestrus, the activity meter is studied most (Rutten *et al.*, 2013). Those activity meters might improve oestrus detection compared to visual detection done by the farmer. Consequently, increasing oestrus detection will increase the chance that a cow in oestrus will become pregnant and thereby shorten the calving interval.

Activity meters and other sensor systems for oestrus detection are available on the market (Personal Communication, 2012). In general, the question whether farmers will invest or not depends on profitability of the investment, the farms financial position, economic prospects, farm size and presence of a potential successor (Aramyan *et al.*, 2007, Oude Lansink *et al.*, 2001). Accordingly, a study among dairy farmers in Kentucky (USA) indicates that the actual or perceived economic benefit of adopting sensor techniques influences a farmer's decision to adopt sensor techniques (Bewley and Russell, 2010). Hence, there is a need for economic models to quantify the economic benefit of activity meters, so that farmers will be able to make informed investment decisions.

Some studies on the economic effect of using sensor systems have been conducted. For online progesterone measurements a study on the economic effects has been carried out (Østergaard *et al.*, 2005). For the analysis of investing in a sensor system, two models have been described and demonstrated (Bewley *et al.*, 2010b, van Asseldonk *et al.*, 1999a). The model of van Asseldonk *et al.* studied investment patterns (i.e. sequences of investment decisions) regarding information technology, which included automated oestrus detection (van Asseldonk *et al.*, 1999a, van Asseldonk *et al.*, 1999b). The model of Bewley *et al.* simulated a dairy herd (Bewley *et al.*, 2010b) and estimated the potential economic value of an automated body condition scoring system for a US dairy farm (Bewley *et al.*, 2010a). So, the study of Østergaard *et al.* (2005) was specific for progesterone measurements and the studies of van van Asseldonk *et al.* (1999a) and Bewley *et al.* (2010a) were general and theoretical.

The aim of this study is to analyse investing in activity meters for automated detection of oestrus. For this investment analysis, an existing stochastic simulation model for reproductive performance of an individual cow was further developed.

## Material and Methods

<u>Model description and model inputs</u>

The simulation model was developed in Microsoft Excel. For the stochastic properties of this model the add-in software @Risk 6 for Excel (Palisade-Corporation, 2010) was used. The developed model simulates fertility events of an individual cow in weekly time steps and extends on a previously published model of Inchaisri *et al.* (2010), which simulated one cow in one lactation. By contrast, the current model simulates multiple lactations, starting with a cow in a random parity. In the next lactation the cow either goes to the next parity or is replaced by a heifer. Accordingly, fertility was simulated with occurrence of ovulation, which could be delayed by occurrence of a reproductive disease. In addition, the model simulated the detection of oestrus cases. When these oestrus cases were detected, the cow could be inseminated. After insemination had occurred, the model simulated whether or not the cow became pregnant and the decrease in milk production due to pregnancy. More information on the model specifications can be found in the work of Inchaisri et al (2010). Model inputs were based on literature, available databases, expert opinions and authors' expertise. The baseline scenario for the simulation is comparing visual oestrus detection (sensitivity 50%, specificity 100%) with oestrus detection with activity meters (sensitivity 80%, specificity 95%). The @ Risk model was run for 50,050 iterations in order to reach convergence.

<u>Economic model</u>

The decision to invest in a sensor system is made on farm level rather than on cow level and therefore a farm with 130 cows was assumed. For the activity meters a technical lifetime of 10 years, fixed costs of € 3,600 per herd, variable costs of € 108 per cow and maintenance cost were assumed. In order to analyse profitability of investing in activity meters for oestrus detection, the outputs of the cow simulation model were used in the economic model. In the investment analysis there are two situation, farms that use activity meters and farms that rely on visual oestrus detection. In effect, the situation with activity meters only differs from the situation with visual oestrus detection by the oestrus detection rate and the detection specificity. Then the average annual net cash flow is calculated for all farms per situation. Finally, the change in average yearly cash flow between the two situations and the investment costs were used to calculate the net present value (NPV), benefit cost ratio (B/C ratio), internal rate of return (IRR) and discounted payback period (DPBP).

The NPV indicates whether or not revenues exceed expenses of the investment, while it accounts for the time value of money. Time value of money is taken into account by calculating the present values of future cash flows by using a discount factor. In this study a discount rate (DR) of 5% was chosen. The calculation of the discount factor (DF) in year k is given by the formula in equation 1.

$$DF_k = \frac{1}{(1+DR)^k} \tag{1}$$

The B/C ratio gives an indication of the returns on invested capital. This return is calculated by dividing the sum of present benefits (returns) by the sum of present costs. The IRR is the discount rate at which the NPV is zero. This percentage is an indicator of the return on invested capital. In this study the IRR was calculated by using an iterative process in Microsoft Excel. The DPBP is the number of years needed to payback the initial purchase costs, which calculated by using discounted cash flows. This period is simply defined by the year in which the sum of cash flows equal or exceed the initial purchase costs.

Internal validation

The model has been validated internally as no suitable data were available for external validation. Different (extreme) input values were used and the resulting model outputs were checked for infeasible outcomes. Al model assumptions were critically evaluated and the credibility of model outcomes has been critically reviewed and discussed with experts.

Sensitivity analysis

As detection performances can vary amongst sensor systems, the detection performance is an important input. Therefore, both the influence of sensitivity and specificity were analysed. For sensitivity, cash flows and profitability were estimated for sensitivities in the range of 70, 75, 80, 85 and 90% with 90% specificity. Accordingly, for specificity cash flows and profitability were estimated for specificities in the range of 80, 85, 90, 95 and 100% with 80% sensitivity. As farm size might also have influence on the profitability of investment, the analysis was also conducted for farms with 65 cows.

## Results and Discussion

Simulation results

Table 1 shows the simulation results of the base line scenario. In this scenario the average calving interval per herd decreased by 17 days from 419 for visual to 403 for activity meters. This led to an increase in annual milk production of about 11,000 kg/year on average. In addition to this, the number of calves born per year and the number of inseminations per year increased. However, the number of inseminations per year increased more than the number of calves did, which results in a higher number of inseminations per calf.

Table 1: Average technical results per year for farms using visual oestrus detection and farms using activity meters, with the respective 5 and 95% percentiles. The number of inseminations per calf is given under the assumption that cows are only inseminated after a true positive alert (TP) and after both true and false positive alerts (FP)

| | Milk production (kg) | Number of calves | Inseminations per calf (TP) | Inseminations per calf (FP) | CI[1] (Days) |
|---|---|---|---|---|---|
| Visual | 1,032,278 | 144 | 1.55 | - | 419 |
| 5% | 1,008,958 | 133 | 1.51 | - | 367 |
| 95% | 1,056,148 | 155 | 1.58 | - | 507 |
| Activity meters | 1,043,751 | 147 | 1.67 | 1.84 | 403 |
| 5% | 1,021,763 | 136 | 1.63 | 1.75 | 365 |
| 95% | 1,067,947 | 157 | 1.72 | 1.94 | 478 |

[1] Calving interval

In the situation with visual oestrus detection with 50% sensitivity, the average calving interval was 419 days on average. This average calving interval was close to the Dutch average calving interval of 422 (CRV, 2011). So, in this study the simulated average calving interval did resemble more or less the real Dutch average calving interval. If cows were inseminated after false positive alerts as well as after true positive alerts, then the average number of inseminations would increase for 1.67 to 1.84.

Financial results

The financial results per year are shown in Table 2. The most important financial result was increased milk production, which increased revenues by € 3,671 per year. Next, the reduced number of culled cows and reduced labour of visual oestrus detection, reduced costs by € 938 and € 417 per year, respectively. By contrast, higher feed consumption increased expenses by € 1,055 per year, and more inseminations and calves increased expenses by € 679 and € 141 per year, respectively. Overall, the difference in yearly net cash flow between farms with visual oestrus detection and farms with activity meters was € 3,151 per year.

Table 2: Average financial results (in €/year) for farms using visual oestrus detection and farms using activity meters. The minus sign indicates that a cash flow was negative. Insem. means inseminations. Δ is the difference in average annual cash flow between visual and activity meters (in €/year).

| | Visual | Percentile (5%/95%) | Activity meters | Percentile (5% / 95%) | Δ |
|---|---|---|---|---|---|
| Milk | 330,329 | (322,867 / 337,967) | 334,000 | (326,964 / 341,743) | 3,671 |
| Feed | -128,275 | (-130,233 / -126,398) | -129,331 | (-131,223 / -127,570) | -1,055 |
| Calves | -7,483 | (-8,060 / -6,916) | -7,624 | (-8,164 / -7,072) | -141 |
| Insem. | -6,728 | (-7,407 / -6,077) | -7,407 | (-8,163 / -6,682) | -679 |
| Culling | -7,400 | (-9,494 / -5,481) | -6,462 | (-8,449 / -6,682) | 938 |
| Labour | -1,096 | (-1,096 / -1,096) | -679 | (-722 / -637) | 417 |

Investment analysis

The difference in yearly net cash flow between farms with visual oestrus detection and farms with activity meters was used in the investment analysis. The results of the investment analysis are shown in Table 3. The NPV and B/C ratio were € 6,155 and 1.34, respectively. As the NPV is positive and the B/C ratio greater than one, the investment is profitable. The IRR shows that the return on capital of this investment was on average 11%. As the investment is profitable the purchase price will be paid back, according to the DPBP this will be done in 7 years.

Table 3: Results of the investment analysis for investing in activity meters. Results are the average annual increase in cash flow between farms with visual oestrus detection and farms with activity meters, Net Present Value (NPV), Benefit Cost ratio (B/C ratio), Internal Rate of Return (IRR) and Discounted Pay Back Period (DPBP) and the 5 and 95% percentiles.

| | Cash flow (€/year) | Purchase (€) | NPV (€) | B/C ratio | IRR (%) | DPBP (Years) |
|---|---|---|---|---|---|---|
| Average | 3,151 | 18,178 | 6,155 | 1.34 | 11 | 7 |
| 5% | 3,389 | 18,178 | 7,989 | 1.44 | 13 | 7 |
| 95% | 3,082 | 18,178 | 5,618 | 1.31 | 11 | 8 |

Sensitivity analysis

The results of the sensitivity analysis are shown in Figure 1. The IRR increases when either sensitivity or specificity was increased. However, the IRR increases more when the sensitivity was increased, than when specificity was increased. Both the profitability of the investment and the average annual cash flow were more sensitive to changes in sensitivity than in changes is specificity.

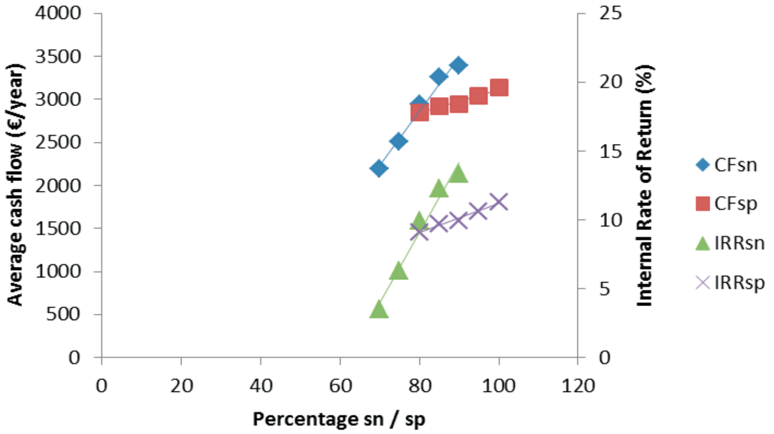


Figure 1: Average yearly cash flow (CF) and Internal Rate or Return (IRR) for different sensitivities (sn) and specificities (sp), with linear trend lines.

There is uncertainty about detection performance of both farmers and activity meters in practice. Sensitivity of a sensor system for oestrus detection has the largest influence on technical results (e.g. milk production) and thereby on cash flow and profitability. Specificity on the other hand influences the number of false alerts and thereby the amount of labour and/or the number of inseminations. The influence of labour and insemination costs related to specificity on cash flow and profitability seems to be lower than the influence of technical results related to sensitivity. This is in contrast with previous findings that farmers perceive false positive alerts as an important problem for automated detection of mastitis (Mollenhorst *et al.*, 2012). Two explanations for this contradiction are possible. First of all, oestrus and mastitis are two very distinct condition and therefore the importance of false alerts could differ. Secondly, the opportunity cost of a farmers labour could have been underestimated in this study.

For a farm with a herd size of 65 cows, investing in activity meters was on average not profitable. The average increase in annual net cash flow was € 1,982 and the IRR 2%. The cause of the difference in profitability between a farm with a herd size of 130 cows and one with 65 cows is caused by economics of scale. For a farm with 130 cows the fixed cost of the activity meters are lower per cow than for a farm with 65 cows. Only when a farm with 65 cows increases its annual net cash flow more than average the investment will be profitable.

In this study, it was possible to simulate a dairy herd with realistic outcomes, for instance the average calving intervals seem to be in line with the values that can be observed in practice. However, fertility problems in general and more specifically failure to conceive are known reasons for culling (Brickell and Wathes, 2011, Dechow and Goodling, 2008, Demeter *et al.*, 2011). However, culling decisions for individual cows in practice are inherently complex (Demeter *et al.*, 2011). Although the effect of increased oestrus detection on the number of involuntarily culled cows is important for investment analysis of activity meters, the available information is insufficient to estimate this effect.

## Conclusions

Investment in activity meters for automated oestrus detection seems to be profitable. The sensitivity of the sensor system is the most important aspect of detection performance with respect to the profitability of the investment.

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# Session 4

# Cattle - Localisation - Lameness

## Validation and application of an indoor localization system for animals

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### Abstract

Tests for validating a system for continuous localization of individual animals in their residence environment are described. The positioning system consists of fixed beacons mounted in a cattle barn. Animals are equipped with an electronic label attached to a collar. All beacons emit a low-frequency signal that is received by the labels. Each label measures with an adjustable frequency the strength of the received signals and passes this information via a UHF signal to an antenna connected with a processing computer. Here the location of the label (and animal) is calculated. The overall average accuracy of the system was 30.5 cm with a standard deviation of 25 cm. The accuracy was negatively affected in the proximity of iron obstacles (walls, feeding fence). However, the obtained results offer sufficient perspectives to use the system for recording and analysing behaviour of individual animals. Observations showed that with the information from the system animal behaviours classified as 'in cubicle', 'on slatted floor' or 'at feeding fence' could be monitored continuously. Obtained accuracies for the behaviours were 95.1% for 'staying in cubicle', 91.9% for 'staying at feeding fence' and 88.5% for 'staying at slatted floor'.

**Keywords:** localization system, system accuracy, monitoring animal behaviour

### Introduction

In 2011 the project Smart Dairy Farming (WUR, 2011) started working on instruments, systems and sensors assisting farmers in monitoring and managing their animals better with respect to animal health and well-being. The instrumentation should help the farmer in his daily management in focussing on that processes or animals that need special attention. This should result in an increased profitability of the farm and better animal health and welfare. One of the tools that is used within the Smart Dairy Farming project is a cow positioning system. The system is able to determine the real time position of each cow inside a cow house. The position of the cows can easily be found on a map of the cow house which is displayed on a pc or smart phone. The main objective of the system is to support the finding of cows that need to be inspected, treated or milked. Besides finding cows other applications of the positioning system might be possible. Not each application of the positioning system requires the same accuracy. For just searching a cow inside the cow house an accuracy of about five meters might be sufficient, while a higher accuracy will be needed for determining behaviour or interactions of cows. Gygax *et al.* (2007) showed that an Abatec positioning system based on radar technology with an accuracy in a range between 0 and 0.5 meters could be used to track cows and to monitor social interactions. Huhtala *et al.* (2007) stated that for monitoring cow behaviour an accuracy of about 1 meter was needed for the position measurements. The research discussed in this paper has two objectives, 1) validation of the positioning system by determining the overall accuracy and quantifying effects of system configuration and barn lay out on the accuracy and 2) exploring the potential of the system for obtaining behavioural information from individual animals.

## Material and methods

### Description of the positioning system

The positioning system is developed to determine the position of cows inside a cow house. The system consists out of beacons, labels and a processing computer which together determine the position of the cows. The beacons are placed at fixed locations in a cow house, with a maximum distance between each beacon of approximately 25 meters. Each beacon sends out a continuous signal with a fixed strength at a unique frequency in between 49 kHz and 55 kHz. These unique frequencies are used to determine which signal is send out by which beacon. Low frequent signals are used, because they do not need a line of sight and are less sensitive for disturbances in the signal caused by reflections. The labels are attached to the collar of the cows. It measures the arrival strength of the signal from each beacon and sends this information to the processing unit with an ultra-high frequency. The ultra-high frequency makes it possible to send this information to the processing unit over a distance of 100 meters, so every label in the cow house is able to send its information to the processing unit. In the test set-up the information was send to the processing unit one time per second. The processing unit uses the information about the signal strengths to determine the position of the cows.

### Set up of the system in the test barn

Experiments were performed inside a cow house which was used for calves. The lay-out and dimensions of this cow house are shown in Figure 1.
The positioning system that was used in the measurements consisted out of six beacons, twelve labels and a processing unit. The beacons (yellow circles) were mounted at a height of 3.50 m at the wall of the cow house. Positions, from position measurements as well as real positions, were expressed with an x- and y-coordinate with the origin in the upper left corner of the cow house (red dot). The x-axis was parallel and the y-axis was perpendicular to the feeding alley. The distances between the beacons in x-direction was about 6 m and in y-direction about 10 m.

Additionally a calibration of the positioning system had to be performed. In this procedure the strength of the signal from each beacon is measured with a label on different positions inside the cow house. Each calibration position is pointed out by hand on a map of the barn and used by the system to improve the accuracy of the position determinations. There should be at least one calibration point under each beacon and in each corner of the cow house. The calibration points under the beacons are used by the system to determine the positions of the beacons. The calibration points in the corners of the cow house are used to determine the boundaries of the area in which the labels (and cows) stay.

Static accuracy tests

Static accuracy tests were conducted in a pen for 12 calves, which was part of the cow house (Figure 1: section B within the right red dashed rectangle). During the static experiments no calves were present in this pen.

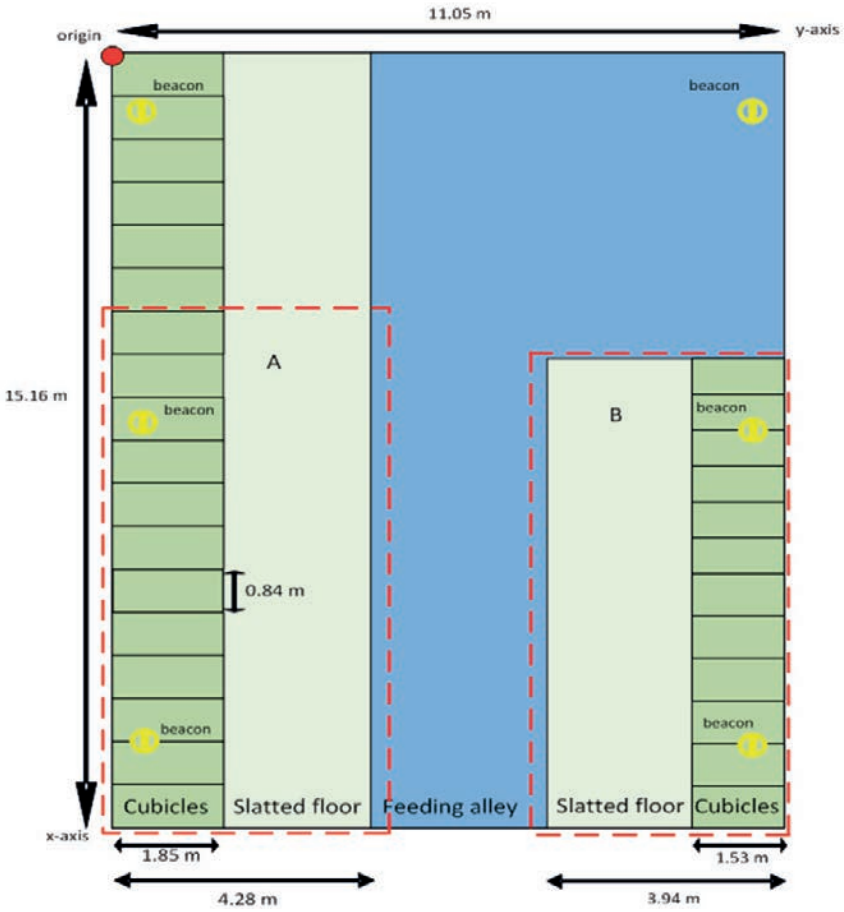


Figure 1. Lay of barn with positioning system.

In the experiments measurements were done with the positioning system, which measured the signal strength of each beacon on all label locations. The labels were placed on 60 different locations, which were equally divided over section B. The positions were divided into five rows parallel to the x-axis and into twelve columns parallel to the y-axis. The rows were placed 1.0 m apart from each other and the columns were placed 0.75 m apart from each other. The real positions, x- and y-coordinates relative to the origin (red dot in Figure 1), were used as the golden standard. At all locations the signal strength of each beacon was measured by a label once every second. Each label sent this signal strength information to the processing unit for calculating the position. During a period of about 50 seconds measurements from the labels were collected and analysed by the processing unit, resulting in calculated label positions expressed as x- and y-coordinates relative to the origin. Because the precision, defined as the difference between the coordinates of a position measurement (each second) and the average coordinates of 30 measurements on a certain label location, showed to be rather high, it was chosen to use the average value of 30 measurements for each label position in the further analyses.

Effects of the configuration of the positioning system, barn construction and equipment on the accuracy were tested. The basic configuration of the positioning system had 6 beacons (Figure 1) and a maximum calibration density of about 1 calibration point per 2.5 $m^2$. First the signal strengths of six beacons and the maximum calibration was used to determine the positions. With the option “simulations” it was possible to use the collected signal strengths data again and calculate the positions with another number of beacons or another number of calibration points. A first simulation was made with only the 4 beacons in the corners of the barn and the maximum calibration density; so in this simulation the signal strength measurements from the two beacons in the middle of the long side of the barn were disregarded. The effect of the number of beacons was tested by comparing 4 and 6 beacons with maximum calibration points. The next two simulations were made with halving the number of calibration points into one per 5 $m^2$ and with the minimum number of calibration points. The minimum number of calibration points was 10 and included the calibration points under each beacon (6) and in each corner of the barn (4). The effects of the barn construction and equipment were tested by analysing the differences in accuracy between the 5 rows and between the 12 columns in which the labels were placed in the test area. These rows and columns had different positions relative to the walls of the barn and the cubicles and the feeding fence in the test area. Finally the effect of two heights of the labels (0.30 m and 0.60 m) was tested with the basic configuration of the positioning system. These heights were chosen, because 0.60 m was by approximation the height of the label when a calf was standing and 0.30 m was the height of the label when lying.

Data from the static experiment was used to determine the accuracy expressed as differences in the x- and y- coordinates and the absolute distance between the real coordinates/positions and the coordinates/positions determined by the positioning system. For the differences in the x- and y-coordinates the values determined by the positioning system were subtracted from the values of the real positions. The effects of the configuration of the system (comparison of 4 and 6 beacons and comparison of minimum, medium and maximum calibration density), barn construction and equipment (comparison of rows 1 to 5 and columns 1 to 12) and height of the labels (height: 0.30 vs. 0.60 cm) were analysed using analysis of variance (ANOVA).

<u>The positioning system and animal behaviour information</u>

Ten 3-4 month old calves  carrying a neck collar with label of the positioning system were kept in a part of a pen of the barn (Figure 1: section A within the left red dashed rectangle) consisting of 12 cubicles for lying, a walking area with slatted floor and a feeding fence. For each calf position measurements were recorded per second from March 22 till April 17, 2013.  The ration fed at the feeding fence was changed during the registration period; till April 7 the calves were fed ad lib with concentrates and dried alfalfa and from April 8 the amount of concentrate was restricted and pre-wilted silage was fed ad lib. On April 4 and 10 the behaviour of the calves was visually recorded each 5$^{th}$ minute during at least 24 hours.  Behaviour was classified as lying or standing in cubicle, standing on slatted floor or standing at feeding fence. In a REML-procedure the effect of the behaviour classes 'in cubicle', 'on slatted floor' and 'at feeding fence' on the y-coordinates generated by the positioning system were tested. Data for the behaviour classes came from the visual observations made each 5$^{th}$ minute. Data from the positing system were transferred to mean coordinates over one minute (~60 measurements) for each label (calf). In the statistical test positioning data from the minutes that correspond with the minutes of the visual observation were used. Results from the statistical analysis were used to set up threshold values for the y-coordinates in order to discriminate between 'in cubicle' or 'on slatted floor' and between 'on slatted floor' or 'at feeding fence'. Based on these threshold values the staying location ('in cubicle', 'on slatted floor' or 'at feeding fence') of each calf in each minute was established. The accuracy (proportion of true results in the population) of in this way established behaviours was calculated by comparing with the observed behaviours (as Gold standard). The accuracy is in this context defined as the number of the true positives plus the number of true negatives as a percentage of the total number of observations. The threshold values were also used to estimate for each day and each calf the time spent 'in cubicle', 'on slatted floor' or 'at feeding fence', providing insight into the day-to-day variation of these behaviours.

## Results and discussion

<u>Static accuracy tests</u>

For the validation tests 120 position measurements (60 label positions in 5 rows, 12 columns and at 2 heights) were made with the positioning system and compared with the real positions of the labels. In Figure 2 the 60 real locations of the labels in the test section of the barn are given as blue bullets on the crossings of the vertical (=columns) and horizontal (=rows) gridlines. The positions estimated by the positioning system are shown as red triangles.

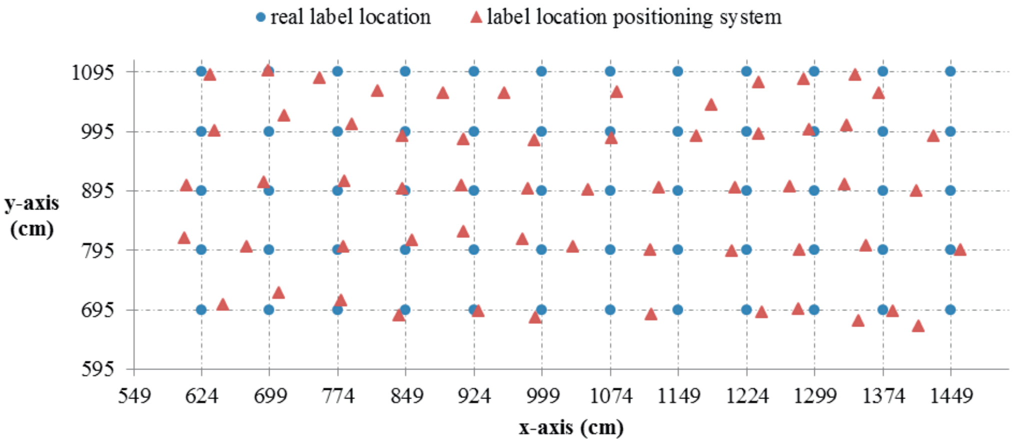


Figure 2. Overview of the real label locations (red bullets) and the locations estimated by the positioning system (red triangles). The system configuration consisted of 6 beacons and had maximum calibration.

For the situation with 6 beacons and maximum calibration the mean accuracy and standard deviation were -6 cm and 34 cm respectively for the x-coordinates and -2 and 19 cm respectively for the y-coordinates. The absolute distance between the real positions and the positions estimated by the positioning system was in average 30.5 cm with a standard deviation of 25 cm. Our results are comparable with the results of Gygax *et al.* (2007), who validated a system developed by Abatec.

The absolute distance in rows 1 and 5 significantly ($p<0.05$) differed from the other rows. The x-coordinates had the largest deviations in columns 8, 11 and 12; the y-coordinates in columns 2, 8 and 12. The resulting absolute distances showed the largest deviations in columns 8, 11 and 12. In general, worst accuracies were found in row 1 and in columns 11 and 12. On these locations the labels were closest to metal sheet pile profile walls and an aluminium roller door; obviously these affected the accuracy. Row 5, that was close to the feeding fence had a significant lower accuracy too. This might be explained by the iron construction of this fence. Gygax *et al.* (2007) also found that the accuracy of the Abatec positioning system depended on the position in the barn.

The height of the labels above the floor (30 vs. 60 cm) only had a significant effect on the accuracy of the x-coordinate; the predicted means for the accuracy of y-coordinate and absolute distance were not affected by height.

The effects of the configuration of the positioning system were tested with simulations.

In Table 1 the effects of decreasing the number of beacons of the positioning system from 6 to 4 on the accuracy is given.

Table 1. Predicted means (cm) of the accuracy with 4 vs. 6 beacons and maximum calibration density.

| Accuracy | 6 beacons | 4 beacons |
|---|---|---|
| x-coordinate | -5.7[a] | 6.3[b] |
| y-coordinate | -2.1 | -3.5 |
| Absolute distance | 30.5[a] | 46.5[b] |

[ab] different letters in the same row mean a significant difference ($p < 0.05$)

The number of beacons had significant effects on the accuracy of the x-coordinate and on the absolute distance. The accuracy of the absolute distance was significantly worse with 4 beacons. Table 2 shows the effect of different calibration densities on the accuracy when used in combination with 6 beacons.

Table 2. Predicted means (cm) of the accuracy with minimum, half and maximum calibration densities and 6 beacons.

| Accuracy | Maximum calibration | Medium calibration | Minimum calibration |
|---|---|---|---|
| x-coordinate | -5.7[a] | -2.9[a] | -29.1[b] |
| y-coordinate | -2.1[a] | -1.4[a] | 24.8[b] |
| Absolute distance | 30.5[a] | 31.6[a] | 84.0[b] |

[ab] different letters in the same row mean a significant difference ($p < 0.05$)

From Table 2 can be concluded that taking away half of the maximum calibration points had no significant effect on the accuracies. The accuracies of a situation with minimal calibration significantly differed from the accuracies of the other two situations.

Animal behaviour information

On April 4 and 10 the behaviour of 10 calves was visually scanned each 5$^{th}$ minute. From these observations the mean daily time budget for lying and standing in cubicles, standing on slatted floor and standing at feeding fence were determined. Between April 4 and 10 there was a strong increase from 11 into 20% of the time for standing at the feeding fence. This was caused by a drastic change in the ration fed to the calves. The calves spent a large part of the day in the cubicles, on April 4 76% and on April 10 66%. Cubicle occupation decreased because more time was spent at the feeding fence.

The effect of the behaviour classes ‘in cubicle’, ‘on slatted floor’ and ‘at feeding fence’ on the y-coordinates generated by the positioning system tested with a REML-procedure are given in Table 3.

Table 3. Predicted means of y-coordinates from the positioning system at different behaviour classes.

| Behaviour class | Predicted means for y-coordinates (cm) |
|---|---|
| Lying in cubicle | 55.0[a] |
| Standing in cubicle | 134.5[b] |
| Standing on slatted floor | 303.9[c] |
| Standing at feeding fence | 395.4[d] |

[abcd] different letters mean a significant difference ($p < 0.001$)

Results from the statistical analysis showed highly significant differences between the y-coordinates of the facilities belonging to the classified behaviours. When lying in a cubicle the label at the neck collar was in average 55 cm from the wall being the origin of the y-coordinate. When standing in a cubicle the calves often were only with the head and the front legs in the cubicle resulting in a larger distance (134.5 cm) from the wall. The predicted mean for standing at the feeding fence was 395.4 cm, while the distance of feeding fence from the wall was 428 cm. This means that when eating the calves often had only their head through the feeding fence, while the neck collar with label was still in the slatted floor area.

Based on the results in Table 3 the threshold values for the y-coordinates in order to discriminate between ‘in cubicle’ (lying as well as standing) or ‘on slatted floor’ and between ‘on slatted floor’ or ‘at feeding fence’ were set at 180 and 380 cm, respectively. With these thresholds the total time per calf per day spent per staying location (‘in cubicle’, ‘on slatted floor’ or ‘at feeding fence’) were compared with the visual observations on April 4 and 10. The accuracies of the in this way established behaviours were 95.1% for ‘staying in cubicle’, 91.9% for ‘staying at feeding fence’ and 88.5% for ‘staying at slatted floor’.

The calculated time budgets on April 4 for ‘staying in cubicle’ and for standing ‘at feeding fence’ were 74 and 10% respectively, compared with 76 and 11% recorded in the visual observations. On April 10 the calculated time budgets for ‘staying in cubicle’ and for standing ‘at feeding fence’ were with 66 and 20% respectively, exactly the same as recorded in the visual observations. The calculated time budgets during the experiment are given in Figure 3.


Figure 3. Mean staying time in minutes per calf per day* in cubicle, at feeding fence and on slatted floor during the experimental period.
* 5 days are left out because during parts of these days position registrations were missing.

This graph clearly shows the effect of changing the feed ration on April 8; time spent on feeding increases largely from this date mainly at the expense of time for lying.

## Conclusions

In the basic configuration with 6 beacons and maximum number of calibration points the mean accuracy and standard deviation were -6 cm and 34 cm respectively for the x-coordinates and -2 cm and 19 cm respectively for the y-coordinates. In general, worst accuracies were found when labels were located in the proximity of iron obstacles (walls constructed from metal sheet pile profiles or feeding fence). The overall mean accuracy of the system was 30.5 cm with a standard deviation of 25 cm.
The effects of the configuration of the positioning system, tested with simulations, showed that taking away half of the maximum calibration points had no significant effect on the accuracies.
For the use of facilities determined on the basis of the information from the positioning good accuracies were obtained, ranging from 95.1% for 'staying in cubicle', 91.9% for 'staying at feeding fence' and 88.5% for 'staying at slatted floor'.
A change in feeding management (drastic change in the ration composition) was clearly visible in the behavioural information derived from the positioning system. This indicates that the system has potential for online monitoring of animal behaviour for management purposes.

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# Accuracy assessment of localisation of dairy cows housed in free-stall barns using a system based on Ultra Wide Band technology

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## Abstract

The objective of this study was to evaluate the localization error of a Real-Time Localisation System (RTLS) based on Ultra Wide Band (UWB) technology within a free-stall barn which represents a particularly hostile environment for the functioning of this kind of system.
Each dairy cow was equipped with an active tag. A video-recording system was installed in the barn. Top-view camera images of the area of the barn under study were rectified and synchronised with the RTLS. Each cow position computed by the RTLS was then validated by visual recognition carried out by an operator using the camera images.
The tags were subdivided into two groups on the basis of a localisation error threshold. The first group had a mean average distance error of about 0.40 m and an average distance error of about 0.80 m at the $90^{th}$ percentile, whereas the second group gave errors of about 0.66 and 1.11, respectively. Although the localisation error was higher than that stated by the producer Ubisense, the RTLS is suitable for use in dairy houses to determine the occupancy level of the different functional areas, compute behavioural indices, and track each animal in the herd.

**Keywords:** UWB tag, Animal behaviour, Animal tracking, Behavioural indices

## Introduction

Many studies have been carried out with the aim of demonstrating that Radio Frequency Identification (RFID) based on High Frequency (HF) and Ultra-High Frequency (UHF) technology could detect and locate individual animals inside specific functional areas of intensive animal buildings (Sowell *et al*., 1998; Schwartzkopf-Genswein *et al*., 1999; Huhtala *et al*., 2007; Reiners *et al*., 2009; Porto *et al*., 2012; Barbari *et al*., 2008). The object localisation accuracy provided by RFID systems based on UHF technology could be improved by using Ultra Wide Band (UWB) technology (Álvarez *et al*., 2010). The advantage of this technology is the signal transmission mode which uses short duration pulses. This mode of transmission means that systems based on UWB have low sensitivity to interference due to the reflection of the wave itself. These features have allowed real-time location of objects and/or persons within enclosed environments

which are sensitive to radio frequency, such as hospitals.
The purpose of this study was to evaluate the localisation error of a group of dairy cows housed in a free-stall barn by using a Real-Time Location System (RTLS) based on UWB technology. The RTLS used in this work, which is produced and sold by the English company Ubisense, currently provides the best accuracy of all RTLS (Weichert *et al.*, 2010; Linde, 2006). In fact, the accuracy which Ubisense states as achievable for the localisation of moving objects in real time is 15 cm in the three dimensions ($x$, $y$, $z$). However, in field tests the accuracy varied between 30 cm and 100 cm in the two dimensions $x$ and $y$ depending on the application, e.g. agriculture, transit yard management, and personnel safety (Ward, 2010; Mok *et al.*, 2010).

## Material and methods

<u>The breeding environment and the RTLS</u>
The trial was carried out from 1st August to 10th September 2011 within a dairy house located in the province of Ragusa (Sicily, Italy). The breeding environment studied (Figure 1) was composed of a sand-bedded resting area with head-to-head stalls, a feeding alley adjacent to the resting area, a service alley and two side passages. An RTLS based on UWB technology was installed in the barn to detect and track the position of 8 dairy cows.
The RTLS was composed of 4 sensors IP30 Series 7000 and 9 Compact Tags IP65. The system was wired and connected to a Power-over-Ethernet (PoE) switch, which in turn was connected to a personal computer.
The four sensors were powered by the switch via PoE cables, operated in a frequency range of 6÷8 Ghz, and communicated with the tags bidirectionally at 2.45 Ghz. Each sensor contained 5 UWB antennae and computed tag positions independently using a combination of Angle-of-Arrival (AoA) and Time-Difference-of-Arrival (TDoA) technologies (Ubisense, 2009). One of the four sensors was set as master and the others as slaves. The master sensor was used to set system parameters and compute positions. The nine tags measured 38×39×16.5 mm and weighed 25 g. They can work at temperatures between -20 °C and 60 °C and relative humidity up to 95%. They sent data to the sensors at an update rate ranging between 0.00225 Hz and 33.75 Hz (Ubisense, 2012).

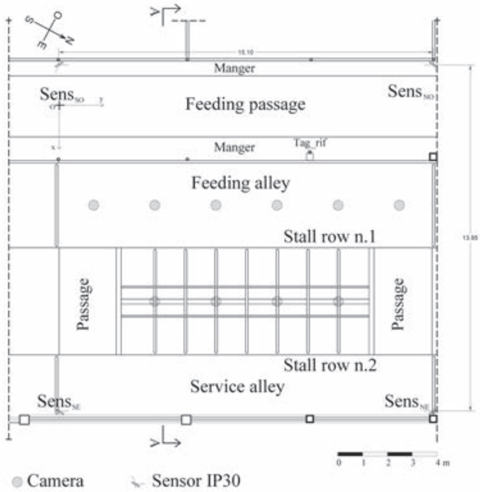

Figure 1: Plan and section of the area of the barn under study.

The Location Engine Configuration (LEC), a software system provided by Ubisense, allowed users to monitor the sensor and tag status in real-time by means of two-dimensional and three-dimensional graphical representations. Moreover, the LEC made it possible to specify a number of constraints for the tags (velocity, height, maximum change of position, etc.) in order to filter out measurements on the basis of the characteristics of the environment in question. A DHCP Server and the software needed to operate the system were installed on the personal computer.

The installation phase of the RTLS hardware was carried out according to the system user guide (Ubisense, 2008-2010).

The four sensors $Sens_{SO}$, $Sens_{NO}$, $Sens_{NE}$, $Sens_{SE}$ (Figure 1) were fixed at a height of 3.78 m by means of adjustable stirrups. The position of sensor $Sens_{SO}$ was chosen as the origin of the Cartesian coordinate system used in the real environment (Figure 1). The same coordinate system was adopted in the virtual reproduction of the area under study which was obtained using the graphical interface of the LEC. This allowed visualisation of cow locations in the virtual environment once the calibration phase was complete (Ubisense, 2008-2010).

To provide resistance to water, mud, humidity and impacts, the tags were covered with an insulating plastic tape and put into a water-resistant bag made from synthetic leather and plastics, as shown in Figure 2a.

A reference tag was installed at a fixed point within the barn (Figure 1) in order to evaluate the quality of localisation of fixed objects, and, as a consequence, make it possible to compare the results of the trial with those in the literature (Steggles, 2005).

Eight active tags were installed on each of the 8 cows. The small size and weight of the tags made it possible to fix them in the animals' ears (Figure 2b).

The RTLS acquired information on the position of the 8 cows at 1-sec intervals. To store this information, specific software was developed using Microsoft® Visual C# Express (framework .NET), a free programming environment distributed by Microsoft®. Specifically, by executing a connection to the Ubisense Platform Control (Ubisense, 2008-2010) at 1-sec intervals, the software requested the latest data acquired by the sensors and wrote the following information to a text file:

- Acquisition date;
- Acquisition time;
- Identification number (ID);
- Location in space, expressed by the coordinates *x*, *y*, and *z*;
- Standard error.


Figure 2: (a) Protective wrapping of tags (front and back) and a Compact Ubisense Tag. (b) Application of the tags to three cows.

<u>Accuracy assessment of the rtls</u>

The accuracy of the localisation error achieved through use of the RTLS was assessed using information from a specially designed video-recording system which was installed in the barn under study.

Ten video-cameras were installed, 6 on the feeding alley and 4 on the resting area, in order to give a panoramic plan-view image of the breeding environment (Figure 1). Further details of the technical characteristics and layout of the video-recording system were reported in a previous paper (Porto *et al*., 2013).

The construction of panoramic plan-view images of the area under study then made it possible to verify the planimetric position of each tag provided by the RTLS. A special software which allowed visualisation of tags within each panoramic image by using graphic elements (points) was developed using Microsoft® Visual C# Express (framework .NET). Using this software, an operator carried out visual recognition of each tag applied to the cows and adjusted the position of the related graphical element when it was visualised in the wrong position.

The positions adjusted by the operator constituted the dataset of the true locations of the tags during the monitoring period.

The accuracy of the localisation error was assessed by computing the Euclidean distance between the position provided by the RTLS and those verified by the operator.
The methodology followed in this trial allowed computation of the planimetric position error. Further improvements should be made so that the error in the *z* direction can also be calculated.
Identification and filtering of anomalous measurements, which were highly different from the central data distribution values, were performed by adopting an outlier data cleaning technique. The measures higher than $q3+w*(q3-q1)$ or lower than $q1-w*(q3-q1)$ (where $q1$ and $q3$ are the 25$^{th}$ and the 75$^{th}$ percentiles, respectively, and $w=1.5$) were discarded.
Two localisation error thresholds were fixed at 0.50 m and 1.0 m for the mean error and the error at the 90$^{th}$ percentile, respectively. On this basis the tags were subdivided into two groups.
The results described in the rest of this paper relate to the tags which showed the mean error and the error at the 90$^{th}$ percentile to be higher than the fixed threshold values. This choice was based on the need to define limits for the application field of the RTLS in a free-stall barn.
The analysed data were obtained from recordings carried out on 2$^{nd}$ August 2011 during a time interval of about 54 minutes. Two different cow behaviours were observed during this time interval. The first time interval between 06h:26m:49s and 06h:53m:39s (about 27 minutes) included cow localisation during feeding activity at the manger, whereas the second time interval between 11h:35m:37s and 12h:02m:27s (about 27 minutes) covered cow lying behaviour in the stalls.

## Results and discussion

After application of the outlier data cleaning technique to the dataset, the mean error and the error at the 90$^{th}$ percentile of five tags were below the fixed thresholds with an average mean distance error and 90$^{th}$ percentile error of about 0.40 m and 0.80 m, respectively. The other three tags gave average errors of about 0.66 m for mean error and 1.11 m for the error at the 90$^{th}$ percentile. The results reported in Table 1.a and Table 1.b refer to these three tags. The tables show the minimum error, the mean error, the maximum error and the error at the 90$^{th}$ percentile obtained before and after outlier data cleaning. The chosen time interval determined the verification of 3840 tag positions through the use of 1600 panoramic images acquired by the video-recording system. Therefore, the accuracy assessment took about 30 hours of operator's work.
Table 2.a shows the errors recorded for the reference tag. In this case the errors were obtained by computing the Euclidean distance between the position of the reference tag determined by the RTLS and that measured in the real environment (Figure 1).

Table 1.a: Errors computed on the data acquired by the RTLS, for each of the three tags analysed.

| Tag ID | Error (m) | | | | Point (n.) |
|---|---|---|---|---|---|
| | Min | Mean | Max | 90° perc. | |
| 004 | 0.12 | 0.59 | 4.41 | 1.12 | 1029 |
| 023 | 0.18 | 0.83 | 2.62 | 1.20 | 1453 |
| 026 | 0.16 | 0.73 | 6.84 | 1.25 | 1358 |

Table 1.b: Errors obtained after the outlier data cleaning process on the errors computed from data acquired by the RTLS, for each of the three tags analysed.

| Tag ID | Error (m) | | | | Point (n.) |
|---|---|---|---|---|---|
| | Min | Mean | Max | 90° perc. | |
| 004 | 0.12 | 0.53 | 1.52 | 1.04 | 1029 |
| 023 | 0.18 | 0.79 | 1.44 | 1.12 | 1453 |
| 026 | 0.16 | 0.66 | 1.71 | 1.17 | 1358 |

Table 2.a: Errors computed on the data acquired by the RTLS, for the reference tag.

| Tag ID | Error (m) | | | | Point (n.) |
|---|---|---|---|---|---|
| | Min | Mean | Max | 90° perc. | |
| 187 | 0.01 | 0.11 | 0.56 | 0.17 | 3672 |

Table 2.b: Errors obtained after the outlier data cleaning process on the errors computed from data acquired by the RTLS, for the reference tag.

| Tag ID | Error (m) | | | | Point (n.) |
|---|---|---|---|---|---|
| | Min | Mean | Max | 90° perc. | |
| 187 | 0.01 | 0.11 | 0.24 | 0.17 | 3672 |

Outlier data cleaning produced a reduction in the localisation errors made by the RTLS, and made the data distribution more homogeneous without losing any relevant information for the analysis performed in this study. The data discarded by applying this technique (about 1.8% of the error dataset) corresponded to measurements which were clearly unreliable.

The number of points verified for the three tags applied to the cows (Table 1.a and Table 1.b) was lower than the number verified for the reference tag (Table 2.a and Table 2.b). This was because the reference tag was always present in the panoramic top-view images analysed in the two time intervals considered in the trial. For the three tags applied to the cows, the number of points verified depended on the presence of the cows in the framed scenes. When cows were outside the areas monitored by the video-cameras (i.e. the passages and the service alley), the measurements acquired by RTLS were discarded because it was not possible to verify the position of the tag through visual recognition.

Under the operating conditions considered in this research, the results highlight the fact that the RTLS produced a higher error than that stated by Ubisense which was derived from both laboratory trails (Mok *et al.*, 2010) and tests carried out in optimum operating conditions (Stephan *et al.*, 2009). Furthermore, the performance of the RTLS was better in static conditions than when monitoring moving objects. A comparison of Table 1.b and Table 2.b shows that the localisation error made by the RTLS for the reference tag (Table 2.b) is definitely lower than for moving tags (Table 1.b). A similar observation was made in a test carried out in a railway tunnel (Mok *et al.*, 2010).
However, since the worst mean localization error (tag ID 023), which was about 0.80 m, is small when compared with the average dimensions of a cow, the results obtained make it possible to state that the RTLS could be used to study some specific aspects of cow behaviour. For instance, the recorded error level does not affect the computation of some behavioural indices that do not require a high level of precision with regard to cow position, such as cow standing index and cow feeding index. With regard to cow lying index, a further trial must be carried out to evaluate the localisation error in the *z* direction in order to distinguish between lying and perching behaviour. Moreover, the RTLS could also be used to track each animal in the herd with a good approximation and to provide a good description of the occupancy level of the different functional areas of the barn.

## Conclusions

The trial carried out in this research made it possible to compute the planimetric localisation error of a UWB-based Real-Time Location System (RTLS) produced by Ubisense when used to identify and localise 8 dairy cows housed in a free-stall barn. The results of the experiment revealed that the mean localisation error of five UWB tags was on average about twice as high as that obtained from laboratory trails and tests carried out by Ubisense in optimum operating conditions. For the remaining three UWB tags, this error was on average about three times higher. Moreover, RTLS performance was less accurate when monitoring moving cows than in static conditions. In fact, in this latter situation, the mean planimetric error obtained by locating a reference tag which was fixed to a pillar of the barn was very close to that stated by Ubisense for moving objects.
Although the mean planimetric errors recorded for all the tags considered ranged on average between about 0.40 m and 0.66 m, they are small when compared with the average body dimensions of dairy cows. Therefore, the RTLS tested in this study could be used to study some specific aspects of cow behaviour which do not require a high level of precision in terms of cow position (e.g. cow standing index, cow feeding index), to track each animal in the herd during the day, and to analyse the occupancy level of different functional areas of the barn.
The methodology proposed in this study for calculating the localisation error of the

RTLS did not allow computation of the error in the *z* direction. This information is fundamental to some studies focusing on analysis of cow behaviour in free-stall barns because information about tag height from the ground makes it possible to discern different cow behaviours within the same functional area (e. g. lying vs perching). Therefore, another study, which is still in progress, is focusing on evaluating the vertical error of the RTLS in the same operating conditions.


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## Video tracking of dairy cows for assessing mobility scores

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### Abstract

Lameness afflicts a large proportion of dairy herds, but could be considerably reduced by automated monitoring by CCTV. Key to this is reliable, robust detection and tracking of individual cows in crowded video sequences. We introduce a novel detection and tracking method, based on the Viola-Jones detector. We show that animals can be tracked and their overall gait patterns and speed automatically extracted from video sequences. Preliminary work on identification of individual animals through principal component analysis and SIFT feature matching is also described.

**Keywords**: cow lameness, video, detection, tracking, PCA, SIFT

### Introduction

Lameness in dairy cows is an issue widespread of concern for the dairy industry. At any one time, it is widely estimated that up to a third of dairy cattle in the UK suffers some degree of lameness. Identification and treatment of lameness at an early stage can help prevent lameness from becoming more severe, with concomitant benefits to the animal and cost savings to the farmer.

Current practice for measuring mobility scores and identifying cows at risk of lameness relies on visual inspection of the individuals; an expert observes the cows as they walk and assigns them a grade depending on their mobility. Although this method is currently the norm, there are some drawbacks of concern:

- Lack of robustness – being subject to human perception, it is possible for two experts to give different scores to the same individual.
- Expense of expertise – being dependent on the availability of an expert, there are constraints in the frequency at which each cow can be monitored.

These constraints, coupled with large herds cared for by only limited staff, mean that daily monitoring is infeasible. In this paper, we present an automatic video processing system which can provide information on the mobility of dairy cows without requiring human intervention. The principal obstacle to automatic monitoring of dairy cows is the accurate identification and tracking of individual cows and we therefore focus on this aspect, showing how cows can be accurately located and tracked in video. This provides ready measurement of the speed of each cow, which has been shown to be well-correlated with the cow's mobility score (Bell *et al*., 2013). It also gives access to measures of the animal's gait which may also be used for mobility assessment. We describe preliminary work on the identification of particular cows from video, with the goal of obviating the need for additional systems such as RFID tags for linking scores to particular cows. We draw attention to another video-based analysis system which, unlike ours, uses back posture to assess lameness (Poursaberi *et al*, 2011)

**Methods**

In this section we describe the main elements of our proposed system. To enable widespread use, we aim to use commodity hardware rather than specialised equipment.

<u>Setup</u>

The hardware component of the system consists of video recording equipment used to monitor the exit of the milking parlour. Cows leaving the milking parlour in batches of 24 after milking, walk down an exit race approximately 10 m long before turning into a large barn. This is monitored by a standard home-security surveillance camera system mounted overhead, providing a view, principally of the cow's back (see for example Figures 1 and 2). This view minimises the possibility of occlusion. Three additional cameras, providing additional viewpoints were also installed but were not used in the work reported here. The video recording equipment was scheduled to record for two hours in the morning and two hours in the afternoon. These are the times when milking typically takes place, however there is no guarantee of any exact timing when the cows start walking out. For this reason, the recording schedules span a generous time window ensuring that the moment when the cows walk out will be captured. This also means that there are long periods where there is no activity of interest in the videos. The captured video files were stored on the recording equipment hard drive. Afterwards video files were recovered and processed off line.

<u>Detection and tracking cows</u>

The first step towards developing the cow tracking system is to detect when a cow is visible and when it leaves the scene. It is also important to detect where in the current frame the cow is located. When cows are absent, the recorded video comprises the farmyard concrete floor and neighbouring buildings and it might therefore be expected that a straightforward way of detecting and tracking individual cows would be by simple background subtraction, which is often effective for interior and man-made scenes (e.g., Sonka *et al*., 2007). However, we find that background subtraction methods are ineffective here due to the changing lighting conditions (particularly as milking is often around dawn) and the varying reflectance of the farmyard floor as animal waste is deposited on it and the floor is washed. A further difficulty arises from the close proximity of the cows as they leave the milking parlour: background subtraction and optical flow methods tend to detect moving objects in the video, but fail to separate individual cows.

Rather than detecting entire cows, we therefore choose to locate and track the heads of cows by constructing a specialised detector for cow heads. By detecting cow heads in individual video frames we avoid false positive detection of other moving objects such as people and shadows. In addition, the heads of cows are generally well separated so that neighbouring cows are easily distinguished.

The Viola-Jones object detection algorithm (Viola and Jones, 2004), commonly used for detecting human faces, was adapted to locate the heads of cows in individual video frames. The Viola-Jones detector uses a set of simple image features and combines them to determine whether a face (or head) has been detected. The features used are very similar to the well-known Haar wavelet basis functions and are very simple in their nature; one feature could detect, for example, a horizontal edge of a shape. These features can be very easily and quickly computed. The Viola-Jones detector computes a large number of these features, each one of which on its own is a *weak* classifier, able to detect the presence of a cow head little better than random. The many weak classifiers are combined during training to form a strong classifier using boosting to select the most useful (Freund and Schapire, 1997). In order to achieve very high true positive detections and a low false positive rate, classifiers are arranged in a cascade. At the top level of the cascade a sub-window of the image is checked to discover whether (on the basis of a few features) it may be rejected as containing a cow head; if not the sub-window is processed by further stages of the cascade. Early rejection of a sub-window means that the detector is computationally very efficient and the whole image may be scanned, one sub-window at a time, for the sought object.

In order to use the Viola-Jones detection algorithm to suit our application, it was necessary to construct a cascade which was trained for detecting cow heads. A training set consisting of 1000 heads was manually selected from our video recordings, from different cows and under different lighting conditions. Each training image was 60 pixels square as shown in Figure 1(a). These samples where used to train the weak classifiers forming the head detector cascade. Note that during training each of the training heads is used multiple times after application of various randomly chosen affine transformations (rotation, scaling, shearing), which confers robustness to changes in pose and precise detail of the head. The training heads are used in conjunction with a range of backgrounds, not just from the farmyard which means that cow heads are effectively detected in a wide range of scenes.

Having trained the head detector, it was applied to every frame of each video being inspected. Figure 1(b) shows an example of a detection. For clarity, this image has been cropped to the region surrounding the cow, but detection takes place across the whole video frame without any additional preprocessing and several cow (heads) may be detected in a single frame, see for example Figure 2.

Track extraction

The head detector described above provides a very high detection rate; we estimate the true positive rate to be in excess of 95% with a false positive rate of less than 1%. However, it is still possible for the detector to occasionally miss a head or detect a head where there is none. Therefore, simply joining detections from one frame to the next would yield erroneous tracks. Detections on a series of frames were joined together and smoothed using the Kalman filter (Kalman, 1960; Roweis & Ghahramani, 1999).

We regard the true location of the cow's head as a hidden state, which is related to the observed location of the centres of the detection squares. The Kalman filter can be thought of as a two-stage process in which the location of the hidden location in the next frame is first predicted and then, on observing the next frame, corrected using the new observation. We model the probability of making a transition from one location to another as a simple Gaussian diffusive process and the observed head location is modelled as the true location plus Gaussian distributed observational noise. Given the location of a head in a frame at time *t*, the predictive step of the Kalman filter is used to estimate the region where the head is likely to be located at time *t+1.* If a head is located within the predicted region, then the true location is updated with the detection at time *t+1* and the new location added to the track.

(a) (b)

Figure 1: (a) Sample cow heads used for training and (b) detected cow head

If no head is located at *t+1*, a predicted location is calculated at *t+2*, with an increased uncertainty, and so on. Notice that for every missed frame, the uncertainty increases until it reaches a maximum uncertainty in which case the track has been lost. In this way detected locations are joined together to form smooth tracks and the location of the cow's head is interpolated in frames where no detection was made. The smoothness of the track and the prediction window in which detections are sought depend on the values of the state noise uncertainty and the observational noise; however, the resulting tracks are insensitive to their precise values. The Kalman filter updates are all accomplished with linear algebra and so are computationally fast. Figure 2 shows a cow head detected as the cow leaves the milking parlour at the lower left of the image, together with a

cow that has been tracked through the exit race. The green squares mark the location of the detected head and the radius of the circle is proportional to the uncertainty in the Kalman filter's estimated true location of the head. The uncertainty in the right-hand cow's location is due to it having just passed under a wire which inhibited head detection for a few frames. Figure 3 shows the tracks taken by several cows.
Once this process is completed, the individual head detections have been merged into tracks which describe the movement of the cow's head over time. From these tracks it is possible to calculate the time it takes a cow to cross the corridor where they have been recorded.

## Results and discussion

### Analysing individual tracks

After the heads detected over a number of video frames have been merged into a single track, it is possible to analyse different aspects of the track. For example it is possible to analyse the path a cow has followed. In this way, the gait asymmetry can be measured. Previous studies (Chapinal *et al.*, 2011) indicate that gait asymmetry is an indicator of mobility scores. Figure 2 illustrates the extracted path which could be used for assessing gait asymmetry.

### Timing tracks

Other information that can be obtained from the tracks is the speed of the cow. Position is known at every frame and the total time elapsed is also known, therefore calculating


Figure 2: Detected and tracked cows. Green squares show the location of detected heads; green circles show the Kalman filter uncertainty in the true location and red lines indicate the true path followed and can be used to measure gait asymmetry.

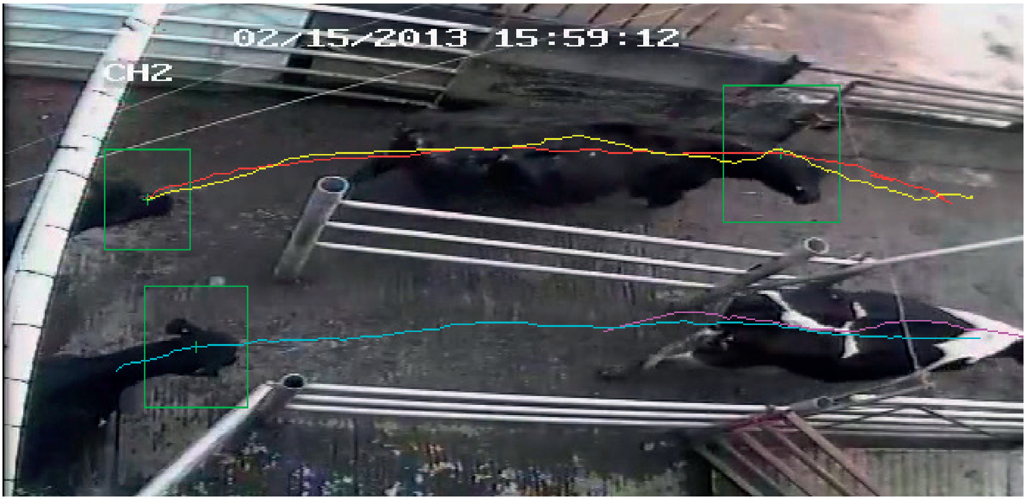


Figure 3: Detected and tracked cows showing the simultaneous detection and tracking of several cows.

speeds is straight forward. Notice that speeds may vary through time (i.e. the cows may slow down or move faster); for this study we use the average speeds over whole tracks.

Bell et al (2012) have established that deterioration of walking speed is one of the characteristic symptoms of lameness. The video processing system presented here can exploit this fact and help in the early identification of lameness. Figure 4 shows a histogram of the speeds of approximately 190 dairy cows inspected by this system over a number of weeks.

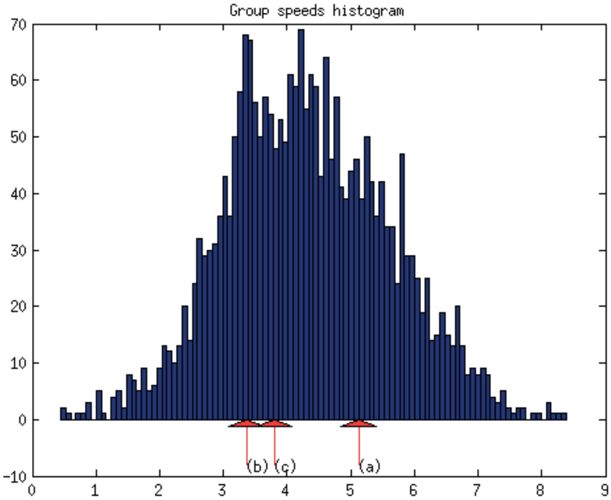


Figure 4: Distribution of average track speeds. Arrows indicate the average speed of three individuals (a), (b) and (c).

The relative speed of a cow with respect to the group on its own is not sufficient to detect lameness; a cow may be consistently slower than the group due to old age or simply due to its own preferred pace of walking. The arrows on Figure 4 indicate the mean speed of a number of the observed individuals. We therefore propose to detect lameness by monitoring each individual cow's speed over a number of days to look for consistent changes in mean speed, excluding those caused by bunching of cows as they leave the milking parlour.

<u>Identifying individuals</u>

Key to monitoring an individual's speed is identifying each individual. While a number of technological solutions to this, such as RFID tagging, are possible, here we report on preliminary work on identify cows from CCTV which if reliable would be a cheaper, more robust alternative.

In computer vision, the problem of individual identification has been addressed repeatedly. Particularly promising methods are eigenfaces (Kirby & Sirovich, 1990; Turk, 1991) and the use of SIFT features (Lowe, 2004).

We extract an image representing each cow's body by capturing the region immediately behind the cow's head when she is walking in an approximately straight line (e.g., Figure 4). Principal components analysis (PCA) is used to find the subspace of these images which best approximates the full space.

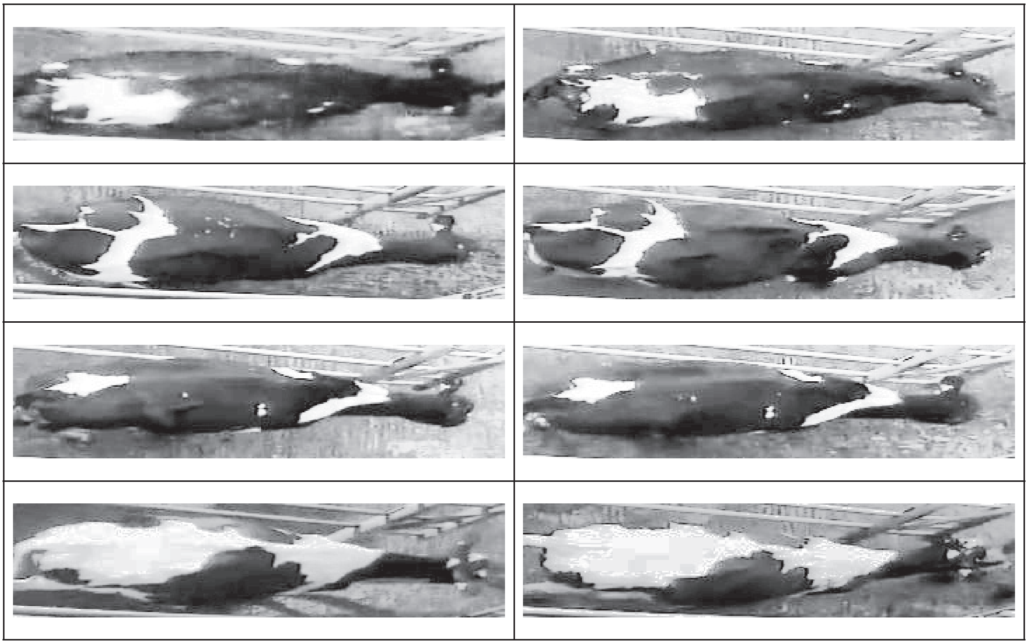

Figure 5: Left column: unidentified images from testing set. Right column: identified images from training set.

The principal components (eigencows) capture the main variation in the data set and discarding those representing small variations helps remove noise. Here 500 sample cow images were used to create a subspace of 150 dimensions. A cow is now identified by projecting her image onto the 150-dimensional space and finding the nearest neighbour to the projections of cow images in the training set, whose identities are known.

Figure 5 shows example images from the training set (left-hand column) which were identified as the closest matches to test images shown in the right-hand column. All test images were taken from videos recorded at different milking sessions to the training images. As the figure illustrates the use of principal components allows matching of images in the presence of noise, focus and lighting.

While PCA provides matching of global image information, scale invariant feature transform (SIFT; Lowe, 1999, 2004), features characterise the local structure of an image such as elements of the patterns on a cow's back). SIFT features were extracted for *keypoints* in each cow image. As Figure 6 illustrates, a large proportion of SIFT features correspond in images of the same cow, whereas the proportion is low for different cows. Our initial work indicates that identification using SIFT features will be more robust than global features such as PCA.

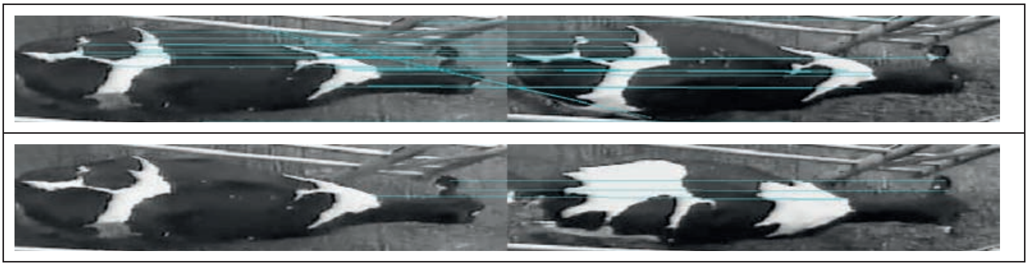

Figure 6: Matching local SIFT features. Lines are drawn between points with matching SIFT features for (top) different images of the same cow and (bottom) images of different cows.

## Conclusions & further work

The principal contribution of this work is the introduction of a method for reliably detecting and tracking cows in video. This permits the easy measurement of their speeds which are well correlated with mobility scores and opens the way to characterisation of their gait and body condition monitoring.

We have also highlighted the need for individual identification and proposed methods for machine identification in video them based on the patterns on their back. Current work is on developing PCA and SIFT identification methods to allow lameness monitoring solely from video.

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# Overview of published sensor systems for detection of oestrus and lameness in dairy cows

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## Abstract

Since the 1980s, sensors have been developed that measure a parameter from an individual cow. The aim of this review is to provide a structured overview of the published sensor systems for dairy health management. The development of sensor systems can be described by the following four levels: I. sensor technique; II. data interpretations; II. integration of information; and IV. decision making. This review has structured a total of 126 publications describing 139 sensor systems and compared them based on the four levels. The found studies concerned the detection of mastitis (25 per cent), fertility (33 per cent), locomotion problems (30 per cent) and metabolic problems (16 per cent). Most of the work fertility (75 per cent) is done at level II. For locomotion (53 per cent) more than half of the work is done at level I. The performance of sensor systems varies based on the gold standards, algorithms, and test sizes chosen. Studies on sensor systems for oestrus have shown that automated detection is possible, but detection performance could be improved. Studies on sensor systems for locomotion problems continue to search for the most appropriate indicators, sensor techniques, and gold standards. No systems with integrated decision support models have been found.

**Keywords:** Automated detection, Sensor, Dairy, Oestrus, Locomotion

## Introduction

There is a trend in dairy farming towards the automation of processes in order to reduce (physical) labour and labour costs (de Koning, 2010, Svennersten-Sjaunja and Pettersson, 2008). This development is partly driven by the economic reality of increasing labour costs relative to capital costs. Automated systems enable dairy farmers to manage larger herds with lower labour requirements (de Koning, 2010), which means that the application of automated systems fits with the trend of increasing herd sizes. Next to this trend, cow health management is an important part of the operational management on a dairy farm. Literature has shown that fertility and locomotion problems are important health issues, both in terms of welfare, economics and reason for involuntary culling of

dairy cows (Bruijnis *et al.*, 2010, Groenendaal *et al.*, 2004, Inchaisri *et al.*, 2010).
Since the 1980s, work has been done on devices that measure a health indicator in, up, on, or from an individual cow (Hogeveen *et al.*, 2010). In these years, pedometers were tested as an possible alternative for visual oestrus detection (Williams *et al.*, 1981). More recently acceleration sensor (attached to the cows leg or neck collar) has been developed, which is a technically more sophisticated successor of the pedometer (Chapinal *et al.*, 2011, Kamphuis *et al.*, 2012). Oestrus detection based on milk progesterone levels has also been studied (Østergaard *et al.*, 2005). For the detection of leg and claw problems the locomotive behaviour and weight distribution over the legs of a cow have been tested as indicators (Chapinal *et al.*, 2011, Pastell *et al.*, 2010). The sensors used to monitor locomotive behaviour are comparable to sensors for oestrus detection that measure activity of the cow.
The objective of this overview is to provide an structured overview of the research done on sensor systems for automated detection of oestrus and lameness in dairy cows.

## Material and Methods

This study considers a sensor to be a device that measures a physiological or behavioural parameter (related to the health or oestrus) of an individual cow and enables automated, on-farm detection of changes in this condition that is related to a health event (such as disease) and requires action on the part of the farmer (such as treatment).
There are two categories of sensors: attached and non-attached. Attached sensors may be on-cow sensors that are fitted on the outside of the cow's body, or in-cow sensors that are inside the body (for example, rumen bolus or implant). Non-attached sensors are off-cow sensors that cows pass by, over, or through for measurement. Two specific forms of non-attached sensors are in-line and on-line sensors. In-line sensors take measurements in a continuous flow of a product from the cow. The only available option for in-line measurement is in the milk line. On-line sensors automatically take a sample (milk, for example) that is analysed by the sensor.
This review has used the framework shown in Figure 1 to categorize sensor systems. The framework describes the steps from a sensor to a decision. Sensors are categorized in the levels of this scheme according to their description in the literature. Sensors are only described if they reach at least level I, known as "technique," which means that they measure an aspect of the cows' condition or status. The two categories identified within this level are solely measuring a parameter and an assumed relation. In some sensors the produced data is processed by a data algorithm (for example a pedometer records clicks of a mercury switch; the data algorithm produces a step count per time unit from these clicks). The next step (level II) is called "data interpretation" and measures changes in the sensor data to produce information about the cows' status (e.g., oestrus). The two categories identified within this level are a statistically tested relation and a validated algorithm. From a statistically tested relation, it is possible to build

a predictive model (detection algorithm) that classifies the cows' status (for example, in oestrus or not in oestrus). For validation, a data set (not the one used to build the detection algorithm) is used to assess the performance by comparing the classification of the algorithm with the gold standard. A further feature can be updating or resetting the detection algorithm with gold standard measurements during operation in practice, this would mean the algorithm adapts to an individual farm or changing circumstances. Level III integrates the sensor information with other information (such as economic information), to produce advice for the farmer. Furthermore, information of individual cows can be aggregated by a monitoring algorithm at the herd level. The output of this algorithm can be seen as either general information on the herd's health for the farmer or additional data input for the detection algorithm. The decision is eventually made either by the farmer or autonomously by the sensor system (level IV, known as "decision making").

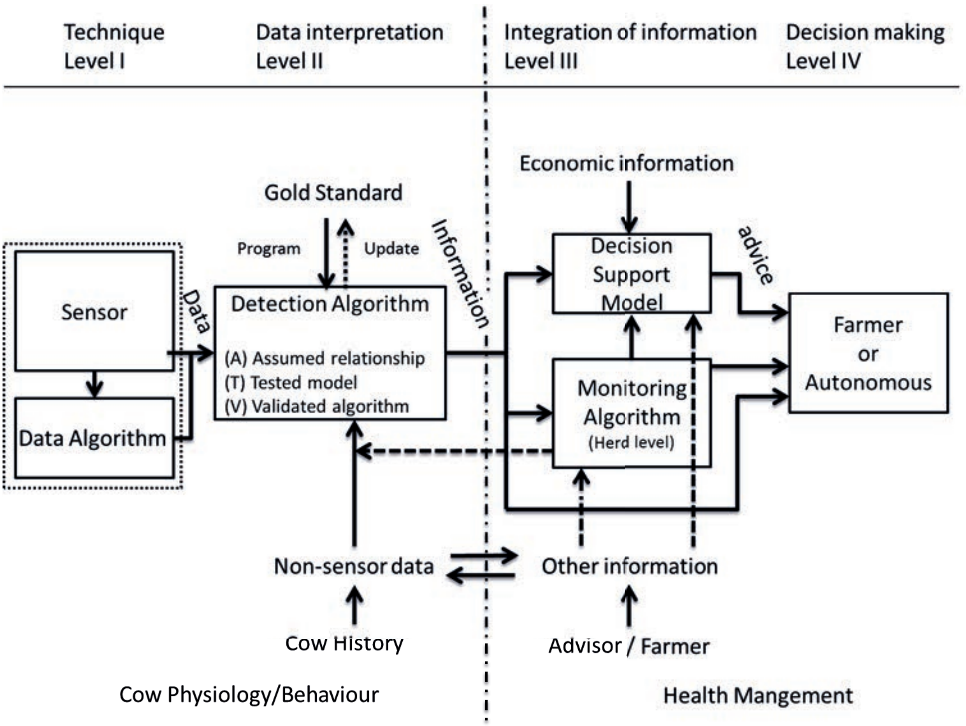


Figure 1: Framework of the use of sensor information in dairy farm management.

<u>Literature selection</u>

Relevant literature was searched based on keywords including sensors, dairy farming, and automated detection, in combination with words such as locomotion, lameness, oestrus, and fertility. Literature was also identified by a forward search, using the citations and a backward search using the references of the papers found through the keyword search. Journals from the ISI database (Web of Science, Thomson Reuters, New York, USA) were used for the period from January 2002 until June 2012, and the proceedings of relevant scientific conferences held between 2007 and 2012 were searched. The conferences included the First North American Conference on Precision Dairy Farming (Toronto, 2010) and the European Conference on Precision Livestock Farming (Prague, 2011 and Wageningen, 2009).

**Results and Discussion**

This review has summarized a total of 126 published studies describing 139 sensor systems for animal health management. For fertility (33 per cent), and locomotion (30 per cent) the number of found papers was nearly equal. The remaining papers (47 per cent) described sensor systems for detection of mastitis and metabolic problems, these papers are omitted in the this proceedings paper.

<u>Fertility</u>
For automated detection of oestrus, 41 publications were found with 48 described sensor systems, six (15 per cent) of these publications were proceedings papers. Most of these studied the activity of the cow (25 studies, 61 per cent). Other publications studied the progesterone level in milk (six studies, 15 per cent), (mounting) behaviour (six studies, 15 present), vocalization (one study, 2 per cent), and body temperature (two studies, 5 per cent). The sensors used to measure activity were pedometers, activity meters (sometimes also called activometers), and 3D-accelerometers. These sensors were all attached to one of the cow's body (pedometers and 3D accelerometers usually to the cow's left hind leg and activity meters to a neck collar) and are therefore classified as on-cow sensors. The sensors used to measure progesterone were biosensors and immunostrips. As progesterone was determined in automatically collected milk samples, these sensors are classified as on-line sensors. The sensors for mounting behaviour were the HeatWatch sensor and a video camera. The HeatWatch sensor is a device that measures the pressure caused when another cow mounts the cow with the HeatWatch sensor. This sensor was attached to the cow's back, which classified it as an on-cow sensor. The video camera is classified as an off-cow sensor. The sensor for vocalization was a microphone attached to the cow's neck (that is, an on-cow sensor). The sensors used for body temperature were a temperature transducer implanted in the cow's body and a bolus inserted in the cow's reticulum (that is, an in-cow sensor).
Most sensor systems require the farmer to rely on his herdsmanship. Sixteen (35 per cent) of the published sensor systems reported sensitivity above 80 per cent, eight (17 per cent) reported specificity above 98 per cent, and six (13 per cent) reported specificity somewhere between 90 and 98 per cent. Two studies (4 per cent) reported sensitivity above 80 per cent in combination with specificity of 99–100 per cent; however, these

studies used confirmed pregnancy as the gold standard. The largest test scale was three farms reported in five studies (10 per cent), while six studies (13 per cent) reported a test scale of two farms, and 25 studies (52 per cent) reported a scale of one farm. None of the studies reported tests done on a few cows.

The pedometer was the most studied sensor system used to detect oestrus, while 3D-accelerometers have been studied. For fertility, performance varies largely in terms of sensitivity and specificity, and varies in terms of the algorithm used and the gold standard. For the reported detection performance there are no recommendations (like the ISO limit for mastitis) available for oestrus detection. The “good performances” mentioned in this paper should not be seen as target values, because determination of strict target values asks for in-depth discussion and experiments. Good performance has been reported for both pedometers and leg-attached 3D-accelerometers (sensitivity ~80–90 per cent and specificity ~>90 per cent). However, a successful insemination was used as gold standard; successful inseminations are for certain preceded by true oestrus cases and also most certainly not all true oestrus cases resulted in successful inseminations. Therefore, the reported performances for such sensor systems should be considered with caution. Progesterone measurements can be considered to be the gold standard for oestrus sensors (Cavalieri *et al.*, 2003a, Friggens *et al.*, 2008), so progesterone sensors seem to be promising sensor systems, although not much has been published on the performance of such sensor systems. Furthermore, on-farm progesterone sensor systems will be costly. Whether or not such a system is profitable remains unknown.

Activity meters showed combinations of high sensitivity (~80–90 per cent) and specificity (~>90 per cent) with milk progesterone measurements as a gold standard. However, this performance was reported in a single study, which suggests using some caution when valuing this performance. HeatWatch, microphones and temperature implants did not show better performance than pedometers or activity meters. A video camera system with automated image analysis has been tested (sensitivity 85 per cent and specificity 99 per cent (Alawneh *et al.*, 2006) with successful inseminations as a gold standard. Automated video analysis requires cows to be within range of the video camera and exhibit behaviour that the sensor system can recognize. Because of this, and the used gold standard, the value of this sensor system in practice would seem questionable. In some studies, the cycles are synchronized before the start of an evaluation experiment, for pedometers a sensitivity of 81 per cent (Cavalieri *et al.*, 2003a, b) and for HeatWatch a sensitivity of 88 per cent (Cavalieri *et al.*, 2003a, b, Cavalieri *et al.*, 2003c) were reported in these studies. Sensor systems that detect oestrus have added value, as farmers are known to miss cases of true oestrus by visual observation (Firk *et al.*, 2002). However, important information about whether and/or when to inseminate a cow could be integrated in these sensor systems to improve the quality of the information provided to the farmer.

Locomotion

Thirty-eight publications describing a sensor system were found for automated detection of locomotion problems, five (13 per cent) of these publications were proceedings papers. Mostly, weight distribution between the cow's legs (17 studies, 45 per cent) and walking behaviour (16 studies, 42 per cent) were studied. Some other publications studied (walking) activity (five studies, 13 per cent). The sensors used to measure activity were pedometers and activity meters, attached to the cow's leg or to a neck collar and therefore classified as on-cow sensors. The sensors used for walking behaviour were 3D-accelerometers and video cameras, which were classified as on-cow and off-cow sensors, respectively. The sensors for the weight distribution between the cows' legs were four balance weighing floors, weighing platforms, two-parallel force plates, and force distribution plates. Because these sensors require the cow to stand on them or walk over them, they are classified as off-cow sensors.

A combination of high (above 80 per cent) sensitivity and specificity was reported for four (11 per cent) of the published sensor systems. The other studies reported performance of detection in the range of 22–80 per cent for sensitivity, specificity, or both. Four (11 per cent) of the published sensor systems were tested on two or more farms, while other studies reported a test scale of one farm. In this last group of studies, 14 (37 per cent) of the published sensor systems were tested on 15 or fewer cows.

For detection of locomotion problems, pedometers and 3D-accelerometers have been studied most frequently. However, video camera systems, with automated image analysis, have also been tested. For locomotion, the performance seems to be high in an experimental setting; however, cows needed to be guided to walk in an appropriate manner in front of the camera (correct walking speed, proper distance to the camera, and one cow at a time). Consequently, application in practice seems to be difficult because it requires important adjustments in barn layout and operational management. The studies on sensor systems for locomotion problems showed an association between sensor data and lameness (either statistical or in data patterns). It seems as though sensor systems could potentially discriminate between clinically lame and non-lame cows. Therefore, the studies seem to focus mostly on finding a good lameness indicator and a good way to assess it. Similarly, the demands for a lameness alert are not clear and subsequent actions by the farmer have not been studied, which means it is unknown whether the sensor systems provided added value compared to farmers' visual observation of the cows' gait. Furthermore, it remains unclear whether the sensor is only able to detect severe locomotion problems that are also easily detectable by visual observation.

Gold standard

The choice for a gold standard is important for the detection performance of a sensor system. How well a gold standard reflects reality determines the number of 'true' cases used for algorithm development and validation. If true cases of disease or oestrus are missing, or false cases are included in the gold standard data (visual observation and scoring system are sensitive for this problem), then the processes of algorithm building and validation will be affected. As cases will be missing or false cases will be included in the data set the algorithm will be misspecified and in the validation some alerts will be wrongly classified as false positive or false negative. In a more practical sense, the intended purpose of a sensor system is important when choosing a gold standard. For the substitution of labour by capital – which means that the sensor system will do a farmer's job – a gold standard that reflects a farmer's detection capabilities could be appropriate. However, for an early warning system, the gold standard should be able to correctly pick up disease or oestrus at an early stage.

Economic implications

For farmers, the decision to invest in sensor technology to support cow health management will partly depend on the profitability of such a sensor system (Bewley and Russell, 2010). In addition, a farm's economic prospects and financial position (farm solvency, for example), the presence of a potential successor, and farm size are general factors that underlie investment decisions (Aramyan *et al.*, 2007, Oude Lansink *et al.*, 2001). The economic benefits of an automated oestrus detection system have been studied, such as the simulation studies (van Asseldonk *et al.*, 1999) and (Bewley *et al.*, 2010). However, these studies ignore the effect of a sensor system on labour requirement of the dairy farm, which also has economic importance.

## Conclusions

Many studies presented sensor systems at levels I and II, but none did so at levels III and IV. Most of the work for fertility (75 per cent) is done at level II and for locomotion (53 per cent), more than half of the work is done at level I.

Sensor systems for fertility have been developed to higher levels (see Figure 1) than for leg and claw problems. Most published studies for fertility clearly describe that they aim to detect oestrus, and most of these studies focus on the performance of the sensor system. For locomotion, the studies focus on finding a good method of measuring a parameter and detecting locomotion problems.

For sensors systems, there is no clear difference in the performance of various algorithms. Detection performance of the sensor systems varies based on the choice of gold standards, algorithms and test sizes (number of farms and cows). The most important remark for further sensor research is to have a clear aim of what information about the cow's health should be produced by the sensor system under study. In respect to the aimed information an appropriate gold standard, algorithm, test size and time resolution should be chosen.

Analysis of investment in sensor systems has been scarcely published. Similarly the economic and management value of sensor information on farms remains unclear. No published sensor systems have an integrated decision support system.

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# Session 5

# Business Development PLF

## Developing SmartFarming entrepreneurship - first results from EU-PLF

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### Abstract

One of the main challenges in modern livestock farming is the lack of well-trained and market-savvy high-tech innovators. The EU-PLF project aims to help by developing a blueprint for a Smart Farming service sector that is driven by high-tech entrepreneurs in conjunction with market leaders. The blueprint will look at service and business models, value creation of Smart Farming technologies and will in particular investigate the relationship between high-tech start-ups and established market players in the innovation process in the Smart Farming sector. The blueprint will be validated by early stage companies or start-ups that are going to be trained in the blueprint and coached using the SO Kwadraat coaching methodology. This methodology is based on an individual coaching by an experienced high-tech entrepreneur. A competition will be held between these entrepreneurs and the best will receive funding to demonstrate their technology on farm. Within the EU-PLF project we call this the SME Drive. In this contribution we will look at the livestock service sector and its analysis from the BrightAnimal project, lay out the foundations for the SME Drive, motivate the methodology that we have chosen for selection of teams and report the results from the selection process.

**Keywords:** entrepreneurship, EU-PLF, high-tech start-ups

### Introduction

The EU-funded coordination and support action BrightAnimal (Smith and Lehr, 2011) analysed the precision livestock farming (PLF) sector (Banhazi *et al*, 2012, Cox, 2003, Cox, 2005, Cox, 2007, Cox, 2009, Lockhorst and Berckmans, 2011) in Europe and world-wide. One of the main conclusions of the project (Lehr, 2011) was that in order to increase adoption of farmer and animal assisting technology on farms there was a need for a precision livestock farming or SmartFarming service sector. Farmers should not be burdened by technology not working properly. Within BrightAnimal, qualitative surveys were made in a number of countries for finishing pigs, broilers, aquaculture fish, dairy cows. Most evidence of activity in the PLF sector was clearly found in Europe, but even there examples of commercially available PLF technology were not abundant. The BrightAnimal project identified a number of reasons why such a service sector has not been established yet. Amongst others, the following were cited:

1. There seems to be a certain hesitance of farmers to invest in non-classical farm technology, i.e. technology that is not related to traditional farm hardware such as tractors, ploughs etc.
2. A large portion of existing farm technology providers lack the focus on high-tech SmartFarming solutions
3. There is a clear lack of success cases (a) for the return of investment of SmartFarming technology to farmers and (b) of successful providers of SmartFarming technology

Based on this analysis, the EU-PLF project set out to assist the creation of a SmartFarming service sector by

(a) Selecting a number of key indicators for animal health, welfare and productivity that can be measured with PLF technology and that would be commercially important to the farmers.
(b) Making a socio-economic evaluation of a number of chosen technologies on 25 commercial farms for different species (fattening pigs, broilers, dairy cows and calves)
(c) Investigating and evaluating possible SmartFarming business models
(d) Collecting the findings in a “blueprint” that should assist companies to get involved in SmartFarming
(e) Validating the blueprint by creating four spin-offs (see below) on the basis of the blueprint

This is shown schematically in Figure 1.

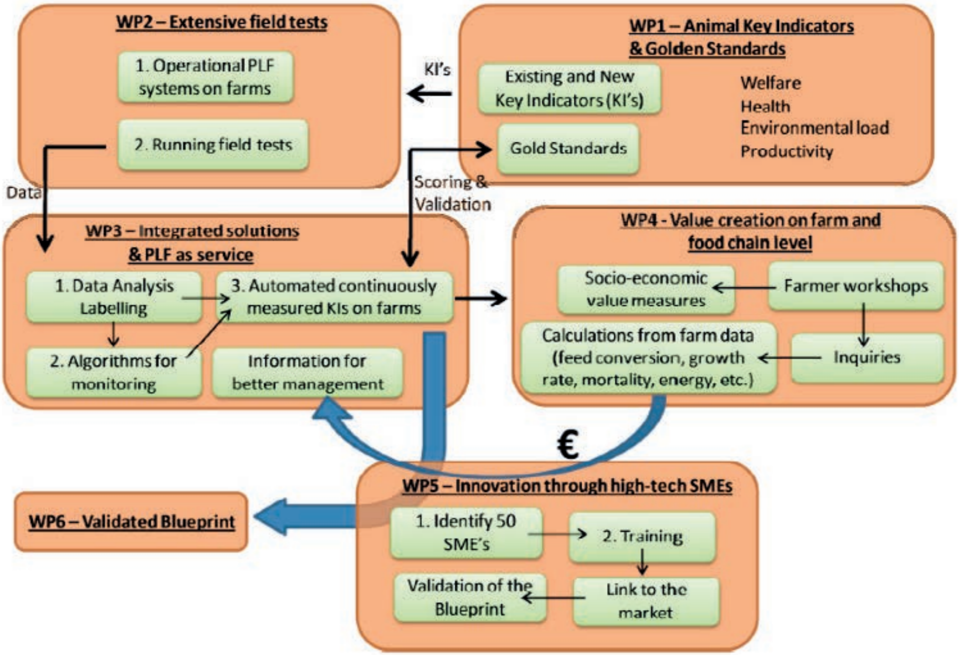



Figure 1 Collaborative model of EU-PLF

The role of work package 5 "Innovation through high-tech SMEs" is precisely the validation of the blueprint by identifying a number of potential SmartFarming spin-offs or start-ups, coaching them using the blueprint, demonstrating the best solutions/ products on farm and feedback the experience into the blueprint for its validation (and/ or improvement).

In particular, the work package has the following four objectives:

1. Identification of valorisation of additional promising PLF technologies in SMEs and research labs
2. Coaching teams in valorisation of existing technology in the field of PLF through spin-off creation
3. Demonstration of valuable PLF application through developed prototypes
4. Creation of four spin-off

To this end, the team made up from experienced initial stage coaches (idea -> start-up) and innovation managers (start-up->business success) are in the process of identifying about ten teams in Europe with SmartFarming technologies that seem to be commercially viable. These teams will enter into a competition and the best four will be provided with a total of 100,000€ funding for on-farm demonstrations of their technology. The aim is to start four spin-offs/start-ups or spin-outs. The basic timeline is

- Team selection Nov 2012-Oct 2013
- Coaching and prototype development, Nov 2013-April 2015
- Creation and valorisation of start-ups, Nov 2013-Oct 2015

This contribution wishes to provide insight into the activity and report our first findings from the selection of teams throughout Europe.

## Materials and coaching Methods

Team selection methodology

The process for attracting new teams with promising technologies is based on (1) organisation of local innovation days, (2) a competition formula for breadboard development financing, and (3) a coaching offering by experienced entrepreneurs. Four mayor university cities were selected, based on presence of a large group of PhD students in different technology domains, and (2) presence of a project partner in the region. Wageningen, Leuven, Barcelona and Milan were selected to organise SmartFarming Innovation days.

The initial scheme for the innovation days was to have two different sessions per day. However, neither in Barcelona, Wageningen nor Milan enough participants signed up to warrant two different sessions.

After the initial experience, we believe a successful format of a SmartFarming innovation day is:

1. About 2h of presentations with
    a. Introduction to SmartFarming and examples of available technologies
    b. The coaching methodology
    c. Case study of a successful SmartFarming spin-off
    d. Requirements for participation in EU-PLF
    e. Questions and answers
2. Buffet lunch to break the ice. Coaches directly approach attendants to engage in conversations about the participants' work
3. Dedicated in-depth conversations with those groups that would like to participate (about 20min for each group)

The information also served as a preliminary selection for the different teams. The events were held exclusively in English for two reasons: (1) a team that wishes to be coached needs to speak good enough English to communicate with the coaches and (2) a SmartFarming offering that does not target at least the European market is not considered to be viable. However, the initial information to Technology Transfer offices and similar institutions was delivered in local languages because we felt that for these gatekeepers the same conditions do not apply.

The target audience was selected using a general mailing campaign towards the different PhD students at the university. A project brochure and an application form were sent around. Based on the received application forms, the teams that could make it to the coaching process and related funding for breadboard construction were invited to the innovation day.

Running competition methodology

As explained above, the EU-PLF project has reserved a certain amount of funding for the selection of about 4 on-farm demonstration activities for spin-offs that are coached by EU-PLF. The selection of the winners will be left to members of a professional Business Angel Network (BAN Vlaanderen). The process of setting up a selection board has started.

The EU-PLF project strongly believes that one of the weakest points in building a SmartFarming service sector will be market access. One possible solution is the collaboration of high-tech SMEs with market leaders where the start-ups provide new technologies and services, whereas the market leader provides the market access. We consider interest from such market leaders in the new technology essential and will require participating groups to provide evidence of such interest to the funding board.

Coaching methodology

The methodology that will be used for the coaching process is based on a successful formula developed by SO Kwadraat (Spin-Off Kwadraat vzw). This not-for-profit organisation has coached over the last 8 years 200 teams, of which 70 started their own high-tech company. Most of these start-ups are based on a team of PhD students. All companies are active in Europe, and 50% is active worldwide. This underlines the importance of high-tech companies for export and internationalisation.

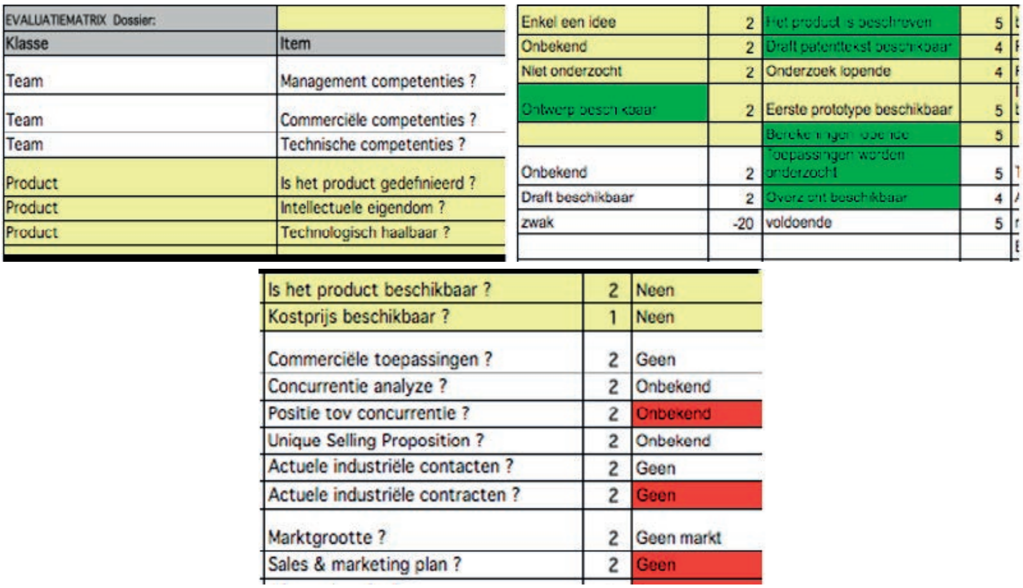
Coaching potential spin-offs is a sensitive business. Coaches from SO Kwadraat follow a written code of conduct (available on the website), so that a clear and transparent behaviour of the coaches is guaranteed. The objective is to help creating sustainable new high-tech companies, and to maximize the survival chances of the new companies. This also maximises the number of newly created employment opportunities and hence the return on investment for society.

The coaching methodology starts with an evaluation of the team. Is there a motivated dream team present? Motivation of the team to start-up a company is the most important non-scientific criterion that is evaluated. In a second phase, the technology is screened in detail. Is it a mature and proven technology or is there still a long way to go to productise the technology? Taking into account the capabilities of the team and the potential of the technology, a first business concept is drafted. This business concept is evaluated in the market through presentations at potential customers. Feedback from these presentations is then brought back into the coaching process and the initial business concept is adjusted. In some cases the business concept is completely re-considered.

In most of the cases, however, the business concept undergoes an evolution towards a market validated concept. This is an iterative procedure and lasts until the point where all involved are comfortable about feasibility, market and finances. This comfort level is monitored through a risk assessment procedure and an evaluation matrix. If the comfort level is high within the team and coach, business and financial plans are written, where the financial plan indicates the required capital. In case of a clear business concept, strong market interest optimally expressed in a first customer order and a strong team, it will be relatively easy to find money on the market (FFF: Family, Fools and Friends, Business Angels or VCs). Our experience indicates that if a company can be started with relatively little money (< 250.000 euro), the survival rate increases dramatically compared to capital intensive start-ups; see Table 1.

Table 1 Funding of high-tech starters versus survivors and drop-outs.

| Funding at start-up (in €) | Survivors | Drop-out |
|---|---|---|
| 0-100.000 | 30 | 0 |
| 100.000 and 250.000 | 20 | 1 |
| 250.000 and 1.000.000 | 12 | 1 |
| 1.000.000 and 5.000.000 | 8 | 5 |
| Total | 70 | 7 |



| EVALUATIEMATRIX Dossier: | |
|---|---|
| Klasse | Item |
| Team | Management competenties ? |
| Team | Commerciële competenties ? |
| Team | Technische competenties ? |
| Product | Is het product gedefinieerd ? |
| Product | Intellectuele eigendom ? |
| Product | Technologisch haalbaar ? |

| | | | |
|---|---|---|---|
| Enkel een idee | 2 | Het product is beschreven | 5 |
| Onbekend | 2 | Draft patenttekst beschikbaar | 4 |
| Niet onderzocht | 2 | Onderzoek lopende | 4 |
| Ontwerp beschikbaar | 2 | Eerste prototype beschikbaar | 5 |
| | | Berekeningen lopende | 5 |
| Onbekend | 2 | Toepassingen worden onderzocht | 5 |
| Draft beschikbaar | 2 | Overzicht beschikbaar | 4 |
| zwak | -20 | voldoende | 5 |

| | | |
|---|---|---|
| Is het product beschikbaar ? | 2 | Neen |
| Kostprijs beschikbaar ? | 1 | Neen |
| Commerciële toepassingen ? | 2 | Geen |
| Concurrentie analyze ? | 2 | Onbekend |
| Positie tov concurrentie ? | 2 | Onbekend |
| Unique Selling Proposition ? | 2 | Onbekend |
| Actuele industriële contacten ? | 2 | Geen |
| Actuele industriële contracten ? | 2 | Geen |
| Marktgrootte ? | 2 | Geen markt |
| Sales & marketing plan ? | 2 | Geen |

Figure 2 Evaluation matrix for different criteria (extracts)

The evaluation matrix indicates the actual readiness of the pre-starters to set-up their own company. A number of topics is evaluated here, such as situation of relevant

intellectual property (IP) and product status. The IP can be patented, resulting in a high score (10), or a freedom to operate investigation can be ongoing, resulting in a low score (4). In order to get green light for the creation of the high-tech company from the coach, on average 80% of the top scores must be achieved.
Besides the status tracking of a project through the evaluation matrix, a risk assessment is performed. This risk assessment evaluates the financial, IP, market, technology and human resources risk of the project. The multiplication of all these risk factors results in the overall company risk index. This risk index should be higher than 80%, indicating that the 3-year survival chances of the company will be higher than 80%.

The coach makes another final evaluation: he or she tries to answer the question: "under the given conditions would I personally start-up this company?" If the answer is yes, the risk assessment is positive and the evaluation matrix scores higher than 80%, the coach will suggest to the team to start-up the company.
The objective in the framework of the EU-PLF project is to coach 10 teams, and to support the creation of 4 new high-tech ventures.

**Results and recommendations**

After initial deliberation, the team chose four locations for the first events based on the following criteria:

- research activity in the region on PLF,
- presence of important livestock farming activities in the region,
- presence of a project partner in the region.

The chosen locations are Barcelona, Wageningen, Milan and Leuven (in September 2013). A fifth location will be chosen based upon the obtained results.
Further it was decided to go for a sequential improvement approach, meaning that results of one event are analysed before the next event is organised. This allows us to optimize the organisation and content of the events and improve our motivation of spin-off candidates.
The first event was planned in Barcelona for mid/end of February 2013, but was effectively organized on March 7$^{th}$, 2013. We made contact with Barcelona Activa, a governmentally-run incubator in Barcelona, which allowed us to organize the event in their facilities. An intensive market search was performed in order to find potential participants from the farming industry, the academic world and the technological industry. This was done through telephone calls, personal visits and via internet. Following groups/people were contacted:

- 12 technology transfer offices of universities all over Spain, local governmental and research organisations
- 250 Direct e-mails to researchers in ICT, mechatronics, sensor technology, biotechnology, agriculture, targeting in particular PhD students

- 150 high tech start-ups through Barcelona Activa
- 5000 technological entrepreneurs (through Barcelona Activa)
- 1000 technological SMEs (through Barcelona Activa)

Contact with technology transfer offices of universities was surprisingly unproductive; the list of 250 researchers had to be developed by own research.

In total, 20 highly interested participants attended the seminar. All of them were very motivated and had ideas or worked in areas related to SmartFarming. Following the individual interviews, 9 out of the 20 participants filed a project information document, including basic information on potential projects they would like to work on. This resulted in following conclusion after the first event

- 2 direct coaching team candidates
- 3 possible coaching cases, under exploration.
- 2 projects not evaluated as Smart Farming target
- 2 possible teams to do further analysis and send more information.

In general, the evaluation of the Barcelona event and obtained results were seen as very positive by our team. We concluded to continue on the same path for the next events, with minor changes in the program.

Through University of Wageningen, a partner in the EU-PLF project, a second event was organised in Wageningen end of May 2013. With 13 participants, resulting in 2 direct coaching team candidates, 1 strong candidate from who more information is required and a number of possible coaching cases, under exploration.

Through University of Milan, a partner in the EU-PLF project, a third event in Milan was organized mid June 2013. With 21 participants, resulting in 1 direct coaching team candidates, 2 strong candidate from who more information is required and a number of possible coaching cases, under exploration.

Together with one coaching candidate who applied directly, this brings us after 3 events to following results: 7 direct candidates for coaching and 3 strong candidates from whom more information is required.

After the event in Leuven we expect to have at least 10 direct candidates for coaching. So, the ultimate goal to have four selected teams going for valorisation of existing technology in the field of PLF through spin-off creation, looks realisable. We monitor this process closely and further actions will be discussed in time.

In the meantime the coaching of the Barcelona teams has been started. As of today, 3 coaching sessions have already been conducted with two of the teams. A third team from Barcelona has now signed up for the coaching. As a first step of the coaching process, the teams are asked to fill in a detailed project description sheet. This is a detailed project description, related to all different aspects of business creation: (i) Project description, (ii) Market and sector data, (iii) Status of development, (iv) Intellectual Property, (v) Business model, (vi) Currently invested effort, (vii) Estimated effort to realize project, (viii) Team, (ix) SWOT analysis of strengths and weaknesses (internal), opportunities and risks (external) and finally (x) References.

## Conclusions

After three organised SmartFarming innovations days, we can conclude that bringing technology to farms is not per se an attractive proposition for PhD students or other potential entrepreneurs related to universities and research centres. Heavy direct marketing of the event in Barcelona resulted in little more attendance than indirect marketing as practised in Wageningen or Milan. We assume that the main reason for this behaviour is the lack of role models, i.e. the lack of successful start-ups or spin-offs in the SmartFarming sector. Quite understandably some candidates needed convincing that animal farming is a potentially interesting sector to engage in compared to other uses of their technology.
However, for our purposes the three events organised so far were rather successful, because the people that do show up at the events are highly focussed, in general already quite knowledgeable and very motivated to enter a business coaching process. The subsection of entrepreneurs with potential SmartFarming applications are generally in need of better understanding how to prepare and start a successful business. Most if not all candidates came from the engineering side and have had no business training during their education.

Comparing the events in Southern Europe to Wageningen, one may also suspect that the complicated economic situation in Southern Europe motivates teams to search for new alleys. Even though many researchers find it difficult to imagine a life fully outside the university, the teams in Southern Europe were clearly more focused on the valorisation of their work. Reduced spending on education and the resulting pressure on universities certainly increase the need for finding alternative sources of funding or income.
As a result of the innovation days, we could observe some teams starting to cooperate, in particular for the commercial exploitation of research results. Being able to access the participants of the EU-PLF project and their knowledge is clearly perceived as a benefit, since most university teams feel quite removed from actual farms and from the farming economy.
The authors strongly believe that any SmartFarming technology will only be successful if an attempt at valorisation is made on at least a European if not directly global level. However, we found that in many groups communication in English is still an obstacle to success. For the successful training of future SmartFarming entrepreneurs, more language training is essential.

## Acknowledgements

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## From animal monitoring to early warning systems through the Internet of Things

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### Abstract

In the livestock sector, farmers are constantly worried about the safety, welfare and quality of animals. Consequently, there is high interest in any technology easing and supporting farm management and, more specifically, the monitoring of animals health status. Nowadays it is difficult to achieve a sustainable and reliable general-purpose system for observing the animal's health status: although a number of highly specialized proprietary COTS devices and solutions exist for this purpose, they are usually designed to be integrated in extremely vertical, "closed", systems.
A recently emerging computing concept, namely the Internet of Things (IoT), could change this scenario, easing the solution of interoperability issues: this novel approach considers any source of information (RFID tags, sensors, actuators, mobile phones, etc.) as a uniquely addressed object able to interact and cooperate with each other to reach common goals. This paper analyses a possible application of IoT technologies to the pigs breeding scenario, performing a real-time pigs' monitoring able to promptly notify the farmer in the case of abnormal eating behavior of one or more animals. This application is supported by a general-purpose IoT infrastructure, which inter-connects applications with legacy systems in re-configurable fashion.

**Keywords:** PigWise, RFID, XMPP, IoT, Middleware, VIRTUS.

### Introduction

Nowadays, Internet is used as a global platform for human communication (web, chat, mail, etc.) such as machines and smart objects interconnection. Accordingly, it has been predicted (Miorandi *et al.*, 2012) that within the next future, will exist a wide class of natively interconnected objects enabling new applications, including new work methodologies, new ways of entertainment, new ways of living, and last but not least, new ways of farming. These concepts address the "Internet of Thing" (IoT), term generally used referring to supporting technologies (sensor/actuators, RFIDs, M2M device, etc.) and internet-based communication infrastructures (ITU, 2005). The IoT vision is applicable also to precision agriculture and farming, as largely confirmed by (Kaloxylos *et al*., 2012). Furthermore, it is often mentioned the term "Farm Management Information Systems" (FMIS), which refer to communication process between farm instruments and its users: 1) collecting and managing data from various farm equipment; 2) exchange of information between the farm and the business people (farmers, suppliers, and reseller). However, mainly all FMIS operate under some specific business model (Sørensen *et al*., 2010): provide or collect information to/from farmers in some specific condition, process data and create services on the top of it. Sørensen (Sørensen *et al*., 2010) also emphasizes the difficulty perceived by farmers in integrating disparate information management systems and transferring information among them.

The project PigWise (PigWise, 2013) addresses this specific need by presenting a new way to design an FMIS, based on IoT concepts: devices heterogeneity, network independence, scalability and flexibility. Even if the project has issued a general purpose infrastructure, it focused on a concrete use case: an individual pig eating behaviour is monitored using a High Frequency RFID apparatus, which identifies the conventionally fattening pigs by generating their "feeding information". This represents the project's key innovation, because this type of reading enables to understand which animal, and when, is close to the feeder and, presumably is eating. On the top of "feeding information", this project provides a Synergistic Control - SGC (Mertens, 2008), whose results are shared with user (the farmer) as a report or an alarm event (if any): this represents the so-called 'Early Warning System'.

The paper will also describe some characteristics of the VIRTUS Middleware (Conzon *et al*., 2012), the IoT component on the foundations of the PigWise project. VIRTUS has been customized in order to fit with the context-specific requirements: i) management of already existing data sources; ii) management of animal behaviors algorithms; iii) flexible and efficient information propagation to the end-user.

## Material and methods

### Initial conditions

Within the introduced scenario, the information treated are HF RFID readings originated by transponders applied to animal ears (so univocally representing each one). The presented paper refers to the first PigWise experimentation, began on March 2013 to last four months, as a complete fattening period, involving 129 pigs. RFID transponders are read when the pig approaches the trough: transponder readings in this phase are filtered to detect eating events and are then further processed to extracts eating patterns and eventually inform the breeder in case of unexpected behavior which may be related to diseases, environmental changes or other issues. The information generated in the stable is made available through the use of the ICE Framework (Henning, 2004), an open source computing platform used to build distributed client–server applications (without the need to rely on HTTP).

VIRTUS Middleware

VIRTUS is a general-purpose IoT middleware, already validated in different environments (Brizzi *et al*., 2011 and Bazzani *et al*., 2012). It is a software designed as a framework to manage and automate server-side business processes and to integrate and federate networks of objects. VIRTUS is based on overlay networks built on the top of a messaging protocol. Indeed all the communication across middleware components are propagated through the use of XMPP - eXtensible Messaging and Presence Protocol (XMPP Standards Foudation, 2013). XMPP has been chosen to realize the communication near-real time, secure and scalable, needed for an IoT solution. XMPP (originally known as Jabber) is a real-time messaging protocol based on XML, which provide the exchange of messages, presence information and events. Furthermore, it is an open source protocol and thus is free and open; this aspect is important to limit the cost of a solution based on its standard.

VIRTUS exploits the "publish/subscribe" functionality in order to have a loose coupling between event producers and consumers, and the capability to compose arbitrarily event. Thanks to the publish-subscribe design pattern implementation, modules can publish events (possibly with data) and all other modules involved can subscribe to these event, to receive the real time published information. All objects observations are asynchronously dispatched to any component via XMPP as soon as they are available. Thanks to the publish-subscribe design pattern implementation, modules can publish events (possibly with data) and all other modules involved can subscribe to these event, to receive the real time published information. The use of XMPP, instead of other traditional protocols like JMS, allows knowing if messages arrive to destination and, furthermore, if a subscriber is offline when the messages are sent (leveraging the XMPP presence system). This last feature is important if the receiver MUST receive the message.

In order to achieve the needs of modularity, flexibility and scalability, VIRTUS is build on using the OSGi framework (OSGi, 2013). The concepts behind OSGi are: 1) modules (called bundle), 2) automatic management of dependencies, 3) simple setup and 4) ease of distribution. In VIRTUS, these features allow changing the composition of modules dynamically at runtime, without restarting the entire environment. Indeed, all the sensors, algorithms and user interfaces have been developed as modules and, in this way, is possible to build many different customization of the middleware using different compositions of the same modules. Thanks to this feature, the middleware is suitable to different application.

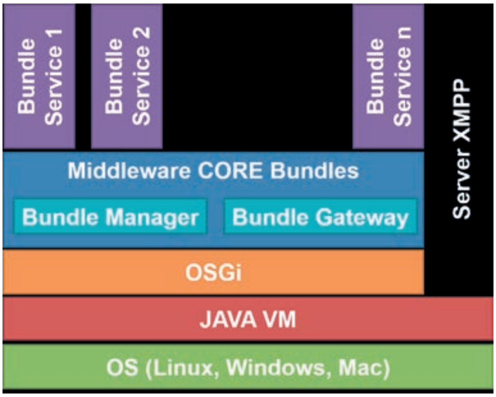


Figure 1- Virtus Middleware software architecture

An instance of VIRTUS is composed by three “core” modules and further “application-specific” bundles, each of which is univocally identified through an XMPP account. The core modules are:

- XMPP server – it is an Openfire XMPP server, a reliable and scalable open-source real time collaboration (RTC) server (Openfire site, 2013).
- Manager – enables the connection between different modules in an instance.
- Gateway - acts as an interface among VIRTUS instances and to any external software.

Figure 1 provide a summary of the VIRTUS middleware software architecture.

<u>Chosen approach</u>
Each RFID reader has been considered as an IoT network node, able to provide data through a common platform, regardless of the actual nature of these data. Furthermore, standing to the IoT vision, huge numbers of data sources may be connected and related to each other. It is also taken into account the necessity to orchestrate data sources through a domain-independent application, in order to guarantee a uniform set of communication rules for the network integration and federation, thus supporting large-scale applications (which can seamlessly use multiple sources of data). Key technical choices related with the middleware customization matched with customs VIRTUS bundles development, in particular to:

- manage an ICE-based communications;
- perform efficient, real-time and lightweight database savings, accordingly to a large number of input data;
- manage the Synergistic Control Algorithm (SGC) in order to realize the Early Warning system
- create automatically messages and feed graphs that are accessible to the end user.

Implementation

The previously described RFID information, generated in the stable, is sent to VIRTUS instance (sited in Italy), through the ICE Framework. This is possible because to the VIRTUS gateway bundle has been added an ICE server (while in one or more stables, a client could run). While the data from the farm are received, they are simultaneously stored in a remote database (ORACLE MySQL) and used for a real-time analysis of pigs' health.

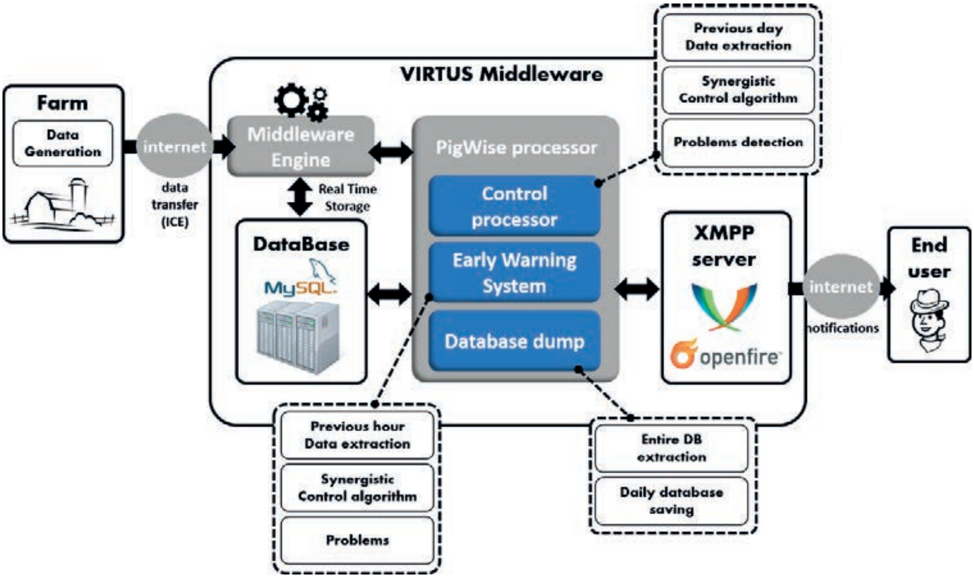
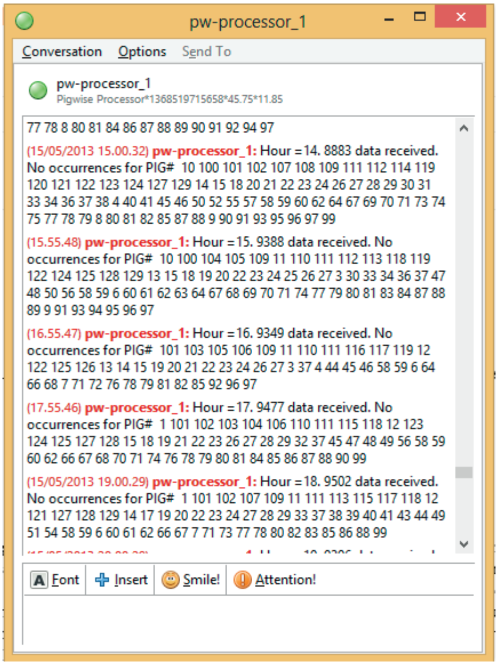


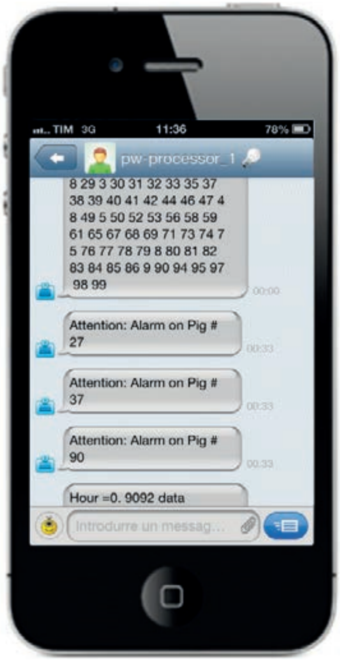

Figure 2 - System Architecture

In order to manage all the operations necessary to transform the event received into useful information has been created a bundle called "PigWise processor". It is the central element of the system, making possible to run properly three data-mining based subcomponent (Figure 2):

- Control processor – performs a system status check through a periodical extraction of database data (total number of entries and ids of pigs who did not generate events in the previous period); furthermore, it automatically sends information to the farmer regarding progress/condition of the entire system (Figure 3 - A).
- Database dump – in order to save data and made them available in the future (for any further analysis) the database is dumped every day without affecting the overall system operation.
- Early Warning System - deals with execution of the Synergistic Control (SGC) algorithms, including the management of the entire database acquisition and the propagation of its results.




A)




B)

Figure 3- Control processor output

In particular, the SGC detects deviations in the feeding data. The SGC procedure is performed for every individual pig. After checking the statistical characteristics, the trend and autocorrelation in pigs' feeding patterns are modeled if necessary.

The algorithm highlights the dangerous or unusual situations; if the time between two events is higher than a certain threshold an alarm is generated. The SGC results contain information about the pig's healthy status. The EWS outputs are fed into VIRTUS, which periodically notifies any alarm as XMPP messages to any registered user: in this way the farmer immediately receives, on his device, a message which address a potential problem of a specific animal, preventing hypothetical relevant economic losses (Figure 3 - B). Figure 3 also demonstrate the possibility to send XMPP messages to disparate device: in the A) case it is a PC, having the Pidgin (Pidgin, 2013) client running. In the case B) it is a smartphone while running the QIP (QIP, 2013) application. Many other XMPP applications exist, mainly freely available, also for Android based smartphone and tablet (Jabiru, 2013).

Web application

In order to provide further information to the farmer has been also implemented a web-based application, which shows pig activity as charts and statistical information regarding database status. This web application is complementary to the

Early Warning System (based on XMPP messages), but require major user interaction in order to access the page, login and choose time period and animal ID to be plotted.

The web application has been developed using a popular programming pattern: the Model-View-Controller - MVC (Leff *et al*., 2001). The MVC is useful to develop applications that separate the input logic, the business logic and the UI logic; it presents different advantages such as flexibility and maintainability. In particular, ASP.NET MVC Framework (Microsoft, 2013) has been used, a platform provided by Microsoft, running under Apache 2.0 open-source license. The choose of version 3 was due to the MySQL database compatibility need.

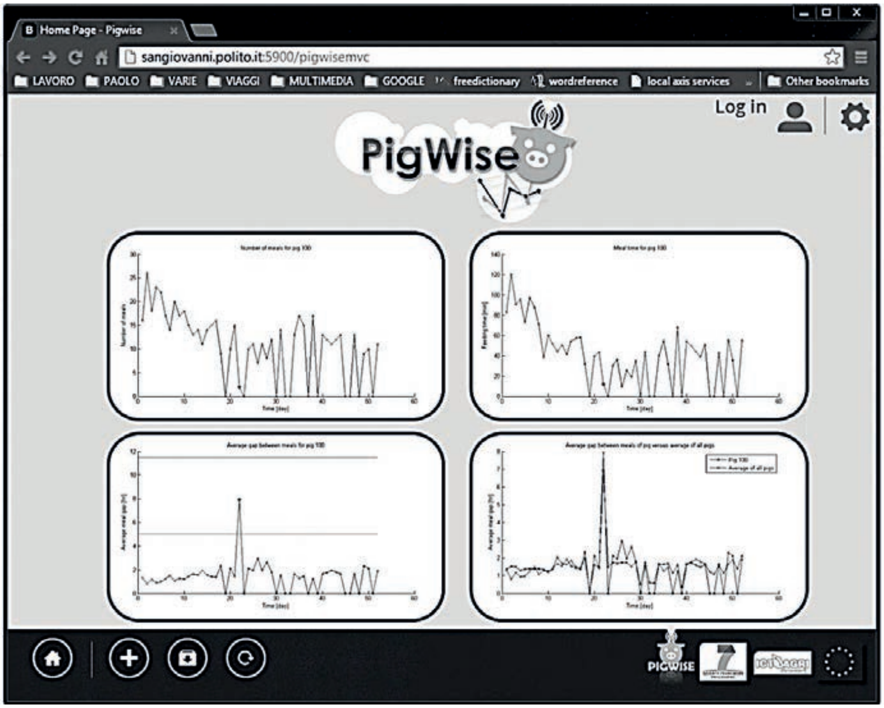



Figure 4- PigWise web application

**Results and conclusions**

In conclusion, this article presented a novel IoT-oriented platform based on the VIRTUS middleware, used for distribution and real-time analysis of feeding information extracted from RFID presence readings and for the delivery of alarms related to animal feeding activity. The proposed solution allows to transparently manage and integrate data from multiple entry points (farms and feeding systems), performing those complex operations related to the specific problem (pig’s feeding observation). The system developed and tested during the PigWise project has proven to be flexible, scalable, multiplatform compatible and easy to use. Moreover, it has proven to be reliable, able to manage an average number of 10500 entry data per hour (in the condition of 129 pigs eating in 4 yard), able to dynamically runs control algorithms and SGC without interruptions. Being this approach successful, it could be deployed in alternative scenarios, and data acquired can be further used, maybe combined with other ones, in order to perform different or more complex services.

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# Precision dairy technology adoption concerns

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## Abstract

A survey was distributed to all licensed Kentucky milk producers (n = 1074) to better understand factors that influence dairy producer decisions. Two hundred thirty-six surveys were returned; seven were omitted due to incompletion, leaving 229 for subsequent analyses (21% response rate). Mean response to each survey question was calculated after assigning the following numeric values to producer response categories: not important: 1, important: 3, very important: 5. With regard to adoption of automated monitoring technologies, producers indicated that modest adoption rates were a result of (1) not being familiar with technologies that are available (55%), (2) undesirable cost to benefit ratios (42%), and (3) too much information provided without knowing what to do with it (36%). As herd size increased, the percentage of producers selecting poor technical support and training and compatibility issues as reasons for slow adoption of automated technologies increased ($P < 0.05$).

**Keywords**: precision dairy, adoption, survey, decision making

## Introduction

The list of Precision Dairy Farming technologies used for animal status monitoring and management continues to grow. Despite widespread availability, adoption of these technologies in the dairy industry has been relatively sparse thus far (Gelb *et al.*, 2001, Huirne *et al.*, 1997). Perceived economic returns from investing in a new technology are always a factor influencing technology adoption. Additional factors impacting technology adoption include degree of impact on resources used in the production process, level of management needed to implement the technology, risk associated with the technology, institutional constraints, producer goals and motivations, and having an interest in a specific technology (Dijkhuizen *et al.*, 1997, van Asseldonk, 1999). Characteristics of the primary decision maker that influence technology adoption include age, level of formal education, learning style, goals, farm size, business complexity, increased tenancy, perceptions of risk, type of production, ownership of a non-farm business, innovativeness in production, average expenditure on information, and use of the technology by peers and other family members. Research regarding adoption of Precision Dairy Farming technologies is limited, particularly within North America.

The objective of this study was to gain new insight into dairy producer decision making, including reasons for lack of adoption of Precision Dairy Farming technologies.

## Materials and Methods

A 5-page survey was distributed to all licensed milk producers in KY (n = 1,074). Two hundred thirty six surveys were returned; seven were omitted because they were incomplete, leaving 229 for subsequent analyses (21% response rate). The survey consisted of questions about dairy operational success criteria, decision evaluation criteria, information sources, and technology adoption. For some questions, producers were asked to select a number on a 1 to 5 Likert (1932) scale with 1 indicating "not important" and 5 indicating "very important." Data were entered into an online survey tool (KeySurvey, Braintree, MA). Statistical analyses were conducted using SAS® (Cary, NC). Surveys were categorized by herd size, production system, region within the state, operator age, and production level. Herds were categorized by herd size to reflect management similarities as follows: 1 to 49, 50 to 99, 100 to 149, 150 to 199, and 200 to 1,200 cows. Producers were asked to categorize their dairy production system by selecting the option that best described their situation, as pasture-grazing, partial confinement, or total confinement. Regions within the state were categorized as East, South Central, North Central, West, and Far West. Operator age categories were defined as follows: < 35, 35 to 44, 45 to 54, 55 to 64, and ≥ 65 yr of age. Herds were categorized into terciles based on reported milk production levels as follows: low (< 22.7 kg/cow per day), mid (22.7 to 26.4 kg), and high (≥ 26.4 kg). With regard to Precision Dairy Farming the following question was presented to survey participants: *"Adoption of automated monitoring technologies (examples: pedometers, electrical conductivity for mastitis detection) in the dairy industry has been slow thus far. Which of the following factors do you feel have impacted these modest adoption rates? (check ALL that apply)."* Least squares means among categories were calculated for quantitative variables using the GLM procedure of SAS®. Tukey's test for multiple comparisons was used and statistical differences were considered significant using a 0.05 significance level. For qualitative variables, $\chi 2$ analyses were conducted using the FREQ procedure of SAS®. Statistical differences were considered significant at a 0.05 significance level.

## Results and Discussion

Among the 229 respondents, mean herd size was 83.0 ± 101.8 cows and mean producer age was 50.9 ± 12.9. Adoption of new technologies among dairy producers has been slow thus far (Gelb *et al.*, 2001, Huirne *et al.*, 1997). Farm profitability can be increased through farm modernization that focuses on increased milk production and employee efficiency (Bewley *et al.*, 2001). Improving efficiency of production has provided an important opportunity for dairy farmers in the United States to achieve an economic advantage (Kellogg *et al*., 2001). Often, producers may underestimate the value of these technologies because of the costs of disease and reduced reproductive performance are not as easy to understand as simply looking at increases in milk production. New technologies give dairy producers the chance to measure physiological, behavioral, and production indicators on individual animals to help improve management strategies. These new technology systems could be the key to helping dairy producers achieve maximum efficiency of production if they were utilized. Knowing the reasons behind slow adoption rates could help extension professionals provide knowledge that is more accurate to dairy producers.

Producers with large dairies (200 to 1,200 cows) are more likely to adopt new technologies than producers with small dairies (< 200 cows) (Jackson-Smith and Barham, 2000). In our study, producers were asked about potential causes for slow adoption in a "check all that apply" question. Reasons for modest adoption rates of Precision Dairy Farming technologies and dairy systems software are presented in Table 1. Not familiar with new technologies was chosen by the most producers with 55% (n=101) followed by undesirable cost to benefit ratio (42%, n = 77), and too much information provided without knowing what to do with it (36%, n = 66) (Table 1). When categorized by herd size producers with 200 to 1,200 cows were more likely ($P < 0.05$) to choose not enough time to spend on technology, poor technical support and training, and compatibility issues as concerns for adopting new technology than producers with 1 to 49 cows. No differences among herd size were observed for the following adoption concerns: too much information provided without knowing what to do with it, not reliable or flexible enough, poor integration with other farm systems and software, undesirable cost to benefit ratio, not familiar with technologies that are available, better alternatives or easier to accomplish manually, too difficult or complex to use, not useful or does not address a real need, fear of technology or computer illiteracy, failure in fitting with farmer patterns of work, immature technology or waiting for improvements, lack of standardization, or lack of perceived economic value. Perceived economic returns from investing in a new technology are always a factor influencing technology adoption.

Additional factors impacting technology adoption include degree of impact on resources used in the production process, level of management needed to implement the technology, risk associated with the technology, institutional constraints, producer goals and motivations, and having an interest in a specific technology (Dijkhuizen *et al*., 1997, van Asseldonk, 1999). Characteristics of the primary decision maker that influence technology adoption include age, level of formal education, learning style, goals, farm size, business complexity, increased tenancy, perceptions of risk, type of production, ownership of a non-farm business, innovativeness in production, average expenditure on information, and use of the technology by peers and other family members. Producers will only adopt these new technologies if the benefits are clear and the technology is user-friendly (Spahr, 1993). How technologies fit within farmer patterns of work is an important consideration for technology adoption and implementation. Technology manufacturers may focus on the technical aspects of technologies while overlooking important sociological considerations. Simply purchasing a technology does not provide the dairy producer with a return on investment. Rather, successful implementation of the technology involves good technical support and continuous training. The producer concerns listed here should serve as valuable information for dairy advisors and technology manufacturers in assisting with technology implementation. Clearly, dairy producers consider economic returns as important selection criteria. The reasons listed here also demonstrate the importance of technologies filling real management voids. Technologies should be provided with adequate technical support with information provided in a user-friendly format.

**Table 1. Factors influencing slow adoption rates of Precision Dairy Farming technologies**

| Factor | N | Percent |
|---|---|---|
| Not familiar with technologies that are available | 101 | 55% |
| Undesirable cost to benefit ratio | 77 | 42% |
| Too much information provided without knowing what to do with it | 66 | 36% |
| Not enough time to spend on technology | 56 | 31% |
| Lack of perceived economic value | 55 | 30% |
| Too difficult or complex to use | 53 | 29% |
| Poor technical support/training | 52 | 28% |
| Better alternatives/easier to accomplish manually | 43 | 23% |
| Failure in fitting with farmer patterns of work | 40 | 22% |
| Fear of technology/computer illiteracy | 39 | 21% |
| Not reliable or flexible enough | 33 | 18% |
| Not useful/does not address a real need | 27 | 15% |
| Immature technology/waiting for improvements | 18 | 10% |
| Lack of standardization | 17 | 9% |
| Poor integration with other farm systems/software | 12 | 7% |
| Compatibility issues | 12 | 7% |

## Conclusions

Using this insight should help industry Precision Dairy Farming technology manufacturers and industry advisors develop strategies for improving technology adoption. Moreover, this information may help focus product development strategies for both existing and future technologies.

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## Economic and social advantages from Precision Livestock Farming in the pig industry

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### Abstract

Three examples are given demonstrating the economic and social value of recording, analysing and interpreting data from pig enterprises. The examples highlight the need to install within piggeries automated measurement, analysis and control systems that will optimise profitability, reduce labour needs and improve animal welfare.

**Keywords:** precision farming, pig, variability, pig model, social impact

### Introduction

The primary aim of pig production enterprises is to maximise profit while maintaining high animal welfare, environmental and social standards. Nevertheless, pig industries in many countries are criticised because of a perceived low status of animal welfare (Barnett *et al*., 2001), high environmental pollution, potential exacerbation of human diseases through inappropriate use of antibiotics leading to antibiotic resistance and the evolution of novel human viruses (Cole *et al*., 2000). Job satisfaction within piggeries is also criticised because of the low skill level required for the many menial tasks frequently performed by piggery workers (Cole *et al*., 2000). Conversely, improvements in health and welfare of pigs normally enhances pig performance, lowers costs, reduces environmental pollution, increases profitability and job satisfaction.

There is substantial scientific literature on factors that influence all aspects of a pig enterprise including pig performance, health, welfare, environmental emissions, carcase value and profitability. However, a relatively small proportion of this information has been applied to individual enterprises. The primary reason for this failure has been an inability to measure in sufficient detail factors that determine production and carcase outcomes. The efficiency of an enterprise can be assessed and solutions determined only from the analysis of factual information. In the past, collection of much of the required information has been difficult and costly. However, precision livestock farming through remote electronic measurement, computer technology and analytical tools has made the collection and analysis of large amounts of data, with automated control systems highly feasible. This paper outlines the type of information that needs to be collected, how it can be analysed to develop alternative management practices and the resulting effects on profitability animal welfare and job satisfaction.

**Records required for comprehensive analysis of a pig enterprise**

Effective analysis of the efficiency of a pig enterprise requires continuous records of all major factors that influence feed intake, growth rate of pigs, reproductive efficiency, health status of the herd and cost of operating the enterprise as well as records of marketing outcomes. A full description is needed for all physical inputs to and conditions within the piggery including, for example, the ingredient and nutrient composition of all diets, the period each diet is offered, air temperature, speed and humidity within each shed, floor type, area and temperature, and the number of pigs in each pen (Banhazi and Black, 2009). Indicators of pig health include measurements of air volume per pig, number of pigs in an air space, proportion of the floor that is wet and covered with dung, concentration of ammonia, dust and viable bacteria in the air and number and time of deaths. Records are required for the actual growth rate of pigs and feed and water disappearance as well as estimates of feed wastage during different periods of growth. Information is also required on final carcass characteristics including weight, dressing percentage, backfat thickness, eye-muscle area and other measurements included in buyer price grids. Full economic analysis of a pig enterprise also requires information on all overhead, veterinary and other variable costs.
Technology for the continuous measurement of many of these factors is now available. For example, growth rate (Banhazi *et al*., 2011b) and feed disappearance (Banhazi *et al*., 2011a) can be now measured electronically. In addition, key environmental variables can be recorded continuously in livestock buildings using electronic instrumentation (Clements *et al*., 2011). Research is proceeding in other areas such as continuous recording of viable bacteria in the air. However, other important information is currently difficult to obtain, such as the amount of feed wasted.

**Economic value of measurement and analysis**

Several examples are given to illustrate the economic advantage obtained from measuring and analysing records similar to those listed above. In these examples, the recorded information has been analysed using the AUSPIG decision support software (Black *et al*., 1986; Black 2002). The model predicts feed intake, growth and body composition of individual pigs based on aggregated biochemistry of nutrient and mineral use in relation to the genotype of the pig and the climatic and air quality environment. Results for individual pigs of each type within an enterprise are passed to a linear program that determines optimal sale weight for each group depending on buyer specifications and ultimately whole enterprise profitability.

Variability in pig performance

Black (2001) analysed the economic consequences of variation in the weight of pigs within a pen and of final weight and slaughter outcomes throughout a year in commercial piggeries.

*Variation within a pen*

Twenty pigs within one pen in a commercial herd were weighed at weaning (28 days old), transfer to grower pens (70 days), transfer to the finisher pens (121 days) at slaughter (161 days). Feed intake of each pig was measured using an electronic feeder over the finisher period. Recorded measurements for each pig are given in Table 1. Four of the 20 pigs died before reaching slaughter weight.

Table 1. The live weight, mean feed intake during the finisher period, hot carcass weight, P2 backfat thickness and dressing percentage of 20 individual pigs in one pen.

| Pig | Weight 28 days (kg) | Weight 70 days (kg) | Weight 121 days (kg) | Weight 161 days (kg) | Mean Intake 121-161 days (kg/d) | Hot carcass weight (kg) | P2 (mm) | Dress Percent |
|---|---|---|---|---|---|---|---|---|
| 1 | 5.4 | 26.4 | 63.2 | 86.8 | 1.86 | 66.0 | 6.4 | 76.0 |
| 2 | 5.5 | 26.6 | 68.2 | 109.4 | 2.45 | 87.4 | 16.8 | 79.9 |
| 3 | 5.7 | 16.6 | 50.4 | 83.2 | 2.10 | 60.6 | 10.0 | 72.8 |
| 4 | 5.8 | 27.6 | 60.4 | 98.0 | 2.67 | 76.0 | 14.0 | 77.6 |
| 5 | 6.1 | 24.1 | Dead | | | | | |
| 6 | 6.1 | 23.8 | 55.8 | 108.2 | 3.07 | 80.6 | 11.6 | 74.5 |
| 7 | 6.4 | 23.6 | 45.9 | 99.6 | 2.89 | 76.6 | 11.6 | 76.9 |
| 8 | 6.5 | 20.3 | Dead | | | | | |
| 9 | 6.8 | 25.8 | 58.2 | 110.6 | 2.90 | 83.4 | 11.6 | 75.4 |
| 10 | 6.9 | Dead | | | | | | |
| 11 | 7.0 | 25.8 | 59.4 | 98.0 | 2.49 | 73.2 | 11.2 | 74.7 |
| 12 | 7.2 | Dead | | | | | | |
| 13 | 7.5 | 30.5 | 65.0 | 108.8 | 3.41 | 82.2 | 16.8 | 75.5 |
| 14 | 7.8 | 26.6 | 63.1 | 99.4 | 2.60 | 75.0 | 14.0 | 75.5 |
| 15 | 8.1 | 21.8 | 55.4 | 103.4 | 2.79 | 81.6 | 12.8 | 78.9 |
| 16 | 8.2 | 28.4 | 74.0 | 117.8 | 2.89 | 92.6 | 12.0 | 78.6 |
| 17 | 8.9 | 35.7 | 81.2 | 133.5 | 2.94 | 101.4 | 14.4 | 75.9 |
| 18 | 9.0 | 32.2 | 70.4 | 124.2 | 3.60 | 95.0 | 14.2 | 76.5 |
| 19 | 9.8 | 31.6 | 68.0 | 110.4 | 2.39 | 83.6 | 13.6 | 75.7 |
| 20 | 9.9 | 31.1 | 66.8 | 109.6 | 2.38 | 87.4 | 10.8 | 79.7 |
| Lowest | 5.4 | 16.6 | 45.9 | 83.2 | 1.86 | 60.6 | 6.4 | 72.8 |
| Highest | 9.9 | 35.7 | 81.2 | 133.5 | 3.60 | 101.4 | 16.8 | 79.7 |
| Mean | 7.2 | 26.6 | 62.8 | 106.3 | 2.71 | 81.4 | 12.6 | 76.5 |
| Range | 4.5 | 19.1 | 35.3 | 50.3 | 1.74 | 40.8 | 10.4 | 6.9 |

The financial consequences of the variation in weight and carcass characteristics of pigs is shown in Table 2 assuming the pigs were sold to five different buyers, each with different specifications and price grids. The price obtained per kg carcass, per pig and per pen is calculated in three ways. First, by selling each pig individually, secondly by assuming all pigs in the pen were identical to the group average and thirdly by assuming that all pigs in the pen were similar to the pig with the greatest return. There were substantial differences in the return per pen depending on the particular buyer used. The cost of variation between pigs can be determined either by comparing the return per pen when pigs are sold individually with the return per pen assuming either all pigs are similar to the pen average or similar to the pig with the greatest return (Table 3). The cost of the variation ranged from $644/pen ($40.25/pig) for buyer 5 to $155/pen ($9.69/pig) for buyer 2 when the price received for individual pigs was compared with the pen average. The cost of the variation increased to $818/pen ($51.13/pig) for buyer 5 if all pigs in the pen were assumed to return the maximum per pig. The lowest penalty for variation when determined on the basis of all pigs giving the greatest return was $362/pen ($22.63/pig) for buyer 2. The differences between buyers in the types of pigs they prefer is shown also in Table 2 where the maximum return/pig was obtained by a different pig for each buyer. The cost of variation between pigs ranged from approximately 5 to 20% of the average return depending upon the price grids of the buyers.

Table 2. Effect of variation within a pen on financial returns

| | Buyer | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| *Returns based on individual pigs* | | | | | |
| Price/kg ($) | | | | | |
| Average | 2.33 | 2.12 | 2.36 | 2.43 | 2.06 |
| Lowest | 1.40 | 1.35 | 1.00 | 1.00 | 1.00 |
| Highest | 2.55 | 2.62 | 2.55 | 2.55 | 2.55 |
| Price/pig ($) | | | | | |
| Average | 187 | 169 | 189 | 197 | 166 |
| Lowest | 168 | 118 | 101 | 144 | 61 |
| Highest | 213 | 192 | 232 | 238 | 219 |
| Return/pen ($) | 3041 | 2763 | 3071 | 3159 | 2678 |
| *Returns based on all pigs representing the pen average* | | | | | |
| Price/kg ($) | 2.55 | 2.24 | 2.65 | 2.55 | 2.55 |
| Price/pig ($) | 208 | 182 | 216 | 208 | 208 |
| Return/pen ($) | 3322 | 2918 | 3452 | 3322 | 3322 |
| *Returns based on all pigs having the highest price* | | | | | |
| Return/pen ($) | 3411 | 3125 | 3706 | 3813 | 3496 |
| Highest priced pig | 19 | 4 | 20 | 17 | 2 |

Table 3. Cost of variation within a pen when pigs are sold individually compared with pigs either representing the average of the pen or the best pig in the pen

| | Buyer | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| *Assuming all pigs represent the pen average* | | | | | |
| Cost/pen ($) | 281 | 155 | 381 | 163 | 644 |
| Cost/pig ($) | 17.56 | 9.69 | 23.81 | 10.19 | 40.25 |
| % return reduction | 8.5 | 5.3 | 11.0 | 4.9 | 19.4 |
| *Assuming all pigs have the highest return* | | | | | |
| Cost/pen ($) | 370 | 362 | 635 | 654 | 818 |
| Cost/pig ($) | 23.13 | 22.63 | 39.69 | 40.88 | 51.25 |
| % return reduction | 10.8 | 11.6 | 17.1 | 17.2 | 23.4 |

This example demonstrates clearly the substantial financial advantage that could be gained from installing automatic weighting and drafting systems that ensure pigs are sold at the optimum weight for the specific buyer.

*Variation over time*

Cook (1999) examined over one year the variation in performance of animals from a commercial piggery selling pigs at 22 weeks of age. The variation in mean growth rate from birth to slaughter and in P2 backfat depth at slaughter is shown in Figure 1 for each week of the year.

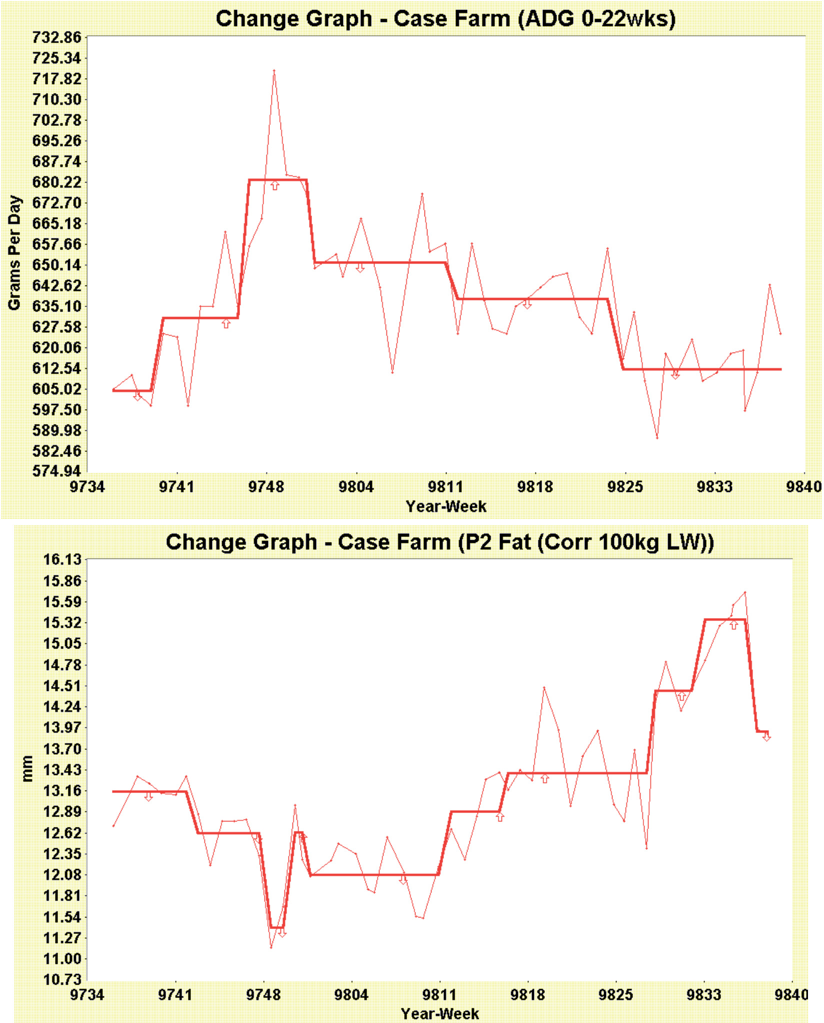


Figure 1: Variation in the average daily gain (ADG, g/day) and carcass P2 (mm) of weekly batches of pigs sold from a commercial piggery (light line). The heavy line is a statistically fitted mean line with arrows indicating significant changes (P<0.05)

Carcass P2 values ranged from 11.4 to 15.3 mm and growth rate from birth to slaughter from 612 to 680 g/day over the year. Six significantly different periods of growth were identified. The growth rate, slaughter weight, carcass weight and P2 values for the last four periods are given in Table 4. The effects of the growth period on the price obtained per kg of carcass, return per pig and cost of the variation per pig are shown for five different buyers in Table 5. The variation in pig performance throughout the year had a substantial effect on piggery profitability with the range in price per pig being from $22.25 for buyer 1 to $63.45 for buyer 3. The variation throughout time caused a range in the return per pig over the year from 11.2 to 22.7% of the highest amount obtained from different buyers.

Table 4. Significant periods of variation over one year in the performance of pigs in a commercial piggery at 22 weeks of age. From Cook (1999)

| Period | Growth rate birth to slaughter (g/day) | Slaughter live weight (kg) | Hot carcass weight (kg) | P2 at slaughter (mm) |
|---|---|---|---|---|
| 1 | 680 | 105.7 | 80.9 | 11.4 |
| 2 | 655 | 101.9 | 78.0 | 12.1 |
| 3 | 640 | 98.6 | 75.4 | 13.4 |
| 4 | 612 | 94.2 | 72.1 | 15.3 |

Table 5. Effect of variation over time on the price paid for pigs and the cost of the variation on returns per pig.

| Period | Buyer | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| *Price per pig ($)* | | | | | |
| 1 | 259 | 242 | 280 | 270 | 270 |
| 2 | 260 | 261 | 270 | 260 | 260 |
| 3 | 251 | 253 | 247 | 251 | 251 |
| 4 | 231 | 229 | 217 | 221 | 236 |
| *Cost of variation over time (lowest compared with highest return per pig)* | | | | | |
| Cost/pig ($) | 29.06 | 32.97 | 63.45 | 48.17 | 34.04 |
| % reduction | 12.2 | 12.6 | 22.7 | 21.6 | 12.3 |

This example of variation occurring throughout the year illustrates the importance of being able to analyse why the variation occurs and how the environment may be changed to maintain the greatest profit throughout the year.

Comprehensive analysis of the pig environment

A pig production enterprise in Australia with many similar pig rearing sheds on the same site found consistent differences over years in the performance of pigs passing through the sheds. Pigs from shed A were consistently 4-5 kg heavier and had approximately 2 mm less P2 backfat at slaughter than pigs from shed B. Many of the measurements outlined above were made in the two sheds (Table 6) and the results analysed using AUSPIG to identify reasons for the differences.

Large white-cross castrated males pigs were grown from 68 days of age to slaughter at 165 days. Four diets formulated to meet the amino acid requirements of pigs weighing 30, 42, 55 and 75 kg, respectively were fed. The change from diet 1 to 2 occurred when the pigs were 81-82 days old, whereas other diet changes were based on estimated pig weight. Pigs were weighed at each diet change and cumulative feed intake measured (Table 7). Mean carcass P2 backfat measurements at slaughter on day 165 were 17.0 mm and 19.3 mm, respectively for pigs from sheds A and B. The pattern of growth and mean feed intake for pigs in both sheds are shown in figure 2.

Table 6. Comparison of conditions within sheds A and B

| Characteristic | Shed A | Shed B |
|---|---|---|
| Position | North side: east-west orientation | South side: north-south orientation |
| Prevailing wind | SE-SW | SE-SW |
| Floor | 1/3 slatted concrete | Fully slatted concrete |
| Shed sides | Completely open | 1 m concrete walls |
| Blinds | Automatic | Automatic |
| Pen area ($m^2$) | 12.75 | 13.18 |
| Mean area ($m^2$/pig) | 0.74 | 0.66 |
| Volume ($m^3$/pig) | 3.00 | 2.67 |
| Pit depth (m) | 0.5 | 0.28 |
| Distance to effluent (m) | 0.45 | 0.25 |
| Ammonia (ppm) | 3.5 | 6.3 |
| Bacteria (CFU/$m^3$) | 85,250 | 112, 333 |
| Respirable particles (mg/$m^3$) | 0.194 | 0.243 |
| Wet floor (%) | 29 | 44 |
| Dung covered floor (%) | 17 | 33 |
| Recordings <12°C 1st 28days | 0.3 | 10 |
| Pig deaths | 1 weaner: 4 finisher | 1 finisher |

Table 7. Age, mean live weight, diet and mean cumulative feed intake for pigs in sheds A and B

| Shed A | | | | Shed B | | | |
|---|---|---|---|---|---|---|---|
| Age (days) | Live weight (kg) | Diet | Cumulative intake (kg) | Age (days) | Live weight (kg) | Diet | Cumulative intake (kg) |
| 68 | 30.8 | 1 | | 68 | 28.9 | 1 | |
| 81 | 41.8 | 2 | 25.5 | 82 | 38.4 | 2 | 23.7 |
| 96 | 56.7 | 3 | 63.5 | 101 | 52.8 | 3 | 66.1 |
| 113 | 74.7 | 4 | 120.8 | 125 | 75.0 | 4 | 137.2 |
| 165 | 119.9 | | 293.2 | 165 | 115.8 | | 279.7 |

AUSPIG analyses showed that pigs in shed B compared with pigs in shed A were below their lower critical temperature for several hours longer on many days from 68 to 82 days of age.  The differences were due to the position and orientation of the sheds causing greater heat loss through higher wind speed and higher proportion of wet skin from floors for pigs in shed B.  Cold exposure resulted in a reduced feed intake because of more huddling and a slower growth rate of 680 g/d (850 g/d shed A), compared with a predicted rate of 790 g/d if the pigs were in thermoneutral conditions.

A consequence of slower growth was that pigs in shed B were lighter than the weigh intended when transferred to diet 2.  AUSPIG predicted that at the change in diet, a methionine deficiency was limiting growth with the requirements of only 35% of the pigs in shed B being satisfied, compared with 75% in shed A.  The simulations showed that if the methionine deficiency was removed for pigs in shed B, they would have been 1.3 kg heavier and have 0.4 mm less back fat at slaughter.

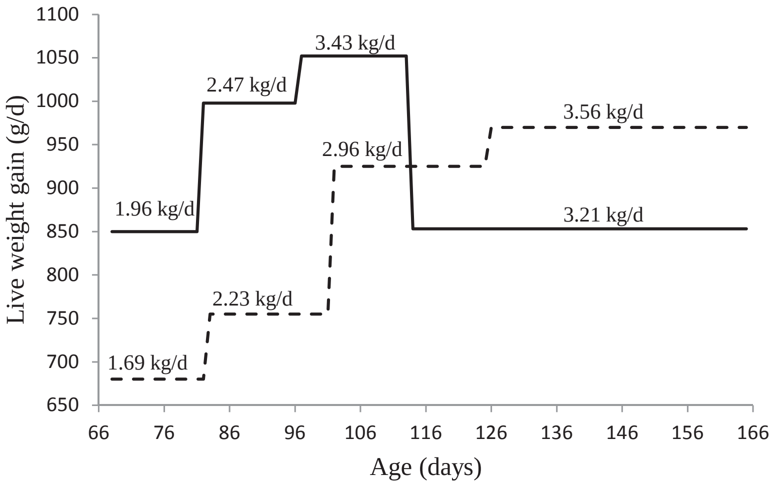


Figure 2:  Change in mean growth rate with age for pigs in shed A (solid line) and shed B (dashed line).  Figures above the lines are mean feed intake over each diet period.

Further AUSPIG analyses predicted that pigs in shed A were overstocked (space allocation <0.035 $m^2/LW^{0.67}$, Black 2009) for 72% of the time during the diet 4 phase of growth, compared with only 41% for shed B.  Feed intake is reduced during overstocking, being 3.31 kg/d for pigs in shed A compared with 3.56 kg/d for pigs in shed B.  The simulations showed that energy intake of both groups of pigs during much of the final growth phase was in excess of that required for maximum protein deposition.  Hence, the extra energy was deposited as fat.  When intake for pigs in shed A was increased to be the same as in shed B, the model predicted P2 backfat thickness at slaughter would be increased to 19.0 mm, similar to the final observed for pigs in shed B.

## Conclusions

The examples given show clearly how measurement of critical factors determining pig growth and effective analysis of this information can identify limitations to pig performance and enterprise profitability. The examples further highlight the need to install within piggeries automated measurement, analysis and control systems that will optimise profitability, reduce labour needs and improve animal welfare. Further research is required to incorporate current developments into precision farming systems for pigs that would include real-time simulation models for data analysis and automated control systems.


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# Session 6

# Cattle - Behaviour

## Automated monitoring of urination events from grazing beef cows

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### Abstract

Urine patches deposited by grazing cattle represent 'hot-spots' of very high nitrogen (N) loading from which environmentally important losses of N may occur (ammonia and nitrous oxide emissions, nitrate leaching). Information on the spatial and temporal distribution of urine patches and their N concentrations and how these may be influenced by pasture management practices is limited. The objective of this study was to assess the potential of recently developed urine sensors, combined with GPS tracking collars, for providing data on urination behaviour by grazing cattle and how this might be used to inform the development of precision grazing management. Urine sensors and GPS tracking collars were fitted to a number of beef cattle grazing a 1 ha paddock in Scotland. Preliminary results indicated that the average cow urinated 8.5 times per day, with a mean volume of 2.2 litres per urination event. Over the monitoring period, cattle showed a distinct preference for the SW part of the paddock, with some clustering of urination events in this area. Further developments to the sensors are required, particularly in the method of attachment of the sensor to the animal, but from this preliminary study it was concluded that the automated urine sensors show great potential as tools for improving our understanding of spatial and temporal distribution of urine N by grazing cattle.

**Keywords:** Urine sensor, Grazing cow, Nitrogen, GPS, Spatial distribution

### Introduction

Cattle urine contains significant quantities of nitrogen (N), mostly in a very labile form (Bristow *et al*, 1992) which is deposited to the soil at very high N loading rates in urine patches when cattle are grazing at pasture. Urine patches therefore represent 'hot-spots' from which losses of N may occur through ammonia volatilisation, nitrate leaching and nitrous oxide emissions with potentially damaging impacts on the environment. The N content and spatial and temporal distribution of urine patches are important factors affecting these potential losses and may be influenced by cattle diet, grazing management, environment and season. Our ability to model N losses and utilisation in grazes pasture systems and to optimise management practices requires good information on cattle urination behaviour. In countries such as New Zealand a nitrogen “cap” is planned for lake catchment areas, and in such a scenario, mitigation strategies are of high importance. However, to date, there have been few published data on urination behaviour by grazing cattle as field observations are difficult to make. Those that have been made suggest that urine patch distribution and overall spatial extent can be influenced by factors including fence line positions, water tank positions, field slopes and preferred night resting areas (Auerswald *et al,* 2010; Augustine *et al,* 2013; White *et al,* 2001).

Betteridge et al (2010) described an automated urination sensor which could give information on the timing and location of urination events by grazing cattle or sheep. More recent developments by AgResearch in New Zealand have produced a sensor specifically for grazing cows which automatically records the time, location, volume and N concentration of each urination event. The objective of our study was to assess the potential of the urine sensors, combined with GPS tracking collars, for providing data on urination behaviour by grazing cattle which might be used to inform the development of Precision Rangeland Management.

**Materials and Methods**

A group of 14 pregnant non-lactating beef cows (Charolais cross, Limousin cross and Aberdeen Angus) were used in the study, grazing a 1 ha paddock at Easter Bush, near Edinburgh, Scotland. Immediately prior to grazing, the cattle were fitted with GPS tracking collars, which gave positional information at a 1-minute resolution, and nine of the 14 cows were fitted with urine sensors (AgResearch, New Zealand). The urine sensors were attached through a combination of glue around the vulva area of the cow and Velcro straps onto the back of the animal, with a diverter designed to prevent any faecal contamination of the sensor. A cow fitted with a GPS collar and urine sensor is shown in Figure 1.

Figure 1. Urine sensor attached to grazing cow (back) and GPS collar (front)

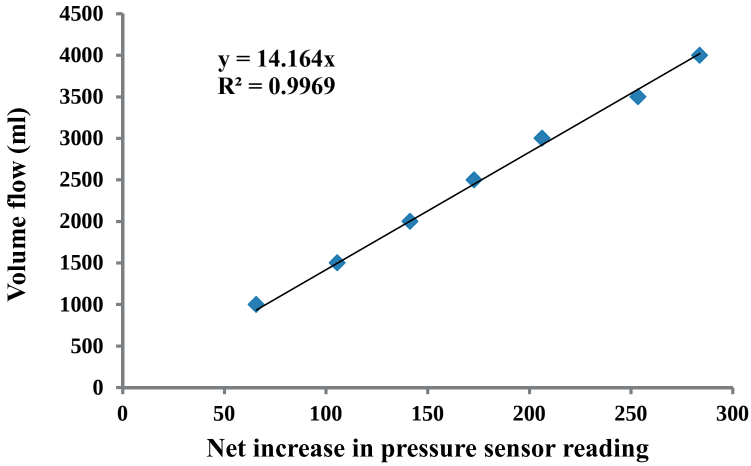


Figure 2. Typical volume calibration function for urine sensor

At each urination event, all urine flows through the urine sensor. Urine flow triggers the sensor to begin recording; a pressure sensor reading every 2 seconds for the duration of urine flow, a refractive index reading on a 20 ml subsample of urine remaining in a cell at the bottom of the sensor (this urine would be flushed out and replaced at the subsequent urination event), a date and time reading and a positional reading related to 4 base nodes placed around the paddock. Total urine volume for each urination event was derived from the pressure readings, whereby cumulative increase in pressure above the base reading is related to total volume flow. A typical volume calibration for a urine sensor is given in Figure 2. Urine N concentration was derived from the refractive index reading, based on prior calibrations using artificial urine. Data were downloaded from individual urine sensors and GPS collars following the grazing period.

## Results and Discussion

Although urine sensors were attached to nine of the cows at the start of the trial, several of the sensors became detached within the first few hours after fitting and one sensor had problems with faecal contamination. This resulted in only four sensors giving data for an adequate length of time (range of recorded data was between 34 and 67 h). Further development of the method of sensor attachment is required to prevent the large losses of potential data as seen in this study through detachment, leakage or faecal contamination.

For the four cows for which sufficient data were obtained, average urination frequency was 8.6 (standard error 0.94) times per day with a mean volume at each event of 2.2 (se 0.25) litres, giving a mean daily total urine volume of 18.8 (se 2.82) litres per cow.

The frequency of urination compares well with that reported by Dennis et al (2011) and Oudshoorn et al (2008) for grazing dairy cows of 8.6 and 6.2 events per day, respectively, and with that reported by Orr et al (2012) for beef cattle (mean live weight of 570 kg) grazing a moderately improved sward of 7.0 events per day. Orr et al (2012) reported a lower mean volume per urination event of 0.8 litres.

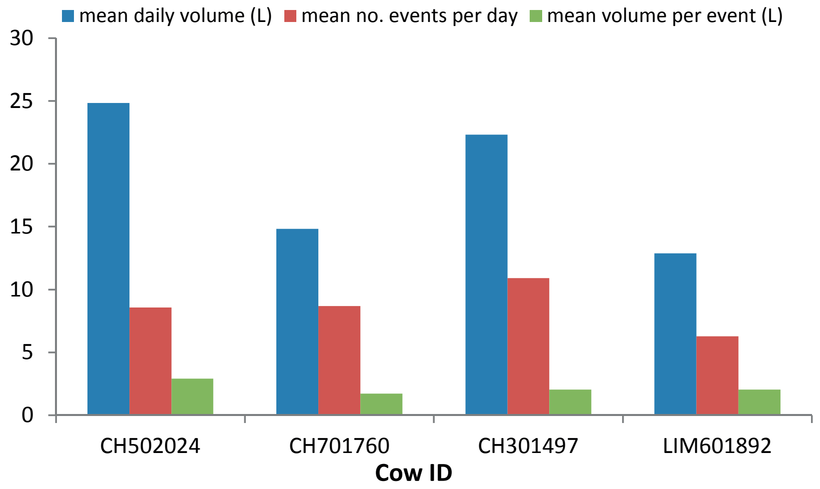


Figure 3. Data on individual cow urination events derived from urine sensors over 2 days of grazing

Based on the sensor calibrations using artificial urine, urine N concentrations for individual urination events ranged from 6.2 to 21.8 g $l^{-1}$. Mean urine N concentrations per cow were in the range 16.1 to 17.7 g $l^{-1}$, with an overall average across all cows for which sufficient data were recorded of 17.0 (se 0.45) g $l^{-1}$. These values are at the upper end of the range of urine N concentrations for beef cattle of 2-20 g $l^{-1}$ given by Whitehead (2005), and much greater than the mean value of 10.8 g $l^{-1}$ reported by Orr et al (2012) for beef cattle grazing a moderately improved pasture. As this may be an artefact caused by calibration with an artificial urine, further calibration tests using real cattle urine of know N concentration are being conducted. Until these calibrations have been confirmed, these data should be treated with caution.

The 1-minute interval locations within the paddock over a single 24 h period of the four cattle for which sufficient urine sensor data were recorded are shown in Figure 4 (open circles, individual animals not identified). In this period, the cattle showed a distinct preference for the SW part of the paddock, particularly along the fence lines (not shown). The gate to the paddock was in the W corner and there was a hedge along the SW boundary, an area which the animals used particularly for resting at night time. Urination events are also shown in Figure 4, differentiated by daytime events (filled yellow circles) and night time events (filled blue circles). While there are insufficient data to draw strong conclusions, the night time events predominantly occurred at the SW end of the field, where the animals predominantly rested at night, whereas daytime events were more distributed according to the animal presence across the paddock.

Data from a larger number of animals over a longer monitoring period (e.g. several days) are required to be able to make conclusions regarding urination behaviour and N returns by grazing cows. This requires the development of an improved urine sensor attachment method as mentioned above. However, this study has shown the potential of these sensors to provide the kind of data that can be used empirically, or as input to pasture models, to assess the impacts of different grazing management practices on excreta N utilisation and potential losses to the environment. Such assessments might include a comparison of set stocking with rotational paddock grazing and/or buffer feeding. The data could also be used to inform potential mitigation strategies such as the targeting of nitrification inhibitor application (to reduce nitrous oxide emissions and nitrate leaching) to areas of the field where most urination events occur.

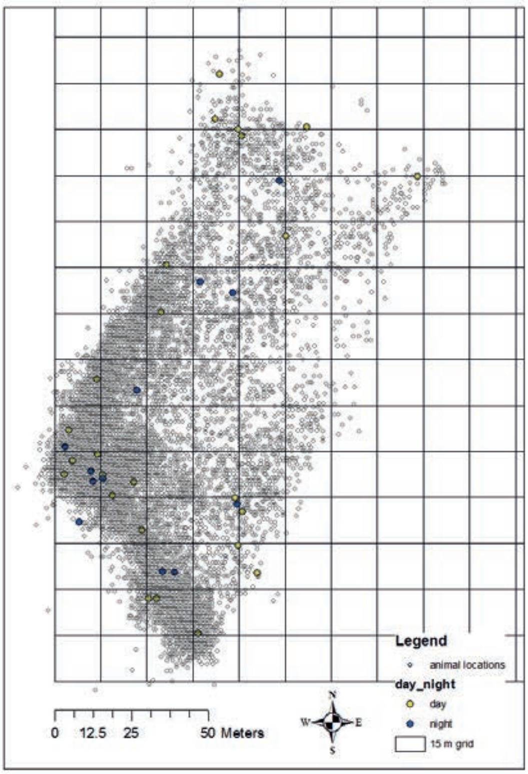


Figure 4. Map showing 1-minute animal locations (open circles) and day and night time urination events (yellow and blue circles, respectively) for 4 monitored grazing beef cattle over a 24h period

## Conclusions

Preliminary conclusions from this study are that urine sensors deployed on grazing cows represent a viable automated way of providing detailed information on timing, N concentration and spatial distribution of urination events. As such, and with some further development, the sensors will be of benefit to research studies in assessing the impact of different grazing strategies on the efficient recycling of nutrients and minimisation of environmental impacts and aid the further development of precision rangeland management.

## Acknowledgements

The authors gratefully acknowledge the University of Edinburgh farm manager for allowing access to the study field and to SRUC technical staff in the management of the livestock throughout the trial. Funding for the urine sensor work was provided by the UK Department for Food Environment and Rural Affairs. Rothamsted Research is sponsored by the Biotechnology and Biological Sciences Research Council.

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## Combining automatic milking and precision grazing on dairy farm systems

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### Abstract

Dairy farming in Europe has adopted automatic milking (AM) at an accelerating rate for reasons such as improvement in lifestyle, reducing physical work, difficulty in attracting skilled labour and increased profitability based on higher milk production and lower labour costs. However, while indoor feeding systems have been well adapted to AM, cow grazing systems have not. Thus, if AM is to become a realistic alternative to conventional manual milking in grass based milk production systems, such as in Ireland, the practical challenges of integrating AM and grazing must be researched. It must be scientifically proven if AM technology is compatible with grazing for successful adoption. That is the aim of the current study. This issue is crucially important as AM could represent an important advancement in precision dairy farming in such countries. AM has the potential to improve automatic data collection, providing herd managers with data that will enable them to make effective management decisions, and through the use automation to reduce manual tasks on farms, allowing farmers to shift their focus from operational tasks to management and strategic tasks that are economically beneficial.

**Keywords:** automatic milking, cow grazing, precision management

### Introduction

During the last several decades, new milking management systems have been introduced, of which development of AM systems is a significant step forward. AM has become an established management system, considered as an alternative to conventional manual milking methods, particularly in Western Europe (Jago 2011). This trend is increasing and it is envisaged that up to 20% of cows in Europe will be milked automatically by 2020. Indoor feeding systems have been well adapted to AM, however cow grazing systems have not. This is leading to a decrease in grazing on farms with AM (Van den Pol-van Dasselaar *et al*., 2011). This is an undesirable trend since grass-based systems of animal production are becoming increasingly competitive. Allied to this is the positive impact on milk quality and reduced environmental footprint associated with increased quantities of grazed grass in the diet as well as increased animal welfare standards.

In a production system where grazing constitutes a significant proportion of cow diet, grass has to be the main motivator for cows to move voluntarily to the AM installation.

Thus, new grazing technologies are needed to optimize integration of AM and grazing. Dairy farmers, policymakers and researchers in North Western Europe consider the combination of AM and grazing to be important from both labour (Irish) and cheaper feed source /milk quality (European) perspectives. This system also offers possibilities for precision management of individual cows in a herd, freeing up of labour and allowing the cow greater control of her activities.

The objective of this study was to determine the feasibility of integrating automatic milking with cow grazing.

## Materials and Methods

<u>Farm System Description</u>

A milk production system trial was put in place at Teagasc, Moorepark, Ireland. The farm-let associated with the AM system consisted of a 24 ha milking platform. During the lactation of 2012 ($1^{st}$ complete lactation) there were 72 cows in the system with a mean calving date of 15th February (range 1st February-15th March). This herd comprised 36 Friesian, 16 Jersey Friesian cross and 20 Norwegian Red cows. The land area was divided into 3 grazing sections of 8 ha each (A, B, C) which are further divided into 1 ha paddocks. Four main roadways radiated from the centrally located dairy. Water was located at the dairy. Maximum distance to the furthest paddock was ~750m. The dairy featured one Merlin AMS unit (supplied by Fullwood for research) installed adjacent to the existing shed. The infrastructure incorporated a pre-milking waiting and post-milking area. There were three drafting units, two positioned at the entrance to the dairy that drafted cows to the pre- or post- milking area depending on readiness for milking, a third positioned at the dairy exit which drafted cows to the holding yard (for treatment or inspection) or to grazing (Section A, B orC). Automatic milk diversion (colostrum, antibiotic) was included and extensive milking and cow information was recorded at each milking (e.g. milk yield, milking time, milk flowrate, SCC, concentrate dispensed).

<u>Grassland management</u>

The grass allocation is critical to optimal cow visits to the AMS unit (it can influence too frequent or infrequent cow visits). Cows grazed defined areas or portions of each of the 3 grazing sections during each 24 h period (Figure 1). Cows were allocated 5 kg DM in each of the 3 grazing sections (A, B and C) over each 24 h period. Cows moved between the grazing Sections A, B and C at 1:00 am, 11:00 am and 6:30 pm, respectively. During the May/ June period cows went into grazing areas with grass covers of 1400-1500 kg DM/ha. Pasture mass was estimated twice weekly. Grass covers greater than 1500 kg DM/ha would discourage cow movement to the AM unit and may reduce milking frequency. Cows grazed to a post-grazing height of 3.5-4.0 cm. Cows were stocked at an average of 3.5 cows/ha. All cows received approximately 1 kg supplementary concentrate feed during the main grazing season.

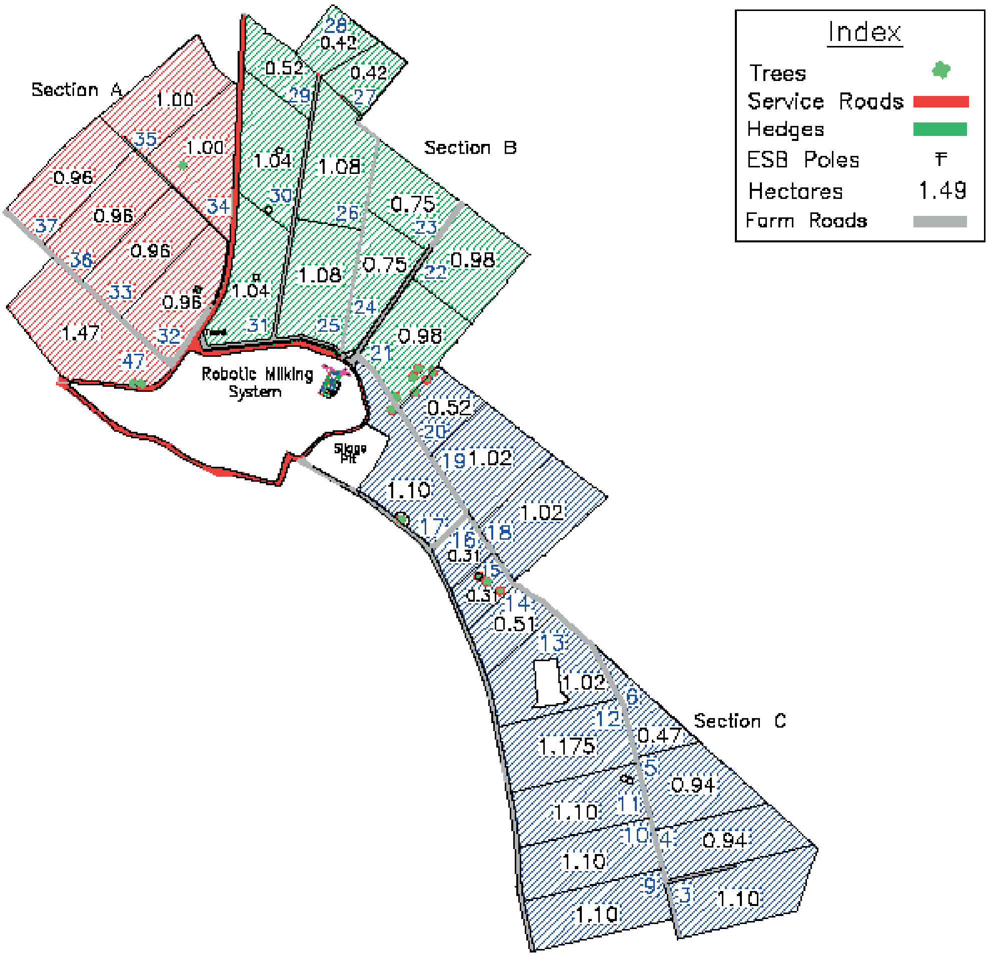


Figure 1. Map of AM farm incorporating sections A, B and C

**Results**

An average milk yield of 4,500 litres and milk solids (MS) yield of 351 kg per cow per lactation was achieved. Total milk volume and MS produced by the AM unit was 284,592 litres and 22,834 kg, respectively. The average number of milkings per day was 108, ranging from 125 to 80 per day in the March-May and October-November periods (Figure 2). The average number of milkings per cow per day was 1.8, ranging from 2 to 1.5 in the March-May and October-November periods (Figure 3). The average distribution of milkings over a 24 h period during the main grazing season is shown in Figure 4. Each milking averaged 7 minutes duration. An average milk somatic cell count (SCC) of 133,000 cells/ml was observed, while average total bacterial counts (TBC) were at 18,000 cells/ml.

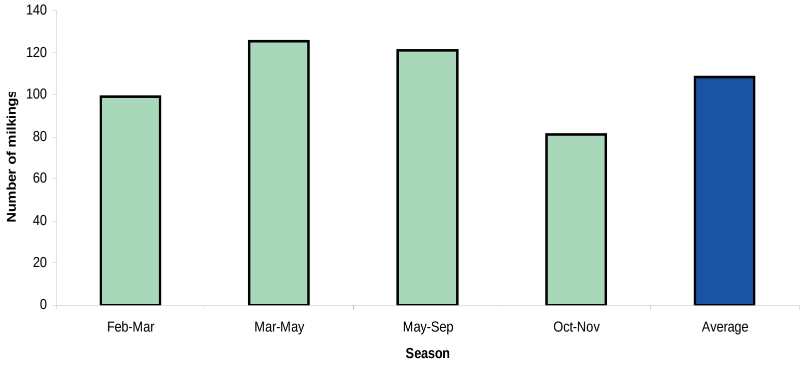


Figure 2. Average number of milkings over a 24 h period

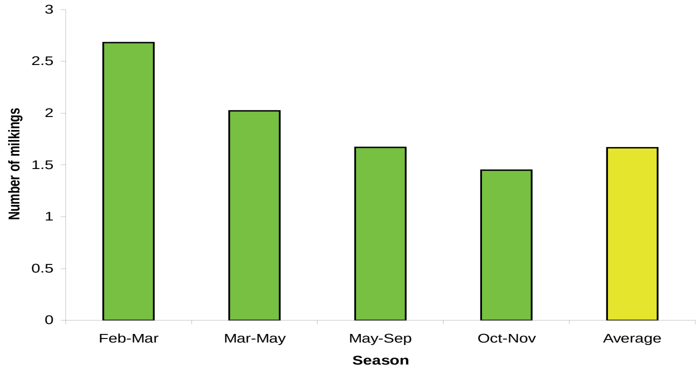


Figure 3. Number of milkings per cow over a 24 h period in different seasons of the year

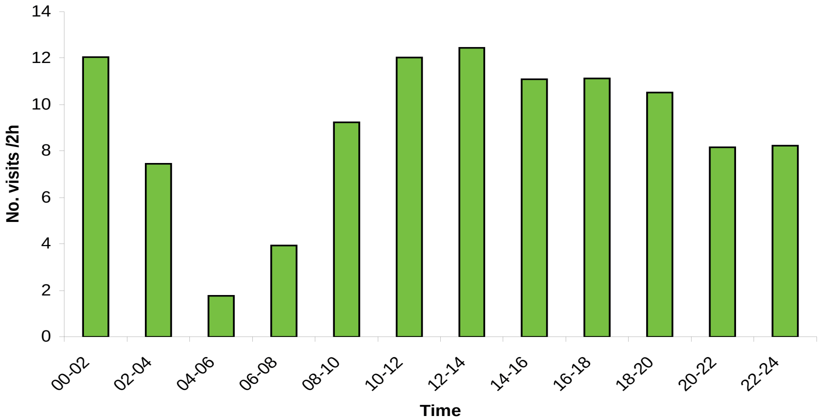


Figure 4. Average distribution of milkings over a 24 h period during the main grazing season

## Discussion

The results obtained in this study are in agreement with those conducted in New Zealand in past years, that AM can be successfully incorporated into pasture based milk production systems with moderate levels of supplementary feed (Woolford *et al*., 2004). The practical challenges to integrating AM and cow grazing include initiating cow movement to visit the AM unit, queuing of cows for milking, achieving high utilization of the AM unit and managing a seasonal calving pattern involving a peak milk yield period. Overall, the integrated AM and grazing system operated satisfactorily. The cows adapted relatively quickly to the system (within approximately 4 days). Milk output was influenced by the fact that it was the first complete lactation of cows on the automatic system, when milk yield is expected to be reduced by 10-15% (Wade *et al*., 2004). The grass allocation was critical to optimal cow visits to the AM unit. If automatic milking is to be considered as a serious alternative to conventional milking in a grass based system, such as in Ireland, then it has to operate with a similar cow nutritional strategy and focus on cow utilization of grass. Factors such as milk yields, milk quality, feeding, cow traffic, grazing, and animal behaviour are essential elements of AM and grazing.

Irish dairy systems normally use high levels of grazed pasture and have seasonal milk production profiles. However, robotic milking systems are capital intensive, and up to now have been considered best suited to year-round milk supply due to the fixed capacity of the technology. But, Svennersten-Sjaunja and Pettersson (2008) concluded that use of AM and grazing systems together is possible as long as the distance from the milking parlour to pasture is short. With proper management routines, it should be possible to achieve a production level and animal well-being in AM systems that are at least as good as in conventional milking systems.

A 3-year FP7 funded EU project (coordinated by Ireland) on the integration of AM and cow grazing, commenced in January, 2013. Planned outputs include: protocols for optimum feeding strategies; pasture management tools; sustainability assessment tool; and a web based decision support tool to optimise economic efficiency of AM in grazing scenarios.

## Conclusion

Successful integration of AM into a grass based milk production system was achieved in this study, however the economic viability of AM will determine how widely the technology will be adopted. A major challenge with automatic milking currently is the high capital cost but the concept of combining automatic milking and cow grazing has potential advantages which could have a positive impact on the dairy industry in the long term. These include reduced labour input, management as opposed to manual labour, ability to expand cow numbers on fragmented land bases and increased knowledge of cow performance data to use as a management tool. However, considerable research needs to be conducted to establish if the concept presents a realistic alternative to conventional milking systems on dairy farms.

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# Complexity of local measurements in cattle behavioural studies

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## Abstract

Investigation of cattle behaviour under rangeland conditions needs an interdisciplinary approach. The aim of our current research is to investigate the correlations between cattle, pasture and weather. The program primarily focuses on animal behaviour, using GPS technology.
The expected results will reveal how a weather-cattle behaviour system works and may present new information about the responses of Hungarian Grey Cattle to the environment on rangeland.
The research methods used include recording spatial data using GPS collars, collecting meteorological information (barometric pressure, wind direction, temperature, weather fronts), and field reports about regular behavioural attributes. Some difficulties were experienced with the GPS receiver due to battery lifetime and the fragile protective covering; therefore, in collaboration with a commercial company, we designed a supplementary battery and a cheap, flexible cover for the GPS data logger. Applying this high-tech technology to cattle farming leads to new perspectives in modern farming, such as geo-fencing or remote heat detection.

**Keywords:** behaviour, cattle, GPS, geo-fencing, meteorology

## Introduction

Behavioural observations today raise many questions and doubts. From the productivity point of view, it is irrelevant how cattle roam and graze on pasture and how they interact with the environment. The ecological point of view however, bases its approach on animal welfare and biodiversity. The two parties are never on the same side but if we look around the world, farmers and scientists need to find a consensus before the fragile ecosystem collapses. Farming in harmony with our ecosystem is becoming more and more important. From the perspective of developing countries, the animal welfare and ecological approach is only relevant when the following question is raised: “How much food can we produce at what cost?”, while governments in Europe, the USA and Australia are spending enormous amounts of money to find out the secrets of “happy chickens and cows”. In this spirit we attempt to describe how Hungarian Grey Cattle behave under rangeland conditions in the eastern steppe region of Hortobagy in east

Hungary. It is important to understand the deeper correlations between livestock and weather, because cost effectiveness is not only about forage versus live weight gain. Extra costs such as more man-hours or weight loss due to bad weather are major factors during severe weather systems or fronts. An understanding of the behavioural profile of Hungarian Grey Cattle in response to air pressure and bio-meteorological factors is a welcome addition to husbandry systems for this breed.

**Material and methods**

The study area was 1191 ha of rangeland divided into two major areas: the North (688 ha) and South (503 ha). The Hortobagy River and two local shadoofs (dug wells) were the only water sources. The 10 (n=10) observed individuals were marked with coloured calf rope for visual identification. The different coloured ropes were tied around the neck. The ropes were sturdy enough to resist rough/range conditions and the coloured plastic cover on the ropes was resistant to ultra-violet radiation from the sun. The coloured ropes could be recognised from a long distance and the animals were not disturbed during behavioural observations. The animals maintained a 50-100 m flight zone, therefore high-visibility markers were essential.

Only the gallery forest and the river bank provided wind shelter. The herd did not receive supplementary feed during the grazing season and in winter housing they were fed on hay and salt feed only. The cattle returned to the herd-hut – shadoof and elevated, dry calving-mount – throughout the grazing-season. The Czakó at al. (1985) terminology was used to describe animal behaviour and the behavioural traits were classified into 3 main groups: feed intake actions (grazing, rumination, drinking), sexual and calf care actions (copulation, nursing) and social actions (fight, play, moving). Two types of GPS receiver were used (Snewi Trekbox, Bluetooth, GT-750 GPS data logger) to describe the spatial position of the animals and calculate the speed, daily travel distance and time spent standing. The loggers recorded 5 days of daily animal movements. The positional data were converted into digital mapping. Trotter *et al.* (2010) have made significant progress in precision farming and satellite tracking for cattle. Their work guided our study in terms of digital mapping and developing tools. The daily weather data, such as wind speed, temperature, air pressure and medical weather front reports, helped us to build the daily weather model which was compared with the daily routes.

Animal behaviour was observed periodically, every 20 minutes, and the duration of recording was approximately 5 seconds on each occasion. The most typical behaviour pattern was logged. Binoculars were used to find the marked animals. It was essential to avoid disturbing the animals. The problem of the “flight zone” (distance from strangers) was managed by using a Land Rover/Bantam car (Malechek & Field, 1975). The typical behavioural patterns (grazing, fighting, calf care) were recorded using a digital video camera. Meteorological data were obtained from the national meteorological survey database and we also made local measurements (air pressure, temperature, air ions).

It is important to track the air ion concentration because of the complex physiological processes (serotonin-behaviour system) which determine the animals' responses to environmental factors such as weather fronts. Both positive and negative ions are present in the atmosphere, but radioactive minerals (radium, uranium), radioactive gases (e.g. radon), cosmic rays, lightning, wildfire and high voltage discharge may change their ratio (Wahlin, 1989; Lee, 1993; Cote, 2003; Komov, 2003; Serrano *et al.*, 2006). Evaporating water produces negative ions, while radioactivity mostly produces positively charged particles. Ions connect with protein membranes and while negatively charged air (oxygen) molecules block serotonin production (Krueger, 1960) positively charged carbon-dioxide cause it to increase (Phelps, 2005). Ion measurements were taken using an Ion Stick™ (Alpha Lab Inc.) and were only for basic information.
Statistical analysis was carried out using the SPSS 20 software pack. We continued to refine the observation methods during the field work. Virtual fencing (Bishop-Hurley *et al.*, 2007), and GPS-based alarm systems (Tell Ltd. and own development) are also promising developments.

**Results**

There was a significant correlation ($r=0.491$, $p<0.01$) between weather fronts, indicated by barometric pressure, and the length of the herd's daily route (Figure 1.).

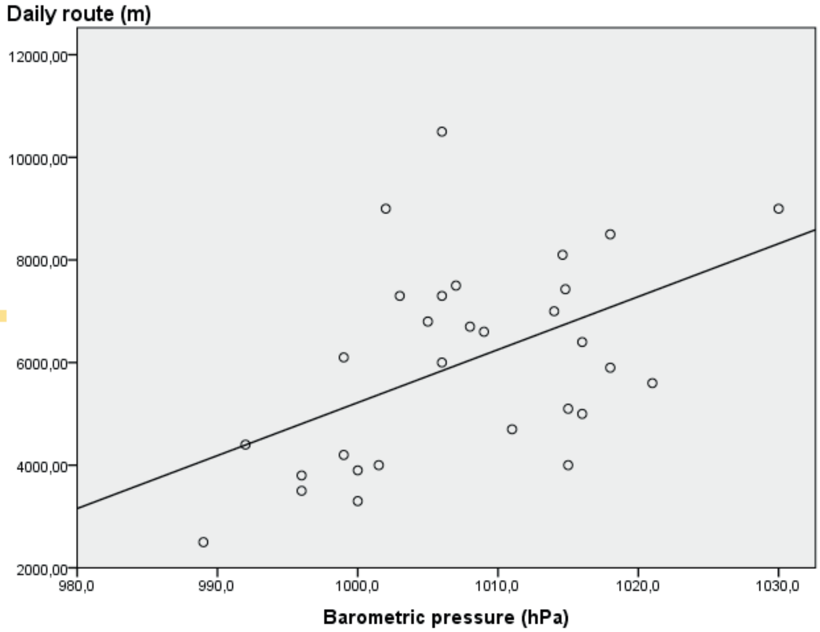


Figure 1: Relationship between barometric pressure change and daily distance walked

Front-free and cold-front weather systems created high air pressure (P≥1005 hPa) which resulted in calmer behaviour. Relaxed cattle spend more time feeding. Looking for fresh, nutritious grass is a natural herbivore behaviour (Gere, 1977), therefore a non-stressed herd's pasture activity is 80% feeding. Results show that warm weather fronts – low air pressure (P≤1005hPa) – cause more stress because the changing (dropping) air pressure affects the parasympathetic nervous system (Kovács, 2010) and is often combined with high temperature and humidity. Stressed animals gather, spend more time in shade at a nearby water-source (river bank) or roam continuously on the pasture and do not complete their daily route (6-8 km; Haraszti, 1977). The preliminary analysis shows that there is a connection between stable weather systems and increased feeding activity (*Table 1*).

Table 1: Distribution of behavioural traits during different weather systems from 2010 to 2011

| **Front types** / **Behavioural traits** | **No Front** | **Warm front** | **Cold front** |
|---|---|---|---|
| Feed intake | **93%** | **47%** | **95%** |
| Sexual | 2% | 10% | 0% |
| Social | 5% | **43%** | 5% |
| Gross count of behavioural traits | 100 % (1049 pc) | 100 % (368 pc) | 100 % (423 pc) |

Source: Own calculation
n=10 marked cattle

The research area was almost flat rangeland where the prevailing north-easterly wind was not interrupted by hills or dense forest. It has long been known that all furry animals in open grassland try to avoid getting wet simply because wet fur does not trap much insulating air among the hairs. Our observations confirmed that grazing cattle in windy-cold-wet weather always seek shelter from the wind and walk with the wind behind them. Reeds, irrigation channels and river banks force the wind to higher altitudes, resulting in lower wind speeds at ground level. Only in the summer does the herd look for a gentle breeze to regulate body temperature and get rid of the hundreds of giant horse-flies. In summary, we can say that the herd moves parallel to the wind direction. At the present stage of our research we have concluded that barometric pressure and daily distance walked must be measured, because the atmospheric ion ratio can change during weather fronts (Wahlin, 1989) and, as a result, fronts have an indirect effect on serotonin production and animal behaviour. Through this complex mechanism we are able to compare pressure, spatial position and behaviour.

## Conclusions

The network of physiological processes (serotonin re-uptake response, thermoregulation) has created an amazingly flexible bio-system (Phelps, 2005), which eventually drives cattle behaviour. We suggest that incoming weather systems change the air ion concentration, which results in serotonin neuro-transmitter stress. Throughout this process the animal becomes more frustrated (after the short period of serotonin indicated calm) and spends less time on grazing and comfort behaviour. The changing weather also affects barometric pressure, which is easier to measure in time-lapse or real-time. Our results show that during calm weather/high pressure periods the herd behaves in a much more balanced way than during periods of low pressure/warm fronts. The research demonstrated that, for future rangeland farming, it is very important to track minor changes in the weather, because money and time can be saved if the herdsman knows in advance that the cattle will lose condition due to bad weather fronts and animal handling would also be easier and faster during calm periods.

## Acknowledgement

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## Animal behaviour analysis with GPS and 3D accelerometers

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### Abstract

A herd of dairy cows were equipped with GPS tracking collars and at the same time, their behaviour was manually scored with Pocket Observer software. TrackLab was used to visualize the data. The manually scored behaviours were used to classify the GPS data, and for foraging, resting and walking, the GPS data had a very high predictive value for the behaviours. Although ruminating and standing could not be distinguished on the basis of GPS data alone, a further experiment on Canada Geese indicated that the addition of accelerometer data to the GPS tags showed very promising results with respect to distinguishing more behaviours than could be classified using GPS alone. This opens up a spectrum of possibilities for farm mangers including automatic detection oestrus in cattle and geofencing applications.

**Keywords:** GPS, Tracking, Cows, Geese, Goose, 3D Accelerometer, Behaviour detection

### Introduction

The spatial movement patterns of individual animals have much to tell us about their behaviour, physiological status and wellbeing. Therefore tracking animals with Global Navigation Satellite Systems (GNSS), of which the GPS is the most commonly used, has become an important research method for studying wildlife behaviour and how human activities affect this behaviour. Feeding, fleeing and resting for instance each have specific spatial and temporal patterns. To study more detailed behaviour, the spatial and temporal resolution of the GPS must be of high accuracy. One way of improving the standard GPS spatial accuracy is the use of EGNOS, a European augmentation system that improves GPS positioning to within 1 meter. The FP7 financed project ETrack (www.etrack-project.eu) develops an integrated system for animal tracking and behaviour analysis. It is using the EGNOS augmentation system to GPS positioning. The objective of E-Track is to better and more reliably track and analyse the movements and behaviour of animals under field conditions. The E-Track system develops data acquisition systems (collars for mammals, backpacks for birds) with GPS + EGNOS receivers and optional 3D accelerometers, data communication systems. The data is transferred in real-time (or another mode if desired) to the analysis and visualisation software. Here, the high accurate positioning and movement data are processed and analysed. The E-Track project aims to develop an end-to-end system for movement tracking and behaviour recognition based on GNSS (Global Navigation Satellite System) telemetry, with high temporal and spatial resolution, sufficient to enable the fine-scale measurement of behaviour and interactions of wildlife.

The use of GNSS collars in animal movement research is growing. An inventory of scientific publications shows that the number of publications in which researchers track the position of animals by a satellite system has been steadily growing since 2006, and still does. 56% concerns publications about tracking wildlife; 17- 22% concerns publications about tracking livestock (personal communication, Albert Willemsen (Noldus) Feb. 2013).

In addition to animal studies and research, the use of GNSS in livestock management has been suggested for applications in animal monitoring (oestrus and illness detection), movement and pasture use (grazing patterns), herd location (free range cattle) and virtual fencing. Barriers for further operationalisation involve the costs of the collars and the power supply to the devices, in particular in comparison to pedometers and close range sensors.

This paper presents two experiments carried out to investigate the possibility of behavioural classification of animals using GPS data. It is known that GPS data can be used to derive certain behavioural data, but also there are limits to the resolution of similar behaviours and it has been suggested that if GPS data is supplemented with accelerometer data, a finer resolution of behaviours might be possible (Anderson *et al.* 2012). These experiments explore those boundaries. In the first experiment, cows were equipped with an EGNOS-enabled GPS collar and behaviour was classified based on manually scored observations with event-logging software. In the second experiment, accelerometers were integrated with GPS tags and attached to Canada Geese whilst their behaviours were manually logged. The accelerometer data was then compared with the manually scored behaviours.

## Materials and Methods

Livestock experiment

This experiment was carried out at two locations. The first was on a pasture of a dairy farm near the village of Bennekom in the east of The Netherlands (52°01' N, 5°62' E). It was a rectangular field with a line of trees on the north side and freely available water plus silage for additional feeding. The second experiment took place in a partially wooded area in the same district (52°01' N, 5°75' E). This site also had water available, and a strip of grassland.

Nine cows (Fresian Holstein) in the first part and 8 in the second were fitted with Lotek EGNOS-enabled GPS collars (GPS6000M from Biotrack, Wareham, UK). They were tracked for ten days spread over three weeks at a variety of sample rates.

The behaviours of the cows were manually scored during 15-minute observations using event-recording software (Pocket Observer 3.1 from Noldus Information Technology, Wageningen, The Netherlands) installed on handheld computers (Psion Workabout) and analysed with The Observer XT 11 (Noldus Information Technology, Wageningen, The Netherlands). The ethogram used was shown in Table 1 (below).

The GPS data were visualized with TrackLab 1.0 (Noldus Information Technology). The dehabitatLT package in R (Calenge, 2006) was used for calculating distance and turn angle. A permutation ANOVA test using the lmPerm package in R (Wheeler, 2010) as conducted to test whether distance and turn angle differed significantly between behavioural types and therefore were likely to be useful in the creation of decision rules to classify the data into behavioural groups. When the permutation ANOVA indicated a significant difference for either distance or turning angle between the behavioural classes, the same test was carried out pairwise on all combinations of behaviour as a post-hoc test (Basso *et al.* 2008) with Bonferroni correction (Zolman, 1993). Decision trees using the CART (classification and regression tree) method (Nathan *et al.* 2012; Lewis 2000) were used to calculate how much of the data could be correctly classified based on thresholds of distance moved and turn angle.

Table 1. Ethogram of cow behaviour

| **Behaviour** | **Description** |
|---|---|
| Walking | Movement from one location to another without the head orientated at the ground |
| Foraging | Grazing or browsing taking frequent bites of forage |
| Standing | Standing still, no movement to another place |
| Ruminating | Cow is lying down |
| Drinking | Drinking at the water supply near the stables |
| Grooming | Cleaning or scratching itself |
| Social | Interaction with other cows (e.g. grooming, mounting) |
| Dry Forage | Consuming silage left by the farmer |

<u>Accelerometer experiment</u>
Six Atlantic Canada geese (*Branta canadensis canadensis*) were fitted with GPPP GPS and accelerometer tags from Biotrack (Wareham, Dorset). The Biotrack GPPP platform contains a u-blox GNSS receiver, 3D accelerometer IC, microcontroller and microSD card memory. It is programmed to log location data simultaneously in two formats: NMEA locations and raw data. The NMEA solution uses ionospheric and other correction factors via EGNOS if a satellite can be acquired. It calculates a location using Precision Point Positioning (PPP), which provides more accurate results by incorporating carrier phase measurements. Raw data provides a means to achieve the same results by post-processing as well as other solutions such as alternative Kalman filters. Data from the accelerometer comprised all three axes sampled at a rate of 30-50 Hz (three readings: X,Y,Z).

The experiment took place in an experimental field of 26 x 26 m at the Netherlands Institute of Ecology (NIOO-KNAW) in Wageningen, The Netherlands. The tags were less than 2% of the body weight of the geese and were mounted on the animals using a backpack. The behaviours of the geese were scored and analysed with The Observer XT 11 (Noldus Information Technology, Wageningen, The Netherlands). They were also filmed with a video camera. The ethogram used is shown in Table 2.

Table 2. Ethogram of Canada Goose behaviour

| Behavioural types | |
|---|---|
| Standing | Running |
| Walking | Flapping the wings |
| Sitting | Calling |
| Feeding while standing | Stretching |
| Feeding while walking | Shaking |
| Feeding while sitting | Looking (stretching the neck) |
| Drinking | Sleeping |
| Preening | Interaction |
| Pecking/preening the tag or ring | |

The accelerometer and behavioural data was plotted and analysed visually.

## Results and Discussion

GPS Tracking of cows

The GPS tracking devices together with TrackLab visualization gave useful information about the spatial and temporal activities of the cows. As can be seen in the figures below, the cows spent relatively more time in the locations where silage and water were available and when they were moving to the far end of the field, they tended to move at higher velocities than when they were nearer to the farm buildings.

Behavioural classification

To find out how distance and turning angle between GPS fixes are related to behaviour these two movement metrics were plotted against each other for the four dominant types of behaviour (Fig. 3).

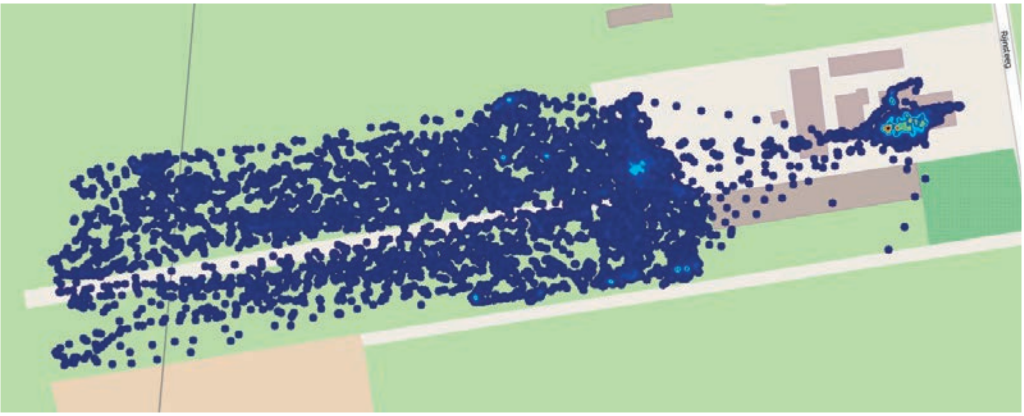

Figure 1: Visualization of GPS tracks of 9 cows in TrackLab from one day. The heat map is generated according to the density of the GPS samples. It can be seen that the cows spent a relatively large amount of time in the stall (on the right), and near the silage and water (in the centre) and that when in the field they spent less time at the far end of the field than nearer to the farm buildings.


Figure 2: Visualization of a single GPS track of a cow in TrackLab from one day. The colour of the line indicates the speed of the cow at that moment. A) At the farm pasture. It can be seen that the cow is moving slower in the region next to the farm buildings where the water and silage were available. B) At the wooded site. Searching behaviour (long flights, high speed) can be distinguished from foraging behaviour (short flights, low speed).

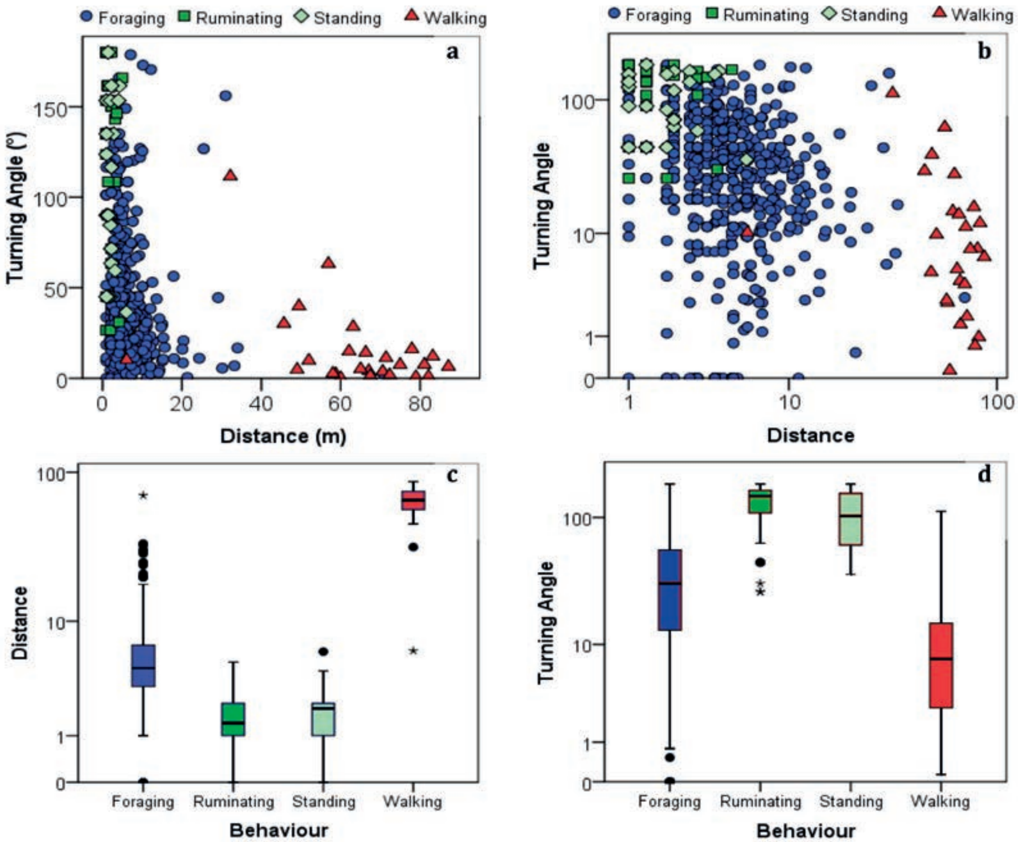


Figure 3. a), b), Relationship between turning angle and distance for each of the four dominant types of behaviour on both a linear and logarithmic scale. c, d) Boxplots show the distribution of both distances and turning angles for the different groups of behaviour. Letters on top of the graphs depict if there are significant differences for these movement metrics between the groups based on permutation ANOVA tests.

Walking can be distinguished most clearly because the distance covered between GPS fixes during the 1 minute sample interval is much larger than for the other types of behaviour and the turning angle for Walking is relatively low. Foraging was the most variable behaviour, with large variations in both distances and turning angles. Ruminating and Standing are related to small distances as expected, but both types of behaviour include turning angles varying from 0 to 180 degrees. A permutation ANOVA showed that both distance ($F_{3.603}=782.46$, $p<0.0001$) and turning angle ($F_{3.593}=95.77$, $p<0.0001$) differed significantly between groups. All behavioural classes were found to be significantly different from each other except for Ruminating and Standing.

A decision tree was then created which formed the model for validation. The data used to form the model was able to correctly classify 93.4% of the data. This was then validated with the other half of the dataset resulting in 87.5% overall correct classification. However, standing was only classified correctly 9.5% of the time, mostly being classified as foraging instead (Table 3).

If standing and ruminating were combined together as one behaviour ('resting') then the percent samples correctly classified as resting in the training and validation datasets were 78.7% and 62.9% respectively.

Table 3: Confusion matrix for the decision tree for the behaviours in the training and validation samples, based on movement and turn angle. The numbers are numbers of samples and the diagonal (in bold) shows the correct classifications.

| Result Training Sample | | | | | |
|---|---|---|---|---|---|
| Observed | Predicted | | | | Percent Correct |
| | Foraging | Ruminating | Standing | Walking | |
| Foraging | **498** | 7 | 0 | 1 | 98.4% |
| Ruminating | 8 | **41** | 0 | 0 | 83.7% |
| Standing | 12 | 10 | **4** | 0 | 15.4% |
| Walking | 2 | 0 | 0 | **24** | 92.3% |
| Overall Percentage | 85.7% | 9.6% | 0.7% | 4.1% | 93.4% |
| | Result Validation | | | | |
| Foraging | **443** | 19 | 5 | 3 | 94.3% |
| Ruminating | 21 | **33** | 1 | 0 | 60.0% |
| Standing | 26 | 12 | **4** | 0 | 9.5% |
| Walking | **0** | 0 | 0 | **42** | 100% |
| Overall Percentage | 80.5% | 10.5% | 1.6% | 7.4% | 85.7% |

GPS and Accelerometer data from geese

Although the accelerometer data have not yet been statistically analysed and classified, it is clear from plots of the data (see Fig. 4 for an example) that they give significant extra information. Whereas the GPS data for the cows were unable to be used to distinguish between ruminating and standing, the accelerometer graphs shows a clearly different waveform for the sitting compared with feeding while sitting. Although of course this must be a tentative conclusion, as it is not yet statistically verified, it is clear that this is a very promising technique.

Future developments

The requirements towards a telemetry system are always rising, asking for an even higher spatial resolution. The measuring of the movements is no more the only target of interest; additional physical, physiological, pathological, etc. data are requested from automated telemetry systems. Sensors collecting information about temperature, light and acceleration are used in frequently to receive important information from the animal investigated. The additional data from the 3D accelerometer enriches the movement data and provides information on detailed behaviour. Depending on where the accelerometer is attached to the animal (i.e. the leg, the back or the neck) it reveals specific movement behaviour. For instance attachment of a 2D accelerometer to the neck provides insufficient information to separate between standing and lying (De Mol, 2009). Additional to the GNSS and 3D Accelerometer the use of 3D magnetometers is interesting. This provides information on the position of the sensor relative to both gravity and magnetic field. At its simplest level, this can tell which direction the cow is facing, for example.

A logical consequence of the use of sensors, in particular the accelerometers, is the huge amounts of data, that must be stored, transferred and analysed. An option is to apply data reduction on board, for instance to measure tilt angle. At this stage, the wealth of information coming from the accelerometers suggests better use than calculating tilt angle.

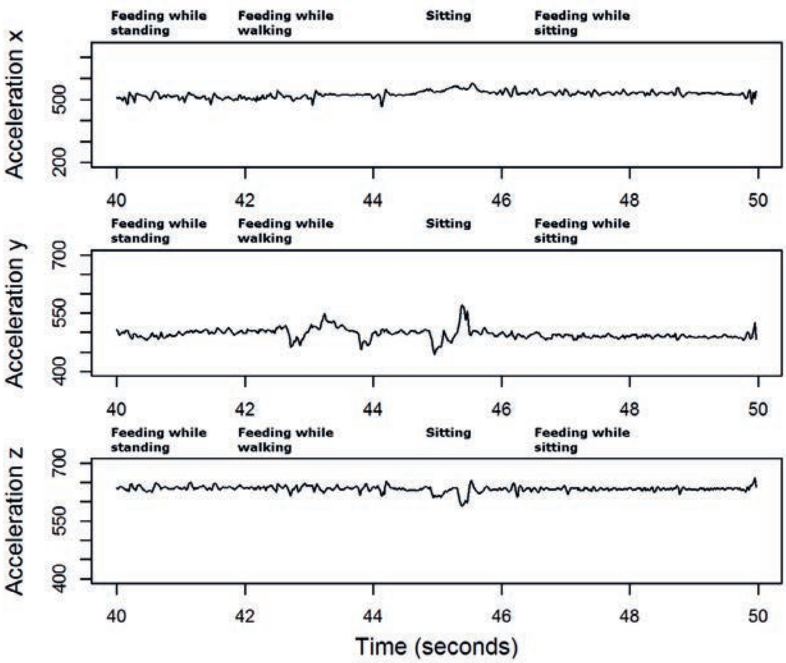


Figure 4. Accelerometer data for Canada Geese plotted against manually scored behaviours. The behaviours started at the time indicated by the first letter of the behaviour name.

Although the GPS data could not distinguish between certain behaviours, it is possible that with application of techniques such as better smoothing of the data (for example using the outlier removal and weighted least square smoothing available in TrackLab), and increased precision using EGNOS Data Access Service (EDAS; Liu *et al.* 2012), some more behaviours will be able to be distinguished. However, the preliminary accelerometer data indicate that a combination of GPS and accelerometer data is probably the most promising route for behavioural detection.

Once it is possible to automatically detect the behaviours in cattle, a range of new possibilities is opened up. Researchers will be able to gain much more detailed information about their experimental animals. Farmers will be able to use this information to improve the efficiency of their husbandry, especially if the data were coupled to a real-time feedback and decision-making software.  For instance dairy cows in oestrus show deviating behaviour such as raised levels of movement, being more restless and more interactive with other cows (Walton & King, 1986; Løvedahl & Changunda 2010). The use of GNSS and 3D accelerometer data can be an addition or improvement to existing systems.

Another application which this sort of data could be applied to would be intelligent geofencing. Geofencing is a technique whereby an animal is trained to recognise and respond to a stimulus delivered to it via a GPS system when it steps out of a virtual arena which is only defined on a computer and not with a physical fence.  It is especially relevant to very large extensive farms, or when the fence would otherwise need to be frequently moved. For example when stock are kept in a small area for intensive grazing, a virtual fence can be moved along the field each day. Geofencing has also been applied to large animals to alert rangers when they enter a village or agricultural area where they might cause harm (Licht *et al.* 2010, Hunter *et al.* 2007). The techniques described in this paper could make geofencing more practical, both by increasing its precision and by using behavioural as well as position data as an input.

## Conclusions

GPS tracks can give valuable information about the movement and use of space of cattle (and other relatively large animals) and this can be visualized and analysed in software such as TrackLab. GPS tracking data can also be used to automatically detect a range of behaviours in cattle so long as these can be distinguished by the path of the animal in terms of the distance moved between samples (that is, its speed) and the turn angle between samples (that is, its meander). However, such analysis is limited when it comes to behaviours which have similar track patterns such as ruminating (lying down) and standing. Preliminary results with combining GPS and accelerometer data look very promising regarding the ability to be able to separate a wider variety of behaviours than with GPS data alone. This technique opens up a wide variety of possible applications for both farmers and agricultural researchers.

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# Session 7

# Pigs - Sound

## Call feeding gestating sows in larger groups.

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**Abstract**

In electronic feeding for gestating sows aggressive interactions most frequently occur while queuing at the feeders' entrance. This may lead to severe injuries. Call feeding has been developed to diminish this drawback while at the same time providing a cognitive challenge for the sows. Results from a total of 67 gestating sows that had been trained for individual acoustic calls have shown that the sows remembered and improved their training over the whole production cycle. The training results at the end of the experiment revealed a theoretical limit of 60 sows per call feeding station, assuming a single 14 hour feeding period and a feed ration of 2800 g on the average.

**Keywords:** call feeding, electronic feeding, sow gestation, group housing, aggressive behaviour

**Introduction**

Feeding is one of the rare diversions for pigs in an industrial farm environment. Together with a restrictive feed rationing for gestating sows, group housing may result in an increased affinity to the feeding station and intensified aggressive behaviour in its vicinity. Weber *et al*. (1993) showed that with electronic feeding stations (EFS) the number of aggressive interactions is strongly correlated with the time of feeding. Aggressive interactions most frequently occur while queuing at the feeders' entrance. In comparison to other feeding systems for group housing, electronic feeding has an increased number of aggressions (Hunter *et al*., 1988; Zurbrigg and Blackwell, 2006), which may lead to severe injuries (Boyle *et al*., 2002). Derived from a previous research project with growing pigs (Ernst *et al*., 2005; Manteuffel, 2009), we developed the call feeding system for group housed sows (Manteuffel *et al*., 2011) to diminish the risk of injuries in the feeding context and to provide a cognitive challenge as an additional environmental enrichment. A large group study with 85 sows showed that the use of call feeding stations (CFS) can lower the number of agonistic interactions in front of the feeder, leading to fewer and less severe injuries (Kirchner *et al*., 2012). Here, we present results for parameters characterising the call recognition performance in the course of the large group study. In addition, we evaluate the limits on the animal number per feeding station for a commercial introduction of call feeding.

## Material and methods

Animals and housing

The study was conducted at the research station Mecklenhorst of the Friedrich-Loeffler-Institute in Mariensee, Germany. Sixty seven gestating sows (German Landrace) of the institute's herd were evaluated. The sows went through the production circle in a three week rhythm, split into seven subgroups of 8 to 12 sows. The gestating sows of a subgroup were held for three weeks in a small pen where replacement gilts were accustomed to electronic feeding and repeat breeders were identified. For the experiment this pen was additionally used as call feeding *learning stable*. Afterwards, the subgroup was transferred for twelve weeks into an open, unheated *gestation stable* where they were integrated into a dynamic large group consisting of all in all four of the small groups. Accordingly, the composition of the large group changed every three weeks. Gestation stable and learning stable had both been equipped with identical commercial EFSs (INTECMAC; PigTek Europe GmbH, Schüttdorf, Germany). For identification, all animals were carrying an ear tag transponder type Mannebeck Animal Control (MAC - PigTek Europe GmbH, Schüttorf, Germany). The station entry was located inside the pens while the exit led to an outside area. Both stables had a concrete floor and provided deep straw litter. Water and roughage (hay and straw) was offered ad libitum. All sows were fed restrictively with concentrate pelleted food. The feed contingent had been increased so that 80% feed uptake corresponded to 100% fulfilment of feed demand. A more detailed description of the animals and the housing conditions is given in Kirchner *et al.* (2012).

Experimental setup

The training and management of call feeding was controlled by software developed at the Leibniz Institute for Farm Animal Biology in Dummerstorf, Germany. The software communicated with the INTECMAC software via an application interface using ISOagriNET (for details see Manteuffel *et al.* 2011). The experiment was divided into two main phases, the adaption phase in which the herd got stepwise adapted to call feeding and the operation phase where all sows performed call feeding and only replacement gilts had to be trained from time to time. During the adaption phase, the sows got conditioned as described in Ernst *et al.* (2005) and Manteuffel *et al.* (2010) using trisyllabic human and artificial names for the calls. This training was conducted in small groups in the learning stable and included an initial Pavlovian conditioning for at least the first four days. Within this time the sows had unhindered access to the CFS, restricted only by their feed contingent. Subsequently, an operant conditioning was performed for up to 13 days, where only the called sow had access to the station. The exact duration of each training phase was manually adjusted according to the individual training performance of the sows. In the operation phase, the training of replacement gilts was performed with a varied training method as described in Manteuffel *et al.* (2011) that made manual adjustments unnecessary. The number of feedings in the learning stable was subject to frequent changes. This was an expression of the efforts to minimize the adaption stress for the sows, which had been fed once until the experiment, and to maximize the daily reinforcement to create a consolidated conditioning. Untrained sows performing electronic feeding and sows performing call feeding were kept mixed in the gestation stable until day 169 of the experiment. Within this time and until day 238 the sows had only one feeding per day in the gestation stable. From day 239 until day 373 of the experiment the sows had two feedings, at which 75% of the feed ration was dispensed in the first and the remaining feed in the second feeding. After day 373, the sows were again fed once daily. These changes were performed to investigate a possible cognitive enrichment effect on the animal behaviour (Kirchner *et al*., 2012).

<u>Statistical analyses</u>

Call feeding imposes a discrimination task on the animals making them classify whether they or a different sow has been called. In this sense, the sows could be seen as classifiers and their performance can be described by the parameters sensitivity (true positive rate), specificity (false positive rate) and precision (positive predictive value). In matters of call recognition, sensitivity is then defined as ratio between the number of feedings of the specific sow and its number of calls. It will be referred here as *correct response* ratio. Specificity is the ratio between the number of erroneously responded calls (detection at the station entry while a different sow is called) and sum of calls of other sows. It will be referred here as *false approach* ratio. Precision, in matters of call recognition, is defined as the ratio between the number of correct reactions (feedings) and sum of all reactions of a sow. It will be referred here as *learning success*. In addition, *latency*, defined here as the time between the first call and the feeding start of the called animal, provides insight on the time overhead of call feeding with respect to EFS. The statistical analyses were generated using SAS/STAT software, Version 9.2 of the SAS System for Windows (© 2009 SAS Institute Inc.). All response variables in the experiment were analysed by fitting and testing generalized linear models applying the GLIMMIX procedure (SAS, 2009). Repeated measures on the same animal were taken into account by the residual option in the random statement of the GLIMMIX procedure. The response variables latency, correct responses, false approaches and learning success were analysed by ANOVA (distribution = normal, link = identity) with the fixed effects experiment month, repetition of the experiment and experiment phase. Least-squares means (LSM) and their standard errors (SE) were computed for each fixed effect in the models. All pair-wise differences between the LSM were tested using the Tukey–Kramer procedure. As the level of significance a probability of 0.05 was chosen.

## Results and discussion

The given herd management resulted in gestations groups containing sows of different ages, different gestation phases, and with reoccurring mixing procedures. In addition, the experimental setup led to the mixing of sows with a different training history regarding the training procedure and number of feedings. These constant changes in the fixed factors render a statistical analysis of learning performance alone impossible. Nevertheless, it gives an image of what call recognition performance can be expected from adapting a herd from electronic feeding to call feeding under less than optimum circumstances. Figure 1 shows the development of the reaction latency and of the correct responses, false approaches and learning success in the course of the experiment.
Here, no attention is paid to any changing fixed factors such as number of animals in stable (19-36), animals called (2-33), number of feedings (1-2), changes in software and the like. In the progression of the experiment (fixed factor month), latency ($F_{14,373}$=14.43, $p < 0.0001$) and the classification performance measured by correct responses ($F_{14,387}$=42.52, $p<0.0001$), false approaches ($F_{14,387}$=82.40, $p<0.0001$) and learning success ($F_{14,381}$=39.53, $p<0.0001$) all in all significantly improved.

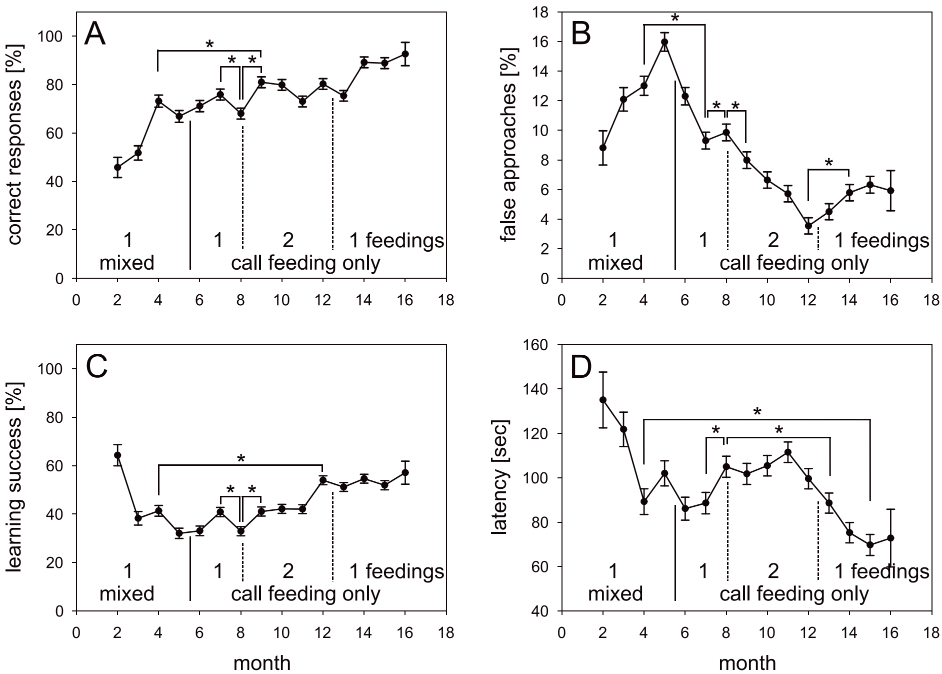


Figure 1: Call recognition in the gestation stable as a function of the experimental

month (LSM±SE). The two feeding settings mixed EFS-CFS feeding and exclusive CFS feeding are indicated in words and separated by a solid vertical line. Changes in the numbers of feedings per day are indicated by numbers and separated by dotted vertical lines. Significantly different values are marked by a star (not all shown).

Three peculiarities can be noted. First of all, the false approaches (month 2<5, $t_{387}$= -6.21, p<0.0001) and learning success (month 2>5, $t_{381}$=7.29, p<0.0001) worsened during the adaption phase with mixed feeding. In this phase more and more sows were fed with call feeding, while the software did not take the social hierarchy of the group into account. The access to the feeder is often regulated by the social status of sows (Anil *et al.*, 2006). Calls ignoring the social hierarchy in combination with a still unconsolidated conditioning led to more and more high ranking sows queuing in front of the feeder. A software update at the end of the adaption phase solved this by assigning one of three rank classes to each animal and calling the animals ordered by rank class (Manteuffel *et al.*, 2011). The rank class had been estimated from age and weight of the respective sow (Ritter and Weber, 1989).

Secondly, after switching from one to two daily feedings beginning on experiment month eight, all three parameters signalled a worse classification performance for a short period (Figure 1A-C). Latency was elevated and stayed on a higher level during the whole period of two feeding events (Figure 1D). With a single feeding, the calls were distributed over the whole day, while with two feedings all animals had been called at least once during the first half of the day. Also, three-fourths of the feed was dispensed at the first feeding. Thus, the sows might have been at least partially satisfied and less alert which might have contributed to a higher latency.

Thirdly, when switching back to a single feeding, correct responses increased (month 13<14, $t_{387}$=-9.69, p<0.0001) as well as false approaches (month 13<15, $t_{378}$=-4.06, p<0.01) while latency decreased again (month 13>15, $t_{373}$=4.2, p<0.01) and learning success showed no significant change. With just one feeding, the calls were distributed over the whole day again, which might have stressed the patience of the animals that just got used to being feed at the first half of the day. Consequently, they might have been more alert leading to a lowered latency.

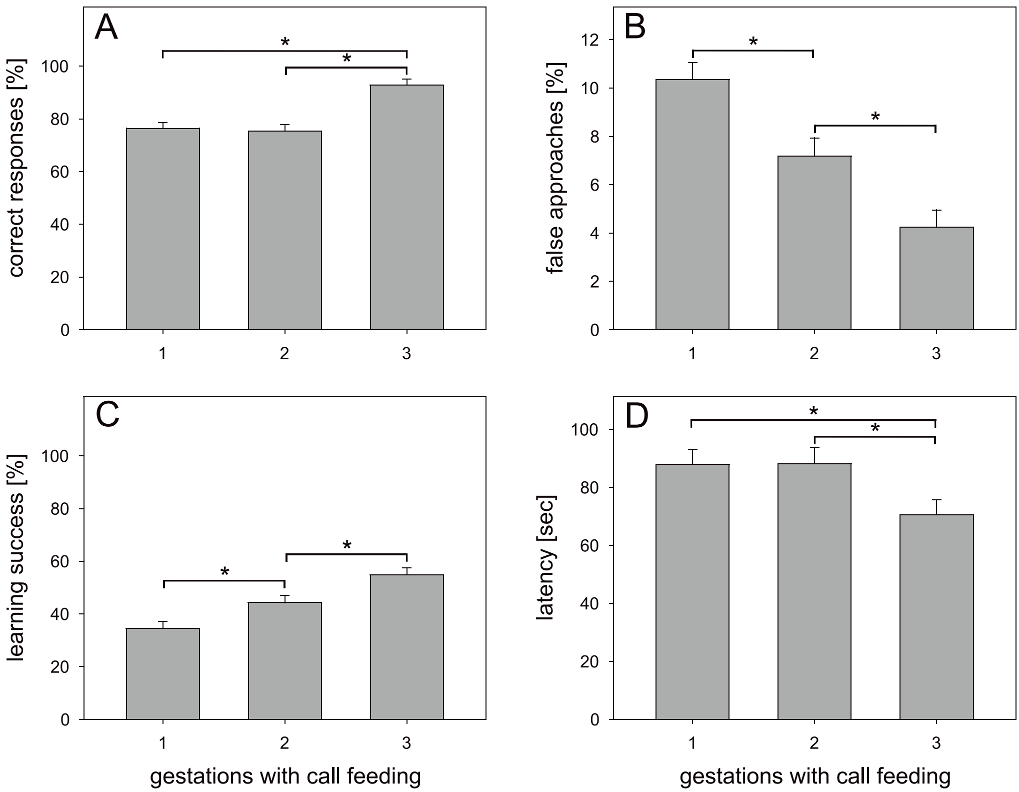


Figure 2: Call recognition in the gestation stable as a function of the number of gestation periods with call feeding (LSM±SE). Significantly different values are marked by a star. Sows per number of call feeding gestation periods (1:40, 2:30, 3:25).

The number of sows that can be supplied by one CFS is an important parameter of call feeding. Together feed rate, latency and learning performance allow estimating how many animals could have been fed at the CFS during the course of the experiment using the equation

$$sows(p) = \frac{p - C \cdot T}{F + L} \tag{1}$$

where p is the length of one feeding period, T is the mean number of nonresponded calls (*timeouts*), L is the average latency, C is the minimum time required between two feedings and F is the average time between feed start and end (Manteuffel *et al.*, 2011). Based on measurements in 4762 feedings, we can assume an average feed rate of 4.4 g/sec and on the average 130 seconds to leave the station. This sums up to F=12.68 min for a 2800 g feed ration. A feed interval of C=130 seconds was enough to cover the latency of 80 % of all sows in the 15th experimental month, whereby the average latency L was 70 seconds (4.7 sec SE). Together with on average T=5.7 nonresponded calls per day in month 15 derived from Figure 1A and a feeding period p=12 h, we get from Equation (1) a station capacity of 51 animals in the 15th experimental month compared to 47 animals in the 5th experimental month. With a feeding period of 14 hours the theoretical limit of a single station increases to 60 sows. In any case and number of feeding events the number of calls and sows were well below the maximum capacity of the feeding system.

During the experiment sows repeatedly returned from farrowing to the learning and gestation stable. Figure 2 shows the latency and learning results for different numbers of gestation periods spent with call feeding during the operation phase. In order to attain a better comparability, only days with one feeding event where more than 25 sows were present and more than 22 have been called were evaluated. The evaluation does not consider the different age and parity of the sows. Under these restrictions 40 sows had one gestation, 30 sows had two gestations and 25 had three gestations with call feeding. The results show an improvement of the parameters for almost each gestation (Figure 2). This proves that the training is persistent over the time spent in the farrowing pen and at the insemination. It also shows that the classification improvement of the herd throughout the entire experiment is mainly due to the higher proportion of experienced animals. Remarkably, the sows with the most call feeding gestation periods, which are presumably heavy and relatively high ranking, have the least false approaches (Figure 2B). This emphasises the increased importance of longevity associated with call feeding. A well consolidated conditioning is vital for the operation of call feeding. With untrained and inexperienced sows, the social rank becomes a major influence on feed access as high ranking animals tend to block the station entry until they are fed (Manteuffel *et al.*, 2010). Hence, lower ranking sows may be hindered to follow their call even if they correctly had classified it.

The initial training of naive sows in the adaption phase with six feeding events and a small group of up to twelve sows yielded results similar to Manteuffel *et al.* (2010) (data not shown). At the same time, the training of naive replacement gilts within groups of experienced sows with only two feedings events per day produced even better results. For this comparison, the results of 25 sows from the adaption phase and 11 sows from the operation phase were included. Here, the correct responses over the whole training period were 81 % (5.1 % SE) in the operation phase compared to 37 % (6.0 % SE) in the adaption phase ($t_{34} = -4.58$, $p < 0.0001$). The mean false approaches where 9 % (2.8 % SE) in the operation phase compared to 16 % (2.4 % SE) in the adaption phase ($t_{34} = 2.11$, $p < 0.05$). The mean learning success was 71 % (4.4 % SE) in the operation phase compared to 24 % (4.0 % SE) in the adaption phase ($t_{33} = -7.87$, $p < 0.0001$). The mean feed uptake was 87 % (5.3 % SE) in the operation phase compared to 62 %

(5.2 % SE) in the adaption phase ($t_{34}$ = -3.73, $p < 0.001$). One could speculate that the gilts learned by example from the experienced older sows. However, the improved learning performance can equally be explained by an eased station access and thus more training opportunities because in the operation phase fewer sows were trained simultaneously. A certain share might also come from the improved training software. Additional test are necessary to identify the regulatory factors here.

Several studies concerning the learning capacity and the acoustic training of pigs have been conducted. Ernst *et al.* (2005) used 10 seconds lasting harmonies based on the c-major-triad to call 7 weeks old male pigs in groups of eight towards four CFSs. The classification challenge for the pigs was to distinguish their call by an individual timbre of always the same harmony. The pigs have been called 24 to 31 times a day, gaining a reward of 40 g feed pellets. After three days of Pavlovian conditioning and seven days of operant conditioning the pigs reached about 80% correct responses on average. Manteuffel *et al.* (2010) used spoken human and artificial names to call adult gestating sows in groups of 6 to 8 animals to a commercial electronic feeder. The classification challenge for the sows was to distinguish their call by identifying their individual "name". The sows have been called six times a day gaining a food reward of 400-500 g feed pellets. After seven days of Pavlovian conditioning and thirteen days of operant conditioning the dominant and subordinate sows reached about 80% correct responses on average. Both studies exhibit a better call recognition performance than the sows in the dynamic large group at least in the first half of our experiment. Here, the call feeding of older sows, which were well acquainted to electronic feeding, together with other sows still performing electronic feeding might be an issue.

High ranking sows might had have to wait for their call while lower ranking sows easily got access to the station. This on the one hand in combination with a not fully consolidated training on the other hand might have provoked some of the sows to switch their feed strategy back to electronic feeding, by simply waiting in front of the station. Re-establishing the call feeding feed strategy in the operation phase with just one feeding event per day and repeated group mixing presumably takes longer than the training in a steady small group with more frequent feedings and thus more training opportunities. Larger groups would consequently have to be adapted in several steps as it has been carried out in this study. This, together with the need for seamlessly integrating replacement gilts, makes individual training and calling strategies necessary which we successfully tested in this study.

## Conclusion

We found call feeding applicable for feeding adult sows in large groups. The capacity of a CFS is at least close to the recommendations for EFS. Also, pigs are able to localize calls from different CFSs (Ernst *et al*., 2005), making the procedure probably applicable for small to mid-sized herds with up to four CFS and at most 240 gestating sows in one gestation stable. The results from training replacement gilts in the operation phase seem to suggest that the number of feeding events and thus the size of the training group can still be improved by applying more advanced automated training routines. Furthermore, long term tests are necessary to study the effects of call feeding on animal welfare and performance.

**Acknowledgements**

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# Acoustic reward learning as a method of reducing the incidence of aggressive and abnormal behaviours among newly mixed piglets

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## Abstract

The aim of the study was to use acoustic reward learning as an approach to reduce the incidence of aggressive and abnormal behaviours in pigs reared in intensive conditions. In one experimental round four litters of 25-day old piglets (BHZP breed) were trained over eight days to create an association between a sound and a sweet reward. The training was carried out five times per day using an electronic dog feeder which generated an acoustic signal 2s before the reward was released. A total of 5 experimental rounds were carried out. After the training period, at the age of 35 days, the piglets were weaned and mixed in two pens, 12 piglets per pen. Immediately after mixing and 24 h later, the animals were directly observed for 3 h by two trained persons (one per pen) hidden behind a transparent blind. They released the sound signal and feeder when aggressive or abnormal behaviour started. A total of 616 aggressive acts and 31 incidences of ear biting were identified, of which 52.4% in total could be interrupted by the acoustic reward treatment. The piglets' response to the feeder sound differed significantly between experimental days (P<0.001). On the second day of mixing the feeder sound made the piglets interrupt 74.9% of aggressive events, compared with only 33.7% on the first day. The type of aggression and the point in time during the aggressive action significantly influence the effectiveness of the acoustic reward treatment (P<0.001).
The results show the potential for distracting piglets from specific aggressive behaviours such as head thrust (odds ratio =0.43), jumping on other pigs (0.56) or attack with bite (0.61). Ear biting was very unlikely to continue (0.55). The risk of continuing elevated aggression level behaviours was doubled in the event of chasing (2.16) and the risk that fighting would continue after the feeder sound was released was seven times higher (7.89). The results suggest that acoustic reward treatment can reduce aggression and ear biting in piglets.

**Keywords**: pig, aggression, abnormal behaviour, reduction training, sound-feed reward treatment

## Introduction

Violent aggression among pigs under farming conditions can cause major physical injuries, social stress and loss of productivity which affects animal health and welfare as well as the economic efficiency of farms. The current practice of mixing pigs, combined with intensive housing conditions such as fully slatted floors, poor environment, little available space and feeding competition, are factors which are known to increase the level of aggression between pigs (Wood-Gush and Bailharz, 1983, Grandin, 1989, McKinnon *et.al*, 1989, Dybkjaer, 1992,Barnett *et al*, 1993, 1994, etc.). The most vigorous fighting to establish a dominance hierarchy is usually induced by mixing unfamiliar pigs (e.g. Erhard *et al*., 1997). Although the hierarchy is usually established within 24-48 h post-mixing (Parratt *et al*., 2006), it is still possible to observe frequent changes of rank, particularly among the middle ranks. This social instability accounts for the maintenance of a continuous, although minimal, level of aggression even long after grouping (Stookey and Gonyou, 1994; Coutellier *et al*., 2007). Other serious animal welfare problems in intensive farming of fattening pigs are tail and ear biting. These abnormal behaviours can reduce production results, increase on-farm costs (e.g. labour and treatment costs) and lead to a variety of physical injuries and carcass condemnation which result in financial losses for the farmer and the abattoir (Zonderland, 2010). Particular attention has been given to the use of environmental enrichment in order to redirect pigs' attention from harmful social behaviours and aggression against their pen mates.(Schaefer *et al*. 1990, Simonsen 1990, Petersen 1995, Beattie *et al*., 1995, 1996, 2000). The use of straw as an enrichment material, shown to be an effective method of reducing aggression (Day *et al*., 2002), is limited because 91% of pigs in the EU are kept on slatted or partly slatted floors where it is not possible to use straw as a bedding material (Hendriks *et al*., 1998). An alternative to straw bedding is the use of point source enrichment objects. These objects are mainly manufactured by the farmers themselves or sold as commercial products (i.e. Bite Rite). Some research indicates that the use of point source enrichment has positive effects on aggression levels (Schaefer *et al*., 1990). In the long term, enrichment objects lose the effect of novelty which is necessary to keep the attention of the animals continuously (Bracke *et al*., 2006).

In recent years, the cognitive abilities of animals have been widely tested (e.g. Held *et al*., 2005; Wredle *et al*., 2006; Jansen *et al*., 2009), showing that pigs can successfully learn to cope with difficult experimental tasks. Authors Ernst *et al*. (2005) and Puppe *et al*. (2007) trained pigs to approach a feeder in order to receive a feed reward whenever they were called at several, unpredictable times each day using an instrumental feed-rewarding learning device. These experiments showed that sound and feed are effective stimuli for instrumental learning in pigs, and that pigs can clearly and selectively associate the sound and the feed reward. Thus, our idea was to use acoustic feed reward learning based on classical conditioning techniques as an approach to reducing the incidence of aggressive and abnormal behaviours in pigs reared in intensive conditions. For this purpose we used a prototype feed-rewarding device in the form of an automatic dog feeder. Piglets learned to approach the feeder, which released a sweet reward, after hearing the sound signal. The main objective was to test the effectiveness of an acoustic feed reward system at redirecting the pigs' attention from harmful social behaviours.

## Material and methods

The acoustic feed reward system consisted of a commercially available electronic dog feeder (Manners Minder Treat and Train®) filled with potentially attractive feed for piglets (chocolate candies).
The study was carried out at the Ruthe research farm of the University of Veterinary Medicine Hannover, Foundation (Germany) and consisted of five rounds. Each round included two sequential phases: training and mixing.

### Training phase

In total 144piglets from 14 entire litters of the German National Breeding Programme (BHZP) were used for training. For each round, piglets were randomly selected from two to four litters. The mean initial weight was 7 kg ±1 kg with an age of 25 days. The piglets were kept with sows from birth until weaning in farrowing pens measuring 2.30 x 2.00 m with a partially slatted floor equipped with a heated piglet area, and provided with dry feed ad libitum. All sows were confined in a farrowing crate throughout lactation. On the first day of the experiment the piglets were weighed and their backs were marked using a standard colour stock marker.

The aim of the training phase was to create an association between the sound and the feed reward, following the principle of classical conditioning (Pavlov, 1927). The piglets were trained to react to the electronic dog feeder sound signal, which was released 2 s before distribution of a feed reward. The electronic feeders were placed on the lateral walls of the two opposite pens with selected litters, one per pen, at a height of 0.6 m above the floor. An observer activated the feeders by remote control from outside the room 5 times per day with a 10 min pause between activations. For every trial the training phase lasted eight days and lasted between one and two hours per day (10:00-12:00 a.m.).

### Mixing phase

After the training period, piglets were weaned at the age of 35 days and moved to rearing pens. On the day of weaning 6 piglets were selected from each trained litter based on their weight (average 10kg ± 1); they were then weighed, spray marked and mixed in two pens, 12 piglets per pen (120 in total). Two groups of 12 piglets were mixed in two pens based on their weight (average 10kg ± 1) and sex. The pens measured

2 m x 1.8m and had a slatted floor (0.38 $m^2$ per animal) and solid pen walls. The piglets had ad libitum access to dry feed (feeding place ratio 1.5 : 1) and water.

The aim of the mixing phase was to test the effect of the electronic feeder on post-weaning aggression in the piglets. Simultaneous observations were carried out by two observers (one per pen) during the first 3 h (09:00 to 12:00 a.m.) after the groups were established (day 1) and then for 3 h approximately 24 h post-grouping (day 2). The observers were separated from the piglets by a transparent blind in front of the pens. The electronic feeders were placed on the lateral walls of the experimental pens at a height of 0.8 m above the pen floor. The observers activated the electronic feeders remotely when they noticed aggressive behaviour.

Video recordings and data analysis

Video recordings were taken by 2 cameras (Guppy F-080C and Guppy GC1350 (Allied Vision Technologies, Germany)), placed at a height of 2.0 m above the pens floor. In total 60 h (6 h per pen, 5 rounds) of recorded videos were analysed by one observer using the "Labelling Tool" software (Viazzi *et al*., 2011) developed in Matlab (R2009a, The MathWorks Inc., MA, USA). The following parameters were recorded: the exact duration of each aggressive event (the start and finish time); initiator and receiver piglet; the behaviour of the piglets within the aggressive sequence at the moment of feeder sound exposure (Table 1); the response of the pigs to the feeder sound during performance of the behaviour (continued aggression; distracted from aggression and approached the feeder).

Table 1: Description of piglet behaviour leading to activation of the feeder.

| Behaviour | Description |
|---|---|
| Aggressive Behaviour | |
| Fight | A fight lasts longer than a single aggressive interaction and begins with open-mouthed contact and ends when the pigs lose contact for at least 5 seconds (based on Erhard *et al.*, 1997 and Gonyou *et al*, 1988). A series of mutual vigorous bites, pushes and head thrusts is carried out by the pigs involved |
| Chase | Pig is following another pig in quick pursuit, usually biting or trying to bite (Erhard *et al.*, 1997), receiving pig withdraws or escapes |
| Push rooting disc | Pushing or ramming another pig with his rooting disc without biting, in an event that is not rated as part of a fight |

| | |
|---|---|
| Head thrust | Ramming or pushing another pig with the head, with or without biting, in an event that is not rated as part of a fight (O'Connell and Beattie, 1999) |
| Lifting other | Pig puts its snout under the body of a pen mate (from behind or the side) and lifts the pig from the floor (after Morrison *et al.*, 2003) |
| Jump on other | The pig starts an aggressive interaction by jumping with his front feet on another pig's head-neck area (McGlone, 1985) |
| Abnormal behaviour<br>Ear biting | Persistent oral manipulation or biting of the ear of another pig (after Taylor *et al.*, 2010). |

Statistics

The PROC FREQ (SAS, 2008) was used to identify the occurrence of each behaviour which led to activation of the electronic feeder. Due to the small number of events, push rooting disc, lifting other and tail biting behaviours were excluded from the analysis.

Logistic regression (PROC CATMOD, SAS 2008) was used to evaluate the effect of behaviours on response to the feeder. Odds ratios, 95% confidence intervals and predicted values of logits were calculated according to the methods proposed by Hosmer and Lemeshow (1989). The odds ratio is a measure of how much more likely (or unlikely) the outcome is among observations with a given risk factor, compared to those without the risk factor (Hosmer and Lemeshow, 1989). A 95 % confidence interval for an odds ratio implies that the true parameter value lies between the two end points 95% of the time (Kleinbaum *et al*, 1982). An odds ratio of 1.0 implies that observations with the risk factor are just as likely to have the outcome as observations without the risk factor.

In order to investigate the association between response to the feeder and day, a 2x2 contingency table ($\chi^2$ test) was used to assess the difference between observed and expected frequencies of each behaviour.

## Results and Discussion

From the whole video database for the five trials, a total of 616 aggressive acts and 31 ear biting events were used in the analysis. Of the behaviours detected when the feeder was activated, the most frequent were chase (n=189 (29.2%)); fight (n=167 (25.8%)) and attack with bite (n=162 (25%)).

The logistic regression showed that the type of behaviour had a significant effect (P<0.001) on the piglets' response to the feeder sound. The behaviours were included in the model as risk factors for continuation of the behavioural event after the feeder sound was released (Table 2). The results show the low risk of continuation of specific aggressive behaviours such as head thrust (OR=0.43; 95% C.I. 0.25-0.72), jump on other (0.56) or attack with bite (0.61) after the feeder sound is released. For elevated aggression level behaviours, the risk of continuation doubled in the case of chase (OR=2.16; 95% C.I. 1.13-2.2), while the risk that fight would continue after the feeder sound was released was seven times higher (OR=7.89; 95% C.I. 5.24-11.89).

Table 2: Risk of continuation: odds ratios and 95% confidence intervals (C.I.) for the behaviours analysed

| Behaviour | Estimate (β) | Odds ratio | C.I. (OR) |
|---|---|---|---|
| Head thrust | -0.85 | 0.43 | 0.25-0.72 |
| Ear biting | -0.59 | 0.55 | 0.05-5.98 |
| Jump on other | 0.58 | 0.56 | 0.26-11.17 |
| Attack with bite | -0.49 | 0.61 | 0.42-0.88 |
| Chase | 0.45 | 1.57 | 1.13-2.2 |
| Fight | 2.06 | 7.89 | 5.24-11.89 |

The response of the piglets to the feeder sound (continued; interrupted) also differed significantly between experimental days ($\chi^2$=129.6, DF=1, P<0.001). On the second day the piglets interrupted 74.9% (197 of 263) of aggressive events, while on the first day of mixing just 33.7% (119 of 353) responded (Fig.1).

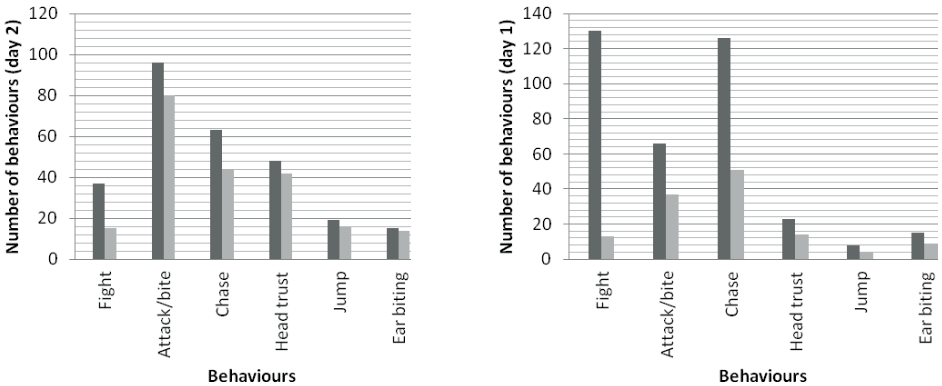


Figure 1: The total number of all behaviours (■) and the number of interrupted behaviours (■) observed at day 1 and day 2 after mixing (five experimental trials)

On the first day a higher proportion of some specific aggressive behaviours occurred than on the second day; such as fights (37% or 130 of 353 versus 14 % or 37 of 263) and chase (36% versus 24 %), while on the second day piglets performed more attack with bite (36% versus 19%) and head thrust (18% versus 6%). The number of ear biting events did not differ for the two days.

A certain behaviour results when an effective stimulus is received or generated by the animal (Lehner, 1996). When one behaviour occurs, an ongoing behaviour may stop if both behaviours cannot be performed at the same time. It is obvious that for an ongoing behaviour to stop, the new stimulus must be stronger than the current one. In pigs, as in most other animals, feed acquisition is highly motivating (McLean, 2001). The specific question in our study was whether the sweet feed stimulus wasstrong enough to inhibit aggressive or abnormal behaviour and could redirect the animal to the feeder. The results show that animals were less likely to be distracted from highly aggressive behaviours such as chase and fight. Behaviours such as jump on other, attack with bite and head thrust were successfully interrupted by the feeder sound. The explanation could be that the majority of hierarchical fights had already occurred on the first day, while during the second day short aggressive events dominated, which were probably just tests of strength (Huntingford and Turner, 1987 ) of dominant animals and did not lead to any violent response by the recipients.

## Conclusion

In conclusion, the method presented has some potential to reduce the frequency of aggressive actions among young piglets. The exception to this is highly aggressive behaviours related to the establishment of a dominance hierarchy within a group, which can rarely be interrupted as this study shows. Aggressive and violent actions among young piglets for reasons other than hierarchy establishment have the potential to be successfully interrupted by a sound–feed reward application.

## Acknowledgements

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## Combination of image and sound analysis for behaviour monitoring in pigs

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### Abstract

Welfare assessment of livestock takes a lot of time nowadays. Automatic, continuous monitoring of welfare measures would make a substantial contribution to the implementation of welfare assessment on the farm. The purpose of this work was to investigate a combination of sound and image analysis techniques for monitoring livestock behaviour which was relevant to the assessment of animal welfare. The non-invasive nature of vision and sound technology makes it very attractive for many monitoring applications in livestock husbandry.

This study comprised measurements on four groups of piglets, with six piglets per group in a pen. Image and sound recordings were taken on 13 days with 12 hours of recording from 7h to 19h. Each pen was monitored by a top-view CCD camera and 3 microphones installed around the pen.

Image processing techniques were used to calculate the difference in pixel intensity between frames in order to measure image activity. The sound analysis involved measuring sound energy together with noise reduction in order to measure the energy of vocalisations. Results for activity and vocalisation energy were then compared. The data demonstrated that there is an 80% correlation between activity and vocalisation in pigs.

**Keywords:** Pig activity, Pig vocalisation, Sound analysis, Image analysis, Monitoring livestock

## Introduction

The combination of image and sound analysis has potential in livestock monitoring applications because it can provide more detailed information about animal behaviour than the use of image or sound alone. Furthermore, both technologies are interesting for monitoring applications because they are non-invasive, contactless and can measure automatically and in real-time. Separately, both techniques have already proven to be valuable. Image analysis, for example, can be used to monitor water intake in pigs (Kashiha *et al*., 2013), while sound analysis is useful for detecting the number of coughs (Van Hirtum *et al*., 1999). A possible application for combining both techniques is monitoring animal welfare. To assess animal welfare, several welfare principles were developed by the Welfare Quality® project (Blokhuis, 2008). Nowadays, a total of 26 measures should be manually assessed for grower pigs on farms, which takes a lot of time. If some of these measurements could be automated and monitored continuously, this would make an enormous contribution to the assessment of animal welfare.
This study attempts to link physical pig activity with the sound energy of pig vocalisation by combining image and sound analysis. Physical activity as defined in this study is movement of the pigs, quantified by the image activity, meaning the difference in pixel intensity between video frames. Pig vocalisation energy is defined as the sound energy that remains after removing the environmental noise from the raw sound data. This paper describes an attempt to gain more insight into the behavioural status of pigs by investigating the extent to which physical pig activity corresponds to the sound energy of pig vocalisation by calculating the correlation between the two.

## Material and methods

Animal and Housing

Twenty-four pigs were held at Agrivet research farm, Merelbeke, Belgium. The pigs, Rattlerow Seghers x Piétrain Plus, were divided equally and assigned to four pens after the battery period. Each pen  had a fully slatted concrete floor with one feeder space and one nipple drinker. There was ad libitum access to food (commercial grower diet) and water during the experiment. Pigs had a timer-controlled 12-hour light period from 07:00 h to 19:00 h. The average weight of the pigs was kg  at the beginning of the experiment and kg  at the end. The average temperature during the experiment was  . This experiment was approved by the Ethical Committee of the Faculty of Veterinary Medicine at Ghent University.

Experiment and Data collection

The experiment lasted for 13 days with recording for 12 hours (from 07:00 to 19:00) per day. During the experiment a top-view CCD camera monitored each pen (Figure 1). These cameras, Panasonic WV-BP330 CCD black and white cameras, were installed at a height of 2.3 m. Videos were recorded in MPEG-1 format, with 25 frames per second, a frame width of 720 pixels and a frame height of 576 pixels. Light was provided by six 36 watt, 120 cm Sylvania Luxline Plus white fluorescent tube lamps.

Eight microphones recorded the sound, positioned so that each pen was surrounded by three microphones (Figure 1). The sound data were recorded with studio condenser microphones of type C-4 at a height of 1.5 m and an M-audio Delta 1010LT sound card with a precision of 16 bit and a sampling frequency of 22050 Hz. In total 156 hours of data from four cameras and eight microphones were used for analysis in MATLAB.

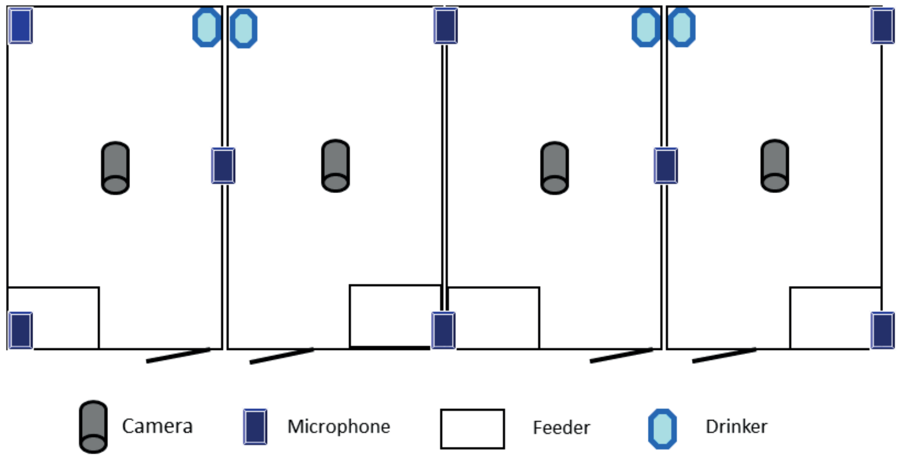


Figure 1: Configuration of the cameras and microphones in the pig barn

Image Analysis

The *activity index (Bloemen et al., 1997)* - referred to as image activity in this paper - can be used to measure physical activity. The principle of this technique is to calculate the change in pixel intensity between two frames. When pigs are inactive the change in pixel intensities will be smaller than when they are active and moving. The change in pixels is calculated as

$$I_{diff}(x,y,t) = I(x,y,t) - I(x,y,t-1). \quad (1)$$

where is the time index and and the location in the image. The image activity was calculated as the ratio between the total change in pixels and the total number of pixels in the image . This gives the following equation:

$$a(t) = \frac{\sum_{x,y \in \mathrm{P}} I_{diff}(x,y,t)}{\sum_{x,y \in \mathrm{P}} 1}. \quad (2)$$

This image activity  was calculated for each of the four cameras and summed together as one value per time period. The values were displayed in two time series, one with values per minute, the other with values per hour.

Sound Analysis

The raw sound data were first filtered to remove most of the environmental noise. After filtering, the sound comprised mainly pig vocalisations and sound resulting from pig activities. Two filters were applied: one high pass 256th order FIR filter at 400 Hz to remove most of the low-frequency noise and the 50 Hz harmonics from the power source. Afterwards a filter performing spectral subtraction after (Martin, 2001) was applied. The sound energy per sample  was calculated from the filtered data  using the following formula:

$$e(t) = y^2(t)\,\Delta t. \tag{3}$$

Where  is the duration of one sample. The sound energies of eight microphones were summed in one time series. After the sound energy per sample had been calculated, the total was summed in minutely and hourly time series.

Correlation calculation

The Pearson (product-moment) correlation coefficient between the image activity and sound energy  was calculated. The following formula for the Pearson correlation coefficient was used:

$$r_{ae} = \frac{\sum_{i=1}^{n}(a_i - \bar{a})(e_i - \bar{e})}{\sqrt{\sum_{i=1}^{n}(a_i - \bar{a})^2 \sum_{i=1}^{n}(e_i - \bar{e})^2}}. \tag{4}$$

This resulted in a correlation coefficient for the time series of the hourly and minutely data.

## Results and Discussion

The image and sound data were processed as described above. The hourly data can be seen in Figure 2 and the minutely data for one day can be seen in Figure 3. The results show that pig activity follows a certain pattern. The pigs were relatively inactive during the morning hours and more active in the afternoon. This behaviour has also been found in other studies (Robert *et al.*, 1987; Gonyou *et al.*, 1992). Similar information was observed for the sound energy.

By investigating the time series of hourly data over the entire recording period of 13 days, two outliers in the sound data become visible. As shown in Figure 2, the sound energy peaks twice, with higher values compared to the other days. These outliers correspond to stressful situations that the animals were faced with. The mixing of animals is responsible for the first outlier on day 5. The end of 24 hours of food deprivation is responsible for the second outlier on day 10. The pigs were fighting and screaming to gain access to the feeder. The stressful events occurred in only two of the four pens, but also affected the sound results for the other two pens. The Pearson correlation was calculated without these two outliers because they would negatively affect the correlation. The argument for removing these outliers is that they were linked to two clearly defined events and therefore can be omitted when testing the relationship between pig activity and the sound energy of pig vocalisation.

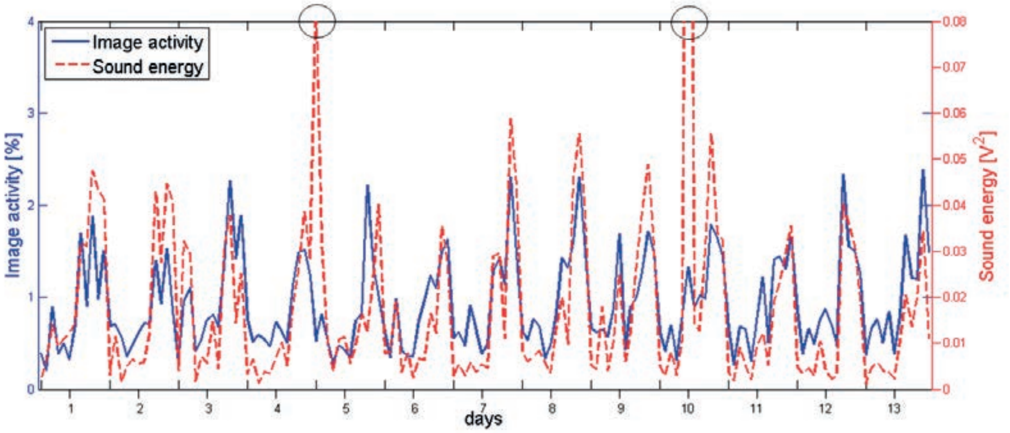


Figure 2: The hourly time series for image activity and sound energy. The two outliers for sound energy are shown in circles. 12 hours per day were recorded, from 7:00h to 19:00h.

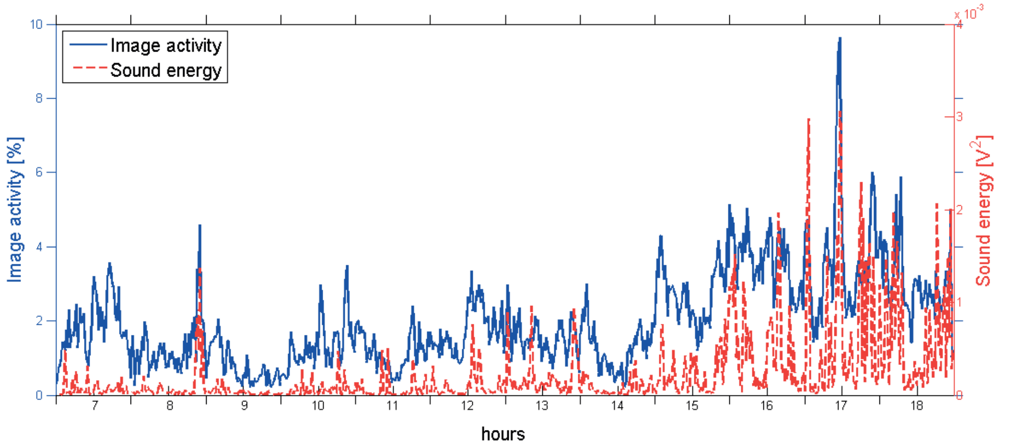


Figure 3: The minutely time series for image activity and sound energy on day four. 12 hours were recorded, from 7:00h to 19:00h.

The correlation between the hourly time series for image activity and the sound energy was significant, . The correlation between the minutely time series for image and sound was lower at . The minutely data were more variable than the hourly data, and this was the main reason for the lower correlation coefficient.
The high correlation of  implies that either image or sound information is needed to determine how active pigs are. However, only a combination of both technologies makes it possible to specify the animals' behaviour more accurately. For example, the two stressful situations were identified with the sound time series while it is less visible in the image time series.

This study investigated very simple measurements using different technologies (sound energy and image activity) and shows a significant correlation between the two. Further research can help to link these technologies in a way which will allow a more precise interpretation of certain behaviours of pigs. Possible improvements would be to take the dB values of the sound energy into account and to localise the sound source in order to calculate the sound energy per pen or even per pig. In the same way, the image activity can be modified so that it can be calculated per pig.

A combination of image and sound technology offers opportunities to automate certain welfare measurements. For example, aggressive pigs may be recognised more easily by detecting a change in their physical activity by image analysis and a possible vocal reaction from the disturbed pig by sound analysis. Another promising application is the early detection of diseases, e.g. sick pigs with a respiratory problem such as porcine reproductive and respiratory syndrome virus (PRRSV) have been shown to be less physically active (Escobar *et al.*, 2007). Diseased pigs with porcine respiratory disease complex (PRDC) will start coughing more (Rajão *et al.*, 2013) than healthy pigs, which will affect the recorded sound.

## Conclusion

The results from this study indicate that pig activity is, in general, significantly correlated with sound energy caused by pig vocalisation. A Pearson correlation of   was found between the hourly time series for a period of 13 days. The study also revealed the clear benefits of combining sound and image analysis for automated monitoring of animal behaviour. For pig sound recording, the authors detected an increase in sound energy when pigs were mixed and when feed deprivation ended, which was not that obvious from the recorded pig activity. This example shows that both technologies can complement each other in the analysis of pig behaviour. At this stage, the exact location of the source of the pig sounds is not available. This is the next step in the research presented. Precise information on the location of the sound source, combined with image information, can lead to the more accurate interpretation of behaviour that is needed for automated animal monitoring.

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## Reducing aggressive behaviour by an electronic feeding system used as environmental enrichment tool for young piglets

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### Abstract

It is known that unacquainted pigs will fight to establish a social hierarchy after mixing. However, vigorous fighting can cause economic losses and welfare problems. Limitation of resources can aggravate the problem. For this reason, environmental enrichment is recommended on pig farms. In our study, we first trained piglets in their farrowing pens to react to the activation of an electronic feeder and after mixing, the potential of the electronic feeding system to reduce aggressive behaviour was studied using confrontations tests. The electronic feeding system had the potential to be used as environmental enrichment being able to reduce aggressive interactions after mixing.

**Keywords:** Training, aggressive interaction, learning, cognition.

### Introduction

It is well known that when unacquainted pigs are mixed, they will fight to establish a social hierarchy. This is a natural process which occurs among pigs of different ages and it has been described under natural, semi-natural as well as in intensive farming conditions. However, in intensive production systems, group compositions change frequently and a larger number of animals is confined in a limited space, giving less chance for escaping from fights. Fighting can cause not only economic losses but also serious welfare problems by injuries and the limitation of resources can aggravate the problem. It is well known that pigs raised in enriched environments express less abnormal and aggressive behaviour (such as tail biting and fighting) than pigs housed in barren pens. For this reason, environmental enrichment has been recommended on pig farms, being an important asset for animal welfare. A novel topic of research in this line is environmental enrichment based on cognitive challenges.

Intentioned enrichment methods contain goal-directed learning behaviour and are carried out using aversive or rewarding reinforcers. These methods are expected to have immensely sustained potential to bring alternation and distraction and to reduce boredom and abnormal behaviour (Manteuffel *et al.*, 2009a.; Manteuffel *et al.*, 2009b.; Meehan &Mench, 2007; Tarou &Bashaw, 2007; Puppe *et al.*, 2007). Especially, enrichment devices which offer extrinsic reinforcement (food, social access, etc.) as a reward have proved to be effective. Challenges that induce positive experience not only improve the welfare of the animals but have many beneficial effects that could be used to solve various problems in animal husbandry, when integrated into management routines and systems. In addition, cognitive enrichment methods could be an useful tool for behavioural management having the potential to reduce unwanted behaviours and to reinforce desired behaviours (Manteuffel *et al.*, 2009a; Manteuffel *et al.*, 2009b; Puppe *et al.*, 2007). For farm animals, cognitive enrichment is not yet used as a common method. There are some investigations about learning behaviour in various farm animal species using e.g. acoustic cues to bring a desired reaction (Zebunke *et al.*, 2011; Wredle *et al.*, 2006; Ernst *et al.*, 2005; Kiley-Worthington & Savage, 1978). Concerning the cognitive abilities and learning behaviour of pigs, it was shown that foraging behaviour is a very useful issue to study links between sensory abilities, cognitive challenges and motivational processes (Zebunke *et al.*, 2011; Puppe *et al.*, 2007; Held *et al.*, 2005; Croney *et al.*, 2003; Held *et al.*, 2000; Laughlin and Mendl., 2000). Pigs' auditory acuity is better than that of humans, thus acoustic signals can serve as discriminative stimuli, or as secondary or conditioned reinforcers (Gieling *et al.*, 2011). Furthermore, pigs seem to like sweet tastes, therefore sweets are well-suited as a reward for some challenges (Gieling *et al.*, 2011; Kennedy & Baldwin, 1972).

The aim of our study was to investigate the suitability of cognitive enrichment based on a sound followed by a food reward for young piglets in order to reduce aggressive behaviour between two piglets after weaning. For testing this hypothesis, we used an electronic dog feeder that emits a "beep" sound and almost immediately dispenses a food reward, in our case, chocolate candies. In this trial, suckling piglets were trained during 8 days before weaning to react on that sound. Our expectation was that the piglets would react to the sound by coming to the feeder to receive the reward. Using this approach, an attempt was made to interrupt aggressive interactions between two piglets in resident-intruder confrontations by distracting the animals from aggressive behaviour. Thus, our main objective was to study whether cognitive enrichment applied to young suckling piglets could reduce excessive aggression, improving animal welfare.

## Material and Methods

### Training

In the first phase of the study, a total of 78 animals of the German National Breeding Programme (BHZP) in 8 entire litters of 8-12 suckling piglets were trained in their farrowing pens to react to the activation of an electronic feeder. The piglets had to learn

the link between a sound given by the feeder and a feed reward in form of chocolate candies during a period of eight days.
The training started in the farrowing unit when the pigs were 25 days old with average weight of 7 kg ±1 kg and ended the day before weaning at the age of 35 days with average weight of 9 kg ±1 kg, giving a total training period of 8 days with 2 days of weekend in between. The suckling piglets were trained in their conventional farrowing pens (2,30 x 2,00 m) with partially slatted floor where the sows were placed in farrowing crates.
The training methodology was based on the use of an electronic dog feeder that plays a "beep" sound and dispenses food after 2 seconds. This electronic reward system is used as positive reinforcement for training dogs to behave appropriately at home and perform better in competitions (Premier Pet, 2010). The equipment works with a remote control, making it easier to limit the contact between the humans and animals, minimizing the human effect and making the process more automated. In our study, the use of this equipment had the principle of arousing piglets' curiosity at first, and train them to react on a sound followed by feed dispersion during a training period of 8 days. The feeder was placed on the wall of a farrowing pen with height of 0.6 m from the ground. The training session took one hour per day (10:00 – 11:00 a.m.) and during this time the electronic feeder was activated every 10 minutes, in a total of 5 times per day. All the trainings, within the 8 days, were video recorded with two cameras (in top view) connected to a computer with LabVIEW Software (8.6, *National Instrument*, TX) that recorded synchronised videos in MJPEG format with variable frame rates from 10 to 20 images per second. The chosen behaviour for analysis was the interest of the piglets towards the training commands, for this reason, the number of piglets around the electronic feeder was registered at 2, 5, 15, 30, 45 and 60 seconds after feeder activation.

<u>Confrontation tests</u>
After 8 days, as a second step of our study, the same piglets used in the training were weaned and transferred to new pens, different from the ones where they were during the training, and mixed in groups of 12 piglets sorted by weight and sex. The animals had *ad libitum* access to dry food and water, were kept separated from other piglet groups by solid pen walls, without litter on totally slatted floor (0.38 $m^2$ per animal, animal:feeding place ratio 1.5:1). Three days after weaning, the reaction of piglets on the use of the electronic feeder was tested during aggressive interactions such as fighting, biting and mounting, in a resident-intruder test.
For conducting this test, an arena was built by partitioning a portion of the home pen where the group of 12 trained piglets was placed by using a black board made of strong plastic. The home pen measured 1.85 m x 1.8 m and the divided portion part measured 1.0 x 1.8 m. The same electronic feeder used during the training of the suckling piglets was placed on the wall of the test arena.

For this test, pairs of piglets were randomly selected. 12 resident piglets were tested once a day with different partners and for a maximum of two days. The resident piglet was first isolated in the arena built in its home pen. The intruder piglet was then collected from another pen and placed into the test arena already containing the resident piglet. All resident and intruder pigs were present during the training phase. The start of the test was defined as the time when the intruder was placed inside the arena and the observation period was on average 7 minutes. If an attack occurred, the electronic feeder was activated in order to break the aggressive interaction. If no attack occurred within 7 minutes, the test was finished and the pair was changed. In all other cases, the test ended either when an escalated attack could not be broken by the activation of the electronic feeder or after 5 minutes of aggressive interactions broken by the activation of the feeder.

All the encounters were recorded using two cameras placed in top view, 2.0 m high in the centre of the pen. Both cameras were connected to a computer with LabVIEW Software (8.6, *National Instrument*, TX) that recorded synchronised videos in MJPEG format with variable frame rates from10 to 20 images per second. All recorded videos were analysed using the software “Labelling Tool” (Viazzi *et al*., 2011) (Viazzi, 2011 #185)developed in Matlab (R2009a, The MathWorks Inc., MA).

From 3 rounds of experiment, a total of 260 aggressive interactions was obtained and the behaviour of the piglets was analysed in relation to their response to the activation of the feeder. In general, episodes with no aggressive interactions, fights that could be stopped, fights that could not be stopped and which piglet responded first to the activation of the feeder were identified.

Statistical analysis was carried out using the statistical software package SPSS, version 20 for windows. The univariate procedure in SPSS was used to assess data for normal distribution. When analysing the training data, ANOVA analyses and Post Hoc tests according to Student Newman Keuls were conducted in order to find significant differences between the tested parameters. The data of resident-intruder test were compiled in frequency tables and contingency tables, and to identify significant differences, the chi square test was used.

## Results

<u>Training results</u>

The results concerning the reaction of the piglets on the electronic feeder after 2, 5, 15, 30, 45 and 60 seconds of feeder activation on different training days are shown in table 1.

Table 1: Percentage of piglets around the feeder on different training days after 2, 5, 15, 30, 45 and 60 sec of feeder activation.

| Training day | Reaction 2 sec (%) | Reaction 5 sec (%) | Reaction 15 sec (%) | Reaction 30 sec (%) | Reaction 45 sec (%) | Reaction 60 sec (%) |
|---|---|---|---|---|---|---|
| 1 | 26,05 | 34,68 a | 43,4 a | 36,69 a | 43,24 a | 42,06 |
| 2 | 18,76 a | 30,38 a | 44,23 a | 48,12 | 47,10 | 44,81 |
| 3 | 28,58 | 54,83 | 67,63 b | 69,19 b | 61,87 b | 52,24 |
| 4 | 33,89 | 50,45 | 56,54 | 56,34 | 52,21 | 43,09 |
| 5 | 22,47 a | 45,32 b | 52,82 | 50,26 | 45,80 | 39,82 |
| 6 | 31,80 | 55,92 | 56,99 | 54,54 | 50,34 | 43,76 |
| 7 | 28,10 | 55,58 | 61,38 b | 59,70 | 58,59 | 48,78 |
| 8 | 38,24 b | 63,17 c | 63,25 b | 59,20 c | 51,50 b | 43,80 |

The letters “a” and “b” represent the statistical significant difference between the values when $p<0.05$.

The analysis of all training rounds revealed that the piglets were able to learn the link between sound and feed given by the electronic feeder during 8 days of training and the number of piglets around the feeder awaiting chocolate candies after sound increased with consecutive training days. In general, the average result for the number of piglets around the feeder waiting for chocolate candies, independent of the training day, increased from 2 seconds to 15 seconds after the feeder activation. After 15 seconds, the percentage of piglets around the feeder decreased and 60 seconds after feeder activation there were still 44% of piglets around the feeder. The highest percentage of piglets around the feeder was found on the third day of training30 sec after feeder activation. 45 seconds after feeder activation, the percentage of piglets around the feeder was lower than the seconds before, reaching a maximum of 61% on day 3. Different from all the data showed previously, 60 seconds after feeder activation, the number of piglets around the feeder was between 39% on day 5 and 52% on day 3 showing a decrease of interest in the feeder during the last observation.

Confrontation test results

The aim of this test was to create aggressive interactions in piglets by placing them in a test arena and to study the effectiveness of the learned behaviour responses to stop aggressive behaviour by feeder activation. On average, 80% of aggressive interactions between piglets in resident – intruder confrontations were broken by the activation of the electronic feeder when fighting started. In 3% of all test situations, no aggressive interaction could be observed and 17% of fights were not stopped by the electronic feeder. In 99% of aggressive interactions that could be stopped by the feeder, only one piglet of the test pair reacted first on the feeder. In 55% of all fights that were stopped by feeder activation, the aggressor reacted to the feeder whereas in 45% the receiver went to the feeder and stopped fighting. If we considered only fights where the aggressor reacted to the feeder activation, 97% of fights were definitively stopped. If only the receiver reacted to the electronic feeder, 93% of aggressive interactions could be broken.

**Discussion**

The objective of our study was to attest the effectiveness of a cognitive environmental enrichment, based on acoustic training and food reward, to reduce excessive aggressive interactions among weaned piglets. According to Puppe *et al*. (2007) foraging behaviour of pigs is a very useful issue to study links between sensory abilities, cognitive challenges and motivational processes. Likewise, it has been shown that pigs can differentiate an individual tone associated with a locally changing feeding site, being able to remember a certain combination. (Puppe *et al*., 2007; Laughlin & Mendl, 2000). The potential use of sound followed by a food reward for conditioning piglets was also confirmed in our study. Different from other studies, where older pigs were trained, we used young suckling piglets still in the farrowing crates and in the presence of the sows. We could show that even at this young age, it was possible for the piglets to learn training commands associated with food reward.

Although the training was done during one of the highest activity period of the piglets, usually in the morning, 2 seconds after the sound was played, i.e. at the moment of the food release, the percentage of piglets around the feeder was not higher than 38%. One possible reason for this result can be simply the amount of time needed to approach the feeder, since after 5, 15 and 30 seconds after the activation of the feeder, the percentage of piglets around the feeder was much higher reaching 63%, 67% and 69%, respectively. Another explanation can be the amount of time necessary to make the connection between the sound and process the information. When Puppe *et al.* (2007) evaluated the learning behaviour of 112 castrated German Landrace male pigs starting at the age of 7 weeks, they had a success rate of 80%, after 20 weeks of training, and the time spent from the acoustical signal to the release of food by a “call-feeding-station” took approximately 15 seconds. Zebunke *et al.* (2011) worked with a similar automatic feeding station for 24 German Landrace pigs at the age of 16 weeks and reported that even after 7 weeks of training, the same time of 15 seconds was necessary from the time of the call until the pigs approached the feed.

In addition, Croney (1999) found that pigs performed better when olfactory rather than visual stimuli were used as discriminative learning tasks. In this sense, a farm environment can be disturbing when taking into account the hearing of the animals, by the fact that equipments and other animal are emitting sounds at the same time.
After 45 and 60 seconds of feeder activation, the number of piglets around the feeder

decreased, which can be explained by the fact that chocolate candies were lacking and piglets lost interest at that latest moment of observation. Held *et al.* (2000 and 2005) and Croney *et al.* (2003) found that generally, pigs are highly motivated if food is introduced as enrichment, however, according to (Puppe *et al.*, 2007), this motivation can vary when the level of competition is high and a constant amount of food is not maintained. This could also explain why never 100% of piglets were observed around the feeder. The food release caused competition between the piglets, with stronger piglets having privileged access to food. Weaker piglets could probably only reach the food when most chocolate candies were already eaten by stronger piglets. Besides this situation, good training results were obtained, which are confirmed by a high efficiency of the feeder in interrupting aggressive interactions during the confrontation test. We showed that even under field conditions, with limited space allowance and in a conventional farrowing crate, it was possible to offer cognitive enrichment and to train young piglets in relation to certain stimuli, in our case sound and feed.

In order to observe aggressive interactions among two piglets and test the efficacy of the training commands for reducing aggressive behaviour, the method of resident-intruder confrontation was chosen giving us a good overview and control over two interacting animals. The training commands were proven to have positive effects during aggressive interactions in 80% of all fights, since fights could be stopped by activation of the electronic feeder, showing that cognitive enrichment is generally suitable to influence aggressive behaviour in piglets. Earlier studies showed that aggressive behaviour can be primarily affected by environmental enrichment. O'Connell and Beattie (2000) verified significant less fights between animals raised in environments provided with straw. Olsson *et al.* (1999) tried a different approach in their experimental design, in which they provide sand to piglets in the farrowing unit in order to reduce aggressive interactions during resident-intruder confrontations, and found that piglets raised in environments with no bedding materials inflicted more wounds on each other during dyadic confrontations. However, what these two studies of environmental enrichment do not have are cognitive challenges, on which our own study was based. In other words, our study is one of the first focused on the investigation of cognitive enrichment efficiency to influence and reduce aggressive behaviour in pigs.

Regarding the number of piglets going to the feeder after the activation, we found that in 99% of cases only one piglet responded immediately to the sound so that fighting stopped. This piglet could be the aggressor or the receiver, since we found no significant difference between the percentages of reaction of aggressor or receiver when an aggressive interaction was stopped by feeder activation (55% vs 45%). We found a tendency for aggressors to react better to the activation of the feeder in a resident-intruder situation than the receivers, however, there was no significant difference between the values for stopped fights when the aggressor or the receiver reacted (97% vs 93% of fights were stopped). In principle, our hypothesis was that the most aggressive pigs would probably be the best to react to the activation of the feeder, by the natural motivation of pigs for competing for resources (Andersen *et al.*, 2000; Keeling and Gonyou, 2001).. From the results obtained, we conclude that it was not essential to influence the piglet that started fighting in order to stop the aggressive behaviour, it could also be useful to act on the piglet that is attacked by another piglet to interrupt a fight. Aggressiveness in resident-intruder situations was reported in several studies, however no information was found concerning the reactions of piglets on different actuators during fighting. Forkmann *et al.* (1995) and D'Eath and Burn (2002) could not find a connection between being high or low resistant in a Backtest and individual aggressiveness during confrontation tests. Erhard *et al.* (1997) and Bolhuis *et al.* (2005) evaluated high or low resistant pigs in a Backtest and found that high resistant pigs were more aggressive towards their penmates after mixing. Individual differences in coping style may explain why no relationship between being aggressor or receiver, and the reaction towards the feeder activation, were found in our study.

## Conclusion

We conclude that the electronic feeding system has the potential to be used as environmental enrichment for suckling and weaned piglets being able to reduce aggressive interactions between two weaned piglets in a confrontation test. Furthermore, ongoing investigations have to elucidate whether the system can be used successfully over longer periods with more practical feed rewards. The possibility of an automated activation of the electronic feeding system combined with an image based monitoring system for aggressive behaviour in pig will be investigated in further experiments as well as the efficacy of the system in larger groups of pigs.

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# Session 8

# Horses

## Data mining as a tool to evaluate thermal comfort of horses

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### Abstract

Thermal comfort is of great importance to preserve body temperature homeostasis during thermal stress conditions. Although thermal comfort of horses has been widely studied, research has not reported its relationship to surface temperature ($T_S$). The aim of this study was to investigate the potential of data mining techniques as a tool to associate surface temperature with thermal comfort of horses. $T_S$ was measured using infrared thermographic image processing. Physiological and environmental variables were used to define the predicted class, which classified thermal comfort as “comfort” and “discomfort”. The $T_S$ variables for the armpit, croup, breast and groin of horses and the predicted class were then submitted to a machine learning process. All dataset variables were considered relevant to the classification problem and the decision-tree model yielded an accuracy rate of 74.0%. The feature selection methods used to reduce computational cost and simplify predictive learning reduced the model accuracy to 70.1%; however the model became simpler with representative rules. For these selection methods and for the classification using all attributes, $T_S$ of armpit and breast had a higher rating power for predicting thermal comfort. The data mining techniques had discovered new variables relating to the thermal comfort of horses.

**Keywords:** Predictive modelling, data mining, surface temperature, infrared thermography, thermoregulation.

## Introduction

Horses are homeothermic animals, i.e. they are capable of maintaining a relatively constant internal body temperature regardless of external influences. Homeothermy is achieved by activating thermoregulatory mechanisms. Among these mechanisms, the physiological ones, such as sweating and changes in heart rate, respiratory rate and skin blood flow, are worthy of particular attention (Jodkowska *et al*., 2011). The effect of thermal environment on thermoregulation in horses has been studied previously by assessing heart and respiratory rate, sweat production and rectal temperature (Castanheira *et al*., 2010). However, none of them has evaluated the skin blood flow as a thermoregulatory response.

The skin blood flow plays an important role in body temperature regulation. The amount of peripheral blood flow produces thermal changes in the temperature at the surface of the body (Tattersall and Cadena, 2010). Therefore, the surface temperature of horses may constitute an indicator of change in thermoregulation (Jodkowska *et al*., 2011). Furthermore, infrared thermography makes it possible to visualise thermal skin temperature variations and has been used to examine the surface temperature in different regions of horses' bodies (Jodkowska *et al*., 2011).

The need for information and knowledge in this area means that data mining techniques are a promising tool. Such techniques involve the use of sophisticated data analysis tools, including machine learning methods and mathematical algorithms, to discover previously unknown patterns and relationships in a data set (Han *et al*., 2011). Among the classification techniques used in data mining, decision tree models are very popular because they are practical and simple to understand. A decision tree is a decision support tool that uses a tree-like graph or model of decisions, where each node denotes a test of an attribute value, each branch represents an outcome of the test, and the leaves represent the predicted classes. Classification rules can easily be extracted from a decision tree (Tsang, 2011).

The aim of this study was to investigate the potential of data mining techniques as a tool to predict thermal comfort of horses using the surface temperature at different points as a parameter.

## Materials and methods

This study was carried out at an equestrian centre located in Campinas, São Paulo, Brazil, over the period February to April 2010. Five dark brown Anglo-Arab horses were studied for eight days. All horses had the same background in terms of housing, management and acclimatisation to exercise. Data were collected at the hottest time of the day, between 13h00 and 15h00, on days with different thermal conditions. Before data collection, horses were in their stall and all measurements were taken inside the facility.

Environment assessment: Air temperature ($T_{air}$ - °C) and relative humidity (RH - %) were monitored simultaneously during data collection. $T_{air}$ was registered using a hot wire anemometer (-18 to 93°C; resolution = 0.1°C) and RH was measured using a multifunction device with an RH sensor (ranging from 25 to 95%; accuracy = ± 5%).

To assess the environmental conditions, a comfort index (CI), as previously used by Jones (2009), was calculated as shown in the equation: CI = $T_{air}$ (°F) + RH (%)

Physiological parameter assessment

Heart rate (beats min$^{-1}$.) was measured using a stethoscope. Respiration (movements min$^{-1}$) was counted by watching the horses' torso for movement of the ribcage and belly. And rectal temperature (°C) was measured with a mercury thermometer introduced into the animals' rectum

Surface temperature assessment: Surface temperature ($T_S$) was assessed using an infrared thermal imaging camera (accuracy = ± 0.1°C; spectrum range = 7.5 to 13 µm) at four sites on the animals' body with 15 randomly chosen points at each site. The camera was placed about 0.7 m from the horse's armpit and groin and 1.6 m from the croup and breast. The measurements were taken at different distances calculated according to the camera manual in order to cover the largest possible surface area. The software used was provided by the camera manufacturing company to analyse thermal images, applying a cold/hot colour scheme and temperature scale between 17°C and 40°C. The emissivity coefficient (ε) was set to 0.95 on all pictures as used by Autio *et al.* (2006).

The armpit and groin regions were chosen because they are highly vascularised (McCutcheon and Geor, 2008) and few studies have reported on the contribution of those body parts to the effectiveness of the thermoregulation process. The croup region is highly exposed to environmental variables and was used as a reference in the study by Kohn *et al.* (1999). The breast region presents high thermal variability and can be estimated as representative of the average body surface area (Marlin *et al.*, 1998).

Data analysis (data mining): A learning algorithm for inducing decision trees was used to find the relationship between $T_S$ and the thermal comfort of horses. The data mining (DM) project was performed in accordance with the six phases of the CRISP-DM methodology (Cross-Industry Standard Process for Data Mining) as described by Chapman *et al.* (2000). The first phase includes understanding the objectives and then converting this goal into a DM problem. In accordance with the aim of this project, CI and physiological parameters were used to determine the predicted class (thermal comfort). The next phase, called data understanding, starts with a literature review and initial data collection.

Subsequently the data preparation phase, which involved tabulation of the data, was carried out. $T_{air}$ and RH data were converted into CI, as shown in Equation 1. To classify the predicted class, physiological parameters and CI received a binary designation (0-inadequate and 1 - adequate) according to a range recommended in the literature (Table 1). The sum of these adjustments resulted in positive integer numbers from 0 to 4. From these summations, we labelled thermal comfort as “comfort” if the sum was 3 or 4, and “discomfort” if the sum was 0, 1 or 2.

Table 1 - Ideal ranges of variables used in the class attribute classification

| Variables | Ideal Range |
|---|---|
| Comfort Index [dimensionless][1] | $CI \leq 130$ |
| Heart rate (beats $min.^{-1}$)[2] | $32 \leq HR \leq 44$ |
| Respiratory rate (movements $min.^{-1}$)[2] | $8 \leq RR \leq 16$ |
| Rectal temperature (°C)[2] | $37.2 \leq RT \leq 38.2$ |

According to [1]Jones (2009); [2] Cunningham (2002).

After defining the predictive class (thermal comfort), the physiological parameters and CI were no longer used for further evaluations and thus they were excluded from the final database. Hence, the final database was made up of five attributes: $T_S$ of four body parts (armpit, croup, breast and groin) as numerical values and the predicted class, classified into one of the following classes: “comfort” and “discomfort”.

The decision tree was built using Weka®3.6.2. software, notably the algorithm J48, referred to as C4.5 (Quinlan, 1993). The Weka default setting for parameters was used, except for the level of pre-pruning (minNumObj) that was made from 5 to 60. The 10-fold cross validation approach was used to test the trained classifiers, i.e. the initial data are randomly partitioned into 10 mutually exclusive subsets or folds, each of approximately equal size. Training and testing are performed 10 times. For classification, the accuracy estimate is the overall number of correct classifications from the 10 iterations, divided by the total number of instances in the initial data. In general, stratified 10-fold cross-validation is recommended for estimating accuracy due to its relatively low bias and variance (Han *et al.*, 2011).

All the decision trees generated were compared taking into account the accuracy rate, the ability to understand the rules generated in the opinion of experts, and the complexity based on the number of rules generated. There was a class imbalance problem in the dataset: 405 of the 600 instances were classified as “discomfort”. Three balancing methods were used including over-sampling (which randomly replicates examples from the minority class) and under-sampling (which randomly eliminates examples from the majority class) (Batista *et al.*, 2004).

The class balancing process changes the class distribution in the training data, allowing the model to learn with minority class examples. This approach provides more accurate results. A stratified sample of 10% of the data was set apart for testing the built model, while 90% of the remaining data was subjected to methods which aim to balance the class distribution, including sampling methods (Resample), NCL (Neighborhood Cleaning Rule) and SMOTE (Synthetic Minority Over-sampling Technique). For the

Resample method, three bias values were tested, which influence the data distribution. The values used were 0 (data distribution is maintained); 1 (the classes in the training set are sampled according to the uniform distribution); 0.5 (classes are balanced intermediately), as used and described by Crivelenti *et al.* (2009).

After applying the balancing methods to data, feature selection methods were used to reduce the computational cost and simplify the model. Such methods also identify the relevance of variables and their contribution to the model. The CFS, *Infogain*, *Gainration*, Chi-square and Wrapper methods were compared. Data balancing and feature selection analyses were performed using the *Weka* environment.

## Results and discussion

The model accuracy gradually decreased, by almost 1%, as the number of objects per leaf increased (Figure 1)([1] Number of objects per leaf corresponds to the minimum number of examples in the test set used to evaluate the rules generated (tree leaves)). In the same way, the number of rules generated decreased as the number of objects per leaf increased. The higher the level of pre-pruning, the less specific is the coverage of the classification rules. Similar results were found by Sikora (2011). However, Crivelenti *et al.* (2009) found that the model accuracy did not differ for the pre-pruning levels used in their study, although they observed a reduction in the number of rules.

According to Wang *et al.* (2010), pruning is an adjustment to avoid data over-fitting and minimise the amount of noise or details in the training data set. Thus, the learning model is more comprehensive as a result of reducing the size of the tree generated. Pre-pruning of 10 objects per leaf presented the highest accuracy (77.2%) and generated 13 rules. However, for an accurate classification, the classifier partitioned the data several times, raising difficulties with regard to the interpretation of rules in practice.

The number of rules dropped by 42% when comparing pre-pruning of 20 and 25 objects per leaf, and the accuracy remained at 75.7%. However, these trees are not useful in practice because of the large number of rules, but they contribute to the understanding and analysis of data partitioning.

Sometimes it is more advantageous to choose a model with a smaller number of rules, even with a loss of accuracy, when the rules generated correspond to the experts' point of view. Thus, the best results, in terms of correlation with expert opinions, were obtained for a pre-pruning level of 35 objects per leaf. The accuracy rate of this model was 74.0% and 6 relevant rules were generated (Figure 2).

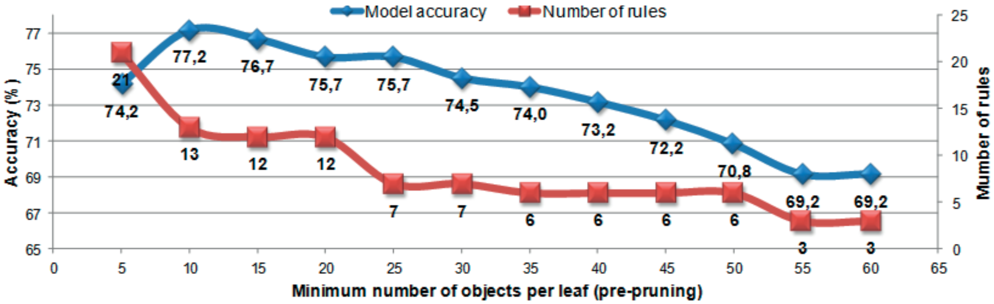


**Figure 1 -** Accuracy and number of rules for different levels of pre-pruning.

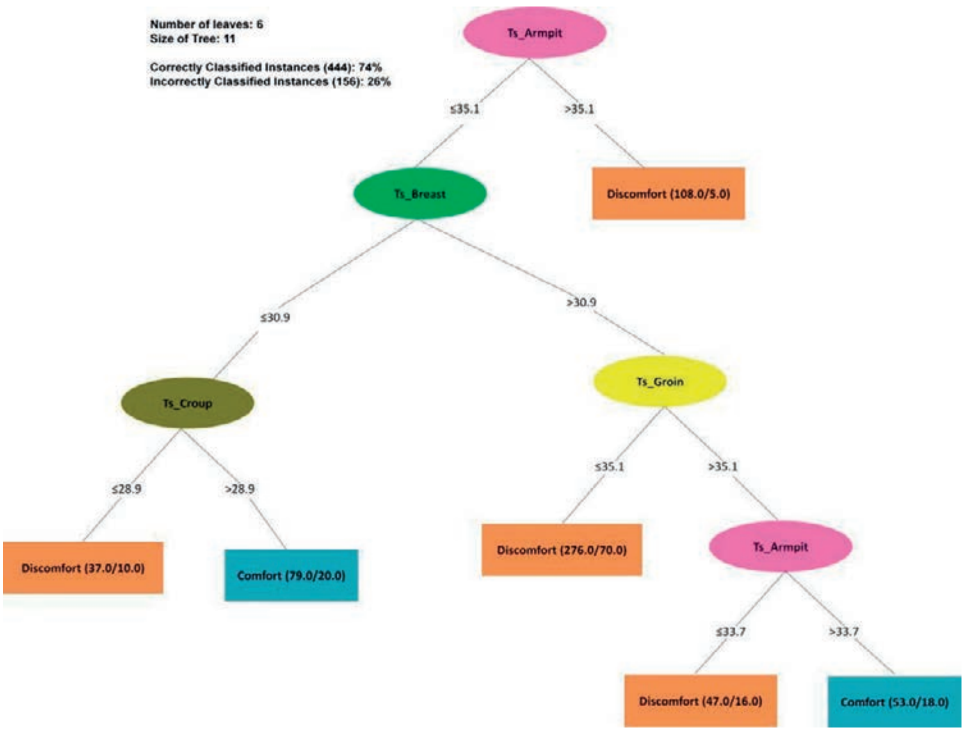


**Figure 2 -** Classification tree for thermal comfort of horses. The expression (x/y) in the leaf of a tree means that x instances reached that leaf, of which y are classified incorrectly (level of pre-pruning = 35 objects per leaf).

The problem of imbalanced data deserves particular attention, since it can compromise the accuracy of the classifier due to the possible introduction of a bias into the model. As expected, the balancing methods altered the class distribution in the training set. For example, NCL, an under-sampling method, caused a decrease of 41.7% in the number of instances in the majority class (discomfort). Moreover, SMOTE, an over-sampling

method, increased the minority class examples (comfort) by 44%.
The balancing class methods did not improve the model accuracy and the model built (after using a sampling method for bias 0.5 and 1) presented the highest results in terms of accuracy. In addition, the level of accuracy was closer to the model generated with unbalanced data, although the decision tree was more complex due to a large number of rules. Precision was higher in the "discomfort" class than in the "comfort" class.
Corroborating results can be found in Crivelenti *et al.* (2009); Witten *et al.* (2011). These authors presented cases in which the balancing methods did not affect the model accuracy. In our study, in particular, the results may be attributed to the small size of the database used to build the model, which has only 600 instances (observations).
According to Japkowicz (2003), the problem of class imbalance is relative and depends on the complexity and size of the database. In small unbalanced data sets, the minority class is represented by an extremely small number of examples, being less representative of the sample, which may not be sufficient for the learning process (Batista *et al.*, 2004).
Witten *et al.* (2011) showed that, depending on the structure and size of the data, node splitting criteria in decision trees are insensitive to the class distribution. In these cases, the artificial balance of the class distribution does not have much effect on the performance of the induced classifiers.
Although the number of variables analysed in this study was small, some feature selection methods were evaluated, since they are able to improve the performance of models by eliminating inconsistent and redundant variables. Except for Wrapper, all feature selection methods used identified breast and armpit $T_S$ as relevant variables; thus the classifier performance was the same for all methods in terms of accuracy (70.1%) and number of rules (3).
Wrapper selected all the attributes of the original dataset as relevant and yielded the best classification accuracy (74%), but in a tree composed of more rules (6). This result was expected, since all parts of the body chosen in this study are anatomically vascularised and have more efficient vasomotor mechanisms (Hogdson *et al.*, 1994).
The representations of decision trees built with raw data (Figure 2) and with attribute selection (Figure 3) show results which are consistent with those published in the literature (Marlin *et al.*, 1998; McCutcheon and Geor, 2008).
According to McConaghy *et al.* (1996), the armpit is a highly vascularised area and has enormous capacity for increasing blood flow (vasodilation) to meet the thermal needs of the animal. In addition, the breast participates in heat exchange, since it is highly correlated with changes in heart rate and breathing.
Corroborating this study, Autio *et al.* (2006) studied differences in heat loss in different horse types at low temperatures and observed body heat dissipation by the groin and armpit during periods of thermal stress. These findings confirm that those regions play a part in thermoregulation.
By contrast, Jodkowska *et al.* (2011), who measured maximum surface temperatures in different regions of a horse's body at rest and after competition at an ambient temperature

of 14ºC, observed that physical effort had an intermediate impact on the increase in temperature in the breast region. The greatest increase in surface temperature following the stress condition was verified in the croup (3.3ºC). The authors considered that this region played a greatest role in releasing heat from the horse's body after effort or hard work.

Although the accuracy of both trees (Figures 2 and 3) is good at 74 and 70.1% respectively, they are interesting to experts because their rules are simple. The class precisions were very similar, so here it may be advantageous to choose the model with fewer rules, despite its lower accuracy. In this context, the tree generated with feature selection has some rules which are more compact and more representative for experts.

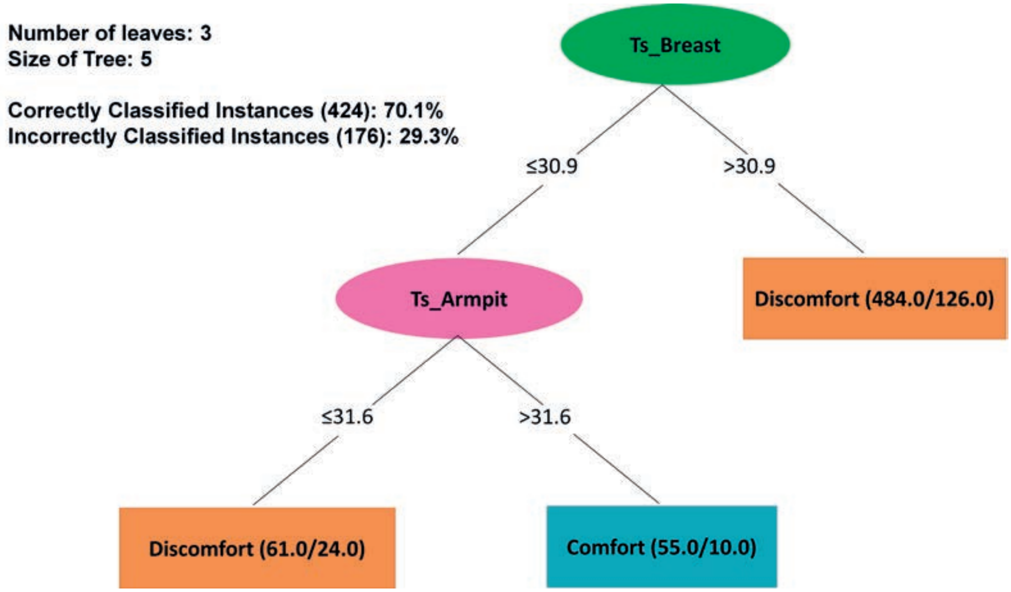


**Figure 3** – Binary classification tree for thermal comfort of horses using feature selection. The expression (x/y) in the leaf of a tree means that x instances reached that leaf, of which y are classified incorrectly (pre-pruning level = 35).

## Conclusion

The decision tree for classifying thermal comfort of horses from $T_S$ yielded an accuracy rate of 74%, containing six relevant rules taking into account all the attributes for classification. The feature selection methods (CFS, Infogain, Gainration and Chi-square) focused on the $T_S$ of armpit and breast, resulting in a tree with low precision, but with more compact and relevant rules from the experts' point of view. Therefore the best classification results were obtained from a model with fewer rules to the detriment of accuracy. The decision tree classifier proved to be a promising tool for seeking new knowledge and find new variables related to the thermal comfort of horses, such as $T_S$.

## Acknowledgments

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## Use of accelerometer based motion registration (IceTag®) to study activity patterns in horses kept in two different housing systems

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### Abstract

The physical activity and lying behaviour of two groups of five horses each were determined by use of accelerometer technology in order to study the potential of the technology in a PLF context and its usefulness to evaluate locomotion and lying behaviour in two different housing regimes. One group (DAY), horses were kept individually in traditional 10 $m^2$ single boxes and outdoors in a group in a 500 $m^2$ sand paddock for four hours during daytime. The other group (NIGHT) was kept in similar boxes from 08:00 to 16:00 and in a group outdoors in a 5000 $m^2$ grass paddock between 16:00 and 08:00. Each horse was equipped with an IceTag® motion registration device (IceRobotics Ltd) on one of the hind legs. The IceTag® detects the duration and intensity of movements and it can also register if the horse is lying down or not. Recordings were made continuously for one week. The collected data show that accelerometer data can be used to study physical activity (including gait) and lying behaviour in horses. Observed differences in locomotion and lying patterns between the two housing systems as well as effects on health, welfare and the potential of the technology for use in precision livestock farming (PLF) are discussed.

**Keywords:** horse, behaviour, activity, automatic recording, housing

### Introduction

Traditional horse housing systems do not accommodate the behavioural needs of horses very well. Free ranging horses walk, in search of feed, for a large portion of the day. In a study of a herd of Prezewalski horses on summer pasture (Boyd *et al.*, 1988), horses spent 46,4±5,9% of the time feeding and 5.3±3.5% lying. Divided over different parts of the day, they spent feeding 68.2±2.2% of the time between 20:00 and 24:00 h, 40.1±5.2% between 00:00 to 04:00 h, but only 31.2±2.1% between 08:00 and 12:00 h. Total recumbent resting per day was about 5% and most of it took place between 00:00 and 04:00 h. Resting in the standing position was the most common form of resting during the day. Horses also need social contact with other horses to maintain their natural behaviour (Jensen, 1995).

Exercise is also crucial for the development of foals into sport horses. In a study of the musculoskeletal and biomechanical development of warmblood foals Back *et al.* (1999) compared different levels of physical restrictions where maximum restriction was keeping foals indoors in boxes and minimum restriction, foals were kept on pasture all the time in the first five months of their lives. Pasture exercise led to a normal locomotion pattern, while foals kept indoors in boxes developed abnormal locomotion. Keeping foals in boxes during the first months of life can also result in a retardation of normal development of bone mineral density and cross-sectional metacarpal area, which can be compensated for when the restriction on exercise is lifted (Cornelisen *et al.*, 1999).

Henderson (2007) suggests that stereotypical behavioural patterns and the overall psychological well-being of today's performance horse could be substantially enhanced with care that acknowledges the relationship between domesticated horses and their forerunners. Feral horses typically roam in established, social groups over large grazing territories, spending 16–20 hours per day foraging. In contrast, today's elite show horses are kept in relatively small stables, eat a limited, but nutrient rich diet at separate feeding sessions, and typically live in social isolation. Although the horse has been domesticated for about 6000 years, there has been no selection for an equine which no longer requires the expression of natural behaviours which only can be performed in the freedom of a sufficiently large paddock. Using equine stereotypies as a welfare indicator, Henderson (2007) suggests that the psychological well-being of performance horses is often compromised. Horses kept in a box all the time, except when training, will show more several negative behaviours (kicking box walls, walking around, gnawing on objects) and also more lying than horses kept on pasture for 4-7 hours (Kwiatkowska-Stenzel *et al.*, 2013). Also horse behaviour while riding has been shown to be negatively affected when horses are kept in a box all the time, except for the training sessions, compared to horses having a limited turnout time before or after each training session (Werhahn *et al.*, 2011).

The use of accelerometer technology to record time-budgets and activity has been established for cattle (e.g. Munksgaard et al 2006) but there are very few studies on horses. Pedometers have been used to study the effect on different barn systems (Rose-Meierhöfer *et al.* 2010a) and the effect of different group size on activity (Rose-Meierhöfer *et al.* 2010b). Bachmann *et al.* (2013) used accelerometer technology (IceQube®) to determine motion activity, lying times and lying bouts on pregnant mares in order to predict foaling.

The aim of this study was to evaluate accelerometer technology for use on horses managed in two different housing regimes. The evaluation included a test of the recordings from the IceTags® using one horse to check lying behaviour and one horse to use the motion index to differentiate between different gaits. The technology is suggested to have a practical use in especially loose housing systems to monitor normal behaviour and activity and deviations from normality in order to detect disease and lameness or to capture the effects of the influence of e.g. changes in housing technology and management on the group or individual level. The trainer could also use the information in order to adjust individual training levels accordingly.

## Material and Methods

IceTag® devices (IceRobotics Ltd, Edinburg, UK) were fitted on one of the hind legs on each of 10 horses. The horses were divided into two groups with five horses in each group. One group (DAY) was kept in traditional 10m² single boxes and turned out together in a 500m² sand paddock four hours during daytime. The other group (NIGHT) was kept in similar boxes from 08.00-16:00 and turned out in a 5000m² grass paddock between 16.00 and 08.00. DAY horses were fed 06.30, 12.00, 16.00 and 20.00, while NIGHT horses had free access to hay/silage outdoors between 16.00 and 08.00 and received no feed in the stable. Horses were ridden for about 1 hour during the day.

The recordings from the IceTags were made continuously for one week. All horses were subjected to the respective housing system for at least 3 weeks before the recordings started. The horses were Swedish Warmblood, age 8-18 years, educated in riding level A and used at the equine studies programs at Flyinge, Swedish University of Agricultural Science. The behavioural parameters produced by the IceTags from the investigated horses were motion index, step count, lying time and lying bouts. Data from both minute and hour levels were used. Data were compiled in Excel.

For the validation of lying/standing, one horse from group DAY, kept in a box, was fitted with two IceTags on the left and right hind legs, respectively, for one night and at the same time being video recorded. Data from the IceTags were compiled on the minute level and compared with the behaviour in the video recording.

The influence of gait; walking, trot and gallop, on motion index was performed on a horse from group DAY which was fitted with two IceTags on the left and right hind legs respectively. The horse was lunged in walk, trot and gallop. Motion index values on the second level were used to study gait specific motion index values.

## Results and Discussion

### Motion index

The motion index per hour for the two groups of horses during one 24-hour periods is shown in figure 1. Activity during riding has been removed. As could be expected, group DAY horses did not move much during the hours when they were kept indoors, but moved considerably more per hour during their few outdoors hours than did group NIGHT horses. Group NIGHT horses had even lower motion indexes (mean=45/min.) indoors than group DAY (mean=75/min.), probably because they had the opportunity to move freely outdoors during 16 hours daily.

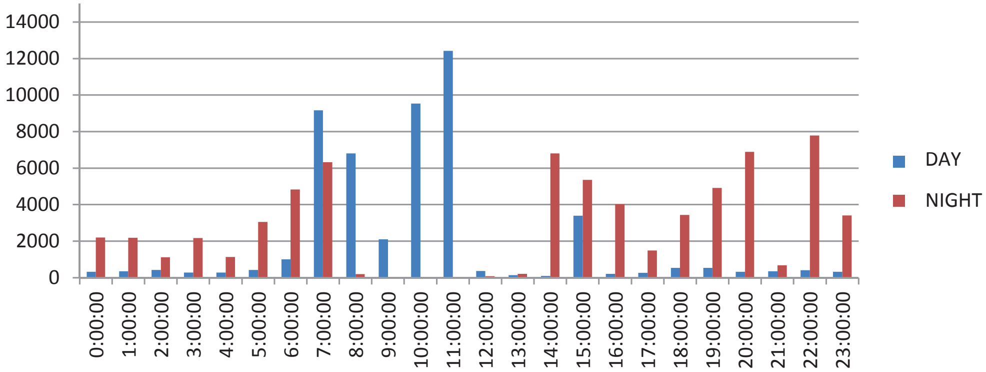


Figure 1. Typical motion index distribution for the two groups over a 24-hour period.

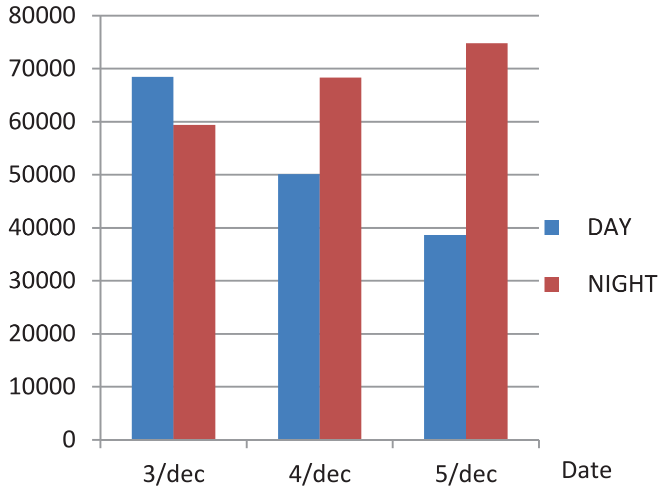


Figure 2. Total 24-hour group motion index sums for three days

In Figure 2, motion index data for 03-05 December 2012 are shown. The total motion index for the five horses in each group was between 38500 and 75000 per 24-hour period. Variations between different 24-hour periods were considerable and on the 3d of December, DAY horses made up for their lack of outdoor time by playing and running during their paddock hours, to reach a higher 24-hour sum than the NIGHT horses, in spite of their comparably small outdoor time (4 vs. 16 hours).

The influence of gait on motion index is shown in Figure 3. Average motion index per minute for walk was 288, for trot 540 and for slow canter 972. This would mean that a 24-hours total motion index of 10000 is equivalent to approximately 35 minutes of walk, which at a normal walking speed of 6 km/h means 3.5 km. Interestingly, using the motion index for trot and a normal trotting speed of 12 km/h gives 3.7 km and the same calculation based on cantering, using an estimated slow cantering speed of 20 km/h gives 3.4 km.

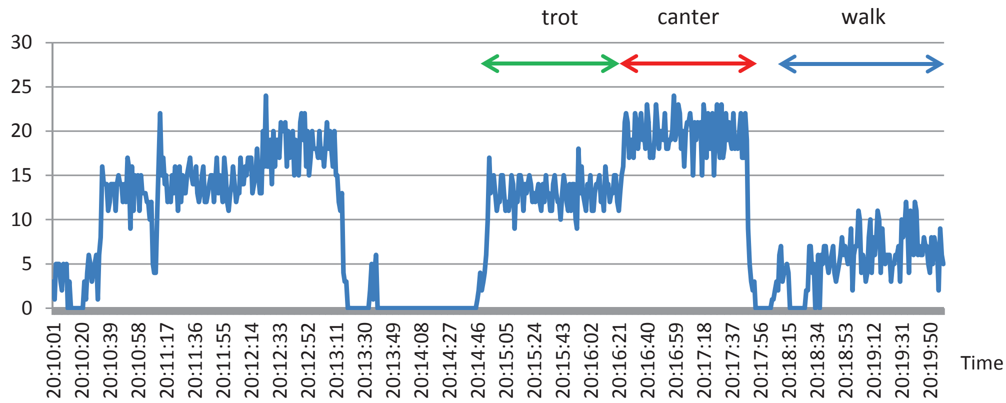


Figure 3. Motion index per second (left hind leg) during lunging in different gaits

In conclusion, the motion index gives a good estimate of the amount of locomotion and the distribution over time. It may also be used to estimate how much horses move in different gaits.

Lying behavior

The data from the lying parameter from the IceTag matched accurately the behavioural recordings from the video recording (Table 1).

Table 1. Lying registered with video recording of one horse kept in a box equipped with one IceTag on each hind leg.

| | Lying registered (min.) | | |
|---|---|---|---|
| Time | Video | IceTag left hindleg | IceTag right hindleg |
| 22:00-22:12 | 12 | 12 | 12 |
| 22:52-23:23 | 31 | 32 | 32 |
| 00:01-00:28 | 27 | 27 | 27 |
| 01:41-01:59 | 18 | 18 | 18 |
| 02:41-03:26 | 45 | 45 | 45 |
| 04:09-04:47 | 38 | 38 | 38 |

In Figures 4 and 5, the distribution of lying over day and night are shown. As could be expected, DAY horses laid mostly during night time (22-05), when there was no activity in the stable and there was nothing left to eat. More surprisingly, NIGHT horses laid mostly during daytime, especially during lunch hours, in the stable. The reason for this can only be speculated, but may be attributed to the fact that they had no feed and nothing else to do in the stable and/or that lying comfort is not optimal outdoors in december and/or that they were simply used to lying down in the stable from long years of habit.

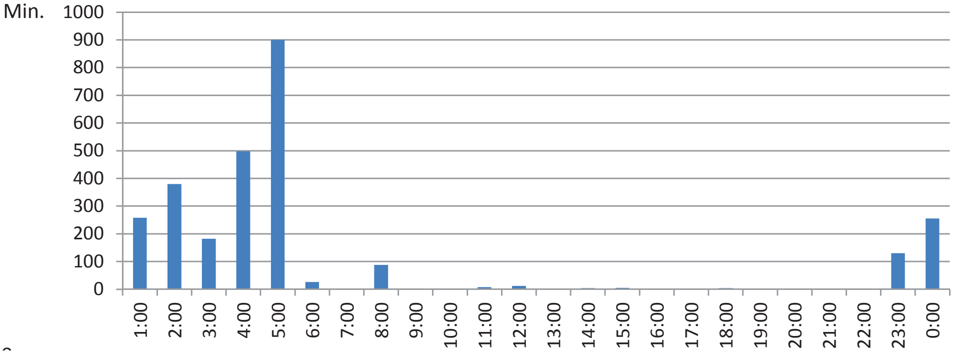


Figure 4. Distribution of total group lying time per hour for DAY horses during the study period

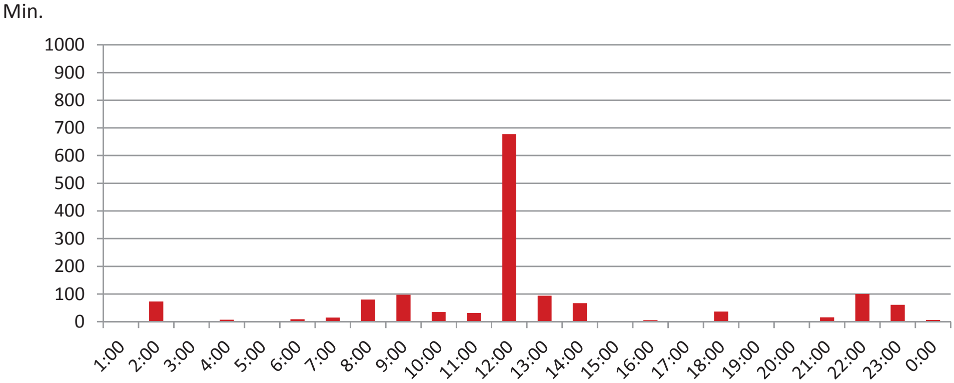


Figure 5. Distribution of total group lying time per hour for NIGHT horses during the study period

There was a tendency for DAY horses to lie down more than NIGHT horses. In Figure 6 the average 24-hours lying time for individual horses are shown.

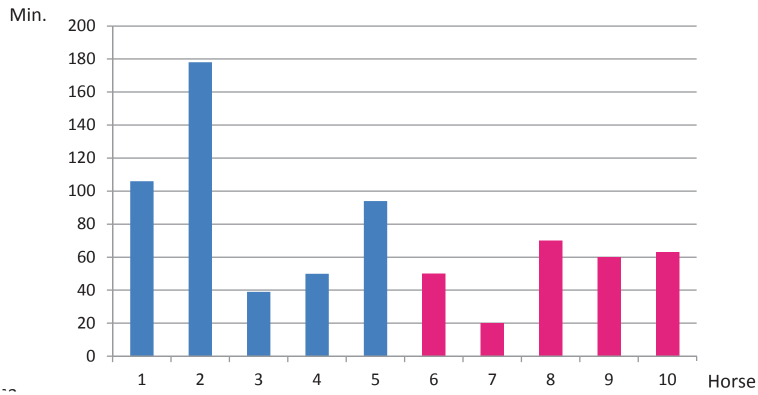


Figure 6. 24-hours lying time (min.) for individual horses. 1-5 are DAY horses, 6-10 NIGHT horses.

The data collected from the two housing systems show behavioural aspects that may be worth further study. Do traditionally housed horses lie down more than they need because they lack environmental stimuli? What caused the NIGHT group to change from normal (Boyd, 1988) night-time lying to lying during the day? The data collected in this study was too limited to try to draw any conclusions about differences between housing systems.

<u>Precision Livestock Farming (PLF) for horses</u>

This pilot study indicates that accelerometer data may be a useful tool to monitor physical activity and lying behavior in stabled horses as well as horses kept in loose housing systems. Similar technologies may well be used for constant monitoring of activities in for example loose housing systems equipped with automatic feeding stations, where data may be transferred frequently (with e.g. bluetooth technology) to the herd computer and used for example to automatically detect changes in behaviour indicating health disturbances or management and technological faults. Trainers and grooms could use the information to adjust training by e.g. monitoring of voluntary activity before and after a training session, but the benefit of such an approach has to be evaluated.

It is worth noting that the IceTag® is designed for use in cattle and the device may cause skin lesions in the fetlock area of individual horses if kept on for several days. We suggest that lighter devices are developed which are better fitted for use on the horse.

## Conclusions

Accelerometer-based data can be used in horse studies in order to monitor locomotion and lying behaviour. This information is suggested to be used in studies on horse behaviour but also as a tool, especially in group housing systems, to monitor health, technical function, management and influence of training. The usefulness of such information has to be further investigated. Accelerometer-equipped devices specifically designed for horses need to be developed.

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## On-line monitoring of human-horse relationship

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### Abstract

The aim of this study is to investigate the influence of the mental state of a rider on the mental state –and therefore behaviour– of a horse during a mood induction experiment with feedback. The mental state of the rider was assessed using PANAS state questionnaires while the behaviour of the horse was evaluated by an expert using an ethogram. The heart rate and the activity of both rider and horse were recorded simultaneously. A static analysis of the scores of the PANAS state questionnaires and ethogram showed significant differences ($p<0.05$) for the positive affect of the riders and the number of positive behavioural signs of the horses. The general trends in the data indicated that the riders were negatively (positively) influenced by the negative (positive) feedback. The behavioural observations indicated that the induced mental states in the riders were mirrored in their horses. The response of the heart rate data of the riders on their activity was simulated using a transfer function model. The change in the mental state of the riders, already induced by the first feedback, could be detected by comparing the simulated and measured heart rate data. Plotting the time series of the model residuals showed a difference between a shift towards a more positive mental state or towards a more negative mental state.

**Keywords:** equestrian sports, mental state, bioresponses, transfer function model

### Introduction

Orlick and Partington (1988) found that of the three factors in sports – the physical factor, the technical factor and the mental factor – only mental readiness was significantly linked with final Olympic ranking. This insight has led to a range of studies investigating the importance, the types, the use and the training of mental skills in practice and in competition (Frey *et al*., 2003; Greenleaf *et al*., 2001). Despite this fact, in equine sports little research has been conducted on the mental interaction between rider and horse.

Compared to motorcycle sport where one serious accident happens in every 7000 hours of riding, horse riding is very dangerous: one serious accident per 350 hours of riding (Firth, 1985). This shows that there is a need for research into a safer way of horse riding. The relationship between rider and horse is a crucial factor in the process.

Munsters *et al.* (2012) found that if there is a match between rider and horse, the latter perceives challenging situations as less stressful. As a horse is a flight animal, it will try to flee from danger and this causes a large number of accidents. A safer situation is created when the horse feels more comfortable. Munsters *et al.* (2012) found that match or mismatch between a rider and a horse can be detected by simultaneously measuring their heart rates. Keeling *et al.* (2009) also found that a horse can sense the mental state of its rider and that this influences its heart rate. Wolframm and Micklewright (2011) tested the effect of mental skills training on non-elite riders and found that post-training performance scores were significantly higher than those obtained before the mental skills training. It was suggested this was due to better communication between rider and horse. These findings suggest that by manipulating the mental state of riders it is also possible to influence the mental state of their horse, and this manipulation may lead to better performance. The aim in equestrian sports, like all other sports, should be to implement training methods that are based on sound, verifiable principles (Channon, 2012) and science should be able to provide this basis. Measurement is therefore a crucial factor (McGreevy, 2006). Apart from evaluating training techniques it may also provide a basis for developing methods of measuring the welfare of ridden horses.

To investigate the constantly changing mental state of an individual it is necessary to monitor it on-line. This paper lays the foundation for development of a method for on-line monitoring of the mental interaction between rider and horse. To this end, it seeks to identify a link between a gold standard for assessing the mental state of a human or a horse and a new non-invasive measuring method based on heart rate measurements.

## Material and methods

<u>Questionnaires and sensors</u>

A complete and an adapted Positive Affect and Negative Affect Schedule scale (PANAS state questionnaire) were used to assess the mental state of the riders. The complete PANAS state questionnaire consisted of 20 items which are rated on a five-point scale. It provides a score for the positive affect (PA) and for the negative affect (NA) of the rider. The adapted PANAS state questionnaire was developed so that the mental evaluation could be carried out more often without disturbing the continuity of the experiment. This questionnaire consisted of three questions: “How pleasant do you feel?”(VAL) - “How calm do you feel?” (AR) - “How well do you think you performed the exercise?” (OP). The adapted PANAS state questionnaire produced three scores, one for each question. As the level of comfort of an animal can be deduced from its behaviour, the mental state of the horses was assessed using an ethogram. The experiments were recorded and afterwards an expert evaluated the behaviour of the ridden horses. An appropriate ethogram was designed based on a study conducted by Groene Kennis Coöperatie (2010). The ethogram provides a score for the behavioural signs of the horse, indicating a positive mental state (P) and a negative mental state (N). A score for the total level of comfort (T) of the horse is also assigned. The rider's heart rate was measured by a Zephyr™ Bioharness™ 2.0. The activity of rider and horse was simultaneously monitored using two Zephyr™ Bioharness™ 2.0 devices.

Mood induction method

The desired mental state was induced in the rider by an explicit mood induction method: a success-failure manipulation using feedback. In a success-failure manipulation the experimenter gives participants a task which is constructed in such a way that they are not able to assess how well they perform. The outcome of the task or the feedback on the task is manipulated so the participants experience success or a failure. Experiencing success will induce a positive mental state and failure will induce a negative mental state (Nummenmaa and Niemi, 2004). Depending on the type of mood induction required, a trainer was instructed to give positive or negative feedback to the rider at certain points during the experiment.

Experimental data

A total of 7 mood induction experiments were conducted, of which 1 was positive and 6 were negative. The experiments were carried out in an indoor arena and used 7 different rider-horse pairs which were supervised by a familiar trainer. 4 female and 3 male riders participated. An experiment started with the rider and horse doing a warm-up and attachment of the heart rate and activity sensors. After a habituation period of 4 minutes they had to perform a dressage exercise during which the trainer gave instructions (part A). Subsequently there was a recovery period of 4 minutes. After the break the dressage exercise was performed again, but this time the trainer also provided the rider with feedback (part B); this was followed by the second recovery period. The dressage exercise was designed so that none of the riders was familiar with it. The riders were assumed to be in a neutral state during part A, therefore the data for part A are the control data. The data obtained from part B are the mood data. The questions from the complete PANAS state questionnaire were asked at the beginning and at the end of the experiments in order to check the mental state of the riders. The questions from the adapted PANAS state questionnaire were asked at the beginning, at the break (during the first recovery period) and at the end. The behaviour of the horse was assessed during part A and part B.

Analysis of the data

A static analysis was conducted on the data obtained from the complete and adapted PANAS state questionnaire, the ethogram and the heart rate and activity measurements. The heart rate and activity data were initially divided into smaller parts with each part containing the data from a walking, trotting or galloping period. The mean and standard deviation of the data were then calculated. Subsequently the data were compared, using a paired t-test and a repeated-measures one-way ANOVA for the normally distributed data and a Wilcoxon matched pair signed rank test and a Friedman test for the data which were not normally distributed. A level of significance of 0.05 for all comparisons was maintained.

The data from the heart rate and activity measurements on the riders were used to model the dynamic response of the heart rate to activity. Using this model the mental component of the heart rate measurement could be detected by comparing the measured heart rate with the simulated heart rate (Jansen *et al*., 2009). Identification of the model structure and estimation of the model parameters were carried out using the CAPTAIN Toolbox 'rivbjid' routine in Matlab (Taylor *et al*., 2007). It returns a single input single output transfer function with estimated coefficients. Identification of the transfer model structure is based on a discrete-time Simplified Refined Instrumental Variable (SRIV) algorithm:

$$y(t) = \frac{B(z^{-1})}{A(z^{-1})} u(t-\tau) + e(t) \tag{1}$$

where *y(t)* is the heart rate of the rider at time *t* (the output); *u(t)* the activity of the horse at time *t* (the input); τ the time delay; e(t) the residual at time *t*; $z^{-1}$ the backshift operator and $A(z^{-1})$ and $B(z^{-1})$ polynomials of the type:

$$A(z^{-1}) = 1 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_n z^{-n} \tag{2}$$
$$B(z^{-1}) = b_0 + b_1 z^{-1} + b_2 z^{-2} + \ldots + b_m z^{-m} \tag{3}$$

where $a_1$, $a_2$,... , $a_n$ and $b_1$, $b_2$,..., $b_m$ are the model parameters of the denominator and the nominator of the transfer function. The residual or model error is the difference between the fitted model at time t and the measurement value at the same time t. The model structure is completely determined by the a- and b- parameters and the time delay τ. For coefficient estimation in Matlab, the routine was limited in terms of the number of parameters: the number of a- and b- parameters varied between 1 and 3 and the time delay varied from 0 to 5. Once the potential model structures were determined, the best model was selected by means of the Young asymmetric Identification Criterion (Young, 1984).

## Results and Discussion

Static analysis

The static analysis of the mean and standard deviation of the heart rate and activity data from the negative mood induction experiments revealed no significant differences ($p<0.05$) between the control data from part A and the mood data from part B. A static analysis of the scores obtained from the questionnaires showed that the PA scores had significantly decreased in part B compared with part A ($p=0.0099$) (Figure 1a). The NA scores did not change significantly although a slight overall increasing trend in the scores was visible (Figure 1b).

Figure 1: Mean and variance of the PA scores (a) and the NA scores (b) at the beginning and end of the negative mood induction experiments

A remark has to be made on these results. Although all riders demonstrated clear signs of discomfort and anger during the experimental feedback, none of them wanted to show this and they tried to repeat the answers they had given on the questionnaires the first time. Therefore it is suggested that the questionnaires or the mood assessment method should be changed in future research. An observer evaluating the behaviour and facial expressions of the riders is suggested as a solution. A survey indicated that none of the riders was aware of the aim of the experiments.

The scores from the adapted PANAS state questionnaire were analysed in order to rule out the possibility of the mood change occurring during part A instead of part B. The trends in the VAL scores for the negative mood induction experiments showed a slight decline between part A and the break, but revealed a larger decrease in part B compared with the break (Figure 2a).The AR scores increased from part A to the break and decreased from the break to part B (Figure 2b). This indicates that riders felt calmer after riding the dressage exercise for the first time in part A, but they were aroused again after part B. The OP scores showed a decreasing trend (Figure 2c). Most mistakes that the riders made the first time, due to the fact they were not familiar with the exercise, were not repeated in part B. Therefore most riders performed better during part B. However this was not reflected in their opinion of their own performances. The negative feedback from the trainer influenced their mental state in such a way that they judged their performance negatively.

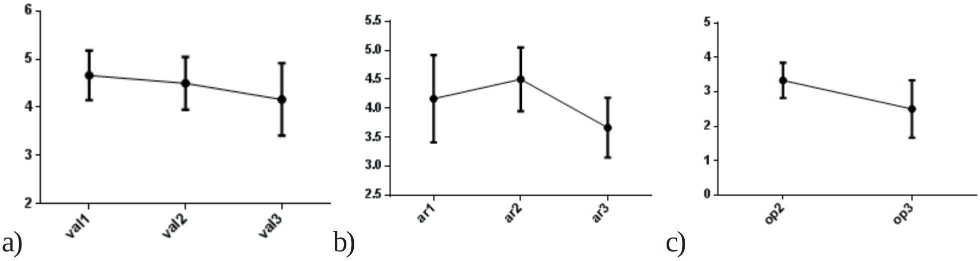
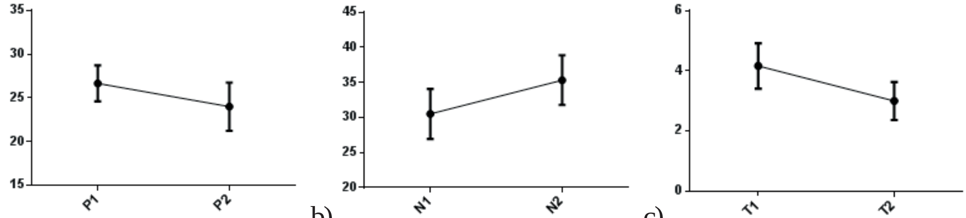


Figure 2: Mean and variance of the VAL scores (a), the AR scores (b) and the OP scores (c) at the beginning, the break and end of the negative mood induction experiments

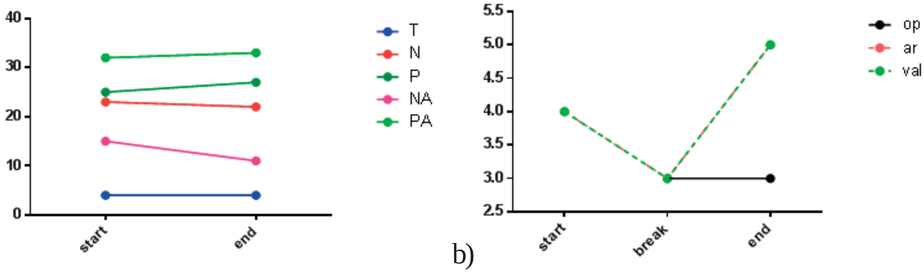
The analysis of the ethogram scores showed a significant decrease in the amount of positive behaviour (P) of the horses in part B as opposed to part A (p=0.0337) (Figure 3a). As the conditions in both parts were the same except for the negative feedback, it is suggested there is a causal connection. This connection can only be made through the rider. The analysis of the amount of negative behaviour (N) revealed an increasing trend (Figure 3b). Also the scores for the overall level of comfort (T) showed a decreasing trend (Figure 3c).




a) b) c)

Figure 3: Mean and variance of the P scores (a), the N scores (b) and the T scores (c) at the beginning and end of the negative mood induction experiments

Plotting the trends in the scores from the positive mood induction experiment revealed an increasing trend for the PA and P scores and a decreasing trend for the NA and N scores for the riders and horses respectively (Figure 4a). The self-esteem of the rider was lower after riding part A than at the beginning of the experiment, but the VAL score was high again after riding part B (Figure 4b). Plotting the AR score showed the same pattern (Figure 4b). The OP scores were the same for part A and part B (Figure 4b). The VAL and AR scores indicate the rider felt insecure about the performance in part A, but this doubt was removed by the positive feedback in part B although both performances did not actually differ in level of performance.




a) b)

Figure 4: The trends in the scores of the PANAS state questionnaires (PA, NA, OP, AR, VAL) (rider) and ethogram (P, N, T) (horse) of the positive mood induction experiment

<u>Analysis using dynamic model</u>

A transfer function model, modelling the heart rate response to the activity input, was constructed for the first walk-trot transition in the dressage exercises in part A (control model) and part B (mood model). The first feedback was given during this walk-trot transition. For 5 out of 7 control models a $R_T^2 > 95\%$ was reached. All mood models had a $R_T^2 > 90\%$. All models had a YIC value below -0.8279. No trend in the model orders was found when each control model was compared to the corresponding mood model, nor were there clear trends in the time delays. Therefore, the response of the heart rate to the activity data from part B was simulated using the control model, which was constructed using the control data from part A, instead of the mood model, which was constructed from part B. This simulated response was then compared to the actual measured heart rate from part B. If the two datasets did not differ at all, both models should be able to fit both datasets. If, however, an internal or external factor influenced the second dataset, the control model would not be able to fit it. As both experiments were conducted under conditions which were as equal as possible, except for the feedback in the second experiment, it is expected that the control model will fit the mood data until the part where the feedback influences the heart rate data by inducing a mental component in the heart rate. At that moment, it is expected that the model error or residual will grow larger as the model does not predict the heart rate properly. The model was constructed using data without a (significant) mental factor so it cannot deal with this extra input. The increasing model error is thus used as an indicator to monitor changes in the rider's mental state. In 4 out of 7 cases the control model fitted the mood data until the time when the first feedback was given to the rider. From that point on, a clear deviation between the measured heart rate data and the simulated heart rate data appeared. The time-series of the model residuals was plotted (Figure 5).

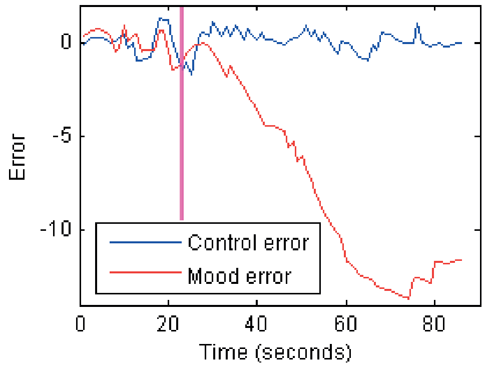



Figure 5: Plot of the residuals when the control data and the mood data are fitted to the control model; the vertical line indicates the first time feedback was given to the rider

For the positive mood induction experiment the control model underestimated the heart rate data from that point on; for the negative mood induction experiment the model overestimated the data. To optimise the on-line detection method the use of a refined algorithm, such as Gustafsson's Cumulative Sum (CUSUM) algorithm which was used in the study of Jansen *et al*. (2009), can be investigated. To explore the mental interaction between rider and horse it is also necessary to monitor the heart rate of the horse. An attempt was made in this study but the measurements need to be improved in order to perform a proper analysis. However, the data analysis method would be the same. Therefore, progress on this topic is to be expected once the difficulties with measuring an equine heart rate are solved. This method could then also be used to monitor the welfare of ridden horses or horses in general.

## Conclusions

Although some improvements to the mood assessment method are necessary, the overall results indicate that the experimental setup is able to induce a negative or positive mental state in a rider. The results also suggest that there is a positive correlation between the mental state of a rider and the behavioural signs of a horse indicating relaxation or comfort and irritation or discomfort. Analysis of the riders' heart rate data indicated that it is possible to detect changes in their mental state by looking at the heart rate. It may also be possible to detect whether this change is towards a more positive or a more negative mental state. Due to the limited number of experiments, no definitive statements can be made on this subject. Nevertheless, this study suggests that more extensive studies will reveal interesting facets of the rider-horse relationship and will gain deeper insight into equine welfare.

## Acknowledgements

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## Real time monitoring of mental status of a horse to a negative stressor

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### Abstract

The objective of this research was to develop a non-invasive real time monitoring tool to detect an emotional response by a horse to a stressor during physical activity. Two horses performed 20 trials each, in which the horse's heart rate (HR) and physical activity were continuously measured, both with a sampling frequency of 240 Hz. Heart rate was measured with a belt including electrodes and activity was measured with a 3D accelerometer. The relationship between the horse's physical activity and HR was continuously calculated by a mathematical model.

The experiments consisted of 5 minutes walking on the lunge then after 5 minutes the horse was asked by a smooth voice to start trotting. It was very important not to induce stress during this transition from walking to trotting. The hypothesis is that a mathematical model can be developed while no stress component is present in the heart rate of the animal. The horse was trained to do this experiment to reduce the risk of emotional stress during the transition from walking to trotting. When the horse had been trotting easily at very low speed for some time, a person came and flipped open an umbrella. It has already been described in the literature that opening an umbrella creates a stressor for a horse whenever it is performed.

A real-time mathematical model of the transition from walking to trotting was constructed using the dynamic data for this individual horse at this moment in this place. From the data it can be shown that the calculated heart rate from activity perfectly matches the measured total heart rate.

These results were confirmed in 33 experiments. The error between calculated and modelled heart rate when there is no stressor was very small (see Figure 1 from time 200 to 600 seconds). The second-order models (mean $R^2 = 0.94$) described the relationship between the horse's physical activity and its heart rate significantly more accurately than the first-order models (mean $R^2 = 0.90$) (Student's $t$ test; $P < 0.05$).

However, as soon as the stressor appears the heart rate calculated from the real-time measurement of activity cannot model the total heart rate any more, as can be seen in Figure 1 from time 650 seconds to around 750 seconds. Although all movements of the horse (stopping, jumping, trotting again with nervous movements, etc.) are measured at 240 Hz and used to calculate the heart rate in real time, there is a serious error between the calculated and measured heart rate. This means that there is a mental component in the total heart rate signal that is not related to the movement of the horse.

However, as soon as the horse is presented with the umbrella as a stressor, the measured and modelled heart rate differ significantly, resulting in an increased model error and therefore a decreasing overall coefficient of determination $R^2$ from a value of 0.94 to a value of 0.43 and 0.73, respectively with a Student's *t* test; $P \ll 0.001$.

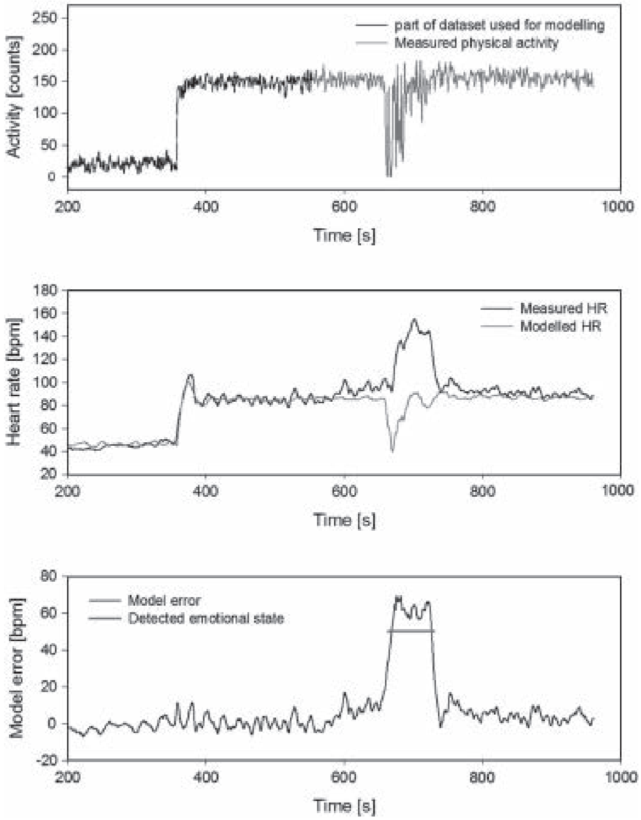


Figure1: Detection of emotional response based on model-based decomposition of heart rate. Top: measured physical activity (grey); part of dataset with minimal emotional stress, used to build a dynamic model (black). Middle: measured heart rate (black); HRphysical, predicted by dynamic mathematical model (grey). Bottom: model error (i.e. part of heart rate containing information about the emotional state of the horse) (black); detection of emotional response to novel object exposure (grey).

Exposure to the umbrella as a novel object resulted in an increase in the emotional component of HR, which allowed automatic detection of an emotional response by the horse in 33/40 trials. In the remaining seven trials no stable model could be built or data were missing.

The results showed that real time model-based decomposition of heart rate into a physical and an emotional component is possible. Experiments and analyses are currently being conducted to show a similar response to positive events in horses.

It has already been shown in the literature that the use of model-based tools can help in training of physical condition in horses (Aerts *et al*., 2008).
Since horses are flight animals and their emotional status is a very important issue during training, this real-time monitoring tool for the emotional component can be used to make training of horses more effective.

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# Session 9

# Cattle - Milking

## Use and interpretation of mastitis alerts by farmers

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### Abstract

In order to study the behavior of farmers with an automatic milking system regarding the use of mastitis alert lists, seven farms were visited five times during 3 weeks. At the first visit, a generic questionnaire was held was held on the criteria farmers used for selecting cows on the alert list to be visually checked. During each visit, the farmers were questioned about the specific alerts on the alert list of that day. After this questioning, the milk of all four quarters of every cow on the alert list was visually checked for clinical mastitis and was checked for subclinical mastitis using the CMT test. Important criteria for farmers were, an alarming change in milk production, flakes and/or clots on the milk filter in combination with high electrical conductivity or a failed milking. Reasons for not checking alerts were: no flakes or clots on the milk filter, no change in milk production, cows that were repeatedly on the alert list or a lack of time. Nine percent of all (421) checked alerts had clinical mastitis, while 31 % of all alerts had subclinical mastitis. This means that a total of 40 % of all alerts could be associated with mastitis. The farmers did check 3 % of the alerts, of which 67 % (10 cases) had clinical mastitis. However, 74 % of the clinical mastitis that was associated with mastitis alerts of the mastitis detection system was not diagnosed by the farmer because of his own selection of cows to check. This can be the cause of the observed phenomenon that farms that switch to automatic milking, on average, do have worse udder health in terms of somatic cell count, but a lower incidence of clinical mastitis. The eventual consequences of this lack of detection of clinical mastitis on overall udder health, use of antibiotics, animal welfare and milk quality remain unknown.

**Keywords:** Automatic milking, Mastitis alert list, Interpretation, Farmers' behaviour

### Introduction

When milking cows with an automatic milking system (AMS), for mastitis detection, farmers have to rely on sensor alerts. It is known that, although the sensitivity and specificity of current mastitis are quite reasonable , the systems still give a relative large number of false positive alerts (Hogeveen *et al*., 2010, Mollenhorst *et al*., 2010). In order to find detect all mastitis cases, farmers have to visually check all alerts. This is a time consuming job with quite some frustration because in most cases a checked cow will not have problems. Although researchers and veterinary specialists do talk a lot about the interpretation of mastitis alerts with automatic milking systems, we do not know that how farmers do use the mastitis alert list that they have and what the consequences of this behavior is.

The goal of this research was therefore to study farmers behavior related to mastitis alerts and the consequences thereof.

## Material and methods

This study was carried out on 7 farms, located around one village in the north of the Netherlands. The farmers needed to be motivated to enter the study. All farms were milking with a Lely Astronaut (Lely, Rotterdam, the Netherlands) AMS. Each farm was visited five times. During each visit, the farmers were questioned about the alerts on the alert list of that day. After this questioning, the milk of all four quarters of every cow on the alert list was visually checked for clinical mastitis and was checked for subclinical mastitis using the CMT test. During the beginning of the first visit, a questionnaire was held on generic farm data and the criteria farmers used for selecting cows on the alert list to be visually checked.

## Results

Farm characteristics

The seven farms that participated in the study had a mean size of 116 cows, with a milk production of 8,427 kg and an SCC of 202.000 cells/ml. The first farm adapted automatic milking in 1996 (farm 2) and the last farm adapted to automatic milking in 2010 (farm 1). In table 1 the available specific characteristics of the different farms are shown.

Table 1. Characteristics of the seven farms in this study

| | Farm number | | | | | | | Mean |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Cows (#) | 103 | 168 | 142 | 101 | 70 | 116 | 115 | 116 |
| AMS stalls (#) | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2.1 |
| Milk production (kg/305 days) | 9,556 | 8,928 | 7,800 | 8,281 | 9,257 | 9,317 | 5,854 | 8,427 |
| BMSCC (* 1,000 cells/ml) | 199 | 173 | 210 | 185 | 142 | 152 | 353 | 202 |
| Clinical mastitis (% cows/year) | 97 | 20 | 14 | 23 | 6 | 22 | 20 | 29 |
| Cases treated (% of clinical cases) | 85 | 18 | 13 | 21 | 5 | 19 | 22 | 26 |
| Milkings/day (#) | 2.9 | 2.6 | 2.4 | 2.5 | 2.8 | 2.6 | 2.4 | 2.4 |
| Udder health alerts (#/day) | 10 | 23 | 16 | 15 | 6 | 10 | 30 | 16 |

Farmers’ interpretation of mastitis alerts

There was a large variation in the frequency that the farmers had in checking the alert list. Most farmers checked the alert list 2 to 3 times per day. However, one farmer checked the alert list 10 times per day (when he was busy 5 times per day) while another farmer checked the alert list 2 to 3 times per week (when he was busy he did not check the alert list). There was no difference between weekdays and weekend days.

Checking as such also difference from farm to farm: from a quick glance to 10 minutes per time. Farmers indicated that it takes 5 to 15 min. to go in the barn and check a cow for clinical signs. Most farmers checked cows on the alert list when they cleaned the stalls or when they selected cows that had too few milkings and had to be chased to the milking robot by hand. The questionnaire answers were confirmed by visual observations of the farmers behaviour during the farm visits.

According to the questionnaire, farmers are going to check an alert to confirm mastitis when there is a high electrical conductivity, when the milk production is reduced, when there are clots on the filter sock, when there a failure in milking or a combination of these elements. However, the definition of reduced milk production differed between farmers from a reduction of 2 kg to 6 kg.

Studied mastitis alerts

In total, 421 quarter alerts were checked by the researcher, including 194 repeated mastitis alerts (Table 1). Of these alerts, 60 % neither had clinical mastitis nor subclinical (as measured using CMT) signs. In total, 39 cases of clinical mastitis were found. Nine of these cases were from a repeated mastitis alert that was checked earlier without signs of clinical mastitis. Two clinical cases were detected in different quarters then on the alert list. Besides the cases of clinical mastitis diagnosed during the study visits, the farmers had diagnosed four cases of clinical mastitis at other days during the study period. A total of 128 subclinical mastitis cases were diagnosed. From this number, 81 were repeated cases, i.e., they were diagnosed with a positive CMT during an earlier visit.

Table 2. Studied mastitis alerts

| | Clinical mastitis | Subclinical mastitis[1] | No mastitis | Total |
|---|---|---|---|---|
| First alerts | 30 | 47 | 150 | 227 |
| Repeated alerts | 9 | 81 | 104 | 194 |
| Total | 39 | 128 | 254 | 421 |

[1]As measured using CMT

The overall success rate was 40 % for all mastitis cases (167 out of 421) and 9 % for clinical mastitis cases (39 out of 421). For first alerts, the success rate for all mastitis cases was lower (30 %) while the success rate for clinical mastitis was higher (13 %). Consequently, for repeated alerts, the overall success rate was higher (46 %) while the success rate for clinical mastitis was lower (5 %).

Only 15 of the 421 quarter alerts were checked by the farmer (3 % of all alerts). From the checked alerts by the farmers, 67 % had clinical mastitis and 13 % had subclinical mastitis. However, the farmers missed quite a large number of mastitis cases. Of the 39 clinical mastitis cases that were found, only 10 were detected by the farmers, which means that 74 % of the clinical mastitis cases were not (yet) detected by the farmers.

Reasons for checking

Criteria for farmers not to check an alert are shown in Table 3. 28% of all alerts hadn't been checked because there were no flakes or clots on the filter sock. 12% hadn't been checked because of no alarming milk production deviation. Another 10% weren't checked because these cows were repeatedly on the report with a history of high conductivity and another 10% because of no time. Besides these, for farmers, more important reasons, there were a large number of reasons (more than 20, of which 10 are presented in Table 3). Farmers did differ in reasons why they did not check mastitis alerts. Three farmers used a check of flakes/clots on the filter as most important criterion not to check alerts in the barn. No time and a not alarming deviation of the milk production deviation were also important criteria for some of the farmers.

Table 3. Main reasons alerts were not checked by the farmers. Reasons that were used for less than 1 % of the alerts are not presented.

| | |
|---|---|
| No flakes/clots on the filter sock | 28% |
| Milk production deviation not alarming | 12% |
| Combination repeatedly on the list and high conductivity | 10% |
| No time | 10% |
| Combination conductivity alert en milk production deviation not alarming | 7% |
| Temporarily physical problems | 6% |
| Conductivity alert not alarming | 5% |
| AMS disorders | 4% |
| Already more cows in mastitis treatment | 4% |
| Green alert | 2% |
| Checked before, not clinical at that moment | 2% |
| Not clinical at the last check, repeatedly on the list | 2% |
| Will be culled | 1% |
| In heat | 1% |

## Discussion and conclusions

We know that mastitis alert systems are far from perfect. In a recent review, a large variation in performance of mastitis alert systems was seen (Hogeveen *et al*., 2010). In the only paper that was published since this review (Miekley *et al*., 2012), results did not improve. A specificity lower than 99 % and combination with a low prevalence of clinical mastitis is the reason behind the low success rate. Although it is thought that using current sensor systems a combined sensitivity of 80 % and specificity of 90 % can reached, in practise this is not the case. So mastitis detection systems are not perfect. That means that farmers, before taking action (i.e., treating a case of mastitis) have to confirm the alert. This is tedious and time consuming work, because you have to be in the barn, fix a cow and check the milk.

Although much work as been done on evaluation of mastitis detection systems, this is the first study that was aimed at the behaviour of farmers. Because we did not randomly sample cows for signs of clinical or subclinical mastitis, we could not evaluate the sensitivity and specificity of the sensor systems. However, we looked at the interpretation of alerts. It was obvious from our study that quite a large number of alerts were associated with mastitis (clinical or subclinical), but that the majority (74 %) of the mastitis cases were not diagnosed by the farmers because they did not check the associated mastitis alerts.

It might be that these results are not representative for al farmers in the Netherlands. Because of practical reasons, this study was carried out on farmers in the same region. The attitude of these farmers can be different than the attitude of farmers elsewhere in the Netherlands. However, previous research showed that farmers gave a high utility to a low number of false alerts, alerts being at the proper time and aimed at more severe mastitis cases (Mollenhorst *et al*., 2012). Those observations are in agreement with the findings in this study, where farmers seemed to be quite reluctant to check the milk of cows on the alert list.

The results of this research might also explain a phenomenon that is earlier observed. It is known that the introduction of automatic milking, on average, decreases the udder health on farms as expressed in the bulk milk somatic cell count (Hovinen *et al*., 2009, Klungel *et al*., 2000, Rasmussen *et al*., 2001, Salovuo *et al*., 2005, Van der Vorst and Hogeveen, 2000). More recent work showed on farms with automatic milking a higher level of somatic cell count of individual cows, but a lower incidence of clinical mastitis (Dohmen *et al*., 2010), results that were confirmed in other countries such as Norway (personal communication). So it seems that the overall udder health, as expressed in somatic cell count, on farms with an automatic milking system is decreasing, while the incidence of clinical mastitis is decreasing. It might be that clinical mastitis is associated with treated cases. When less cases are diagnosed, the treatment rate decreases and so the incidence of clinical mastitis before and after introduction of automatic milking cannot be compared.

This research did show that farmers did use different “algorithms” to decide whether or not to check a cow. Although we do not know all of it yet, some work has been done on using cow specific data to make specify true positive and false positive cows on the alert list. Results of that study showed that further selection of cows to be checked was not possible (Steeneveld *et al*., 2010). In order to not miss any mastitis cases, all animals on the alert list have to be checked. If that is not done, a farmer accepts that a number of mastitis cases will be missed.

A question that needs to be answered then is whether it is a problem that not all clinical mastitis cases are diagnosed immediately. Some mastitis cases that are missed might cure spontaneously, others might become more severe and give more damage, or cows might become chronically infected (this could explain the higher somatic cell count on farms with an automatic milking system). Our data could not be used to study these questions, but seem interesting enough for further research.

In conclusion, in order to detect all clinical mastitis, farmers should check all alerts visually. For the 7 farmers in this study this would mean that, on average, 12 cows need to be checked each day. By the way the farmers did select animals to check, 74 % of the clinical mastitis cases that were associated with alerts were not diagnosed. It is not known what the eventual consequences of these findings are on udder health, animal welfare, use of antibiotics and milk quality.

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# Ketosis detection in early lactation of dairy cows by behaviour and performance sensing

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## Abstract

The aim was to develop and validate an automated detection model for post-calving ketosis based on rumination time, activity and milk yield.
Data were collected in four commercial dairy farms. In total, 203 cows were diagnosed with ketosis and 503 cows were healthy. Rumination time, activity and milk yield were measured online by commercial sensors.
A logistic regression model was (i) calibrated on the large farm and validated on other farms, (ii) calibrated on a percentage of all farm data and validated on all remaining farm data and (iii) calibrated and validated on individual farm level.
When calibrated on the large farm, validation specificities ranged from 0.54 to 0.85 and sensitivities ranged from 0.45 to 0.82 in the different farms. When calibrated on all farm data, validation specificities ranged from 0.53 to 0.85 and sensitivities ranged from 0.55 to 0.96 in the different farms. The best model performance was obtained when calibration and validation dataset came from the same farm, with model specificities ranging from 0.74 to 0.84 and sensitivities ranging from 0.68 to 0.82 in the different farms.
A general model gave reasonable results in all farms. A better model performance was, however, obtained with a farm-specific calibration.

**Keywords:** ketosis, rumination and activity sensors, logistic regression model

## Introduction

Ketosis is a common health problem in early lactation of dairy cows. The first symptoms of ketosis are loss of appetite, reduced food intake (Kahn and Line, 2010) and consequently significant milk losses (Fourichon *et al.*, 1999; Rajala-Schultz *et al.*, 1999). Ketosis is also associated with changes in milk composition (Krogh *et al.*, 2011) and decreased reproductive performance (Walsh *et al.*, 2007).
Information on (changes in) behaviour of cows can be used for early diagnosis of diseases as suggested by Tolkamp *et al.* (2010) and Steensels *et al.* (2012b). A recent study by

Steensels *et al.* (2012a) demonstrated that ketotic cows have a lower rumination time, lower activity and lower milk yield than healthy cows, recorded by commercial sensors. To our knowledge, no attempt was done to develop a model that detects post-calving ketosis with continuous monitoring of rumination time, activity and milk yield in commercial farm conditions. The aim of this study was to develop and validate a mathematical model to detect post-calving ketosis in multiparous cows based on individual rumination time, activity and milk yield measured with existing commercial sensors.

## Material and Methods

Animals and housing

The research was conducted in four commercial dairy farms with Israeli Holstein cows. The farm practices in Israel include routine post-calving health checks by the farm veterinarian. The farm veterinarian is part of Hachaklait Veterinary Services Ltd. (Caesarea, Israel), the main cattle veterinary organization in Israel. All veterinarians in this organization use the same post-calving protocol; every cow is examined between 5 to 12 d after calving for ketosis with the help of a Ketostix strip (Bayer Corporation, Hod HaSharon, Israel), detecting acetoacetate (AcAc) in urine. A cow was considered as ketotic when the test result was higher than 1470 µmol AcAc/L or 15 mg AcAc/dL. Ketotic cows were drenched with 1 L propylene glycol, and in severe cases (Ketostix test result higher than 7,840 $\mu$mol/L or 80 mg AcAc/dL) a 500 mL 20% glucose or dextrose infusion was used.

A healthy cow was considered as a cow that (i) was declared healthy by the veterinarian in the routine health check 5 to 12 d postpartum, (ii) was not treated by the farmer after calving and prior to the visit of the veterinarian and (iii) had a normal lactation curve without collapses. Reasons to exclude multiparous cows from the database were (i) occurrences of other health problems - such as milk fever, retained placenta, mastitis, lameness or digestive problems that were not routinely checked by the veterinarian, (ii) unknown diagnosis, or (iii) data collection problems.

The cows were housed in groups in no-stalls fully roofed open cowsheds with dried manure bedding, which is the common dairy housing in Israel. The cows could move freely in the open yard and the available space was about 20 $m^2$ per cow.

The cows were milked thrice daily in intervals of eight hours in a conventional milking parlor (small farms: herring bone; large farm: parallel). All cows were fed a TMR according to NRC (NRC, 2001) recommendations. A local feeding center distributed the feed twice daily. In every farm, scattered food was neared (at least) 5 times per day.

Sensors and software

All cows were equipped with an acoustic HR-Tag™ monitoring system (SCR Engineers Ltd., Netanya, Israel), that was fitted to the neck collar of each cow. The tag had 3 functions: (i) identification of the cow based on optical signal transmission; (ii) measurement of the activity level of the animal in real-time, and (iii) measurement of the rumination time of each individual cow in real-time. Activity measurement was based on the signal analysis of the neck movements, and was expressed by a filtered activity index ranging from 0 to 255 units per 2 h. The index was proportional to the number, the intensity and the direction of the neck movements. Rumination time was based on the analysis of the distinctive sounds of regurgitation and rumination recorded by a microphone. Rumination time was expressed as minutes of rumination/2 h. The rumination time and head movement data signals were stored in the memory of the logger in intervals of 2 h. Every milking, milk yield was recorded by electronic milk meters (Free Flow™, SCR Engineers Ltd., Netanya, Israel). All data were transferred automatically during each milking to the herd management software (DataFlow, SCR Engineers Ltd., Netanya, Israel).

Reports in Excel (Microsoft Office Excel 2007, Microsoft, Redmond, Washington, U.S.A.) were extracted daily from the DataFlow software. One report included the 2 h data for rumination time and activity of all cows. Another report included the milk yield per milking session of all cows.

All diagnoses, treatments and vaccinations were recorded using the same definitions and coding schemes and entered into the herd management program NOA (Hebrew acronym for ‘Managing the National Dairy Herd’; Israeli Cattle Breeders Association, Caesarea, Israel), which was also connected to the herd management software. Reports in Excel were extracted weekly from the NOA software and included diagnoses, treatment dates, calving dates and lactation numbers.

Database building

The data were normalized according to the day of the routine health check by the veterinarian. For rumination time and activity, a daily sum of 2 h data was calculated for every cow. For milk yield, a daily sum of the three milking sessions was calculated for every cow.

Model Design

The model aim was to detect ketosis based on behavioural and performance data. The model inputs (rumination time, activity and milk yield) were compared to the dichotomous output variable ‘HealthStatus’, which indicated if the cow was ketotic or healthy.

A logistic regression model was constructed because it can handle categorical variables and it provides a risk probability between 0 (healthy cow) and 1 (sick cow). The logistic regression model used a combination of the $n$ model variables in order to fit the response variable $z$ (Hosmer and Lemeshow, 2000). The model was developed with MatLab software (MATLAB, The MathWorks Inc., Natick, MA, USA). Before entering the logistic regression model, each model input variable (var) was transformed to a uniform scale [0-1], using Equation 1. The general logistic regression equations are presented in Equation 2 and 3. The cut-off threshold for classification as healthy or ketotic was set at 0.5.

$$xrescaled = (var - minimum(var)) / (maximum(var) - minimum(var)) \quad \text{(Equation 1)}$$

$$f(z) = (1 + e^{-z})^{-1} \quad \text{(Equation 2)}$$

$$z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k \quad \text{(Equation 3)}$$

Model Calibration and Validation

In a first step, the model was calibrated on the database of each farm separately. Two third of the sick cows and an equal number of healthy cows were randomly selected. In order to overcome the random selection effect, this procedure was repeated 100 times and the average values of the coefficients in Equation 3 were used for model validation. Validation was done on farm level on all cows with the average coefficients obtained after 100 repeated calibrations.

Then, the model was calibrated on all farm data, using the same calibration procedure as described above. Validation was done on farm level on all cows with the average coefficients obtained after 100 repeated calibrations.

In total, 706 cows (203 cows clinically diagnosed with ketosis and 503 healthy cows) were included in the database for model calibration and validation.

Accuracy, specificity, and sensitivity were used as performance measures (scale 0-1) for the model. Accuracy was defined as the proportion of cows, both sick and healthy, that was correct classified by the model. Specificity was defined as the proportion of healthy cows classified as healthy by the model. Sensitivity was defined as the proportion of sick cows classified as sick by the model.

## Results and Discussion

Table 1 shows the accuracies for logistic regression model calibration and validation on i) each of the 4 farms and ii) on a proportional number of cows from each farm one day before diagnosis and treatment. Within-farm accuracy (diagonal), ranging from 0.74 to 0.79, is higher than between-farm accuracy (not on diagonal), ranging from 0.49 to 0.72, in all farms. When model calibration was done on a proportional number of cows from each farm, the validation accuracies ranged from 0.68 to 0.74 across farms.

Table 1. Tabular overview of accuracies (acc) for logistic regression model calibration and validation on four different farms (1-4) and on a combination of the four farms (All) one day before diagnosis (HS - HealthStatus: K - ketotic; H - healthy) and treatment. The total number ($N_{Tot}$) of ketotic (K) and healthy (H) cows in each farm are presented in the third column.

| | | | | Calibration dataset | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Farm 1 | Farm 2 | Farm 3 | Farm 4 | All |
| | Farm | HS | $N_{Tot}$ | **acc** | **acc** | **acc** | **acc** | **acc** |
| Validation dataset | Farm 1 | K | 121 | **0.74** | 0.62 | 0.49 | 0.56 | 0.68 |
| | | H | 309 | | | | | |
| | Farm 2 | K | 29 | 0.64 | **0.77** | 0.70 | 0.66 | 0.70 |
| | | H | 46 | | | | | |
| | Farm 3 | K | 33 | 0.69 | 0.56 | **0.79** | 0.53 | 0.74 |
| | | H | 61 | | | | | |
| | Farm 4 | K | 20 | 0.72 | 0.70 | 0.66 | **0.75** | 0.73 |
| | | H | 87 | | | | | |

*Two third of the ketotic cows and an equal number of healthy cows were used for calibration. The model was validated on the average coefficients obtained after 100 repeated calibrations.*

Within-farm accuracy is higher than between-farm accuracy, demonstrating that there are between-farm differences, despite the fact that all farms have similar housing and veterinary attention. Between-farm differences could be climate, distances to the milking parlor or management practices. For example, Farms 3 and 4 were located in a warmer and drier climate zone of the country and in Farm 1 the walking distance to the milking parlor was bigger. These differences can affect either performance or activity or both.
Table 2 shows the specificities and sensitivities for logistic regression model calibration and validation on i) each of the 4 farms and ii) on a proportional number of cows from each farm one day before diagnosis and treatment. When calibration was performed on the data of farm 1 (big farm) and validation on each farm separately the specificity ranged from 0.63 to 0.72 and the sensitivity ranged from 0.65 to 0.78. The within-farm specificity and sensitivity were higher than the between-farm specificity and sensitivity. When calibration was performed on the small farms (2, 3, 4), specificities ranged from 0.32 to 0.74 and sensitivity ranged from 0.64 to 0.93.  When calibration and validation were performed on data of the same farm, within-farm specificity ranged from 0.71 to 0.74 and within-farm sensitivity ranged from 0.78 to 0.90.

Table 2. Tabular overview of specificities (spec) and sensitivities (sens) for logistic regression model calibration and validation on four different farms (1-4) and on a combination of the four farms (All) one day before diagnosis (HS - HealthStatus: K - ketotic; H - healthy) and treatment. The total number ($N_{Tot}$) of ketotic (K) and healthy (H) cows in each farm are presented in the third column.

| | Farm | HS | $N_{Tot}$ | Calibration Farm 1 spec | Farm 1 sens | Farm 2 spec | Farm 2 sens | Farm 3 spec | Farm 3 sens | Farm 4 spec | Farm 4 sens | All spec | All sens |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Validation | Farm 1 | K | 121 | **0.72** | **0.78** | 0.51 | 0.91 | 0.32 | 0.93 | 0.41 | 0.93 | 0.68 | 0.67 |
| | | H | 309 | | | | | | | | | | |
| | Farm 2 | K | 29 | 0.63 | 0.65 | **0.73** | **0.84** | 0.65 | 0.78 | 0.59 | 0.76 | 0.72 | 0.68 |
| | | H | 46 | | | | | | | | | | |
| | Farm 3 | K | 33 | 0.71 | 0.65 | 0.36 | 0.92 | **0.74** | **0.88** | 0.33 | 0.91 | 0.77 | 0.68 |
| | | H | 61 | | | | | | | | | | |
| | Farm 4 | K | 20 | 0.72 | 0.70 | 0.71 | 0.64 | 0.66 | 0.65 | **0.71** | **0.90** | 0.75 | 0.66 |
| | | H | 87 | | | | | | | | | | |

*Two third of the ketotic cows and an equal number of healthy cows were used for calibration. The model was validated on the average coefficients obtained after 100 repeated calibrations.*

The performance of the model should not be judged separately for specificity and sensitivity. Only when both specificity and sensitivity are high, the model can be considered robust. When the model was calibrated on data of the big farm (Farm 1) or on data of all farms together, robustness seems to be satisfactory, with small ranges for within-farm specificity and sensitivity. However, when the model was calibrated on a relatively small number of cows (farms 2, 3 and 4), specificity and sensitivity ranges (Table 2) were greater in these farms than when calibrated on data from farm 1 or from all farms. This indicates that a model calibrated on a higher number of cows is more robust than models calibrated on a lower number of cows.

Sensitivity and specificity are always a trade-off between each other. The selection of the cutoff threshold in the logistic regression model influenced the sensitivity and specificity of the model. The cut-off threshold for the model was set at 0.5. Future research could reveal the optimal farm-specific cut-off thresholds.
A lower specificity means that more healthy cows will be presented to the veterinarian. A lower sensitivity on the other hand implies that some ketotic cows were missed by the model. Because ketosis is associated with significant milk losses (Rajala-Schultz *et al.*, 1999; Bareille *et al.*, 2003), a decrease in reproductive performance (Gillund *et al.*, 2001; Walsh *et al.*, 2007) and an increased incidence of other health problems (Dohoo and Martin, 1984; LeBlanc *et al.*, 2005), it is important to detect sick cows as soon as possible. A higher sensitivity is therefore preferred, even on the account of a lower specificity, because treatment for ketosis (i) can be applied by the farmer, (ii) is a

relatively cheap medicine and (iii) has a low risk of side effects, such as hyperventilation, salivation or depression (Nielsen and Ingvartsen, 2004).
Cows that were not detected by the model (1-sensitivity) would most likely be detected by the model the next day or 2 and treated then. One or 2 days delay is, however, undesirable. Nevertheless, the model is still alarming in time without the presence of the veterinarian. Ketotic cows that might be missed in the routine health check and therefore were not treated, might recover spontaneously. Simensen *et al.* (1990) reported a spontaneous recovery in 40% of the ketotic cows. However, ketotic cows might not reach full potential (Rajala-Schultz *et al.*, 1999).
In this study, the diagnosis of the veterinarian in the routine health check was used as reference. Unlike other studies (Hansen *et al.*, 2003; DeVries *et al.*, 2009), the disease was not induced in this study. Therefore, the exact timing of the disease occurrence is not known; the disease might have developed earlier. In optimal circumstances, the cows should be checked for ketosis every day after calving to reveal the occurrence of ketosis more accurately. However, no test is 100% correct, so some cows might be misclassified (category sick while being healthy or vice versa). Another possibility is to induce the disease, but in this case only a small number of cows can be analyzed.
In real farm conditions, also other diseases than ketosis occur after calving. In this study, only strictly healthy cows and ketotic cows were analyzed. Some of the ketotic cows had a coincident illness, mostly metritis and to a lesser extent mastitis. Possibly other diseases might show up as ‘ketotic‘ as well in this model. It is, however, more important that the cow is detected as ‘sick‘ than that she is correct diagnosed. The farmer can bring the cow to the veterinarian for an exact diagnosis.
Several ketosis detection methods were described in literature, focusing on performance variables, behaviour variables and management factors. Lark *et al.* (1999) found significant deviations in milk yield from 3 d before the diagnosis in ketotic cows using a time series model of daily milk yield. They discuss, however, that deviations from milk yield forecasts are not sufficiently sensitive and specific predictors of clinical ketosis in their own. Bareille *et al.* (2003) applied a mixed linear model and found that on the day of diagnosis, ketosis was associated with a reduced milk production and feed intake. Edwards and Tozer (2004) analyzed the short-term effects of disease on steps per hour and milk yield based on a repeated measures regression model. Their results suggest that ketosis might be detected 8 days before diagnosis based on walking activity and 6 days before based on milk yield. Nir (Markusfeld) (2003) found by using logistic regression that heavier cows at dry-off, cows that calved in summer, cows that suffered from uterine diseases or cows that were in a negative energy balance were more likely to develop clinical ketosis. Stengärde *et al.* (2012) showed that a large herd size, a high maximum daily milk yield in multiparous cows, keeping all dry cows in one group and not cleaning the feeding platform daily were risk factors for a high herd incidence of ketosis by using a multivariable logistic regression model.

To our knowledge, this study is the first attempt to use existing farm data on behaviour and performance from no-stalls fully roofed open cowshed farms in the automatic detection of ketosis. Two behaviour variables (rumination time and activity) and one performance variable (milk yield) were measured in all farms and included in the logistic regression model. Extending this model with milk component sensor data and factors regarding housing, management, feed and so on, could increase the sensitivity and specificity of the detection model presented in this study.

The practical application of the model developed in this study could be an automatically created list of cows at risk for ketosis. In practice, a two month period could be used as a calibration database. In future research the developed model can be improved, variables from other sensors can be added or other models can be explored to reach a higher sensitivity and specificity.

## Conclusion

The combination of existing farm data including rumination time, activity and milk yield was used to develop a model to detect of post-calving ketosis. Farm-level models and a general model using data of four farms were developed and validated. Within-farm accuracy is higher than between-farm accuracy. Between-farm differences affect model robustness.

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**Economic comparison of dairy farms with an automatic milking system and a conventional milking system**

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**Abstract**

Changing from a conventional milking system (CMS) to an automatic milking system (AMS) necessitates a new management approach and a corresponding change in labor tasks. Together with labor savings, AMS farms have been found to have higher capital costs, primarily because of higher maintenance costs and depreciation. Therefore, it is hypothesized that AMS farms differ from CMS farms in capital/labor ratio and possibly their technical efficiency. The technical efficiency measures the ability of firms to use inputs (e.g., capital and labor) to produce outputs (e.g., revenues). The current study used actual farm accounting data from dairy farms in the Netherlands with an AMS and a CMS to investigate the empirical substitution of capital for labor in the AMS farms and to determine if the technical efficiency of the AMS farms differed from the CMS farms. The technical efficiency estimates were obtained with data envelopment analysis.

The 63 AMS farms and the 337 CMS farms in the data set did not differ in general farm characteristics such as the number of cows, number of hectares, and the amount of milk quota. AMS farms have significantly higher capital costs (€12.71 per 100 kg milk) than CMS farms (€10.10 per 100 kg milk). Total labor costs and net outputs were not significantly different between AMS and CMS farms. A clear substitution of capital for labor with the adoption of an AMS could not be observed. Although the AMS farms have a slightly lower technical efficiency (0.76) than the CMS farms (0.78), a significant difference in these estimates was not observed. This indicates that the farms were not different in their ability to use inputs (capital, labor, cows and land) to produce outputs (total farm revenues). The results indicate that the economic performance of AMS and CMS farms are similar. What these results show is that other than higher capital costs, the use of AMS rather than a CMS does not impact farm efficiency.

**Keywords**: automatic milking, dairy, economics, data envelopment analysis, technical efficiency

## Introduction

The number of dairy farms using an automatic milking system (AMS) is increasing rapidly, especially in northwest Europe. The first AMS was introduced on commercial dairy farms in the Netherlands in 1992, and by the end of 2009 worldwide over 8,000 commercial farms used one or more AMS (De Koning, 2010). In the Netherlands, almost 2,000 farms (10%) have an AMS (De Koning, 2010), and that number continues to increase.

Research on the economic consequences of using an AMS and the economic comparisons between farms with an AMS and a conventional milking system (CMS) have been mainly based on normative models, and focused on the profitability of the investment. Hyde and Engel (2002) found that the investment in automatic milking was cost effective. In contrast, the study by Dijkhuizen *et al.* (1997) concluded that investment in an AMS was not cost effective, and Rotz *et al.* (2003) concluded that an AMS does not offer an economic benefit for most farm scenarios in the US. These normative models use different methods and assumptions and are completed for different countries. The only empirical economic comparison between farms with an AMS and CMS was conducted by Bijl *et al.* (2007) who concluded based on data from 2003 that CMS farms had more money available for rent, depreciation, interest, labor, and profit than AMS farms. Since that time no additional economic comparisons based on empirical research have been reported. These limited and conflicting results, based on a large difference in assumptions, make it difficult to determine whether AMSs are good investments.

Changing from a CMS to an AMS necessitates a new management approach (Svennersten-Sjaunja and Pettersson, 2008) and a corresponding change in labor tasks. Milking with an AMS eliminates some labor tasks, but new labor tasks are required. Field data on labor savings is limited. Labor savings recorded were around 20% on average, with a large variation among farms (Mathijs, 2004). AMS farms have been found to have higher capital costs, primarily because of higher maintenance costs and depreciation (Bijl *et al.*, 2007). Because of the expected substitution of capital for labor on farms with the adoption of an AMS, it is expected that AMS farms differ from CMS farms in capital/labor ratio and possible their technical efficiency. Previous research has not determined whether adoption of an AMS empirically results in the substitution of capital for labor. Although technical efficiency of dairy farms have been measured previously (e.g., Oude Lansink *et al.*, 2002; Stokes *et al.*, 2007), no emphasis has been placed on the differences in efficiency among dairy farms with an AMS and CMS.

The objective of this study is to compare quantities of labor and capital of farms with a CMS and AMS to determine if empirical substitution of capital for labor has occurred from CMS to AMS. The second objective is to estimate and compare the technical efficiency of farms with an AMS and CMS. These objectives will be met by the empirical analysis of farm accounting data.

## Material and Methods

Data

Data for this study originated from a Dutch accounting agency (Accon AVM, Leeuwarden, the Netherlands). A database was available containing farm accounting data from the year 2010 for 408 Dutch dairy farms having either an AMS or a CMS. Three farms were excluded because of incomplete information on labor, one farm was excluded because of reporting an extremely small quota quantity in comparison with the other farms in the dataset, and four farms with an AMS were excluded because these farms had an average of 125 cows per automatic milking unit, which can be an indication of incomplete adoption of automatic milking, since each AMS unit cannot milk those number of cows recorded. The final dataset consisted of 400 dairy farms (63 AMS farms and 337 CMS farms). The database included information on revenues (e.g., revenues from milk and other farm activities), depreciation (e.g., on buildings and machinery), fixed costs (e.g., costs for maintenance of buildings and machinery), variable costs (e.g., costs for feed, energy and water) and general farm information such as the number of cows, number of hectares, amount of milk quota and the available full-time equivalent (FTE). All revenues and costs are expressed per 100 kg of milk (by using the total amount of milk quota), and subsequently these numbers were analyzed with a t-test to compare CMS and AMS farms. General farm information was analyzed with a t-test to compare CMS and AMS farms. Data preparation and the analysis was performed using SAS version 9.2 (SAS Institute Inc., Cary, NC).

Data Envelopment Analysis

The technical efficiency measures the ability of firms to use inputs (e.g., capital and labor) to produce outputs (e.g., revenues). The technical efficiency of the farms was identified using data envelopment analysis (DEA), which is a nonparametric method of calculating the efficiency of individual decision-making units (DMU). DEA compares the levels of inputs and outputs for a given DMU against all other DMUs in the dataset to determine which DMUs are producing at efficient levels relative to the entire group. The concept of DEA efficiency can best be illustrated with a simple example (Figure 1). Herds A, B, and C are DEA-efficient as they use the least amount of labor and capital to produce one unit of output. The line connecting A, B and C is called the ‘efficient frontier’. An estimate of technical efficiency can be obtained for each herd by projecting a ray from the origin to each herd point, like point D. An estimate of technical efficiency is then calculated as the ratio of the distances from the origin to point x, divided by the distance from the origin to point D. An efficiency estimate is between 0 (inefficient) and 1 (efficient), and indicates the percentage by which both inputs of an efficient DMU could be lower to produce the same level of output as an inefficient DMU (Cooper *et al.*, 2000). For example, an efficiency of 0.80 would imply that the use of each input is lower by 20% for DEA efficient production.

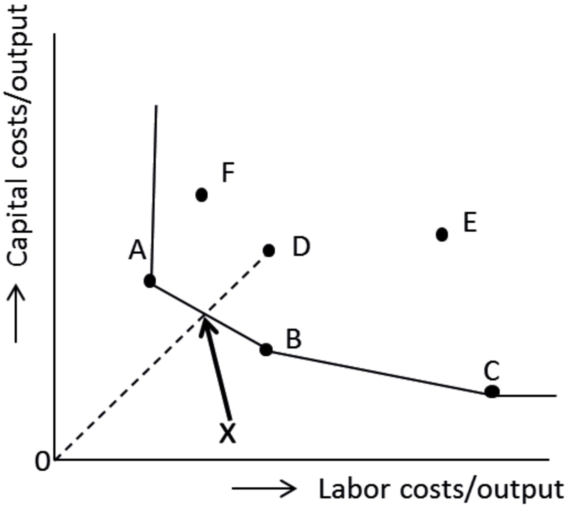


Figure 1: Example of a data envelopment frontier for 6 farms using labor and capital as inputs and producing 1 output. The farms A, B, C have the lowest combination of labor and capital costs, and form therefore the frontier. The technical efficiency of farm D was calculated as the ratio of the distances from the origin to point x, and the origin to point D.

One of the main drawbacks of the DEA is that its results may be affected by the sampling variation suggesting that distances to the frontier are likely to be over or underestimated. In order to assess the sampling variability of the results, 95-percent confidence intervals were constructed using the bootstrap algorithm specified in Simar and Wilson, 1998, 2000. The basic idea of the bootstrap algorithm is that if the data are viewed as a set of random draws from an underlying population, random draws from the sample are also random draws from the population. Therefore, the known bootstrap distribution will mimic the original unknown distribution if the known data generating process is a consistent estimator of the unknown data generating process. After many simulations, a distribution of efficiency scores is obtained and represents an estimate of the true distribution.

To allow capital for labor substitution an AMS DEA efficiencies were estimated. The capital items were defined as the number of cows, total number of hectares used by the dairy farm, and other total capital costs and then total labor costs are defined as input variables. All other inputs were subtracted from output to arrive at a net output consisting of output minus materials. Total capital costs included all expenses and depreciation on buildings, machinery and equipment. Total labor costs included the costs for customer work, paid labor and calculated costs for own labor, which was calculated by using the available FTE and assuming 52 weeks, 40 hours a week at the rate of

€18/h (Huijps *et al*., 2008). The net outputs of the farm are calculated by summing all revenues from farm activities (milk revenues, livestock revenues, revenues from other farm activities, and miscellaneous revenues) minus the total costs for materials, such as costs for feeding, breeding, healthcare, energy and water.
All calculations on the technical efficiency were performed using the statistical computing software R which was supplemented by the efficiency computational software library FEAR 1.0 (Wilson, 2008). For calculating the efficiency estimates, an input orientation model with a single output and four inputs was applied using a variable returns to scale assumption. The FEAR software allows bootstrapping results and adjusting for bias estimates (because of the upper bound of 1.00 on efficiency) as presented in Simar and Wilson (1998). For this study 2,000 number of bootstraps were run.

## Results and Discussion

Total land use, milk quota, total FTE and number of cows did not differ between the AMS and CMS farms (Table 1). Because of this observation, all farms were included in one dataset for calculation of the technical efficiency scores, and differences in the technical efficiency scores can be interpreted as the result of variables not included in the DEA model, most likely the milking system used.

Table 1: Overview of general farm information of farms with an automatic milking system (AMS) and a conventional milking system (CMS).

| | AMS | CMS | p-value |
|---|---|---|---|
| Total land use (ha) | 71 | 70 | 0.7737 |
| Pasture (ha) | 57 | 59 | 0.4666 |
| Milk quota (kg) | 897,426 | 903,827 | 0.9019 |
| Nr of dairy cows | 110 | 113 | 0.6819 |
| Milk per cow (kg) | 8,297 | 8,111 | 0.1061 |
| Fat (%) | 4.47 | 4.44 | 0.1677 |
| Protein (%) | 3.48 | 3.53 | 0.0006 |
| Total labor FTE[1] | 1.54 | 1.51 | 0.6237 |
| Cow/ FTE | 74 | 78 | 0.3587 |
| Milk/ FTE (kg) | 597,615 | 622,947 | 0.4772 |

[1] FTE = full-time employee.

The number of FTE was not different between AMS and CMS farms (Table 1), which is in contrast with Bijl *et al*. (2007) who found a lower number of FTE on AMS farms. A possible explanation for this difference could be that the farmers who invested in

2003 (Bijl *et al*., 2007) invested to lower the amount of labor and to have more free time, as described by Mathijs (2004). Farms in the current dataset may be more focused on increasing size than on having more free time thus showing no decrease in FTE as they plan and transition to more cows. Many more dairy farmers may be focused on increasing their herd size than in 2003 because of the announced abolishment of the milk quota in 2015 and the expected need to increase in size to remain profitable after that year. This movement to an increased size probably means that any released labor when starting milking automatically is put into other farm activities that coincides with size increase. As a result there was no decrease in FTE on the observed AMS farms. Unfortunately, the dataset did not include any information about possible expansion plans, and therefore this explanation could not be confirmed. Another explanation for the almost equal FTE, could be that labor savings after adoption of an AMS are not as large as first expected. It is clear that some labor requirements are reduced, but those may be replaced with other increased labor requirements, which results in the net labor change being ambiguous. Comprehensive recent field data on possible labor savings is lacking (Sonck, 1995; Mathijs, 2004). In addition, the FTE estimated available in the current dataset were provided by the farmers themselves and these farmers may record a full FTE regardless of the actual hours worked each year, which may be reduced with an AMS but still considered full time by most. Therefore, given these considerations, it is difficult to conclude, based on the information on FTE in the current database, whether adoption of AMS led to a decrease in labor used.

Table 2. Average of the input and output variables (all in €/100 kg milk) used for the efficiency analysis for dairy farms with an automatic milking system (AMS, n=63) and a conventional milking system (CMS, n=337) in 2010.

| | | AMS | CMS | p-value |
|---|---|---|---|---|
| Capital costs | Expenses on buildings | 1.57 | 1.58 | 0.9215 |
| | Depreciation on buildings | 2.69 | 2.51 | 0.5643 |
| | Expenses on machinery and equipment | 4.57 | 3.48 | 0.0029 |
| | Depreciation on machinery and equipment | 3.88 | 2.53 | <0.0001 |
| Labor costs | Customer work | 2.89 | 2.96 | 0.7406 |
| | Paid labor | 0.46 | 0.70 | 0.1165 |
| | Own labor | 6.95 | 7.06 | 0.8677 |

| | | | | |
|---|---|---|---|---|
| Materials costs | Roughage | 0.70 | 0.82 | 0.2866 |
| | Concentrates | 6.51 | 6.51 | 0.9935 |
| | Substitutes for concentrates | 0.50 | 0.77 | 0.0131 |
| | Milk products | 0.29 | 0.22 | 0.0112 |
| | Minerals | 0.34 | 0.27 | 0.1085 |
| | Fertilizer and pesticides | 1.42 | 1.48 | 0.1270 |
| | Breeding and healthcare | 2.22 | 2.16 | 0.7792 |
| | Energy and water | 1.58 | 1.22 | <0.0001 |
| | Miscellaneous | 3.61 | 3.54 | 0.7651 |
| Revenues | Milk revenues | 39.72 | 40.44 | 0.7528 |
| | Livestock revenues | 2.97 | 2.96 | 0.9706 |
| | Other farm activities revenues | 1.34 | 1.05 | 0.4506 |
| | Miscellaneous revenues | 0.84 | 0.74 | 0.6067 |
| Net output | Total revenues – total materials | 27.70 | 28.34 | 0.7675 |

Table 2 shows an overview of the inputs and output for the 337 CMS and 63 AMS farms. The capital and labor inputs and the output were expressed per 100 kg of milk to allow comparison across farms. As expected, the total capital costs of AMS farms were significantly higher than for CMS farms. These higher capital costs were mainly due to higher expenses and depreciation on machinery and equipment. These expenses are mostly greater due to the higher maintenance costs because of high replacement rates of AMS. The depreciation is higher not only because of the cost of an AMS but also because AMS units may have shorter economic lives than CMSs. No reliable estimates are available however on the economic lifespan of an AMS, and it would be beneficial to collect and analyze the actual economic lifespan of AMSs to allow more reliable comparisons with CMS farms. Surprisingly, the costs for substitutes for concentrates and milk products were significantly different between AMS and CMS farms, and no explanation for this difference is obvious. The AMS farms had, as expected, significantly higher costs for energy and water (€1.58 per 100 kg of milk) than the CMS farms (€1.22 per 100 kg of milk). As a consequence of not finding a difference in FTE between the AMS and CMS farms, owner labor costs were also not much different between AMS and CMS farms. It was expected that after adoption of an AMS paid labor costs would decrease because these are direct and cash costs for the dairy farmer, in contrast with the owner labor costs; results indicate that paid labor costs were on average almost €0.24 per 100 kg milk lower for AMS farms, but the difference with CMS farms was not significant. Costs for paid labor consists of the expenses of people working (temporarily) on the farm, including household members. There are no differences observed between the AMS and CMS farms in outputs sold or net outputs. The total revenue for AMS and CMS farms were €44.87 and €45.33 per 100 kg milk, respectively, and net outputs for AMS and CMS farms were €27.70 and €28.34 per 100 kg milk. So, from Table 2 it can be seen that AMS farms have higher capital costs, but the net outcome is not different between CMS and AMS farms. This means that small non-significant differences of labor and material costs compensate for the higher capital costs of AMS farms.

Previously, results from normative studies showed that investments in AMS were not cost effective for the Netherlands (Dijkhuizen *et al*., 1997) and the US (Rotz *et al*., 2003). Based on farm accounting data of 2003, it was concluded that the gross margins of AMS and CMS farms did not differ, but by also incorporating costs not directly associated with cattle husbandry or land use (e.g., costs for water, electricity, customer work and maintenance costs for machinery and equipment) it was concluded that CMS farms had more money available for rent, depreciation, interest, labor and profit (Bijl *et al*., 2007). In that study, depreciation was not taken into account, and if depreciation were taken into account, the difference between AMS and CMS farms would have been even greater. The results of the current study show that, by also including depreciation and costs not directly associated with cattle husbandry or land use, the net output of CMS and AMS farms did not differ (Table 2). These results indicate that the economic performance of AMS and CMS farms are similar in 2010 in comparison with year 2003 data. This trend might be explained by the improved technical performance of the AMS and improved supervision of farmers that start milking automatically. This small difference in economic performance between AMS and CMS farms might only be true for farms in northwest Europe, with farms with a relative small size and high labor costs. For the US, the difference in economic performance between CMS and AMS could be larger. The herd size of US dairy farms is larger requiring multiple AMS units, which will make total investment costs, and yearly maintenance costs and depreciation much higher than for a single CMS. Since labor costs in the US are lower than in northwest Europe, total labor costs on a CMS farm would logically be lower than all yearly maintenance costs and depreciation when milking with an AMS. However, empirical data would be needed to substantiate these assertions.

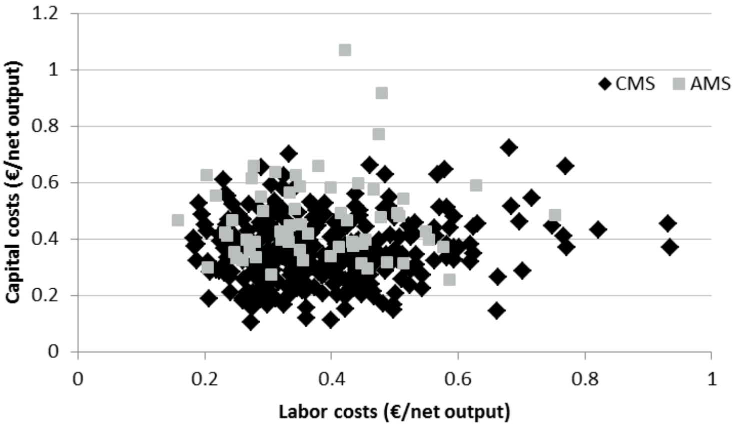


Figure 2: The inputs labor and capital for dairy farms with an automatic milking system (AMS) and a conventional milking system (CMS).

In Figure 2, the total labor and capital costs per net output were plotted for the AMS and CMS farms. No specific pattern for the AMS or CMS farms can be seen. The pattern seen in Figure 2 indicates that no big differences in technical efficiency estimates between AMS and CMS farms were found. The difference in technical efficiency was small (Table 3), with an estimate of 0.78 for CMS farms and 0.76 for AMS farms. Using the confidence intervals of both estimates it must be concluded that this difference is not statistically significantly different. Not finding the substitution of capital for labor and no difference in technical efficiency was probably caused by the almost equal number of FTE for both types of farms. The observed lower amount of paid labor for AMS farms was relatively small to show a clear substitution of capital for labor.

Table 3: Technical efficiency estimates for farms with an automatic milking system (AMS) and a conventional milking system (CMS).

| | Average | Min - Max | Confidence interval (95%) |
|---|---|---|---|
| AMS (n=63) | 0.76 | 0.54 – 0.95 | 0.73 – 0.78 |
| CMS (n=337) | 0.78 | 0.49 – 0.97 | 0.75 – 0.81 |

## Conclusions

The current study used actual farm accounting data from dairy farms in the Netherlands with an automatic milking system (AMS) and a conventional milking system (CMS) to investigate the empirical substitution of capital for labor in AMS farms and to determine if the technical efficiency of AMS farms differed from CMS farms. The 63 AMS farms and the 337 CMS farms in the data set did not differ in general farm characteristics such as the number of cows, number of hectares, and the amount of milk quota, allowing unbiased comparison. AMS farms have significantly higher capital costs (€12.71 per 100 kg milk) than CMS farms (€10.10 per 100 kg milk). Total labor costs and net outputs were not significantly different between AMS and CMS farms. A clear substitution of capital for labor with the adoption of an AMS could not be observed. Although the AMS farms have a slightly lower technical efficiency (0.76) than the CMS farms (0.78), a significant difference in these estimates was not observed. This indicates that the farms were not different in their ability to use inputs (capital, labor, cows and land) to produce outputs (total farm revenues). The results indicate that the economic performance of AMS and CMS farms are similar. What these results show is that other than higher capital costs, the use of AMS rather than a CMS does not impact farm efficiency.

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**The effects of quarter-individual milking in conventional milking parlours on the somatic cell count and udder health of dairy cows**

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## Abstract

The objective of this study was to examine the quarter health status of quarter-individually and conventionally milked cows. Quarter foremilk samples of 84 German Holstein cows were taken every week to determine somatic cell count. Bacteriological examinations and udder palpation were conducted at three different times. The results of the F test showed that the milking system (P=0·0587) and days in milk (P=0·8066) had no significant effects on the quarter health status. On the other hand, lactation (P=0·0396), quarter health status in the previous week (P<0·0001) and trial week (P=0·0061) affected quarter health status significantly.

**Keywords:** Somatic cell count, udder health, quarter-individual milking system, dairy cow

## Introduction

Mastitis is considered to be the disease affecting milk production the most (Bansal *et al*., 2005) and is one of the most costly and prevalent production diseases in the dairy industry worldwide (Seegers *et al*., 2003; Halasa *et al*., 2007). Moreover, mastitis leads to decreased milk quality, increased somatic cell count (SCC), milk production losses, clinical modifications of the udder and other problems related to animal welfare (Seegers *et al*., 2003; Halasa *et al*., 2007). Pathogens are the predominant cause of mastitis (Hamann, 2005). In addition, factors such as udder tissue damage, stage of lactation, parity, nutrition, milking machine, milking routine, weather and housing conditions affect a cow's SCC (Brade, 2001). SCC of milk from healthy quarters is lower than 100000 cells/ml (Urech *et al*., 1999; Hamann, 2005; Sarikaya & Bruckmaier, 2006). Both clinical and subclinical mastitis induce an increase of SCC (Berglund *et al*., 2007) as a result of an inflammatory response to an intramammary infection (IMI) (Schukken *et al*., 2003). Measuring SCC in milk is the standard method for detecting the inflammatory process in the udder and for monitoring udder health (Bruckmaier *et al*., 2004; Jayarao *et al*., 2004). Forsbäck *et al*. (2010) found that the day-to-day

variation at quarter level was 2% for cows without bacteriological findings. This variation is considered to be due to factors not related to inflammation (Klastrup *et al.*, 1987). However, it may also point to the beginning of a more serious and long-lasting inflammatory reaction. To detect this kind of SCC alteration, frequently performed analyses of quarter milk samples are required (Berglund *et al.*, 2007).
The experimental design of the present study had the benefit of comparing two different systems within the same herd over the same time period. The object of this study was to determine and compare the effects on Somatic cell count (SCC) and the health status of quarters of quarter-individually (MULTI) and conventionally milked (CON) cows.

## Material and methods

<u>Animals and analysis of foremilk samples</u>
A total of 84 German Holstein cows, randomly divided into two groups, were included in the study. Both groups were housed in the same freestall barn and were fed the same mixed ration. The evaluation period consisted of 27 trial weeks or until a cow reached the 305$^{th}$ d in milk (DIM) respectively. Parities ranged from the first to the seventh lactation. Only cows up to the 120 DIM at the onset of the trial and without clinical indications of udder inflammation were considered. During the trial, group 1 was milked with a conventional (CON) and group 2 was milked with a quarter-individual (MULTI) milking system. Milking operations were performed by two milkers in each group. Pre-milking procedures included fore-stripping and cleaning of the teats as well as teat dipping at the end of milking. Teat cups were flushed in both milking systems with water and disinfectant after each cow being milked. Back flush, meaning the cleaning of only the interior surface of the teat cups, was used in the CON milking, whereas in the MULTI milking, the teat cups were purified on the inside and outside. Quarter foremilk samples were taken every week to analyse the somatic cell count (SCC). Before milking, all teats were prepared using disinfectant tissues until no dirt was visible. The unpreserved samples were stored in a cool box at 4–6 °C for a maximum of 1 d. Determination of SCC was performed with a fluorescent-based electronic cell counter (Fossomatic 5000, FOSS, Hillerød, Denmark). Bacteriological examinations and udder palpation were conducted at three different times.

<u>Milking Systems</u>
Both used tandem milking parlours had a low-level milk line and were equipped with milk meters. The conventional milking system (CON, GEA Farm Technologies, Germany) had a system vacuum level of 40 kPa, a pulsation rate of 60 cycles/min and a pulsation ratio of 60:40. The quarter-individual milking system MultiLactor®) (MULTI, Siliconform GmBH (Germany) had a vacuum level at 37 kPa (MULTI) a pulsation rate of 60 cycles/min and a pulsation ratios of 65:35. The MultiLactor® used single-tube guidance with silicon liners and periodic air inlet under the teat end

(BioMilker®). Furthermore, MULTI has a different concept in terms of pulsation, called sequential pulsation. In contrast to alternative pulsation, where pulsation starts in two teat cups at the same time, alternating with the remaining two teat cups starting a half pulsation cycle duration later, sequential pulsation works with four pulsators. The MultiLactor® system also applied a special pre-stimulation (50 s), with a mechanical actuator stimulating all four teats with vibrating movements of the long milk tubes. CON was equipped with a milking cluster (Classic 300, Westfalia®) and a claw volume of 300 ml as well as silicon liners. Teat cups were detached when the milk flow at udder level was below 300 g/min (CON) and 200 g/min (MULTI), respectively. Subject of the experiment were the milking systems as a whole as they are intended to be used by the manufacturers. These were the settings that ensure that the milking systems functioned optimal and reliably.

Statistical analysis

The study was based on a data set consisting of 5455 measurements. Data from the eleventh trial week could not be included in the study because of a malfunction in the dairy management software. Quarter health status can take discrete values in two different states: healthy or suspicious. Therefore,quarter health status was coded in binary terms and assumed to be Bernoulli-distributed. A generalized mixed linear model was used to estimate the influence of several factors and co-variables on quarter health status. SAS (Version 9.2, SAS Institute Inc., Cary NC, USA) was used for all of the following statistical analysis. The data were evaluated with the GLIMMIX procedure, using an inverse logit-function as a link function.

(1) $P(Y=0) + P(Y=1) = 1$ probability

(2) $E(\underline{y}_i) = \mu_i = \dfrac{\exp(\eta_i)}{1+\exp(\eta_i)}$; $\exp(\eta) = e^{\eta}$ expected value

(3) with $\eta_{ijklqw} = \mu + MS_k + LN_l + SB_j + QA_q + TW_w + D(LN_l)t + Mm + C_i + e_{ijklqw}$

with $\eta_{ijklqw}$: linear predictor for udder quarter health status;
$\mu$: general mean;
$MS_k$: fixed effect of the *k*-th milking system; (*k*=1,2)
$LN_l$: fixed effect of the *l*-th lactation; (*l*=1,2,3)
$SB_j$: fixed effect of the *j*-th quarter health status in the previous week; (*j*=1,2)
$QA_q$: fixed effect of the *q*-th quarter; (*q*=1,2,3,4)
$TW_w$: fixed effect of the *w*-th trial week; (*w*=1,...,27)

$D(LN_l)$: co-variable (DIM t nested with lactation *l*);
M: co-variable (milk yield m);
$C_i$: random effect of *i*-th cow; (*i*=1,...,59)
$e_{ijklqw}$: residual.

The emphasis in this analysis lay on possible differences between the examined milking systems. Global hypotheses for the fixed effects and co-variables were tested with F tests at a significance level of $\alpha$=0·05. Within the above mentioned effects, differences were tested by pair-wise t tests between levels and the results were presented as Least Square Means (LSM)±SE. The SIMULATE option was used to keep a global significance level of $\alpha$=0·05 when adjusting P-values for multiple testing.

## Results and Discussion

SCC and variation over time

The median of SCC was 32000 cells/ml (25% quantile: 14000 cells/ml and 75% quantile: 97000 cells/ml), calculated for MULTI and CON together. The median of MULTI (n=2603) was 40000 cells/ml (25% quantile: 15000 cells/ ml and 75% quantile: 121000 cells/ml) and the median of CON (n=2852) was 27000 cells/ml (25% quantile: 13000 cells/ml and 75% quantile: 74000 cells/ml) in foremilk samples during the trial period. At the beginning, median values of both groups were close to each other (<70000 cells/ ml). Both groups displayed an increase of SCC with increasing duration of the trial (Fig. 1).

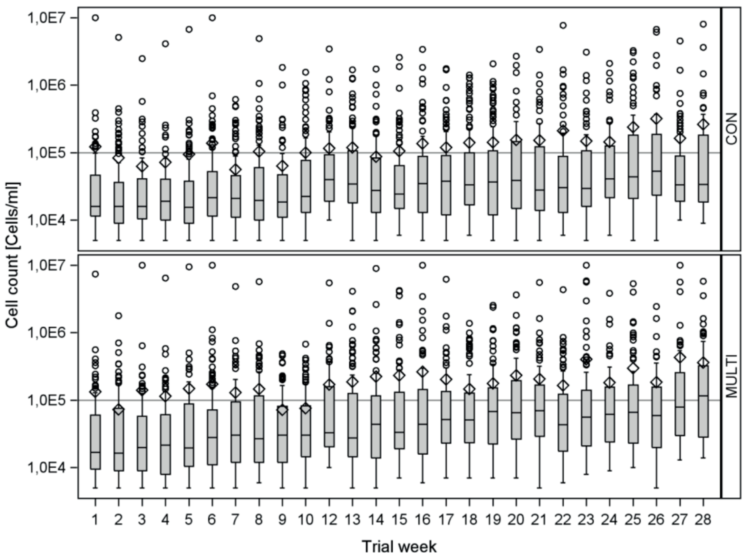


Figure 1: Course of cell count (cells / ml) for MultiLactor ® (MULTI) and conventional milking system (CON) over the experimental period

MULTI and CON did not permanently exceed the 100000 cells/ml threshold during the trial period, respecting the median, with the exception of the last trial week (MULTI). Overall, the examination results demonstrated that the share of healthy quarters amounted to 75·78% (n=4134 quarters) and the share of suspicious quarters amounted to 24·22% (n=1321 quarters), with respect to the SCC in both groups. The percentage of healthy quarters (SCC<100000 cells/ml) was 70·92% for MULTI (n=1846 quarters) and 80·22% for CON (n=2288 quarters) during the entire trial period. The percentage of suspicious quarters (SCC>100000 cells/ml) was 29·08% for MULTI (n=757 quarters) and 19·78% for CON (n=564 quarters) considering all foremilk samples, accordingly. The relation between SCC measured at the udder level and IMI must be interpreted with caution, because an increase in SCC associated with an IMI in one quarter may be reduced by a dilution effect, if all other quarters are found to be bacteriologically negative (Djabri *et al*., 2002). Therefore, the authors decided to collect foremilk samples exclusively at the quarter level. Several authors (Urech *et al*., 1999; Hamann, 2005; Sarikaya & Bruckmaier, 2006) used a SCC threshold value of 100000 cells/ml to distinguish between healthy and suspicious quarters. In contrast, Dohoo & Leslie (1991) suggested that the exceeding of SCC above a threshold value of 200000 cells/ml was optimal for making predictions of new IMI. The present study was in line with the lower SCC threshold because SCC values which are already over 100000 cells/ml may be a sign of the stress related to the housing conditions, or an inflammatory process in the mammary gland. There was a tendency for both groups (Fig. 1) to show a rise of SCC over the duration of the trial. This result might partly be due to the mechanical load on the udder tissue with increasing DIM. Another factor may well be that milk yield decreased during lactation and the dilution effect was reduced. It has been demonstrated by Schepers *et al*. (1997) that SCC increases more at the end of lactation in cows with parity >1. Laevens *et al*. (1997) reached similar conclusions. They observed that first-lactation cows had a constant excretion of cells and older cows did not increase cell output until >240 d postpartum. The present study also demonstrated that DIM had no significant influence on quarter health status, although there is a tendency for a slow increase in SCC with increasing time during lactation. The DIM effect interfered with the trial-week effect to some extent, as the examined cows were in a similar stage of lactation during the entire duration of the trial. Milk from quarters with mild health disorders had a more variable SCC. Fluctuations in SCC, even if the SCC on the quarter level was below 100000 cells/ml, appeared to influence milk synthesis (Berglund *et al*., 2007). Furthermore, Berglund *et al*. (2007) showed that milk production and milk composition per quarter, within a pair of quarters, was similar if the quarters were healthy and if compared within the front and rear quarters, respectively. The present study showed that left front quarters had a significantly higher probability of becoming suspicious than the other three quarters. The increased SCC in left front quarters can be safely assumed to result from the sequence of taking foremilk samples. Left front quarters usually were the first quarters with the highest foremilk content and least dilution, with cistern or even alveolar milk.

Factors influencing quarter health status

The results of the F test stated that milking system (P=0·0587) and DIM (P=0·8066) had no significant influence on quarter health status. On the other hand, lactation (P=0·0396), quarter health status of the previous week (P<0·0001), quarter (P=0·0023), trial week (P=0·0061) and milk yield (P<0·0001) affected the quarter health status significantly. The estimated probabilities of the occurrence of a suspicious quarter were 19·97% (CON) and 31·72% (MULTI). Therefore, the tendency of the occurrence of a suspicious quarter was higher for quarter-individually milked cows compared with conventionally milked cows. But the test of differences of LSM showed no significant differences (Adj P=0·0585) between CON and MULTI. The estimated probability that a quarter which had SCC>100000 cells/ml in the previous trial week was suspicious once again in the following trial week was 50·52%. In contrast, the probability that a healthy quarter became suspicious in the next trial week was relatively low (10·20%). As expected, the quarter health status of the previous week showed significant differences (Adj P<0·0001) between health status 0 (healthy) and 1 (suspicious). In the authors' view, one possible explanation for the result that there were no significant differences between MULTI and CON is the fact that the systems as a whole were analysed, and not their individual components. Dufour *et al.* (2011) analysed numerous studies with regard to the effect of management practices on SCC. They found that many authors reported on associations between different components of the milking system and SCC. Dufour *et al.* (2011) expressed that the results from earlier studies were very unequal. They suggested that a milking system can only be correctly assessed in its entirety. The estimated probability that quarters became suspicious during the first lactation was 12·51%. With an increasing number of lactation, the probability for a quarter to become suspicious increased clearly (2nd lactation: 32·73% and 3rd lactation: 36·19%). Comparisons showed that significant differences concerning the number of lactation existed between 1st and 2nd (Adj P=0·0038) lactation as well as between 1st and 3rd (Adj P=0·0019) lactation. On the other hand, no significant differences (Adj P=0·9258) between 2nd and 3rd lactation could be detected. Left front quarters became suspicious with a probability of 30·93% during the trial period. The other three quarters showed lower probabilities (23–24%) for SCC>100000 cells/ml. Significant differences (Adj P40·0042) between left front quarters and the other three quarters existed concerning the probability that suspicious quarters appeared during the trial period. Reitsma *et al.* (1981) described how the duration of the liner closure per pulsation cycle affected bovine mastitis and noticed that the occurrence of new IMI increased considerably with a decrease in duration of liner closure, especially at the pulsation ratio 70:30 and the number of infected quarters increased as vacuum increased from 33·to 50 kPa (Mahle *et al.*, 1982). They also found out that rear quarters were infected more readily than front quarters (Reitsma *et al.*, 1981). These results could not be verified by our own investigations; only left front quarters had a significantly higher probability of becoming suspicious.

Quarter health categories

The following bacteria were found or detected in bacterial findings (BAF) quarters: Escherichia coli, streptococci, coliforms, CNS, Staphylococcus aureus, Arcanobacterium pyogenes. The percentage of quarters with BAF was smaller than for quarters with clinical findings (CLF) (Fig. 2), with the exception of the last examination (week 28).

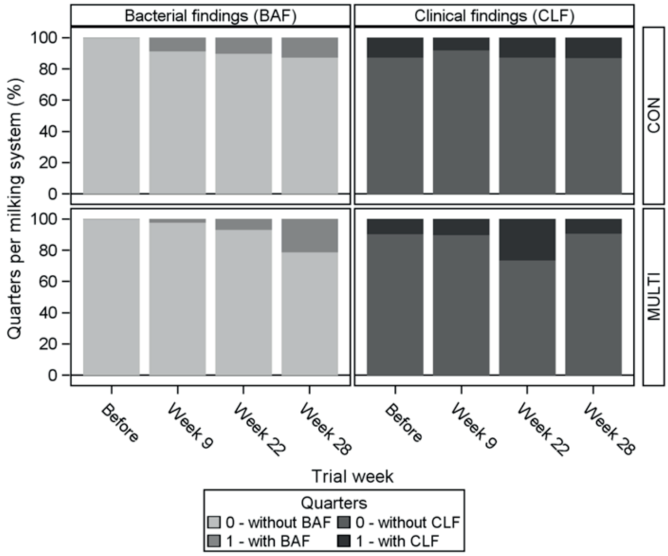


Figure 2: Percentage of bacteriological findings (BAF) and Clinical findings (CLF) for both milking systems (MULTI and CON)

The percentage of quarters with BAF increased slightly from 8·62% up to 11·94% (CON) during the trial period. On the basis of a smaller percentage (2·08%) of quarters with BAF (week 9) at MULTI, the percentage rose to 25% to the end of trial. The increase of BAF in the MULTI-group is mainly caused by newly diagnosed streptococcal infections in the week 27 of the trial. In all, cow associated streptococci were the most common bacteria detected during the trial period. One obvious reason for the increase in BAF within MULTI-group in week 27 can be traced back to the illness of one animal. Cow no. 516, which was inconspicuous during the trial period in terms of udder health, had three quarters with BAF at the last investigation. The bacteria found were streptococci. However, it is not possible for the authors to specify or name other causes for the increased rate of BAF in MULTI. According to Buelow *et al.* (1996), some chronically infected quarters eliminate bacteria in milk sporadically, leading to possible false-negative results. At least for this reason, it is safer to take repeated samples in order to minimize the number of false-negative samples (Djabri *et al.*, 2002). Bansal *et al.* (2005) described that latent infections were not associated with significant alteration in milk constituents. Up to 10·42% (MULTI) and 25·86% (CON) of quarters showed positive CLF at the first examination after adaptation phase (week 9). Thirteen weeks later (week 22), the percentage of quarters with CLF (MULTI) increased up to 27·38% whereas in the case of quarters with CLF (CON) the percentage remained nearly the same (29·89%). At the end of the trial, examination results showed that the percentage of quarters without CLF increased again in both groups (week 28).

## Conclusions

Quarter health status was not significantly affected by the milking system and DIM nested with lactation. In contrast, all other factors significantly affected quarter health status, e.g. parity, milk yield, trial week and udder quarter health status of the previous week. A main finding of this trial was that for MULTI, the probability of the occurrence of suspicious quarters was tendentially higher. However, the results of multiple comparisons did not show any significant differences between MULTI and CON concerning the quarter health status based on a SCC threshold value of 100000 cells/ml. It has been presumed that the tendential differences between both groups cannot be traced back to the milking systems used. This indicates a smooth adaptation of heifers and cows previously milked conventionally to the new milking system with single-tube guidance. MULTI fulfills the required standards which are currently being placed upon new milking techniques in terms of udder health.

## Acknowledgements

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# Session 10

# Pigs - Image

## Automatic monitoring of pig activity using image analysis

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### Abstract

The purpose of this study is to investigate the feasibility and validity of an automated image processing method to detect active pigs housed under experimental conditions. Top-view video images were captured for forty piglets, housed ten per pen. On average, piglets had a weight of 27 kg (SD = 4.4 kg) kilograms at the start of experiments and 40 kg (SD=6.5) at the end. Each pen was monitored by a top-view CCD camera. The image analysis protocol to automatically quantify activity consisted of several steps. First, ellipse fitting algorithms were employed in order to localise the pigs. Subsequently, activity was calculated by subtracting the image background and comparing binarised images. To validate the results, they were compared with manually labelled behavioural data ('active' versus 'inactive'). This is the first study to show that active pigs in a group can be detected using image analysis with an accuracy of 89.8 %. Since being active is known to be associated with behavioural status, careful monitoring can give an indication of the health and welfare of pigs.

**Keywords:** Active pigs, ellipse fitting, eYeNamic, image analysis

### Introduction

Every year, over 60 billion animals are slaughtered for food production (Prakash and Stigler, 2012). This strong demand for animal products forces producers to increase their capacity, with fewer available resources per animal. To reconcile market forces with the animal's need for individual care, farmers might use automatic tools to monitor their welfare and health (Cornou *et al*., 2008).

Activity in animals can be monitored for different purposes. Researchers have previously investigated different approaches to monitoring activity and locomotion in animals, including image analysis. Electronic tags were a popular method in this field.

Moore and Spahr (1991) researched the accuracy and efficiency of oestrus detection using an electronic activity monitoring tag in milking cows. More recently, accelerometers have been used for activity monitoring. Cornou and Lundbye-Christensen (2010) fitted sows with a neck collar containing an accelerometer to automatically classify types of activity that are common among group-housed sows.

Many of these earlier studies required animals to be fitted with sensors or tags which give rise to biosecurity risks and pain (Hernandez-Jover *et al*., 2008). Vision-based monitoring technology, however, is a non-intrusive technique that can be employed to assess a certain behaviour such as activity in livestock. In one study, Lind *et al*. (2005) introduced a system for automatically tracking pig locomotor behaviour. In another study, Cangar *et al*. (2008) developed an automatic real-time monitoring technique to identify locomotion and posture of pregnant cows prior to calving.

Current vision systems need pigs to walk in front of the camera one by one (Lind *et al*., 2005) or to be marked (Noldus *et al*., 2001; Kashiha *et al*., 2013). Otherwise, they can only provide activity information for the animals as a group (Costa, 2007). The disadvantage of the latter approach is that variation in activity between pigs cannot be measured.
To the authors' knowledge, there is currently no tool available that uses vision technology to automatically detect unmarked active pigs in a group-housed environment. The objective of this study is to measure such a parameter through automated quantification of activity levels using continuous image analysis.

## Materials and methods

<u>Animals and housing</u>
The experiments in this study were carried out at Agrivet research farm, Merelbeke, Belgium. Forty pigs, Rattlerow Seghers x Piétrain Plus, were selected after the battery period and randomly assigned (10 per pen) to four fully slattedpens *(2.25 m x 3.60 m)* with concrete floors at a stocking density of 1.23 pig/m$^2$. Each pen was equipped with a double feeder space and one drinker nipple. Animals had ad libitum access to feed (commercial grower diet) and water for the whole experimental period. Pigs had a timer-controlled 12-hour light period from 07:00 h – 19:00 h. The barn temperature was maintained at an average of 22 centigrade using Hotraco IRIS climate control equipment,  with a minimum of 18.6 centigrade and a maximum of 25.4 centigrade over the total experimental period. On average, piglets weighed 27 kg (SD = 4.4) at the start of experiments and 40 kg (SD = 6.5) at the end.
This study was approved by the Ethical Committee of the Faculty of Veterinary Medicine at Ghent University, Belgium.

Equipment and data collection

In order to capture top-view images, cameras were installed in the rafters of the barn, at the location shown in figure 1.

Using MPEG Recorder software from Noldus and black and white Panasonic WV-BP330 cameras, images were recorded during 13 days for 12 hours per day. Images were captured between 07:00 and 19:00, resulting in 156 hours of video. Videos were recorded in MPEG-1 format, with a frame rate of 25 frames per second, frame width of 720 pixels, frame height of 576 pixels and a data rate of 64 kbps. To provide light in the barn, six 36 watt, 120 cm Sylvania Luxline Plus white fluorescent tube lamps were installed at a height of 200 cm at the locations shown in figure 1.

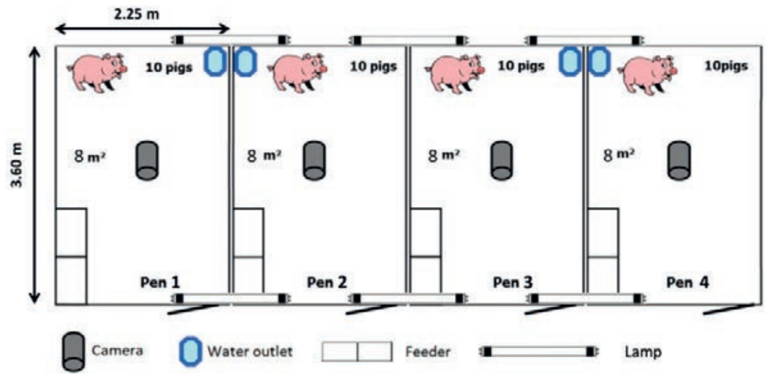


Figure 1**:** Ground plan of the 4 pens in the research barn at Agrivet, Merelbeke.

Development of the automated activity quantification protocol

The processing flowchart to monitor activity in a pen is shown in figure 2. First, to eliminate light effects, the histogram of the image was equalised using adaptive histogram equalisation (Sherrier and Johnson, 1987).

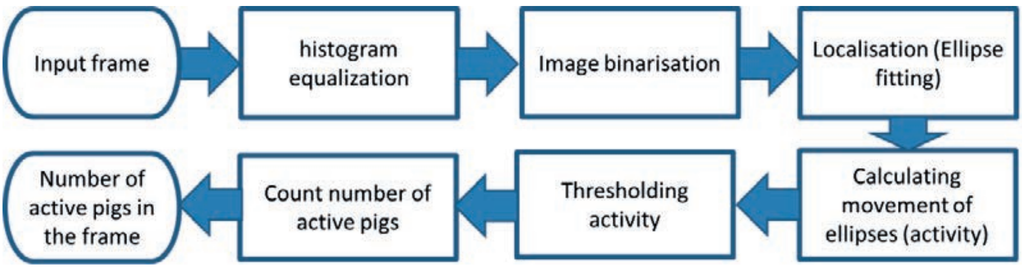


Figure 2: Image processing flowchart to monitor activity in a pen

Secondly, each image was binarised to eliminate the background. The binarisation procedure was as follows: 1) the image was filtered using a 2-D Gaussian low-pass filter; 2) a global threshold was calculated using Otsu's method (Otsu, 1979); 3) the image was

subsequently hard-thresholded; 4) to remove small objects such as slat edges from the image, a morphological closing operator using a disc-shaped structuring element with a size of 10 pixels (Gonzalez and Woods, 2001) was applied.
Thirdly, each image was segmented in order to find the location of the pigs. To segment the image, within each pen, the pigs' bodies were extracted as ellipses (Zhang *et al.*, 2005). The procedure for fitting ellipses to the binary image was as follows: 1) ellipses were fitted to objects in the image using the direct least-squares ellipse-fitting method (Zhang *et al.*, 2005); 2) ellipse parameters such as "orientation", "major axis length", "minor axis length" and "centroid" were calculated for all objects in the image. Figure 3.a illustrates these parameters and figure 3.b shows the ellipses fitted to the pigs' bodies.
The next steps according to the flowchart in figure 2 are explained in the following sections.

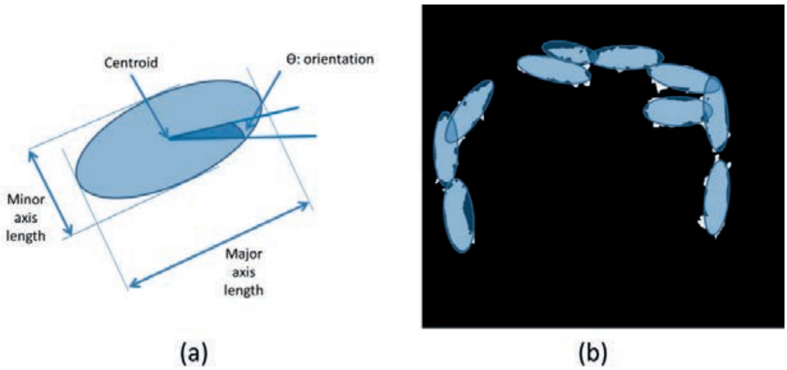


Figure 3: a. Ellipse parameters; b. Ellipses fitted to pigs' bodies

Active Pig Detection by Image Analysis (APDIA) algorithm

Image Activity (IA) is defined as the amount of movement in pixels that an object produces. Using the ellipse models presented in the previous section, IA is mathematically explained as shown in the following equation and illustrated in figure 4.

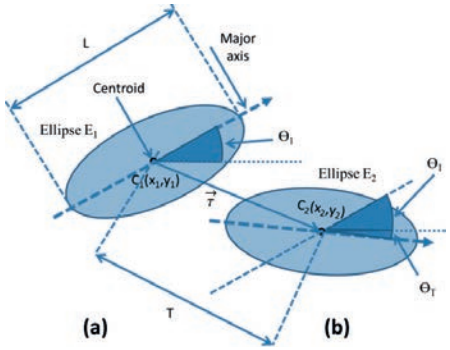


Figure 4: Ellipse fitted to pig's image: (a) at time "t-1"; (b) at time "t"; T is the distance travelled;

$$IA = |Linear\ motion| + |angular\ motion| = |\vec{T}| + \left|\left(\measuredangle \vec{T}\right) * \frac{L}{2}\right| = T + \theta_T * \frac{L}{2} \qquad (1)$$

where IA is the Image Activity; in pixels,  is the movement vector (from ellipse $E_1$ to ellipse $E_2$); in pixels; T is the size of the movement vector; in pixels; $\Theta_T$ is the difference in orientation between ellipses $E_1$ and $E_2$; no units; L is the average size of the major axis of ellipses $E_1$ and $E_2$; in pixels;  is the angle operator;

Pig Activity

IA was monitored over time and Pig Activity (PA) was determined based on the following equation:

$$PA = \frac{IA}{L} \qquad (2)$$

where PA is the Pig Activity; no units; IA is the Image Activity; in pixels; L is the average size of the major axis of ellipses $E_1$ and $E_2$ (figure 4); in pixels;
The next step was to use the PA to decide whether a pig was active or inactive. Based on the PA parameter and an experimental threshold of 0.4, active pigs were determined as follows: inactive if $PA < 0.4$ or active if $PA \geq 0.4$.

Manual labelling

As a reference for the number of active pigs, manual "labelling" of recorded videos was carried out by an experienced ethologist. Human observations of pig behavioural activity were performed off-line using 2-min instantaneous scan-sampling in four 30-minute sessions on 6 selected days as labelling is very time-consuming work. The behaviour of each individual pig was labelled using the Observer XT 10.2 (Noldus, Wageningen, The Netherlands) software. For each scan, all 10 individual pigs from one pen were scored as either active or inactive. Active behaviour was defined as a pig walking or running and/or performing other behavioural activity that includes physical movements of any body part. Otherwise, it was considered to be inactive. Finally, the numbersof active pigs were summed to calculate how many pigs were scored as active in a pen.
Data that were recorded but were not within one of the selected 30-minute sessions and therefore not labelled were analysed by the image analysis technique discussed.

## Results

Validation of APDIA algorithm

In order to validate the APDIA algorithm, image-based detection of active pigs was compared with labelling results, as shown in table 1.

Table 1: Active vs inactive pigs in 4 pens, comparing labelling and automated image analysis;

| | | Labelling | | Image analysis | |
|---|---|---|---|---|---|
| Pen | Samples | Active pigs | Inactive pigs | Active pigs: True positives | False positives |
| 1 | 3600 | 1515 | 2085 | 1432 (94.5 %) | 48 (3.17 %) |
| 2 | 3600 | 1343 | 2257 | 1209 (90.0 %) | 21 (1.56 %) |
| 3 | 3600 | 1316 | 2284 | 1131 (85.9 %) | 61 (4.63 %) |
| 4 | 3600 | 1722 | 1878 | 1525 (88.6 %) | 32 (1.86 %) |
| **Total** | 14400 | 5896 | 8504 | 5297 (89.8 %) | 162 (2.75 %) |

In total, 14400 frames were analysed, which were recorded from four pens. Out of 5896 active pig samples, 5297 were identified correctly, while 162 false positive events (2.75 %) and 599 false negative events (10.2 %) were detected. This gives an overall accuracy of 89.8 %.

Continuous data analysis using APDIA algorithm

After the method had been validated, all 13 days of the experimental data were analysed. There were in total 13 (days) * 12 (hours) * 3600 (seconds) * 10 (pigs) or 5.616 million (432k per day) samples per pen to analyse. Figure 5 shows the average active pigs per pen during the days of the experiment.

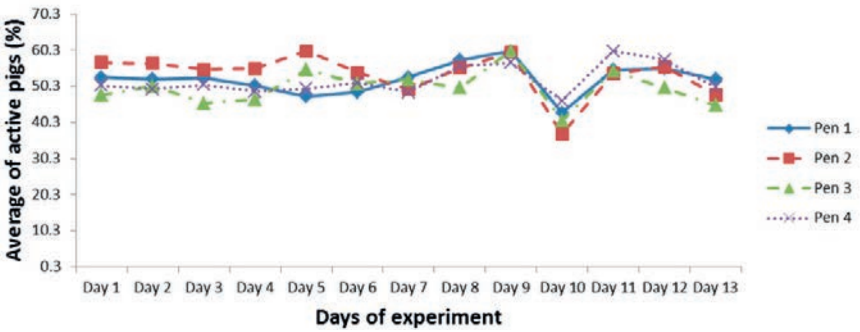


Figure 5: Average active pigs during 13 days of the experiment detected by APDIA algorithm

## Discussion and conclusion

Camera technology has made it possible to monitor every second of animal behaviour and has also proven especially suitable for studying group behaviour (Pastorelli *et al.*, 2006).

Monitoring animal activity in groups is an essential aspect of analysing different behaviours such as locomotor and agonistic behaviour. In this study, an innovative approach using movement calculation of ellipses fitted to pigs' bodies was chosen to investigate the potential for automatic detection of active pigs for fattening pigs using vision technology. It was shown that it is possible to detect active pigs by localising individual pigs in the group by fitting ellipses onto their top-view body image and tracking those ellipses over time.

The results presented in figure 5 show that the number of active pigs remained stable during the 13 days of the experiment except for day 10 in which it dropped by about 10%. An investigation of environmental or behavioural parameters did not reveal any reason for this event.

Of the previous methods used for pig activity monitoring, the eYeNamic tool was the most successful (Leroy *et al*., 2006) and was used as a reference for the technique described. This tool calculates the difference in image intensity between consecutive frames. The binary 'activity image' $I_a(x, y, t)$, containing the pixels for which the intensity change exceeded a certain threshold, is derived from this difference image. A summation of the number of these pixels yields the total amount of activity at time t (Leroy *et al*., 2006). Since eYeNamic cannot determine the number of active pigs, one development phase focused on identifying a threshold for the number of pixels required to decide how many pigs in a pen were active. In the validation phase, the data presented in table 1 were also analysed with eYeNamic. Table 2 shows the results when the performance of eYeNamic is compared with the performance of the APDIA method. These results indicate that the newly introduced APDIA method exhibits a 10.2% error in detecting the number of active pigs while eYeNamic categorises active pigs with an error of 39.2 %. In addition, false positives were 2.75% and 11.8%, respectively. Thus, the APDIA method yields a higher accuracy in detecting active pigs.

Table 2: Comparison of labelling, APDIA technique and eYeNamic tool in detecting number of active pigs in a pen; AS = Active Samples

| | | Labelling | Image analysis | | Image analysis | |
|---|---|---|---|---|---|---|
| Pen | Samples | AS | AS (Image) | Absolute error = \|AS-AS (Image)\| | By eYeNamic (eYe) | Absolute error = \|AS-eYe\| |
| 1 | 3600 | 1515 | 1432 | 83 (5.5 %) | 1042 | 473 (31.2 %) |
| 2 | 3600 | 1343 | 1209 | 134 (10.0 %) | 1851 | 508 (37.8%) |
| 3 | 3600 | 1316 | 1131 | 185 (14.1 %) | 891 | 425 (32.3 %) |
| 4 | 3600 | 1722 | 1525 | 197 (11.4 %) | 2640 | 918 (53.3 %) |
| **Total** | 14400 | 5896 | 5297 | 599 (10.2 %) | 6424 | 2324 (39.4 %) |

The APDIA technique also dealt robustly with body shape variations in the standing and lying positions. This made it highly suitable for the purpose of this study since there was considerable variation in brightness between pigs' different postures and locations. It is worth mentioning that, due to variation in data, the occurrence of false positives in detection of activity is unavoidable. Nevertheless, our method could still detect active pigs in a light intensity range of 11.7 to 176.1 lux with an accuracy of 89.8%.

However, there are still challenges to be overcome before the technique proposed can be used in practical settings. A daunting challenge would be to employ this technique in conditions with higher (practical) stocking densities where segmentation might be an issue. One way of addressing this problem is to combine the APDIA method with activity calculation by comparing consecutive frames, as in eYeNamic (Leroy *et al.*, 2006).

Automated monitoring of active pigs can help to continuously analyse pig behaviour in a more detailed way. By combining the APDIA output with other parameters such as spatial use of the pen area, it would be possible to analyse pig behaviours including playing, resting, drinking, feeding and manipulation.

In conclusion, a simple automated activity measurement such as the APDIA method might have a role in future as a practical tool for better monitoring of health, welfare and performance in livestock husbandry.

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**Consumer grade range cameras for monitoring pig feeding behaviour**

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**Abstract**

RFID technology can be used for registration of slaughter pigs' visits at a trough. The registration can be used for health monitoring systems by analysis of the individual pigs' feeding frequency. An RFID system can detect when the head of a pig is placed near or above a trough, placed in a feeder. This RFID-system is complex and vulnerable. In addition, ear tags mounted on the pigs can be lost during the pigs' fattening period. A person can visually verify each RFID-registration at the feeder to ensure valid operation, but this work is very time consuming. Instead of human observations to detect lost or degraded functionality of the RFID system an automatic computer vision based system was developed during the PIGWISE project to ensure valid RFID observations. The computer vision system was based on consumer grade range cameras. Range cameras were placed above each feeder. A computer vision algorithm that dynamically counts the current number of feeding pigs was developed. The algorithm defines a feeding pig as a pig which body is placed above the trough at the feeder, in the same manner as an RFID registration. The detected part of the body is typically the pig's head. Furthermore, an algorithm was developed that is able to compare the current number of feeding pigs counted by the RFID system with the current number of feeding pigs counted by the computer vision system. The events from the sensors are compared within a time window. If the compared counted number of feeding pigs differs too much over a given time, the farmer is alerted.

**Keywords**: Slaughter pigs, RFID, range cameras, computer vision, validation.

## Introduction

A salient goal for modern pig farmers is to combine a profitable business with animal welfare. To reach this goal, the pig farmer has to be a manager besides being an animal caretaker (Frost *et al*, 1997). To achieve animal welfare in big herds a number of employees are required to inspect the pigs, which leads to a reduction of profit. Therefore a system which is able automatically to monitor the animal welfare in the pig stable is attractive for the farmer.
Different systems have recently been developed for automatic monitoring of big herds of slaughter pigs. Systems are developed that alert the farmer based of analysis of audio input (Moura *et al*, 2008). An alert is generated if the result of noise analysis in the pen indicates stress. Other systems are developed that uses the consumption of drinking water as indicator for the pig welfare (Kashiha *et al*, 2013; Madsen & Kristensen, 2005). The systems described above do not detect illness on an individual level, but indicate an abnormal situation in the herd as a whole. To achieve individual monitoring of the pigs, a unique identification method is necessary. The pigs can be recognized by a number or a symbol, spray painted or tattooed on the back of the pig and identified by computer vision technique. This painting or tattooing is cheap, but it is typically invisible after a few weeks, due to dirt build-up.

Ear tags based on the Radio Frequency Identification (RFID) technique seems to be the best method today for unique pig identification. RFID is a collection of techniques based on radio communication between an RFID ear tag and an RFID reader. The ear tag is typically a passive component without battery. The necessary power for transmitting an ID from the ear tag to the RFID reader is delivered from the RFID reader to the ear tag as electromagnetic energy when energized. The ear tag returns a unique response to the reader. The RFID based ear tags are continuously getting cheaper, therefore these tags are suitable for unique identification in the stable (Artmann, 1999; Eradus & Jansen, 1999; Ruiz-Garcia *et al.* 2011; Finkenzeller, 2010). A suitable technique for RFID identification of slaughter pigs is the passive High Frequency RFID technique (HF-RFID), successfully used for larger herds of pigs, where many (4-6) pigs are feeding simultaneously at the trough. The maximum distance between ear tag and reader is approximately 30 cm (Hessel & Van den Weghe, 2011; Reiners *et al*, 2009).

The goal of the PIGWISE project is to develop a health monitoring system for slaughter pigs based on the individual feeding behaviour using HF-RFID identification and synergistic control. This leads to the possibility of automatic detection of illness at individual level sooner than any employee would be able to identify the pig's illness.
The quality of this system relies on that no ear tags are lost during the fattening period,

and no failure occurs in the stationary part of the RFID system (RFID reader, cables, multiplexers etc.).
Different methods for computer vision based monitoring of slaughter pigs have previously been developed. A three dimensional extraction of pigs shape using stereo photogrammetry, made by standard cameras has been evaluated (Wu *et al*, 2004). Standard cameras are also used for tracking of pigs in a pen (Ahrendt *et al*, 2011). Range cameras have recently been used successfully in different consumer applications. Their main advantages are noise-robust range data and low price (Andersen *et al*, 2011).
In this paper a computer vision based system is presented where range cameras are placed above the pigs. The computer vision system counts, in real time, the total number of pigs that feed at a circular trough, placed in a feeder. The counted pigs are (in real time) compared with the number of pigs, detected by the HF–RFID system. If the difference between the counted pigs from the two independent sensor systems exceeds a certain limit, the farmer is alerted, since the RFID system may be degraded.

## Materials and methods

The study was carried out at ILVO (Institute for Agricultural and Fisheries research, Merelbeke, Belgium). The test pen measured 4.3 m by 9.0 m and contained 59 pigs during the study in spring 2013. Two Swing MIDI feeders (Big Dutchman Pig Equipment GmbH, Vechta, Germany) were used in the pen. The pigs were fed ad libitum. The RFID Reader (ID ISC.LR2500-A, Feig Electronic GmbH, Weilburg, Germany) received RFID feeding events from a custom-made circular antenna (DTE Automation GmbH, Enger, Germany), placed just above the trough in the feeder. The tags used were IN Tag 300 I-Code SLI tags (ISO15693, HID Global Corporation, California, USA). Two tags were mounted on each pig. Feeding events were sent via a multiplexer (ID ISC.ANT.MUX-A, Feig Electronic GmbH, Weilburg, Germany) to a PC which also received input from range cameras. This PC contained the computer vision analysis process and the sensor comparison process. The RFID system detected when the head of a slaughter pig was placed near or above a trough, placed in a feeder. The RFID-system was complex and vulnerable because it consisted of RFID readers, multiplexers, long RFID antenna cables and a long cable to the PC containing the RFID database. In addition, ear tags could be lost from some pigs during their fattening period. Seven tags were lost and replaced during the study.
The computer vision system was based on consumer grade range cameras (Xbox 360 Kinect Sensor, Microsoft, USA). Two of these cameras were placed above each feeder. Each camera was housed in a metal box with clear glass as bottom, shown in figure 1. The feeding coverage for each feeder, seen from above, was 360 degrees. Each of the cameras could inspect 180 degrees of the complete coverage, seen from above. Therefore two cameras could inspect the complete feeding situation around each feeder in the pen.

Figure 1: Feeder, trough, circular RFID antenna placed above the trough, 2 encapsulated cameras placed above the feeder and two computers monitoring two feeders in the pen.

A computer vision algorithm that dynamically counts the current number of feeding pigs was initially developed. The algorithm defines a feeding pig as a pig which body is placed above the trough at the feeder, in the same manner as an RFID registration. The detected part of the body is typically the pig's head. It is presumed that a pig will place itself at the trough because it intends to feed. The number of pigs within a virtual zone matching the physical trough is counted. For each camera, the counting algorithm sends the counted number of pigs to a process, which compares the sum of pigs as seen by both cameras with the number of pigs detected by the RFID system. The range cameras are illuminating the pigs by means of their own infrared light pulses, therefore daylight or artificial light is not required. The images from the cameras contain accurate range information for each pixel in their pictures, therefore it is possible to eliminate the dirty floor from each image and let the algorithm focus on the outlines of the pigs as seen from above. In figure 2 the right side of each feeding pig is marked with a yellow dot, the left side of the pig is marked with a blue dot. A green or red center point at the selected concentric circle is the base point for a green or red vector that points in direction of the trough. The number of green vectors represents the number of feeding pigs. The red vectors are candidates for feeding pigs, but not qualified to be detected as feeding pigs. One concentric circle is selected by the algorithm among all concentric circles as the most suitable for evaluation in the current scenario.

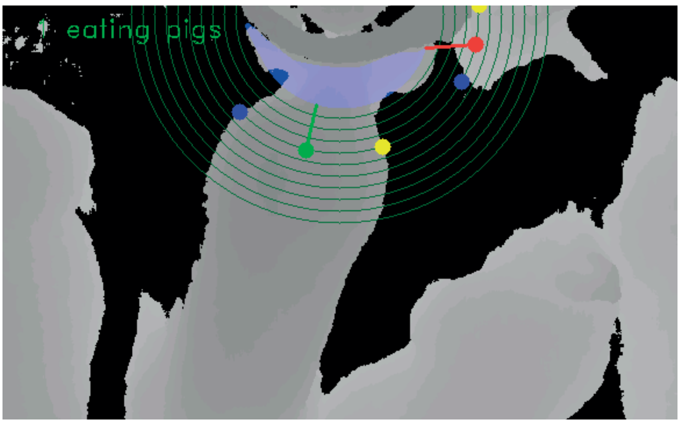


Figure 2: The computer vision algorithm counts the current number of feeding pigs.

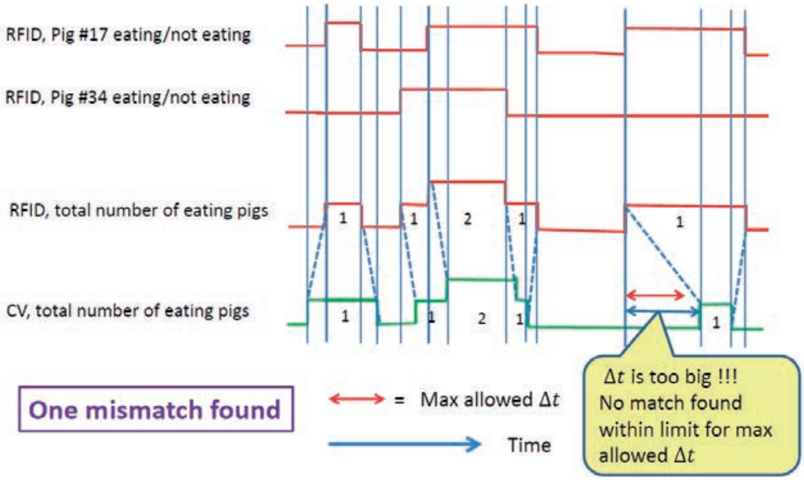


Figure 3: The comparison algorithm detects differences between the current number feeding pigs detected by two sensor systems.

Furthermore, an algorithm that is able to compare the current number of feeding pigs, counted by the RFID system with the current number of feeding pigs, counted by the computer vision system, was developed. The events from the sensors are compared over a time window. If the compared number of feeding pigs differs too much over a given time, the farmer is alerted.

During the study the size of the critical time window were set to 1.1 second. For each front edge of an RFID feeding event the algorithm searches for a corresponding front edge of a computer vision based feeding event within the critical time window. Future search and historical search is performed, seen relative to the timestamp of the referenced RFID event. If the number of counted pigs from the RFID system is

matching with the number of counted pigs from the computer vision system within the critical time window, a match is found.
The same procedure for comparison takes place for each RFID back edge, computer vision based front edge and computer vision based back edge. Figure 3 shows the principle for the comparison algorithm. All RFID based front/back edges and all computer vision based front/back edges are evaluated each minute. If the number of mismatches per second exceeds a critical error frequency, set as a system parameter, the operator is alerted because the RFID system is presumed to be degraded or stopped. Furthermore, all feeding events from the RFID system and the computer vision system are logged with timestamps in the PC. New log files are created every day. Therefore it is possible to find any event from any sensor at any day to make a camera/RFID-comparison by inspecting and analyzing old events.
By using a remote desktop connection it is possible to follow this live camera-/RFID-situation from a remote location. It is possible to inspect the situation at the feeder by depth pictures and/or by RGB-pictures.

## Results and discussion

The comparison system was able to count the current number of feeding pigs based on RFID feeding events and computer vision based feeding events. Usable images could be fetched continuously from the range cameras night and day. It was necessary to place two cameras near each other above the feeder to inspect the feeding area. In spite of this, each camera did not make any significant interference to the other camera's image, even if the range cameras are emitting infrared light pulses.
The accuracy of the timestamp for RFID feeding events were based on an optimal 3-dimensional orientation at the pig's ear, compared with the radiation characteristic for the circular RFID antenna. The range was not always the theoretical 30 cm, but typical shorter, depending on the orientation of the pig's ear. Therefore a small inaccuracy is evident for timestamps of feeding event detected by the RFID. This leads to an inaccuracy for the timestamp of increasing/decreasing the total number of feeding pigs, as detected by the RFID system. To reduce this inaccuracy an ear tag was mounted at both ears of each pig during the study.

The accuracy of the total number of feeding pigs detected by the computer vision system depended on the orientation of each pig's head, compared with the radius of the virtual trough, created by the computer vision system.
If the pig's head was placed straight into the feeder, and above the trough, the pig was registered without problems by the computer vision system. If the pig was moving its head in and out of the feeder in a fast manner, each of such cycles was detected as individual feeding events, leading to inaccuracy of the number of pigs, counted by the computer vision system.

Furthermore, in some situations the pig's ear could be interpreted as an extra, small pig at the selected concentric circle. This led to an inaccuracy of the number of counted pigs.

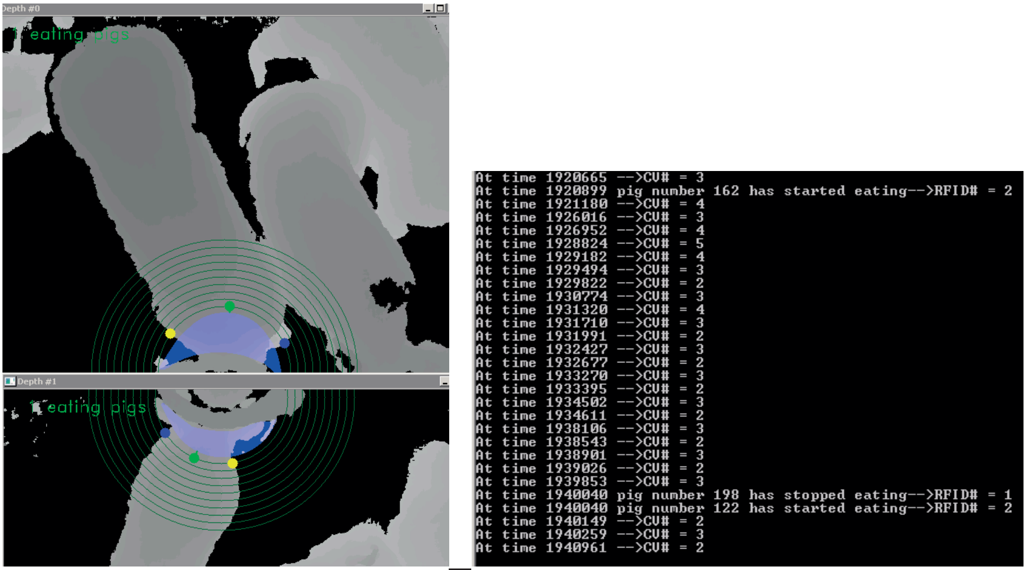


Figure 4: The comparison algorithm detects equality between the counted pigs from two sensor systems within critical time limit (1.1 second).

Figure 4 shows RFID-based feeding events with time stamps as long lines and computer vision based feeding events with time stamps as short lines. All lines are written to a terminal, and all data is stored in a table for sensor comparison each minute. At time 1940040 millisecond the counted number of pigs detected by RFID is 2. At time 1940149 millisecond, 0.109 seconds later, the computer vision system has also detected 2 feeding pigs. In this case a match is found, because the match is found within the critical time limit, 1.1 second.
Figure 5 shows an irregular registration of an extra pig, because the ear of the main pig is seen as an extra pig at the concentric circle. At time 243891 millisecond the counted number of pigs detected by RFID is 2. At time 259788 millisecond, as 15.897 seconds later, the computer vision system has again detected 2 feeding pigs. This time difference exceeds the critical time window, 1.1 second. By analysing the historic events, two pigs are counted at time 241832 millisecond, 2.059 seconds earlier. Again, this time difference is greater than the critical time window, 1.1 second. In this case no match is found. From time 258930 to 267167 the number of feeding pigs detected by the computer vision system is alternating between 2 and 3, because the ear of the pig is sometimes detected as an extra pig. The main reason for the mismatch is irregular detection of the number of feeding pigs, seen by the computer vision system. Too many

fast movements in/out of the feeder and too many ears, detected as extra pigs, disturbs the accuracy of the counting done by the computer vision system.

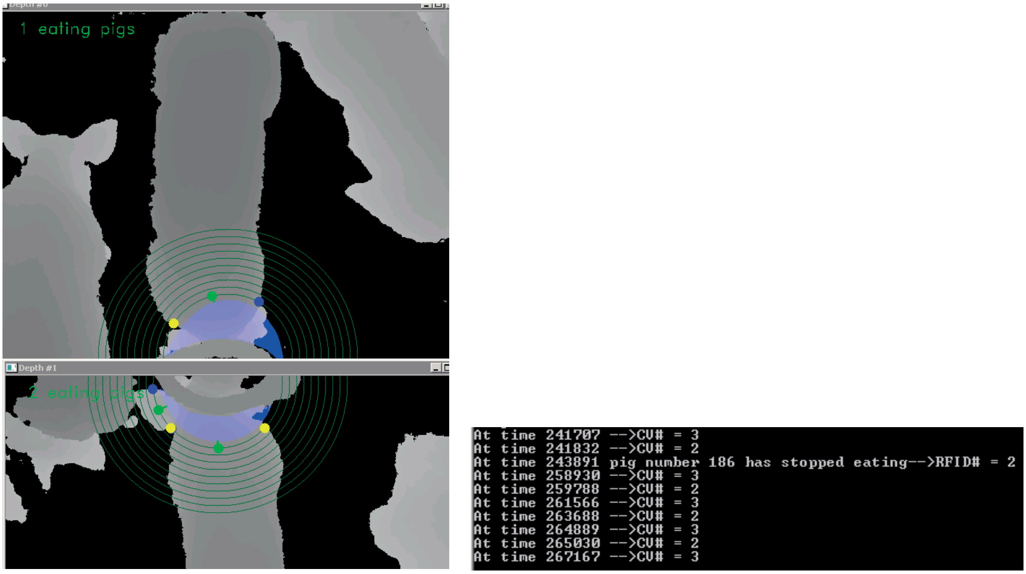


Figure 5: The comparison algorithm detects inequality between the counted pigs from two sensor systems within critical time limit (1.1 second).

To improve the accuracy of the computer vision based counting of the feeding pigs the depth information from the range cameras could be used to improve the separation of the pigs. In the existing system only a 2-dimensional outline were used to separate the pigs from each other.
To improve the precision of the comparison algorithm further adjustments of the critical time limit value and other system parameters are necessary to optimize the comparison.

## Conclusion

This paper shows some promising results for a system, which automatically verifies the quality of the RFID part of a health monitoring system for slaughter pigs, based on individual feeding behaviour. By using consumer grade range cameras it is possible to continuously fetch depth images and RGB images with a useful quality during a fattening period. An algorithm is developed that counts the current number of feeding pigs at the feeder. This counted value is continuously compared with the number of feeding events as detected by an HF-RFID system. If the difference between the counts from the two sensor systems exceeds a critical limit, the operator of the system is notified. The computer vision algorithm and the comparison should further be optimized and analysed to find an optimal performance of the automatic quality validation of the essential and vulnerable RFID system.

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## Automatic sow pattern detection in videos: an AI approach

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### Abstract

This paper presents an algorithm for recognition of sow patterns in live images of a camera-based surveillance system, based on a semi-supervised design. We introduce a set of separable image features coupled with a non-linear supervised classifier for real-time pattern recognition. Then we improve capabilities of underlying classifier by exploiting a clustering technique to make a robust semi-supervised approach with minimum dependency to pre-training set.

**Keywords**: sow pattern recognition, artificial intelligence, neural network, machine learning, image processing.

### Introduction

A big challenge in modern agriculture is automatic monitoring of animals. Nowadays one of the most economical and flexible monitoring tools is a surveillance camera. Image processing techniques are indeed necessary to handle the complexities of digital images and produce requirements for other computational routines.
A number of animal behavior predictors could be potentially designed in a way to accept geometric attribute as input. The role of image processing will be clearer especially for high risk situations which without human supervision could lead to animal injuries or even death (e.g. during parturition). Cost of a continuous supervision by a human is high and an efficient automatic monitoring by a computer is an asset (Oliviero *et al.*, 2008). Therefore image processing techniques can be used inside predictive routines to help big farms taking care of individuals or groups of animals automatically.
During last decade many methods have been deployed to locate animals in videos. Hu and Xin (2000) used the combination of likelihood ratio and shading to segment pigs from background. Chen *et al.* (2003; 2005) implemented an averaging/thresholding routine inside an FPGA to detect animals. Sun and Tang (2011) used Haar of Oriented Gradients (HOOG) to capture the shape and texture features of animals head. Viazzi *et al.* (2011) used frame difference to extract pig pattern. A combination of fuzzy-c means clustering, morphological operation and blob analysis has been used for segmentation by Xuejun *et al.* (2012).
Multi-Layer Perceptron (MLP) is among the most powerful non-linear classifiers

which can adapts to extremely non-linear high dimensional data. A well-optimized implementation of this classifier can be fast-enough and acceptable for many of real-time applications.

A well designed image/video analysis routine can be considered as an intelligent routine which extracts information about the current status and activity of the sow (like position and movements) in order to predict upcoming events. Therefore the quality of the algorithm affects the quality of consecutive predictors.

This problem could generally be considered as a supervised machine learning approach (because there is prior knowledge about the underlying pattern that we are looking for) but it can also be treated as a semi-supervised problem by combining prior knowledge and on-line estimations.

The main motivation for our research is to prepare algorithmic and structural software platforms for automatic prediction of sow behaviors.

The aim of this work is to offer a set of separable image features and then bring a novel design in our modular framework to create a semi supervised approach for live detection of sow patterns.

## Material and Methods

### Description of data

The data used for this research consists of three separate farrowing recordings each of which is captured within one week for 8 different sows in farrowing crates. Each single recording contains 2 hour information and was recorded using "MPEG-4 Video (XVID)" codec. The frame rate is 12(fps) for each video and they contain 352x288 RGB color images. The camera was positioned in the ceiling between two crates so that two sows were recorded in the same video (Figure1).

### Description of feature-set

Based on the fact that there are many similarities between the colors of pig's body and background so in order to define a set of separable coordinates a small dense neighboring patch of size 7x7x3 is selected for each point as main feature set. The size of the neighboring window and point distribution are defined as free parameters for later studies. The non-linear classifier then should be applied to those coordinates.

### Description of software bed

An object-oriented design for an acyclic directed graph (ADG) is used in order to split an algorithm into smaller connected parts without explicit dependency to user interface (UI). Each graph (G) represents by the list of its nodes (N) and edges (E). Each node represents a small process and each edge represents a data connection between two adjacent processes. A graph can be saved in a customized binary format (.grp) and contains a network of units in which the output of one is feed to the others. By using this architecture one can easily debug a machine learning algorithm. Figure 1 depicts an example of a loaded graph inside the system. The programming language is C++, the application is designed by using Microsoft Visual Studio 2008 IDE. The user interface used Qt 4.8.2 . The application uses OpenMP to parallelize many loops in order to improve the overall performance. By the underlying data structure an avoidable data redundancy produces which can be removed in final stages to release the algorithm. The underlying ADG structure makes debugging, side-running and comparing of different algorithms much easier than direct calls inside the code.

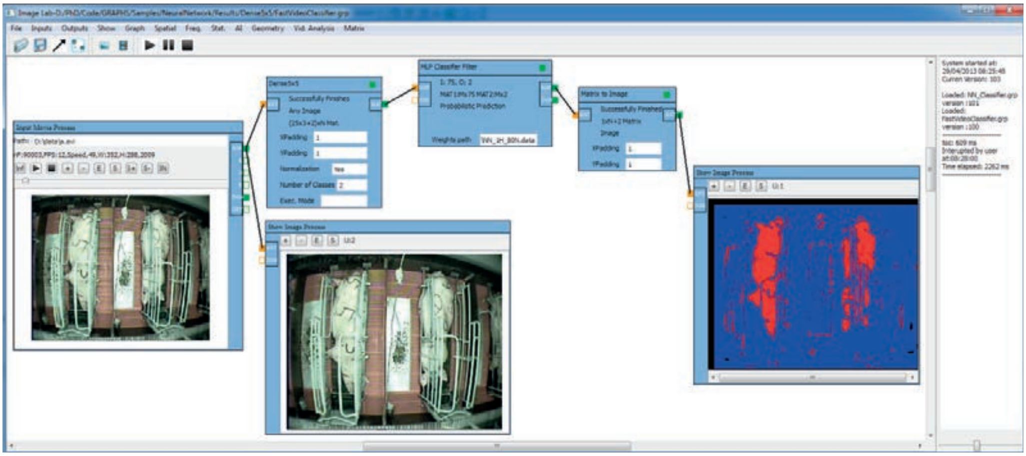

Figure 1: A view of application with a graph for classifying a *video*. The processing nodes are connected by edges which make the data to flow through them.

Description of the algorithm

MLPs are feed-forward nets with one or more layers of nodes between the input and output nodes (Lippmann, 1987). Each node (in Hidden/output layer) applies Logistic function (Eq. 1) on the summation of its inputs and sends the result (Eq. 2) to its connected nodes (in next layer):

$$g(x) = \frac{1}{1+e^{-x}} \tag{1}$$

$$\alpha_j^l = g(\theta_{j0}^l . \alpha_0^{l-1} + \theta_{j1}^l . \alpha_1^{l-1} + \cdots + \theta_{jm}^l . \alpha_m^{l-1}) \tag{2}$$

Where  is activation of node (j) in layer (l) and  is the corresponding weight to the connection between node (j) in layer (l) and node (k) in layer (l-1).

We have developed a semi-supervised classification approach (based on using an MLP classifier) for near real-time performance (figure 1). It consists of using a three layer MLP as the main classifier with an input layer with 147 nodes (7x7x3), one hidden layer with 40 nodes and an output layer with 2 nodes (two different decision boundaries for background (BG) and Target pattern).

After training phase the network can efficiently extract the pig patterns even in complicated occluded scenes where the whole body is not visible to the camera (Figure 4 and Figure 6). Its performance (as it designed and expected) is superior for the pre-training data set (and also in frames with similar conditions). The underlying method contains the following steps:

1- A randomized process selects the location of training points (positive and negative cases treated separately), then for each point a (7x7) neighborhood (Figure 2) is selected. The padding for positive and negative cases remained as an adjustable parameter.
2- A preprocessing routine normalizes input data (removes the mean and makes the variances equal to one).
3- A trainer process randomly initializes the weights (or loads the previous weights if any exists) then calls the optimizer function. When optimizer needs the gradients of the network, it calculates them with Back-propagation. The optimizer trains the network by a set of pair tagged images each of which consist of an image and a corresponding map (Figure 5). The desired regions are indicated in maps by filling up with a tag color. The learning method is Accelerated Gradient Descent (Nesterov, 1983).
4- An MLP process uses forward-propagation to classify new data.
5- An unsupervised clustering routine (Figure 3) automatically determines the number of clusters and detects the outliers. After recognizing the main clusters it joins “near clusters” to make a better estimation of desired pattern (Figure 6). It finally updates the online training set.
6- An online-gradient descent is responsible to use new on-line training set for updating the weight vector. The whole algorithm provides a semi-supervised full shape extractor for animal surveillance cases when there is no access to empty scene (highly static video).

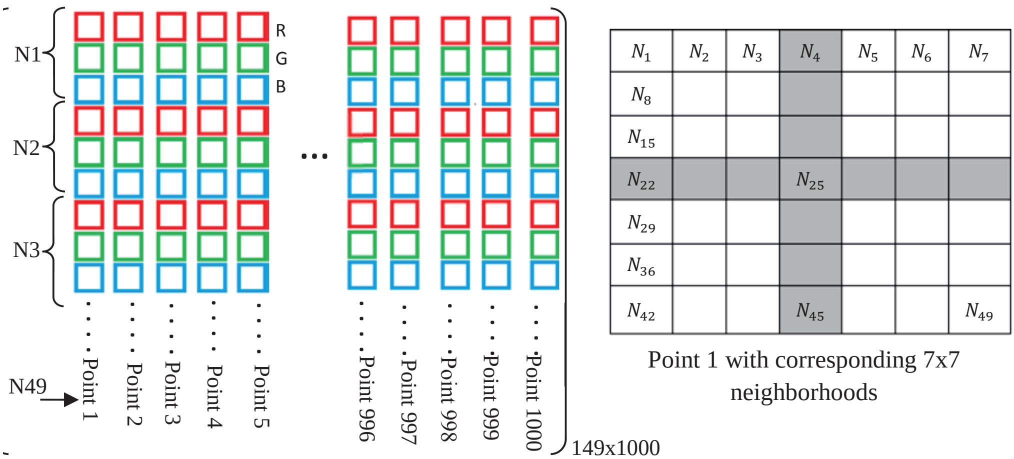


Figure 2: An example of a vectorized MLP input for 1000 points with 149 features (7x7 neighborhood) for each point.

Description of the training data set

Training data set comprising two sub sets:

1- A pre (Offline) training set which is used to achieve a good estimation for the weight vector.
2- An on-line training set, which is updated by clustering routine and used to adapt to new conditions.

Description of the pre-training data set

The pre-training set consists of 14000 patches from only 7 different frames with dissimilar lighting condition. An online training routine then will take care of adapting the network to inexperienced new conditions. A randomized sampling routine is designed inside the algorithm to change the density of training point in different classes. It can modify the number and location of positive and negative cases to make a better training process (Figure 4).

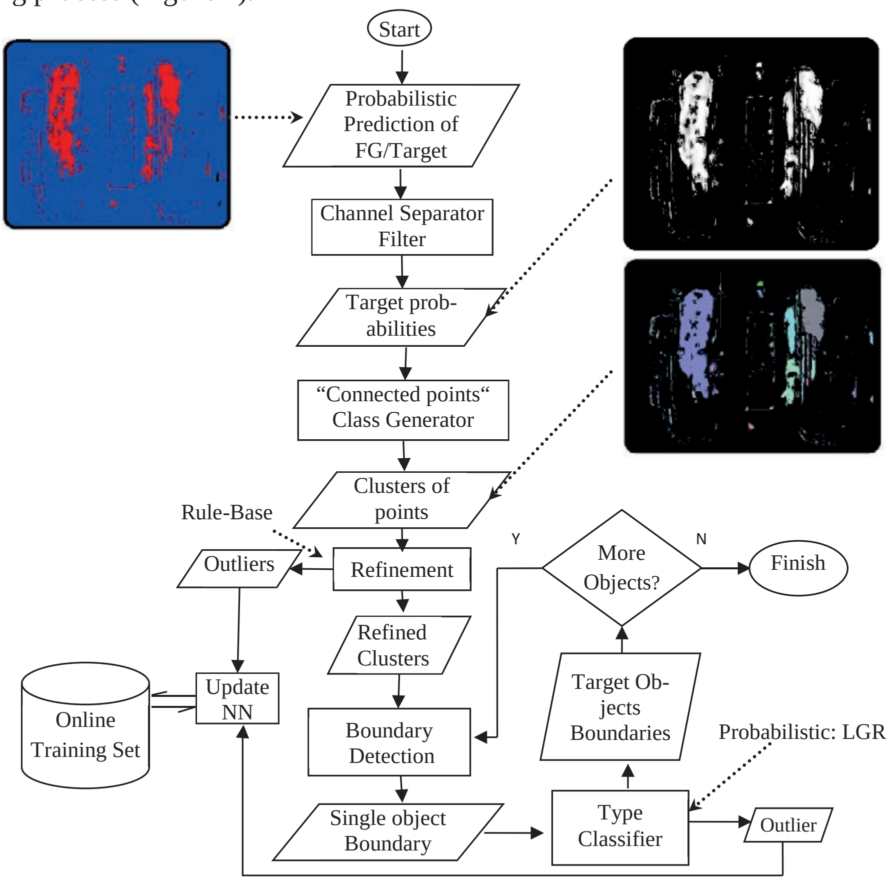


Figure 3: *Boundary Analysis* and *Target Unification* flow chart. The outcome will be used for updating the network.

## Results and Discussion

Classification showed 94.6% overall accuracy in cross validation set with TPR (True Positive Rate) of 84.8% and FPR (False Positive Rate) of 3.8%. The overall accuracy for training set was 95.27% with TPR of 82.5% and FPR of 3.13%. The classifier was able to process 8.5 fps with a Core i7 (2620M, 2.7 GHZ) processor. The results show that significant amount of the desired pattern were detected by the pre-trained network. Some regions with similar structure to the desired pattern were falsely detected on the first run but were removed by the on-line training routine later on.

In new situations the algorithm needs a couple of minutes for adaptation and then works as expected. The results show that by pre-training even on small data sets we can attain acceptable initial status.

The underlying approach generally works in conditions that the other BG/FG probabilistic approaches like (Friedman & Russell, 1997) and (Zivkovic, 2004) fail. The main reasons are the static nature of the recording system and lack of information about the empty scene. It is also superior to techniques based on image differencing and averaging (Chen *et al*., 2003; Viazzi *et al*., 2011) in terms of completeness and also the required number of frames.

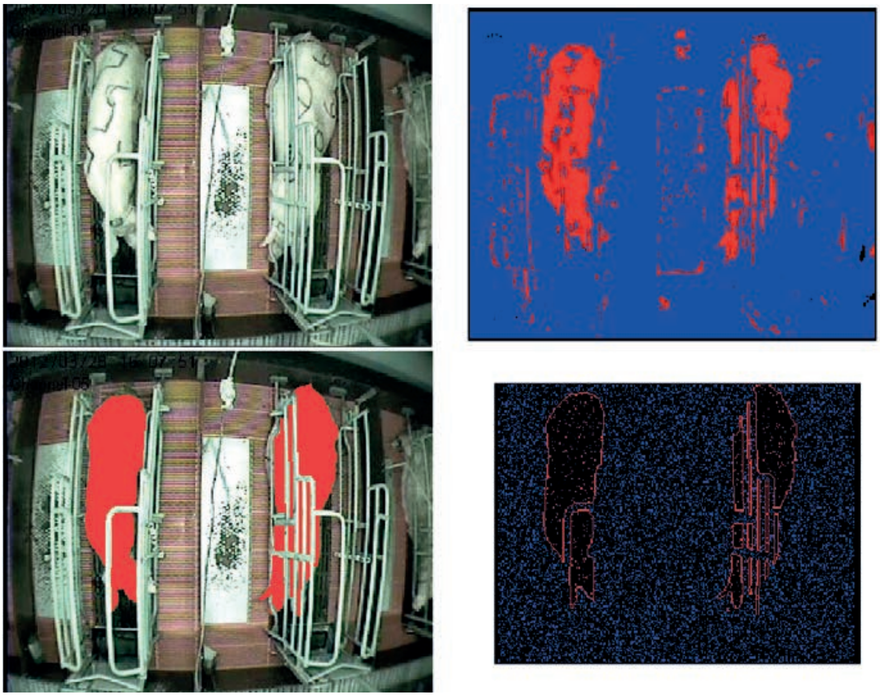

Figure 4: (Top/Left) the original image, (Bottom/Left) corresponding map, (Bottom/Right) location of designed training points. (Top/Right) Probabilistic Prediction of desired pattern in pre-training set.

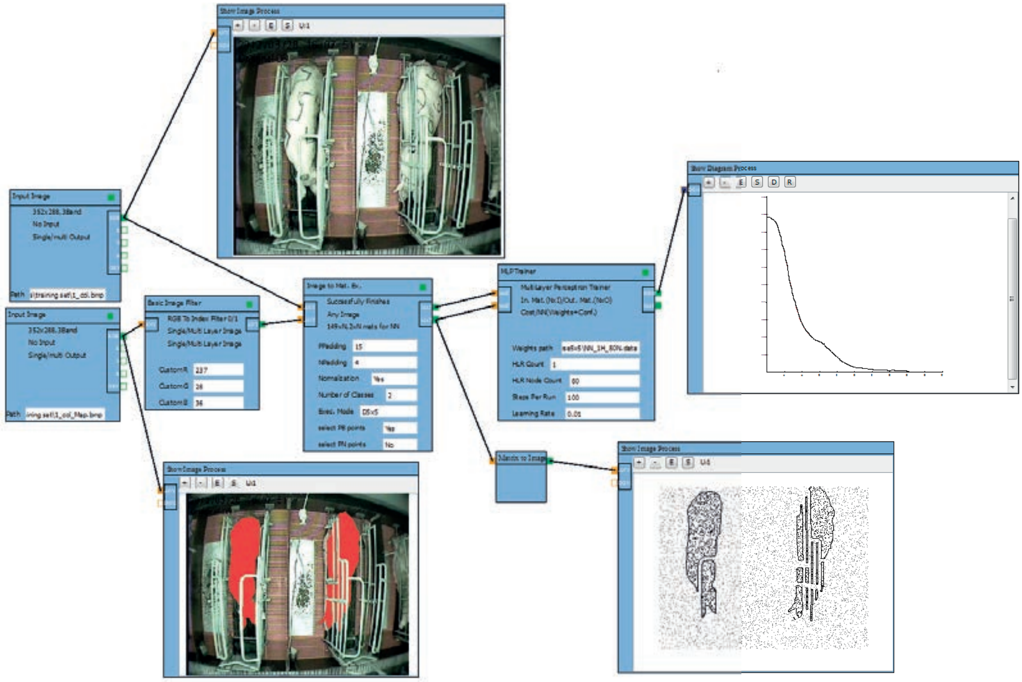

Figure 5: A training graph loaded inside the system. The Top/Right diagram depicts the learning curve of classifier.

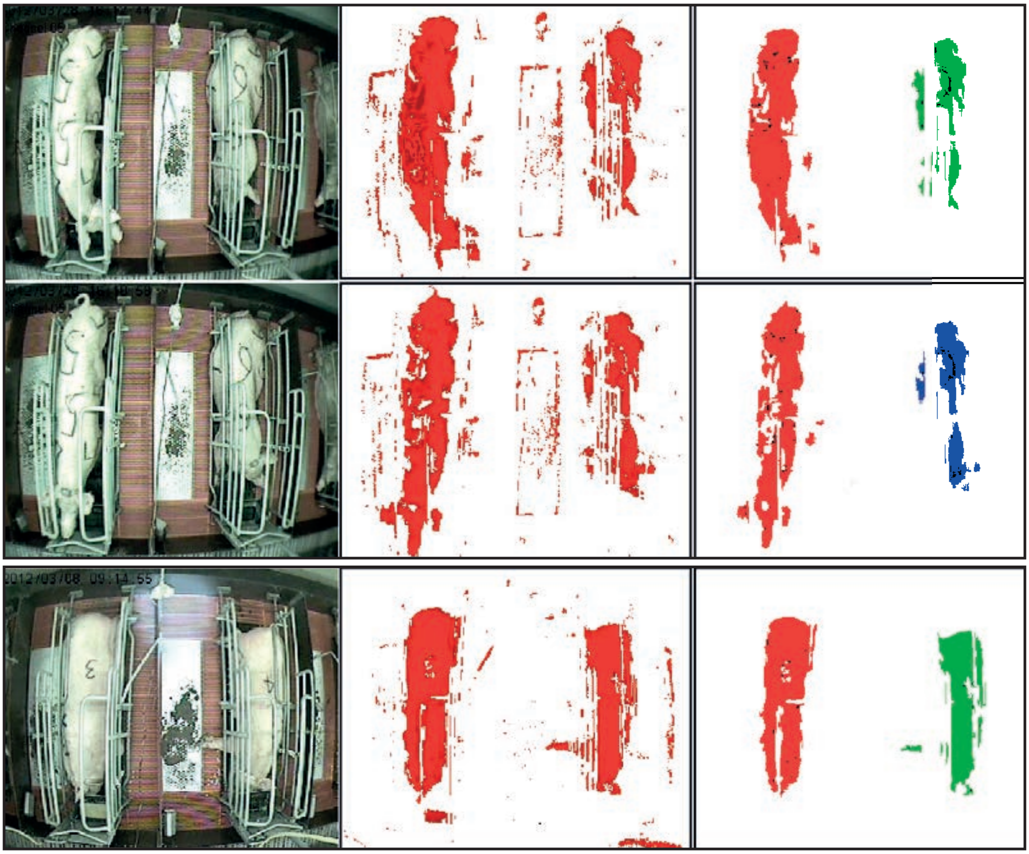


Figure 6: First column: Image from video, Second column: Probabilistic Prediction (blue represents the back-ground, red represents the target pattern), Third Column: Result of clustering (each cluster shown with a unique color).

## Conclusions

A semi-supervised algorithm for online recognition of pig patterns from videos has been presented. An automatic clustering approach and an online learning method were proposed. A set of features were studied and their separability was confirmed. The results of this work can be used in development of systems to predict animal behaviors.

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## Classification of aggressive behaviour of pigs by multilayer feed forward neural network

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### Abstract

Aggression among pigs is one of the most significant problems in modern production systems. Pigs kept in the confined environment of today's farms express a higher level of aggressive behaviour than pigs in a natural environment. The aim of this study was to develop a method of automatically detecting aggressive behaviour among pigs by using a multilayer feed forward neural network classification technique. An experiment was carried out at a commercial farm on a group of 11 male pigs weighing on average 23 kg and kept in a pen measuring 4 m x 2.5 m. During the first 3 days after mixing, 8 hours of video recordings were captured with a top view camera for later analysis. Of 28800s of video recording captured during the experiment, 643s were labelled as high aggression and 1253s as medium aggression events. An activity index was calculated based on the recorded videos. The results revealed that an ANN supplied with 70 activity index features calculated for 241s time intervals classified high aggression events with a sensitivity of 96.1%, specificity of 94.2% and accuracy of 99.8%. The results indicate that a multilayer feed forward neural network can be used to classify aggressive events expressed by pigs.

**Keywords:** automatic classification, pig aggression, activity index, artificial neural networks,

### Introduction

Aggression is a significant problem in modern pig production systems. The occurrence of aggression results in reduced animal health and welfare (McGlone *et al*., 1981, Marchant-Forde, 2010) and lower farm productivity (Stookey and Gonyou, 1994, Arey and Edwards, 1998). Complex aggressive interactions among pigs comprise sequences of aggressive behaviours. A fight breaks out gradually as the pigs investigate each other using a series of specific and often reciprocal behaviours, characterized by nosing, sniffing and gentle nudging. This may then escalate into more vigorous pushing, pressing, bites and head-knocking, of which biting is considered to be the most damaging (Turner *et al*., 2006). Thus the intensity increases as the fight progresses, which means that more damaging behaviours occur more frequently later in the fight. The last phase of aggressive interactions consists of direct sampling of actual fighting ability, through overt, dangerous fighting (Jennsen and Yngvesson, 1998).

Low-cost cameras combined with image analysis techniques can be used to quantify an animal's behaviour (Wathes *et al*, 2008). In order to detect aggressive behaviour of pigs on images recorded by a camera, it is necessary to correctly interpret the visual scene using image analysis techniques. An image analysis technique known as the activity index allows segmentation and quantification of animal behaviour. The technique can be applied to multiple camera-based monitoring systems and allows measurement of responses by the animals to their environment (Bloemen, 1997). In order to classify aggressive events on the basis of activity index, a multilayer feed forward neural network classification technique was tested in this research. An artificial neural network (ANN) is a mathematical modelling tool that is especially powerful in complex systems. In this research, a multilayer feed forward neural network is used as this type of network is most commonly used for the function approximation problem, and also because of its strong learning capability. This type of network is able to approximate almost all types of function, regardless of their complexities (Gardner and Dorling, 1998). ANN have been applied successfully in different areas such as function approximation and pattern recognition and are capable of representing complex systems (Moradi *et al*., 2013)
The aim of this study was to test a method of automatically detecting aggressive behaviour among pigs on the basis of five activity index features (average, maximum, minimum, sum and variance) calculated for 14 time intervals and fed into a multilayer feed forward neural network.

## Material and methods

### Animals and housing

In order to achieve the aim of the study, behavioural observations were carried out at a commercial farm located in Heusden, the Netherlands, with a capacity of approximately 6000 fattening pigs (Topigs 20 (large White x Landrace) x Pietrain) weighing from 23 to 120 kg. Eleven non-castrated male pigs, weighing 23 kg on average, were observed in a 4 m x 2.5 m pen. The pen was surrounded by a solid, plastic wall. The floor of the pen was constructed from concrete. All the pigs used in the experiment originated from different pens and were mixed immediately before observation started. The pigs were fed *ad libitum* with a dry feeding system at one feeder with two feeding places.

Experimental installation

The video recordings were taken using a camera (Allied Vision Technologies®, model F080C) with a 4.8 mm lens, placed above the pen in a central position at a height of 2.3 m, which provided a top view of the whole pen. Colour images were captured at a rate of 11 frames per second and a resolution of 1032 x 778 pixels. The videos were stored on a computer for later analysis. A total of 8 hours of video recordings were taken in this way over the first 3 days after mixing (day 1: 2 h, day 2: 3 h, day 3: 3 h).

Labelling procedure

Video recordings taken by the camera during the experiment were labelled using a video labelling procedure. The labelling procedure is necessary in order to identify whether every selected behaviour occurred during a certain period of time. The procedure involved a labeller watching the video recordings and noting his observations. Aggressive behaviours were observed on the video frame by frame (11 frames per second) to determine the exact starting frame and the time and duration of the aggressive interaction. It took approximately 90 man-hours to label 8 hours (316,800 frames) of video recordings. In order to be classified by the labeller as a behavioural event, behaviour by the animals had to last for at least 1 s.

Data obtained as a result of the labelling procedure were carefully analysed in order to identify aggressive behaviours performed by pigs. The behaviours chosen for labelling during the video labelling procedure are presented in Table 1. Aggressive interactions were divided into 2 groups: medium aggression and high aggression. The division between the two groups of aggressive interaction was based on the level of damage that the behaviours cause to the animal (Table 1).

Table 1: Behaviours labelled

| Aggression group | Behaviour name |
|---|---|
| Medium | Head to head knocking |
| | Head to body knocking |
| | Parallel pressing |
| | Inverse parallel pressing |
| | Flee |
| High | Neck biting |
| | Body biting |
| | Ear biting |

Two databases were created for further analysis. In the first database, each second of the videos was labelled as medium aggression (digit - 1) or no aggression (digit – 0). A second of the video was labelled with digit 1 if one of the medium aggression behaviours was performed within that second; otherwise the second was labelled with digit 0. The second database was created for high aggression behaviours. A second of the video was labelled with digit 1 when one of the high aggression behaviours was performed within that second; otherwise the second was labelled with digit 0. The two databases created were analysed in the data analysis procedure.

Features of the activity index

The activity index was extracted from all the videos recorded during the experiment. The method of calculating the activity index was described by Bloemen *et al.* (1997). In order to represent dynamic aggressive behaviour of pigs on the basis of the activity index, five features of the index were calculated over 14 different time intervals. Different time interval lengths were used in order to test whether the length of the interval influenced the accuracy of ANN classification of aggression events.

The features calculated were: average, maximum, minimum, sum and variance. The time intervals for which the features were calculated were: 7s, 13s, 19s, 25s, 31s, 41s, 51s, 61s, 71s, 81s, 91s, 121s, 181s, 241s. The intervals covered an equal time period before and after a specific second (Figure 1).

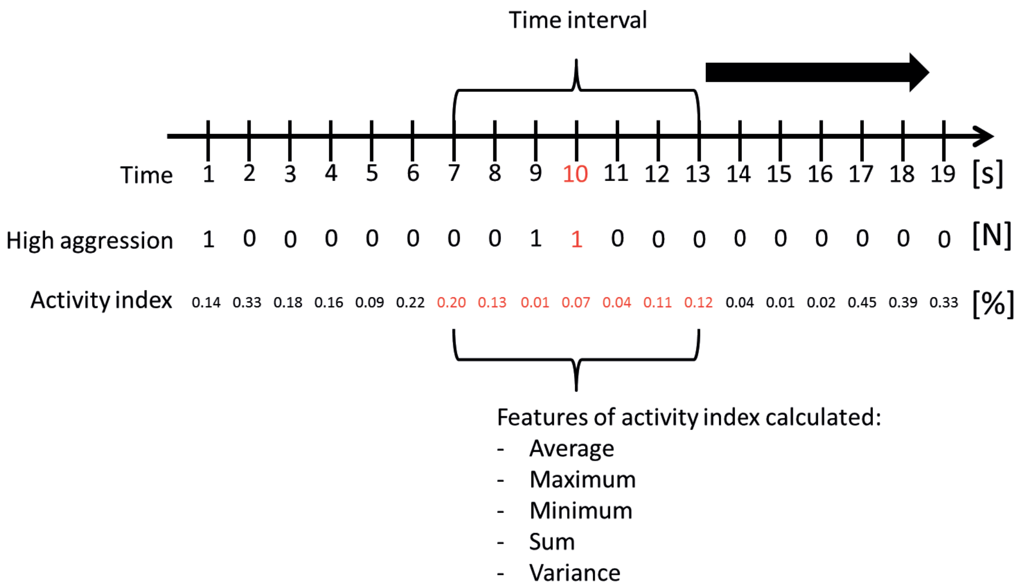


Figure 1:. Calculated features of the activity index – time interval of 7s

Artificial neural network architecture

The ANN designed in this research consisted of an input layer, a single hidden layer and an output layer. The number of units (neurons) in the input layer was dependent on the number of calculated features of the activity index, i.e. on the size of the time interval and number of corresponding sub-intervals. Five features were calculated over each sub-interval; therefore the input layer size ranged from 5 units (7s) to 70 units (241s) (Table 2).

The size of the output layer was one neuron. In the training process the output neuron contained a binary number (0, 1) representing an occurrence of aggression in a certain second of the video. Digit one represented the occurrence of an aggression event (high or medium) while digit 0 meant that no aggression (high or medium) occurred in a particular second. In the validation process the output neuron contained a range of values from 0 to 1. The values represented a probability of aggression occurring in a certain second.

It was decided that it was sufficient to use only one hidden layer in the network as it is able to approximate almost any type of nonlinear mapping (Cybenko, 1989). In order to determine the number of neurons in the hidden layer, a rule was used that the number of hidden neurons should be 2/3 the size of the input layer, plus the size of the output layer (Panchal *et al*., 2011). The size of the hidden layer therefore varied from 4 to 50 units depending on the length of the time interval for the activity index (7s to 241s) (Table 2). The architecture of the network is presented in Figure 2.

Table 2: Overview of time intervals and number of units in layers of ANN

| Time interval (s) | Sub intervals (s) | Quantity of sub intervals | Number of units of ANN | | |
|---|---|---|---|---|---|
| | | | Input layer | Hidden layer | Output layer |
| 7 | 7 | 1 | 5 | 4 | 1 |
| 19 | 7, 13, 19 | 3 | 15 | 11 | 1 |
| 31 | 7, 13, 19, 25, 31 | 5 | 25 | 18 | 1 |
| 61 | 7, 13, 19, 25, 31, 41, 51, 61 | 8 | 40 | 29 | 1 |
| 121 | 7, 13, 19, 25, 31, 41, 51, 61, 71, 81, 91, 121 | 12 | 60 | 43 | 1 |
| 181 | 7, 13, 19, 25, 31, 41, 51, 61, 71, 81, 91, 121, 181 | 13 | 65 | 46 | 1 |
| 241 | 7, 13, 19, 25, 31, 41, 51, 61, 71, 81, 91, 121, 181, 241 | 14 | 70 | 50 | 1 |

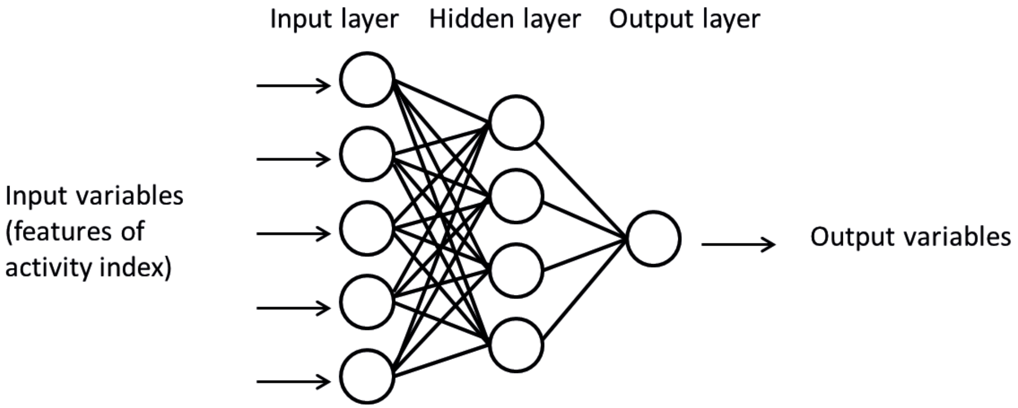


Figure 2: Architecture of ANN designed for 7s time interval (5 features of activity index)

It was decided that ANN training should not take more than 24 hours. Therefore the maximum number of iterations in ANN training was set to 200,000. This limitation made it possible to train the ANN in less than 24 hours.

Data analysis

The procedure used to analyse the data was as follows. In the first step the activity index was calculated on the labelled videos. In the second step five activity index features (average, maximum, minimum, sum and variance) were calculated for 14 different time intervals. In the third step the database comprising the activity index features was divided into 7 groups (main time intervals) with a number of sub-intervals ranging from 1 to 14 (Table 2). In the fourth step the database was divided into a training set (70%) and a test set (30%). In the fifth step the neural network designed was trained using 70% of the database. In the final step validation was performed with the remaining 30% of the database. The procedure was carried out for high aggression and medium aggression events respectively.

## Results and Discussion

A total of 28800s (8h) of videos were recorded during the experiment. Of 28800s of recorded videos, 634s were labelled as high aggression events (Table 3) and 1253s as medium aggression events (Table 4). In the high aggression data set, the training set accounted for 455s out of a total of 634s and the validation set for 179s (Table 3). In the medium aggression data set, the training set contained 867s and the validation data set 386s (Table 4).

Table 3: High aggression data set

| Class | Overall data set | | Training set | | Validation set | |
|---|---|---|---|---|---|---|
| | N seconds | % | N seconds | % | N seconds | % |
| High aggression | 634 | 2.2% | 455 | 2.3% | 179 | 2.1% |
| No high aggression | 28166 | 97.8% | 19705 | 97.7% | 8461 | 97.9% |
| Total | 28800 | 100.0% | 20160 | 100.0% | 8640 | 100.0% |

Table 4: Medium aggression data set

| Class | Overall data set | | Training set | | Validation set | |
|---|---|---|---|---|---|---|
| | N seconds | % | N seconds | % | N seconds | % |
| Medium aggression | 1253 | 4.4% | 867 | 4.3% | 386 | 4.5% |
| No medium aggression | 27547 | 95.6% | 19293 | 95.7% | 8254 | 95.5% |
| Total | 28800 | 100.0% | 20160 | 100.0% | 8640 | 100.0% |

Validation of the ANN classification revealed that sensitivity, specificity and accuracy were higher for classification of high aggression events than for medium aggression events in all time intervals. For the shortest time interval (7s) the sensitivity of high aggression event classification was 89.4%, specificity was 85.5% and accuracy was 99.5%. In the same length of time interval (7s) for medium aggression classification, sensitivity was 77.7%, specificity was 73.5% and accuracy was 97.8%. In the longest time interval (241s) the sensitivity of high aggression event classification was 96.1%, specificity was 94.2% and accuracy was 99.8%. In the same time interval (241s) the classification sensitivity for medium aggression was 86.8%, specificity 94.5% and accuracy 99.2% (Table 5).

Aggressive behaviours by animals that were defined as high aggression in this research were classified with higher accuracy, sensitivity and specificity than behaviours defined as medium aggression (Table 5). Behaviours defined as high aggression were three types of biting (neck, ear and body). Biting behaviour is a form of aggressive behaviour that occurs in the final phases of aggressive interactions and is usually preceded by the other aggressive behaviours. The behaviour is characterized by the pig opening its mouth on another pig's body (Jensen and Yngvesson, 1998). Movement of the pig's relatively small mouth might not be significant enough to be reflected in the activity index value which was calculated at whole pen level. The other characteristic associated with biting behaviour is vigorous (fast, rapid, dynamic) movement (Fraser, 1974). While biting each other, pigs move the whole body rapidly, creating a relatively high level of activity in the pen. In addition to fast movement of the pig's body, when expressing biting behaviour the animals may run in circles while the behaviour is performed (McGlone, 1985). Both circularity and speed of movement of the animals during the expression of biting behaviour seem to distinguish this behaviour from non-aggressive and medium aggressive behaviours and thus influence the higher accuracy, specificity and sensitivity in the classification of high aggression events compared with medium aggression events (Table 5).

Table 5: Validation of ANN classification: sensitivity, specificity and accuracy

| Time interval (s) | High aggression | | | Medium aggression | | |
|---|---|---|---|---|---|---|
| | Sensitivity | Specificity | Accuracy | Sensitivity | Specificity | Accuracy |
| 7 | 89.4% | 85.5% | 99.5% | 77.7% | 73.5% | 97.8% |
| 19 | 89.9% | 81.3% | 99.4% | 87.6% | 68.8% | 97.7% |
| 31 | 88.3% | 88.1% | 99.5% | 83.2% | 76.2% | 98.1% |
| 61 | 89.9% | 93.8% | 99.7% | 80.3% | 86.3% | 98.6% |
| 121 | 92.7% | 95.5% | 99.8% | 84.5% | 93.7% | 99.1% |
| 181 | 92.7% | 96.2% | 99.8% | 86.5% | 94.9% | 99.2% |
| 241 | 96.1% | 94.2% | 99.8% | 86.8% | 94.5% | 99.2% |

A more complex ANN often means that the network is more capable of learning the training patterns in the training data set (Gardner and Dorling, 1998). The methodology used in this research meant that an increase in the length of the time interval for which the activity index was calculated entailed an increase in the number of sub-intervals, nodes and therefore the number of features processed in the ANN. For both types of aggression (medium, high), increasing the length of the time interval from 7s to 241s resulted in higher specificity, sensitivity and accuracy of classification for validation data sets (Table 5). A main shortcoming of using ANNs to model complex relationships is that they are "black boxes"; it is therefore very difficult to determine why an ANN makes a particular decision (McCann, 1992). Nevertheless, better ANN classification performance for longer time intervals might be explained by higher complexity of the ANN applied to those intervals. Increasing the complexity of the ANN allowed better representation of aggressive behaviour in time, and therefore better classification of aggressive events (Table 5).

## Conclusions

The technique presented in this paper allows classification of aggressive events with an ANN on the basis of activity index features calculated for time intervals. In the longest time interval (241s) the classification sensitivity for high aggression events was 96.1%, the specificity was 94.2% and the accuracy was 99.8%.


## Acknowledgments

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# Session 11

# Sheep

## Development of models to assess potential sheep heat-stress during heat waves

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### Abstract

It is well documented that heat-stress burdens sheep welfare and productivity. It is expected that peak heat-stress levels are observed when high temperatures prevail, i.e. during heat waves. However, continuous measurements are not usually available for long periods so as to study the variation of summer heat-stress levels for several years, especially during extreme hot weather. This paper proposes a methodology to develop a long time series of summer temperature and relative humidity inside a naturally ventilated sheep barn. The accuracy and the transferability of the models are verified. Then, the variations of the Temperature Humidity Index inside the barn during heat wave days are examined.

**Keywords:** Sheep, sheep barn, potential heat-stress, regression analysis, temperature humidity index

### Introduction

Climate conditions within a livestock facility affect animal health and welfare. A poor thermal environment can affect the incidence and severity of certain endemic diseases, as well as the animals' thermal comfort, growth rate and milk yield (Panagakis and Chronopoulou, 2010; Sevi *et al*, 2001; Silanikove, 2000). Heat-stress affects crucially the body growth, the biological functions and the productive and reproductive characteristics of sheep, therefore, it is considered as a serious threat for their short- or long-term thermal welfare. A widely accepted method to study animals' heat stress is the application of the Temperature Humidity Index (THI).

A common method that is used to achieve quantitative short-term prediction is the application of regression analysis. This method has been applied in many environmental studies, including studies about the livestock sector (Haeussermann *et al*, 2008).
This paper aims to develop a long time series of summer indoor T and RH values so as to study the variations of the during heat wave (HW) days inside a naturally ventilated sheep barn.

## Material and methods

### Data

Hourly averaged values of T and RH recorded inside two sheep barns and at an outdoor site were used. Relevant information is presented in Table 1.

Table 1: Information for the location of monitoring sites and for data temporal coverage

| Monitoring site | Code name | Coordinates | Temporal coverage |
|---|---|---|---|
| Sheep barn No1 | BIPE | 22º 52´ E – 39º 23´ N | August 2010,<br>July 2011, August 2011 |
| Sheep barn No2 | Dimini | 22º 53´ E – 39º 20´ N | July 2009, August 2009 |
| Outdoor site | Velestino | 22º 45´ E – 39º 24´ N | July and August,<br>from 2007 to 2011 |

### Development and validation of models

Regression analysis was applied to develop two models (eq. 1 and 2) that were used to estimate T and RH at BIPE ($T_{in}$ and $RH_{in}$, respectively) based on T and RH recorded at Velestino ($T_{out}$ and $RH_{out}$, respectively). Data observed during July and August of 2011 were used to develop the models, while data observed during August of 2010 were used to validate the models. The validation was based on two statistical indices [i.e. mean absolute error (MAE) and index of agreement (d)] (Joliffe and Stephenson, 2003). These indices are considered as good overall measures of model performance and have been widely used in environmental studies. The validated models were used to develop the indoor T and RH time series for July and August of the period 2007 – 2011.

$$T_{in} = a \cdot T_{out} + b \tag{1}$$

$$RH_{in} = c \cdot RH_{out} + d \tag{2}$$

The indoor T and RH time series produced by the models for the period July 2009 – August 2009 were comparatively assessed to measurements recorded at Dimini in order to check the transferability of the time series in the greater area.

Identification of HW days

Temperature data observed at Velestino in July and August during the period 2007 – 2011 were used. The 90$^{th}$ percentile of the daily maximum hourly values (DMHVs) of temperature was calculated. When DMHV of temperature > 90$^{th}$ percentile, a HW day is identified. The criterion is suggested by IPCC.

Estimation of sheep's heat-stress

THI given in equation 3 was applied (Marai *et al*, 2007). Heat-stress categories are presented in Table 2 (Marai *et al*, 2007).

$$THI = T_{in} - (0.31 - 0.0031 \cdot RH_{in}) \cdot (T_{in} - 14.4) \tag{3}$$

Table 2: Definition of heat-stress categories according to THI values

| THI class | Heat-stress category |
|---|---|
| THI < 22.2 | absence of heat-stress |
| 22.2 ≤ THI < 23.3 | moderate heat-stress |
| 23.3 ≤ THI < 25.6 | severe heat-stress |
| THI ≥ 25.6 | extreme severe heat-stress |

## Results and Discussion

Validation of models

The low values of MAE and the high values of d (Table 3) reveal that the models are capable to simulate the indoor experimental data. MAE illustrates the presence of significant mispredictions, while IA indicates the degree to which the predictions of the model are error free.

Table 3: Assessment of the models performance

| | MAE (% of the mean of the observed values) | d |
|---|---|---|
| Model for T | 3.7 | 0.95 |
| Model for RH | 10.4 | 0.85 |

When the produced time series were compared to measurements recorded in another livestock facility, MAEs were increased ~40% (Table 4). However, MAE values still remain at relatively low levels, while d values remained almost the same (Table 4). Therefore, it could be concluded that the time series produced by the models can successfully predict the indoor climatic conditions that prevail in other sheep facilities located in the greater area, provided these facilities have similar characteristics regarding their structure (e.g. thermal insulation, ventilation rate) and the population of housed animals (e.g. breed, weight, housing density).

Table 4: Assessment of the transferability of the models results

| | MAE (% of the mean of the observed values) | d |
|---|---|---|
| Model for T | 5.2 | 0.93 |
| Model for RH | 14.6 | 0.84 |

Identification of heat wave days

The 90$^{th}$ percentile of the DMHVs of temperature observed at Velestino in July and August during the period 2007 – 2011 was found equal to 35.8 $^{o}$C. The DMHV of temperature exceeded this threshold in 31 days, therefore 31 HW days (10.2%) were identified. 11, 5, 5, 7 and 3 HW days were identified in years from 2007 to 2011, respectively. Figure 1 shows the distribution of the DMHVs of temperature during the HW days. The maximum DMHV was 42.8 $^{o}$C and it was observed on 25 July 2007, when the peak of a strong HW occurred (Papanastasiou *et al*, 2010). The non HW days were 273 (89.8%). No data were available for 6 days.

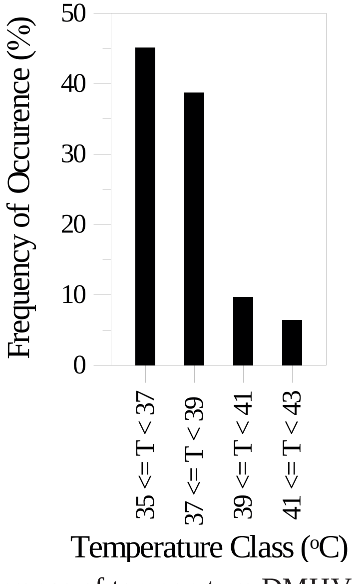


Figure 1: Frequency of occurrence of temperature DMHVs during HW days.

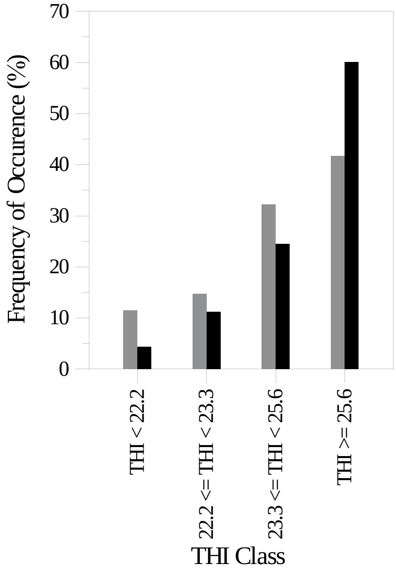


Figure 2: Frequency of occurrence of THI classes during HW (black bars) and non HW (gray bars) days.

<u>Assessment of potential sheep heat-stress</u>

The frequency of occurrence of THI classes during HW and non HW days revealed that a clear shift to higher classes is observed during HW days (figure 2). The averaged diurnal variation of THI during HW and non HW days (Figure 3) showed that (a) heat-stress is always observed during HW days, (b) extreme severe heat-stress is observed between 10:00 and 24:00 during HW days and (c) the daily range of THI is higher during HW days than during non HW days.

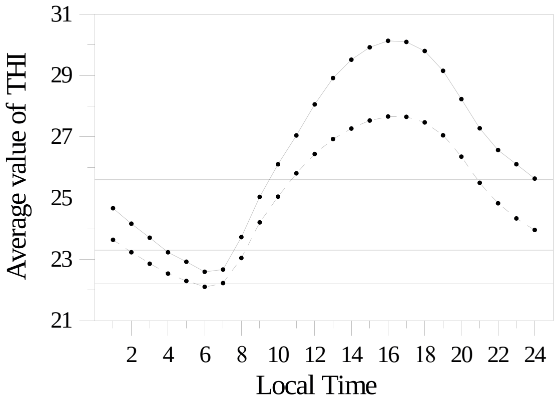


Figure 3: Averaged diurnal variation of THI during HW (solid line) and non HW (dashed line) days. The horizontal solid lines correspond to THI thresholds (i.e. 22.2, 23.3 and 25.6)

## Conclusions

This paper presented a methodology to develop a long time series for T and RH inside a naturally ventilated sheep barn. Two models were developed by applying regression analysis that could also be applied to other sheep facilities located in the greater area, provided these facilities have similar characteristics regarding their structure and the population of housed animals. As continuous indoor measurements are not usually available for long periods, the application of this methodology provides the opportunity to assess summer sheep heat-stress levels for several years. In this paper, heat-stress levels were assessed during HW and non HW days for a 5-year period and significant differences in THI levels were detected.

## Acknowledgements

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# Environmental and endocrine assessment of sheep welfare in a climate-controlled room: A preliminary study

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## Abstract

The nutritional status of sheep grazing in the Montado ecosystem varies considerably throughout the year, due to variations in the availability and quality of pastures, strongly influenced by the typical climatic conditions of the Mediterranean region: dry summer and autumn with very little rain. These variations lead to severely restricted feeding for approximately half the year, causing under-nutrition, limitations on animal production and a poor level of welfare.

The main objective of this work was to test the use of a salivette device to measure salivary cortisol concentrations in order to assess heat stress situations. The idea is that those variables will be used with PLF techniques to provide a rapid diagnostic test that could have a major impact on the assessment of animal welfare.

Experiments were conducted in a climate-controlled room using pregnant adult ewes, fed on dehydrated alfalfa pellets at a restricted level (20g/kg$^{0.75}$). The air temperature, humidity and $CO_2$ concentration were recorded continuously inside and outside the room. The temperature and humidity index (THI) was used to assess heat stress level. Samples of blood and saliva were collected and cortisol, used as indicator of animal welfare, was determined by enzyme-linked immunosorbent assay (ELISA).

The THI was compared with the cortisol concentration and the results showed that cortisol levels in saliva collected using the salivette device correlated highly with levels in the plasma. There appears to be evidence that salivary cortisol is a promising biomarker for automatic measurement of chronic heat stress.

**Keywords:** Temperature-humidity index, automatic monitoring, salivary cortisol, thermal stress

## Introduction

In the south of Portugal sheep are produced in extensive sheep farming systems with animals kept outdoors throughout the year. Although raised without restrictions and closer to their natural behaviour, sheep in this production system can be exposed to a variety of stressors which will affect their welfare and productivity. Frequent stressors in those systems are high temperatures and nutritive level restrictions (Lamy *et al.*, 2012), even though sheep are considered to be one of the most resistant species to extreme climatic conditions, in this case high temperatures.
The main changes caused by heat stress in sheep are reduced feed intake and changes in the metabolism and hormonal secretions (Marai *et al.*, 2007). The efficacy of thermoregulatory mechanisms largely depends on sheep breed and individual animal genetics (Sevi and Caroprese, 2012) but the upper critical temperature for sheep is assumed to be in the range of 25 to 31ºC (Echevarría and Miazzo, 2002) and temperatures often exceed 30ºC in a Mediterranean summer. Another important stressor is nutritional status. The nutritional status of sheep grazing in the Montado ecosystem varies considerably throughout the year, due to variations in the availability and quality of pastures, strongly influenced by the typical climatic conditions of the Mediterranean region: dry summer and autumn with very little rain. These variations lead to feeding restrictions for approximately half the year, causing under-nutrition which usually coincides with gestation. Due to these characteristics, sheep represent a good animal model for the study of chronic prolonged stress situations.
Consumer concern for and awareness of animal welfare issues is increasing, and the humaneness of farm animal management is coming under closer scrutiny. Precision Livestock Farming (PLF) has the potential to contribute to better welfare assessment through automatic monitoring and control, but although many methods of assessing stress levels and consequently welfare exist, in order to achieve this goal there is a critical need to establish a biomarker and develop simple monitoring techniques to determine the stress levels suffered by animals under various environmental and social conditions.
Several indicators of heat stress can be found in the literature (Kelly and Bond, 1971; Ravagnolo *et al.*, 2000; Marai *et al.*, 2007; Papanastasiou *et al.*, 2012). However, it is still difficult to identify one index for widespread use, because they are influenced by specific environmental factors in each region and by factors related to the animal and its management (Gaughan *et al.*, 2008). One of the most used is the Temperature-Humidity Index (THI), which combines both temperature and relative humidity.
Another commonly used heat stress indicator is the level of plasmatic cortisol. Various hormones have been linked to the stress response. The front-line hormones to overcome stressful situations are the glucocorticoids and catecholamines. These hormones are determined as a parameter of adrenal activity and thus of disturbance. The concentration of glucocorticoids (or their metabolites) can be measured in various body fluids, but

has traditionally been measured in the blood, involving some form of restraint and discomfort, and often causing changes in the physiological parameters being measured. Non-invasive methods are becoming increasingly available. The use of salivary cortisol as a measure of adrenal activity has been applied in humans since the early 1980s and is now seen as a reliable stress marker (Aardal and Holm, 1985). Direct correlations between salivary and plasma cortisol in domestic animals have been shown in basal and stressful situations (Cook *et al*.,1996).
The main objectives of this work were to evaluate the effect of under-nutrition and heat stress on the welfare of sheep and to compare the THI index with the results of plasmatic and salivary cortisol analysis. The idea is that it will be possible to combine those variables with PLF techniques.

## Material and methods

Experiments were conducted in a climate-controlled room located in the animal facilities of the University of Évora between 7 June and 20 July 2012. Ten pregnant adult ewes in the last trimester of gestation were used but only five were assessed for cortisol levels in this preliminary study. They were fed with dehydrated alfalfa pellets at a restricted level (20g/ $kg^{0.75}$). Animals were kept grouped together to minimise stress, but were individually penned when feed was distributed. The room had an area of approximately 40 $m^2$ and a volume of 108 $m^3$.The ventilation system used mechanical extractors and was designed to ensure good air quality.
The minimum temperature was set at 28ºC during the daytime (8 a.m. to 8 p.m.) and 18ºC at night (8 p.m. to 8 a.m.) and was maintained automatically by an air conditioning system. Ventilation was automatically controlled based on the air quality and with a temperature set-point of 29ºC + 2ºC. The room was equipped with windows which opened automatically in the event of a power failure in order to maintain a minimum ventilation rate.
Climate data, such as the air temperature and humidity and $CO_2$ concentration, were registered continuously inside and outside the room. Mean, maximum and minimum daily values were obtained. The temperature-humidity index (THI) was calculated using the equation proposed by Marai *et al*. (2001, 2007), calculated for all the days of experimental work for the whole day, night-time and daytime.

$$THI = Tdb - (0.31 - 0.0031 \times RH) \times (Tdb - 14.4)$$

where *Tdb* is the dry bulb temperature (◦C) and *RH* is the relative humidity (%). The values obtained indicate, in accordance with Marai *et al*. (2001, 2007):

- No heat stress if THI < 22.2 or THI
- Moderate heat stress if 22.2 ≤ THI < 23.3
- Severe heat stress if 23.3 ≤ THI < 25.6
- Extreme severe heat stress if THI ≥ 25.6.

Blood samples were obtained once a week from the jugular vein using a vacuette® K3 EDTA tube (Greiner Bio-One), and saliva was collected with salivettes® (Sarstedt). The salivary and serum cortisol concentrations were assessed using an EIA kit (IBL International, Ref. RE52611) and used as indicators of animal welfare.

Although blood samples were collected during six consecutive weeks in this exploratory trial, only two dates, 8 June and 19 July, were used to analyse the cortisol concentrations. These dates were chosen because the different external air temperature conditions represented very different heat stress levels.

**Results and Discussion**

During the experimental period the maximum inside air temperature was 39.1ºC and the minimum was 19.3ºC. The maximum relative humidity was 87% and the minimum was 30%. The maximum $CO_2$ concentration was 1000 ppm and the minimum was 360 ppm. Outside conditions were characterised by a maximum air temperature of 39.7ºC and a minimum of 7ºC. Relative humidity varied between 29% and 62%. Mean solar radiation was 350 W/m$^2$, mean wind velocity 2.7 m/s and $CO_2$ 360 ppm.
The average climate data and THI index for the whole of the experimental period are presented in Table 1. On average, the air temperature was in the range of the sheep's thermo-neutral zone. Also, in accordance with Marai *et al.* (2001, 2007), the THI calculated for the day period shows that animals were in conditions of moderate to severe heat stress, whereas no heat stress conditions were observed at night; this allowed the animals to dissipate heat gained during the day and control their body temperature.

Table 1: Description of daily average climate data and THI index during the experimental period (7 June to 20 July) (mean ± standard deviation)

| Daily Average | Mean ± SD |
|---|---|
| Mean inside temperature | 26.4 ± 2.3 |
| Maximum inside temperature | 31.2 ± 3.3 |
| Minimum inside temperature | 22.0 ± 1.9 |
| Mean inside relative humidity | 47.7 ± 9.1 |
| Maximum inside relative humidity | 67.8 ± 8.9 |
| Minimum inside relative humidity | 27.8 ± 11.8 |
| $CO_2$ inside concentration | 582.1 ± 58.4 |
| Daily THI | 22.8 ± 1.2 |
| Day period THI | 24.4 ± 1.3 |
| Night period THI | 20.6 ± 1.4 |

Figure 1 shows the THI values calculated for the experimental period, using the equation proposed by Marai *et al.* (2001, 2007), for the day and night periods and also daily (24 h). Some days are missing due to errors in data registration. There is a clear difference between the first set of data and the two others, corresponding to different climate conditions. In fact, early in June the air temperature was lower and relative humidity was higher than in the following periods (Figure 2). After 20 June extreme heat stress conditions occurred during the daytime, while no heat stress was identified during the night for most of the time. Over the 24 h period the animals experienced severe to extreme heat stress conditions. Between 7 and 16 June extreme heat stress conditions occurred only sporadically during the daytime and no heat stress occurred during the night time, while over the 24 h period animals experienced moderate to severe heat stress conditions.

In this first approach we only tested cortisol concentration for two days, which represented outlying temperature points. We chose 8 June to represent a “no heat stress situation” and 19 July as a “heat stress situation” (Figure 1). Detailed climate data registered during the two days chosen for the blood and saliva analysis are presented in Table 2 and results for THI and cortisol levels are presented in Table 3.

From this exploratory data it appears that cortisol values from both serum and saliva increase in situations of extremely severe heat stress (THI ≥ 25.6, Marai *et al.* 2001, 2007). The THI values were calculated for the 24 h period as blood and saliva were collected during the morning. Similar values were obtained by Papanastasiou *et al.* (2012) in Greece, when investigating seasonal heat stress experienced by sheep housed in a naturally ventilated barn with no thermal insulation. They reported that the THI remained higher than the extremely severe heat stress threshold (i.e. THI = 25.6) during the vast majority of summer daytime hours, and that the daily maximum hourly values of THI remained higher than 25.6 on 90% of summer days.

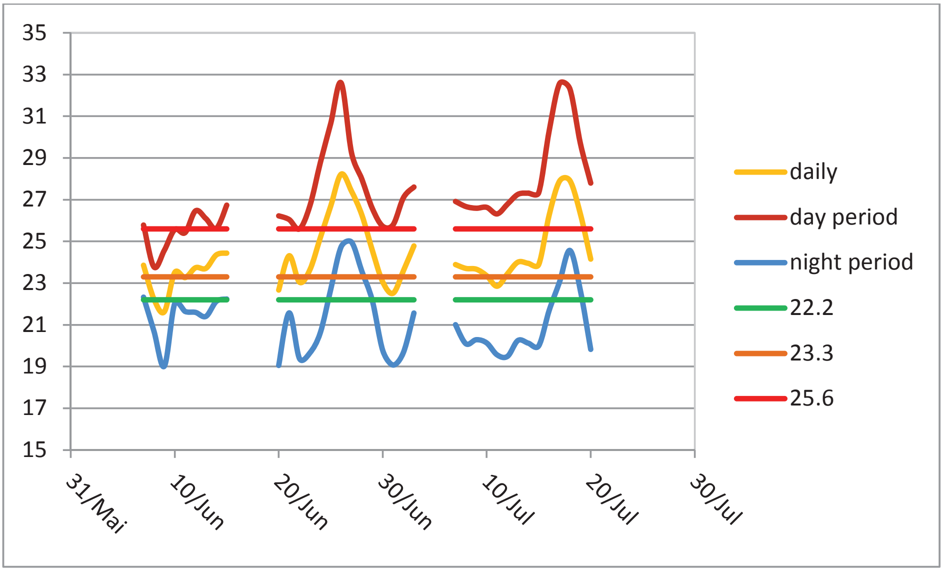


Figure 1: Temperature Humidity Index calculated for the experimental period. Lower, medium and upper limits are in accordance with Marai et al (2001, 2007)

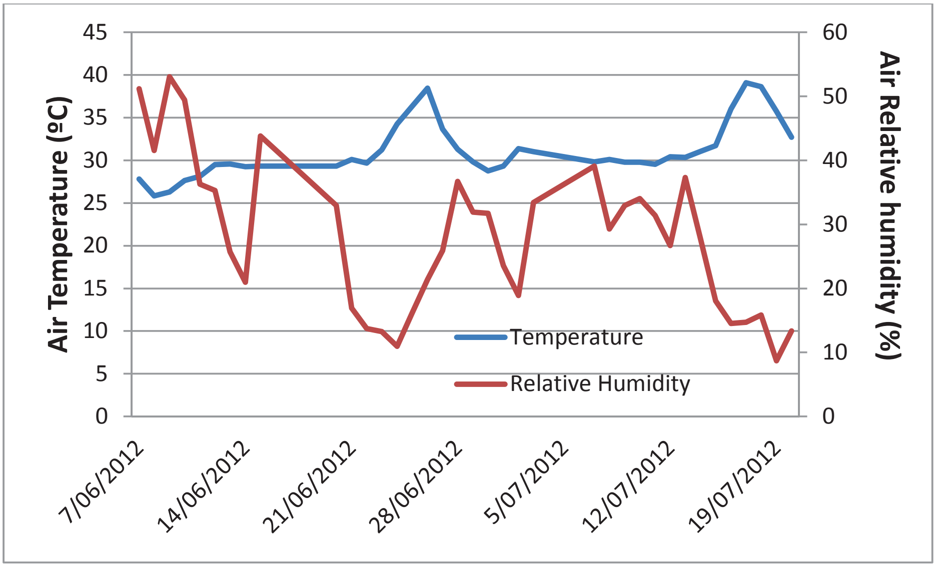


Figure 2: Inside Air Temperature and Relative Humidity during the experimental period

Table 2: Inside and Outside Temperature, Humidity and CO2 for the No-Heat Stress and Severe-Heat Stress dates

| | No Heat Stress | Severe Heat Stress |
|---|---|---|
| Inside Air Temperature (ºC) | | |
| Mean | 23.4 | 29.4 |
| Maximum | 25.9 | 35.8 |
| Minimum | 21.1 | 24.1 |
| Outside Air Temperature (ºC) | | |
| Mean | 15.9 | 25.5 |
| Maximum | 23.3 | 37.1 |
| Minimum | 10.0 | 15.7 |
| Inside Air Relative Humidity (%) | | |
| Mean | 59.1 | 33.1 |
| Maximum | 80.0 | 51.8 |
| Minimum | 41.5 | 8.7 |
| Outside (Mean) | | |
| RH (%) | 53.3 | 36.5 |
| Inside $CO_2$ (ppm) | | |
| Mean | 625.1 | 475.5 |
| Maximum | 985.6 | 711.6 |
| Minimum | 433.1 | 396.3 |
| Outside (Mean) | | |
| $CO_2$ (ppm) | | 363.2 |

Table 3: The temperature-humidity index (THI) and cortisol concentrations (ng/ml) in serum and saliva samples of sheep for the No Heat Stress and Severe Heat Stress dates (Mean±SD)

| | No Heat Stress | Severe Heat Stress |
|---|---|---|
| THI | 22.24 | 26.33 |
| Serum Cortisol | 19.72 (± 5.0) | 31.12 (±21.0) |
| Salivary Cortisol | 1.02 (±0.6) | 1.27 (±1.0) |

In these circumstances it is expected that stress hormones will increase (Bell *et al*., 1989; Ferreira *et al*, 2009). This was confirmed by our preliminary data. According to Meyer (2010), in homoeothermic conditions the average serum cortisol level in sheep is 24 ± 0.36 ng/mL, and we observed higher values (31.12 ng/mL). We also found that salivary cortisol rose when the serum cortisol increased. Umeda *et al*. (1981) looked at morning levels of salivary and serum unbound cortisol in humans and found that the values had a correlation coefficient of 0.893. In our study the correlation between cortisol levels in both fluids was not significant (0.497) due to the small number of animals (n=5) and the great variation between individual values, but a similar trend was detected.

Although salivary cortisol levels are lower than serum total cortisol concentrations (Gozansky, 2005), Umeda *et al*. (1981) reported that changes in cortisol levels in response to stimulation are seen more accurately in salivary cortisol than serum total cortisol. Therefore, monitoring of salivary cortisol may be used to provide diagnostic information. It has the additional advantage of being suitable for adaptation to immune-chromatographic or lateral flow devices (LFDs). This area of diagnostics has grown significantly in recent years, with the most common and well-known device being the home pregnancy test. A specially designed device has already been applied to the determination of cortisol in the saliva of pigs (Lane *et al*., 2004). The most important finding is that cortisol values (both serum and salivary) were consistently higher in extreme heat stress situations.

## Conclusions

This study was an initial approach to collecting data to assess the welfare of pregnant ewes in a climate controlled room. We were looking for the possibility of using salivary cortisol to provide data that will make possible to establish a link between environment and welfare. Research in this area could support the development and validation of a rapid field test kit.

Cortisol, one of the substances most frequently investigated in saliva, is a hormone that acts by increasing the rate of gluconeogenesis during stress. In the wide variety of studies on stress and endocrinology, there is a consensus that salivary cortisol increases dramatically under chronic stress (please refer to Gröschl, 2008 for a comprehensive review). Our results, although preliminary, support the hypothesis that salivary cortisol can be used in PLF to assess animal welfare.

In this context, more work is needed and further examination of our data is warranted. Examining the physiological and psychological responses of livestock to Mediterranean environmental conditions may assist in the development of better and more precise tools for managing livestock production.

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## Adaptation of stationary readers to the different RFID devices coexisting in sheep and goat Spanish flocks

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### Abstract

The aim of this work was to adapt stationary readers for small ruminant farms, through the study of different orientation of the antennas, in a situation of coexistence of electronic ear tags, ruminal bolus, leg tags and injectable transponders. A flock of 80 sheep was identified with HDX boluses (n=9), FDX-b boluses (n=9), FDX-b electronic ear tags (n=42), FDX-b leg tags (n=10) and 3x15 mm, FDX-b injectable transponders (n=10). To obtain the maximum efficiency of reading in flocks with different electronic tags, the orientation of the antennas (lateral, on the floor, or both) should be adapted to the device.

**Keywords**: RFID, sheep, goats, antenna

### Introduction

The Regulation 21/2004 of the Council of the European Union established a system for the identification and registration of ovine and caprine animals. Doing so, all animals born after 9 July 2005, in member states with more than 600,000 animals or more than 160,000 goats, shall be identified by an ear tag and a passive electronic transponder. This can be inserted either into an electronic ear tag or a ruminal bolus. At the end of 2008 the Council revised the available electronic devices existing in the market through the Commission Regulation 933/2008. The “competent authority” shall approve means of electronic identification in the form of a ruminal bolus or an electronic ear tag, and for those animals not involved in intra-community trade, an electronic identifier in the form of an electronic mark on the pastern (electronic leg tags) or of an injectable transponder on the metatarsus. The political division of Spain in 17 Autonomous Regions, which have the competences in Livestock Policies (“competent authority”), has led to a situation where each region has designed its own method to identify sheep and goats. Under this situation, when farmers buy animals from another region or from another European country, or when sheep and goats live together in the same flock, the four electronic devices, and moreover, the two technologies available (HDX and FDX-b), can be found in the same flock. It hampers dynamic readings by a static reader passing through a runway.

The aim of this work was to adapt stationary readers, through the study of different orientation of the antennas, in a situation of coexistence of electronic ear tags, ruminal bolus, leg tags and injectable transponders in small ruminant flocks.

## Material and methods

The work was performed at the Experimental Farm of the University of Zaragoza, (41ºN), with protocols approved by the Ethics Committee for Animal Experiments from the University of Zaragoza, Spain, under Project License PI06/09. The care and use of animals were performed accordingly with the Spanish Policy for Animal Protection RD1201/05, which meets the European Union Directive 86/609 on the protection of animals used for experimental and other scientific purposes.

A flock of 80 sheep was identified as follows (Figure 1): 9 HDX ruminal boluses (Datamars), 9 FDX-b ruminal boluses (Felixcan), 42 electronic ear tags (FDX-b, Felixcan), 10 leg tags (FDX-b, Reyflex) placed around the right hind leg, and 10 injectable transponders (FDX-b, Felixcan) located subcutaneously at the metatarsus region of the right hind leg. All these devices have been approved by the International Committee for Animal Recording (ICAR).

Ruminal bolus dimensions were (Ø x length, weight): 11 x 55 mm, 20 g (Datamars) and 13 mm x 60, 20.5 g (Felixcan). Ear tags data are (Ø x height, weight) 28.7 x 13.7 mm, 5 g. The electronic leg tags used in the experiment consists of a yellow polyurethane bracelet (160 x 30 x 2 mm, 14 g), which was placed on the right hind limb, around the metatarsus, covering the entire region. Injectable transponders dimensions were (Ø x length) 3x15 mm.

Dynamic readings were recorded by a static reader (Centurion, Felixcan), fixed on a runway (width 45 cm) which can be connected simultaneously to two antennas, one (85x68 cm) standing up vertically and fixed on the left side of the runway (lateral), and the other one (85x40 cm) lying on the floor of the runway (floor) (Figure 2). The efficiency of the reading was calculated as

$$(\text{n read devices}/\text{n readable devices}) \times 100$$

after 10 consecutive passes through the runway. Percentage of readings was compared by chi-square tests.

## Results and Discussion

Boluses and ear tags reached 100% readings with the lateral antenna or with both connected simultaneously, although no more than 14% (ear tags) or 50% (boluses) were read when only the floor antenna was on (Table 1). Both leg tags and injectable transponders were fully read when the floor antenna was connected, either alone or with the lateral one at the same time. Leg tags were 100% read with the lateral antenna. It is important to note that these leg tags contain an “air coil” antenna, so that they behave as an ear tag. Injectable transponders were not read at all with the lateral antenna. The lateral antenna by its own was able to read with the same efficacy boluses, ear tags and leg tags, but was not able to read any injectable transponders. The floor antenna was able to read those devices inserted on the legs (leg tags and injectable transponders) but was inefficient for boluses and ear tags.


Figure 1: Electronic tags used in the study

Table 1: Mean dynamic reading efficiency (minimum-maximum) of the different devices tested according to the position of the antennas, after 10 consecutive passes through the runway

| | **Lateral** | **Floor** | **Lateral+Floor** |
|---|---|---|---|
| Bolus | 100% (100-100)$^{a,x}$ | 40% (25-50)$^{a,y}$ | 100% (100-100)$^{a,x}$ |
| Ear tags | 99% (98-100)$^{a,x}$ | 13% (12-14)$^{a,y}$ | 99.5% (98-100)$^{a,x}$ |
| Leg tags | 100% (100-100)$^{a}$ | 100% (100-100)$^{b}$ | 100% (100-100)$^{a}$ |
| Injectable | 0% (0-0)$^{b,x}$ | 100% (100-100)$^{b,y}$ | 100% (100-100)$^{a,y}$ |

(a,b) in the same column (within antenna position) indicate $p<0.05$
(x,y) in the same line (within type of tag) indicate $p<0.05$

Dynamics reading efficiency of the ruminal bolus with the lateral antenna is similar to that obtained by Caja *et al.* (1999) (100%) or Ghirardi *et al.* (2006) (99.6%). Carnè *et al.* (2010) have shown reading efficiencies for electronic leg tags in goats lower than in our study, either with lateral (68.2%) or floor antennas (92.4%). Using the same device in goats, previous works of our group have also reported similar reading efficiencies for the electronic leg tag under study (100%; Abecia *et al.*, 2010). Regarding the injectable transponders, our results are coincident with studies of the Ministry of Agriculture of

Spain, which presented a dynamic reading efficiency of 99.7% with 15-mm transponders injected in the foreleg pastern of Murciano-Granadina adult goats when the antenna was placed on the floor (MAPA, 2007).


Figure 2: Static reader and antennas used in the experiment

## Conclusions

In conclusion, after the observations of this experiment, we can recommend:

- Static readers with only one antenna: the best position is the lateral one, when the flock is identified with boluses and/or electronic ear tags. In the case of leg tags or injectable transponders (usually goat flocks), the antenna should be on the floor.
- Static readers with two antennas: both antennas connected to ensure that all sort of devices can be read.

Regarding the device applied, we can recommend:

- Only electronic boluses: antenna fixed on the left side of the runway.
- Only ear tags: antenna fixed on the left side of the runway, as high as possible.
- Only leg tags: antenna fixed on the floor or on the left side of the runway, as low as possible.
- Only injectable transponders: antenna on the floor
- Boluses + ear tags: antenna on the left side of the runway, half height of the runway.
- Boluses or ear tags + leg tags: two antennas if it is possible; if only one is available, laterally half-low height.
- Boluses or ear tags + injectable transponders: the most difficult combination to reach high percentages of readings. It can be found in some Spanish mixed flocks (sheep and goats). Two antennas should be used.

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## Integrating electronic identification into hill sheep management

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### Abstract

This paper reports on the first year of implementation of a 5-year research programme to integrate electronic identification into hill sheep management. A sheep flock was allocated to two system groups, one managed conventionally and the other with a new Precision Livestock Farming (PLF) management protocol. The PLF protocol involves ewe winter feeding groups based on weight change, Targeted Selective Treatment for worming finishing lambs and changes on culling age policy of ewes to try to increase longevity. The first year demonstrated successfully that it is feasible to implement the PLF tools into sheep management on a hill farm.

**Keywords:** Targeted Selective Treatment, winter feeding, lamb, ewe, extensive system

### Introduction

It is compulsory in the European Union (EC No. 21/2004, amended by EC No. 1560/2007) for all sheep born after 31/12/2009, and not destined for slaughter before they are 12 months old, to have electronic identification (EID). While most sheep farmers and shepherds may perceive electronic tagging just as an additional burden, EID can be an opportunity to improve farm management and benefit from Precision Livestock Farming (PLF) in the sheep sector. A precise sheep system can benefit farmers, as well as the environment. It is also predicted to improve sheep welfare, as the system is dealing with individual sheep. Therefore, we set out to investigate how to integrate EID within flock management and to quantify potential costs and benefits. Additionally, a detailed study on farm labour, using an automated weighing and shedding system, is currently being undertaken. In this paper, we will describe how the new PLF management protocol is implemented and show the first preliminary results.

### Material and methods

In this study, a hill sheep flock was allocated to two system groups, one managed conventionally (used as a comparison) and the other run with a new PLF management

protocol (Table 1). This paper focuses on two major differences in management through the introduction of winter feeding groups based on weight change for ewes, and of a Targeted Selective Treatment (TST) for worming the lambs during the summer (from marking in June) until the autumn when they are housed for the final finishing period.
The ewes were allocated to the two systems, Conventional and PLF, balanced for age, live weight, litter size the previous year and sire.
It should be pointed out that the Conventional system in place is already sophisticated compared to many hill sheep farms in Scotland, using an automated weighing scale. Ultra-sound pregnancy scanning, however, is commonplace amongst hill farmers in the UK (Morgan-Davies *et al*, 2006).
The sheep production year beginning in autumn 2012 was the first year when changes were implemented. During the course of the project, the two system groups will be investigated in terms of costs, outputs, labour use and estimated carbon emissions. Genetically, the flock consists of two different breeds, Lleyn and Scottish Blackface. The Scottish Blackface sheep consist of two different genetic lines. The genetics do not play an important role in the described experiment, but were taken into account in the analysis.

Table 1: Management protocols for the Conventional and the PLF group.

| | Conventional group | PLF group |
|---|---|---|
| Winter feeding of ewes from end of mating to just before lambing | Based on Body Condition Score (BCS) + the number of expected lambs after ultrasound scanning in February | Based on percentage of weight change + the number of expected lambs after ultrasound scanning in February |
| Worming of lambs | Whole flock approach based on pooled faecal egg counts | Targeted Selective Treatment based on weight change of individuals |
| Flock longevity | Breeding sheep culled at a maximum age of 5.5 years | Sheep culled on individual fitness criteria, irrespective of age |

Anthelmintic resistance is relatively common on Scottish sheep farms, where the prevalence of benzimidazole resistance has been reported to be 64% (Bartley *et al*, 2003) and macrocyclic lactone resistance approximately 35% (Bartley *et al*, 2006).
TST is a refugia-based worming method, where only a proportion of the flock is treated at any one time in order to maintain an anthelmintic-susceptible parasite population (Kenyon *et al*, 2009; Kenyon *et al*, 2013). The ability to effectively target anthelmintic use relies on the identification of those animals that will most benefit from treatment using short-term weight change. This method has been shown to prolong the efficacy of current anthelmintics (Kenyon *et al*, 2013).

In the PLF group, the creation of feeding groups for ewes over the winter is based on individual weight changes with weighing at pre-mating as a reference point (Table 2). Due to the balancing of the two systems, factors, such as age and live weight do not account for any differences found in the results. The animals are split into different feeding groups in January, and moved to different groups at scanning in February. Figure 1 gives an overview about the handling dates. In comparison, the Conventional group is separated into “good”, “medium”, “poor” and “very poor” body condition, where the shepherd quickly allocates them to feeding groups based on their condition at the time, which is assessed by “eye” and by palpating the loin area. A “poor” animal will need more feed than a “good” animal to achieve and maintain optimum weight and condition for pregnancy. In February, the scanning results (e.g. barren, single, twin or triplet lambs) are also taken into account when animals are newly separated into feeding groups.

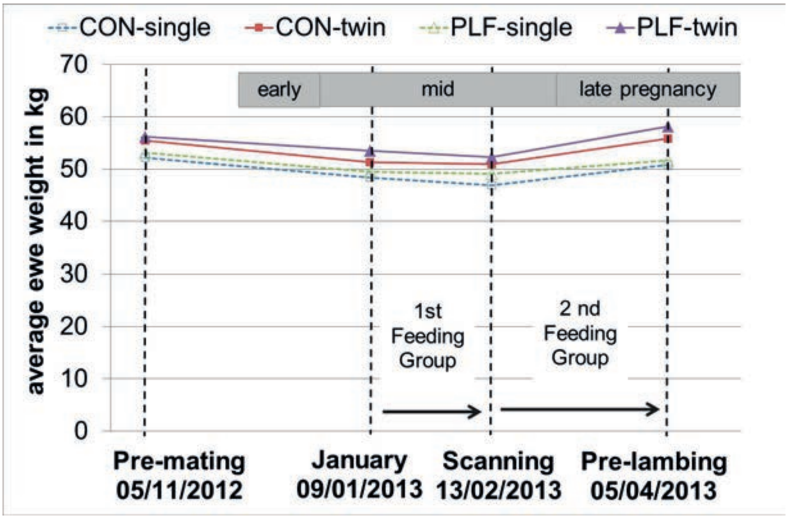


Figure 1: Overview over weighing dates and body weight development for the two groups split into ewes carrying singles or twins.

All ewes are ultrasound scanned to identify their pregnancy status, if they are barren (empty), or carrying singles, twins or triplets. This information is also included when adjusting the feeding groups in February for both the PLF and Conventional treatment groups.

Table 2: Feeding group rules. The different colours/patterns indicate the different feeding groups. There were 4 different feeding groups in the 1st period and 6 different feeding groups in the 2nd period.

| 1st feeding group rules | | 2nd feeding group rules | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1st feeding group classification | | | |
| Pre-mating to Jan % wt | feeding group | Scan | Jan to Scan % wt | Good | Medium | Poor | Very poor |
| Lost 10% or more | Very poor | single | Gain over 10% | | | | |
| Lost less than -10% | Poor | | Gain over 5% | | | | |
| Lost less than -5% | Medium | | Gain over 0% | | | | |
| Gain > = 0% | Good | | Lost less than -5% | | | | |
| | | | Lost less than -10% | | | | |
| | | | Lost 10% or more | | | | |
| | | twins | Gain over 10% | | | | |
| | | | Gain over 5% | | | | |
| | | | Gain over 0% | | | | |
| | | | Lost less than -5% | | | | |
| | | | Lost less than -10% | | | | |
| | | | Lost 10% or more | | | | |
| | | triplets | Gain over 10% | | | | |
| | | | Gain over 5% | | | | |
| | | | Gain over 0% | | | | |
| | | | Lost less than -5% | | | | |
| | | | Lost less than -10% | | | | |
| | | | Lost 10% or more | | | | |

In the PLF group, the lambs are subject to the TST treatment and are weighed monthly after birth and wormed only if they do not achieve their expected individual weight gain. In addition, those lambs are shed in three different weight groups and wormed according to their body weight. The lambs in the Conventional group are wormed using a whole flock approach, based on pooled faecal samples. That means that 10 samples are taken per group and pooled. If the result is > 500 eggs/g, all lambs are wormed, if it is lower, no worming will take place. When those lambs are wormed, they receive a maximum dose of wormer to cater for the heaviest lambs in the group. This is the standard approach for most Scottish hill flocks. The expected individual weight gain for the PLF group is calculated by using the “Happy Factor” algorithm developed by Greer et al (2009). That algorithm requires the input of the animal weight and the expected biomass intake. For that, biomass was measured using the Grassmaster II (Novel Ways, New Zealand) throughout the summer. A Prattley system was used for automatic weighing and autodrafting in combination with a Tru-Test® XR3000 weigh head. A selection of different low frequency RFID ear tags, such as Ritchey’s RD2000, Shearwell Data’s EID SetTag and Allflex’s EID Button tag were used.

To analyse the weight data, consisting of weight changes between the different weighing dates, a Linear Mixed Model in Genstat 11th Edition (Payne *et al*, 2008) with the fixed effects: treatment (Conventional or PLF management); genetic line (Lleyn, Scottish Blackface high index, Scottish Blackface control line); scanning results (single, twin, triplet); ewe age (3, 4, 5, 6 years); and the interactions between these effects (2-way) was used. Primiparous ewes (gimmers), ewes carrying triplets and barren ewes (not pregnant) were excluded in the preliminary analysis due to differences in management for these groups.

## Results

Currently there are 433 ewes in the Conventional group and 446 ewes in the PLF group. The results presented are based on the Scottish Blackface flock using the single- and twin-bearing ewes only. The results are mirrored in the Lleyn flock. By implementing a more individualised system, it is very likely that ewes can be fed in a way that helps to reduce weight loss and, therefore, improves the number of lambs born and weaned relative to the amount of feed provided.

In this investigative period, we have weighed the ewes at pre-mating in November, and at subsequent weighing sessions the feeding groups were re-adjusted. Due to the additional parameter of pregnancy status (barren, single, twins) the number of feeding groups increased in February. Figure 2 shows how the two different treatment groups responded from pre-mating to scanning.

Overall, the PLF group lost slightly less weight between pre-mating and scanning than the Conventional group, with a difference of -1.2 % in the raw data. In general, the weight loss ranged from -31 to +20 % of body weight this winter. Table 2 illustrates the significant effects for the Scottish Blackface sheep. There is a significant effect for treatment for the weight change between pre-mating in November and scanning in February (PLF losing less weight). When the time from scanning to pre-lambing is included, the scanning results are highly significant, which is to be expected with the conceptus growth increasing, especially after the first 100 days of pregnancy; (Wheeler *et al*, 1971). However, management treatment did not have a significant effect on weight change when considering the whole winter period.

When the Lleyn sheep were included in the dataset, the results were similar. However, due to some issues with the January weighing data, the Lleyn data was excluded from Table 3.

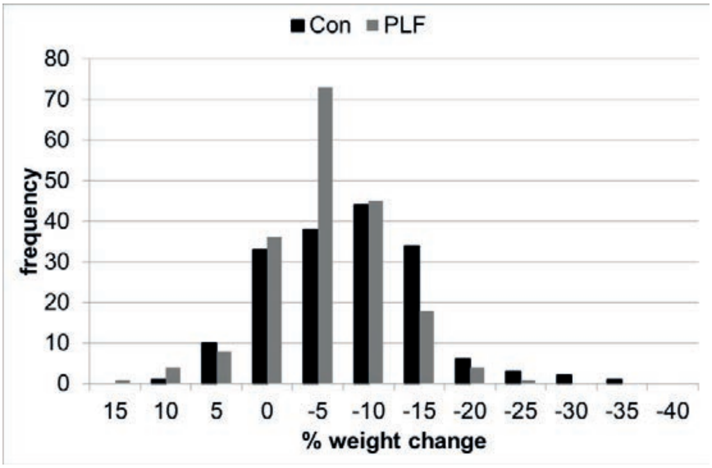


Figure 2: Frequency distribution of percentage of weight change between pre-mating to scanning for Scottish Blackface single and twin baring ewes.

When using the same model on the data set with barren ewes included, a highly significant relationship between scanning result and the pre-mating weight can be found, which suggests that the animals stay barren if they are too thin to conceive.

Table 3: Significance (P values) of fixed effects, fitted in the Linear Mixed Model for Scottish Blackface ewes, on weight changes between different time points (CON n = 179; PLF n = 191).

| Weighing dates | | | | Treatment | Lines | Scan-results | Age |
|---|---|---|---|---|---|---|---|
| Pre-mating | Jan | | | 0.123 | 0.083 | 0.180 | 0.076 |
| Pre-mating | | Scanning | | 0.001 | 0.227 | 0.105 | 0.508 |
| Pre-mating | | | Pre-lambing | 0.284 | < 0.001 | < 0.001 | 0.520 |
| | Jan | Scanning | | 0.500 | 0.779 | 0.653 | 0.023 |
| | Jan | | Pre-lambing | 0.463 | 0.010 | < 0.001 | 0.505 |
| | | Scanning | Pre-lambing | 0.063 | 0.013 | < 0.001 | 0.003 |

The amount of concentrate fed was higher in the PLF group compared to the Conventional group, with a difference of 0.9 tonnes. On the other hand, the Conventional group received more hay and haylage. By taking all the different feed types, and their costs this year, into account, there were £156 less spent on feed for the PLF group compared to the Conventional group (Con = £5055; PLF = £4849).

In the PLF group, 244 lambs were subject to the TST at weaning (at the end of August/ beginning of September), whilst 245 lambs were in the Conventional group. The TST rules were only applied once during the summer at a weighing day, as a pilot trial. Results for this weighing day showed that in the PLF group only 61% of wormer was used compared to the Conventional group (Table 3), which equates approximately to a £20 saving (Con = £49.6 and PLF = £30.3). Due to the fact that this was a pilot year and the TST management was only used once, reliable information on growth rates can not be provided, but will be available for the 2013 lambs and consecutive years.

The results obtained from consecutive weighing each fortnight did not reveal any disadvantages for the non-drenched lambs compared to the drenched TST lambs, with an average daily growth rate of 0.19 kg between weaning (31$^{st}$ of August and 5$^{th}$ of September) and weighing on the 8$^{th}$ of November 2012.

Table 4: Count of number of lambs wormed (with total wormer volume in brackets).

| | System | |
|---|---|---|
| Wormer (ml)[1] | PLF | conventional |
| 0 | 64 | n/a |
| 4 | 6 (6x4=24ml) | n/a |
| 6 | 109 (109x6= 654ml) | n/a |
| 8 | 65 (65x8 = 520ml) | 245 (1960ml) |
| Total | 244 (1198ml) | 245 (1960ml) |

[1]*Wormer: 4 ml for lamb live weights ≤ 20 kg; 6 ml for live weights from 20.5-30 kg; 8 ml for live weights ≥ 30.5 kg*

**Discussion**

The winter 2012/2013 was a first attempt to implement feeding groups based on different decision-making policies for the two different management treatments. Overall, it has been possible to demonstrate that such a system could be implemented on a large scale. However, some improvements could be made for the future use of the system. The on-going data collection will show to what extent a more precise winter feeding will affect farm economics, in terms of amount of feed used, for instance, as well as lambing performance (e.g., birth weights, lamb survival rate and maternity scores). The winter 2012/2013 results also showed that there can be a real benefit in continuous, more in-depth, monitoring of the animals and, with increasing knowledge base, the amount of feed could be optimised. Thompson & Meyer (1994) describe two trials conducted at Oregon State University, which demonstrate a similar message. In one study, the authors' state that there was a 33 % difference in total weight of lamb weaned (64 versus 85 pounds per ewe) between ewes with pre-lambing BCS of 2.5 to 3.5. This increase in pounds of lamb weaned was primarily due to improved lamb survival for offspring from the ewes with the higher BCS.

Another important fact that was demonstrated was how easy it is to bias weighing results in a commercial setup. Possible influences could be animal gut fill, variation in fleece weight due to dry or wet conditions and also possible problems with calibrating the weigh scale sufficiently throughout the day (without slowing down the weighing process excessively). Future research will look into these issues.

In literature, at the stage of gestation (corresponding to February in our trials) it can be assumed that the contribution of conceptus to ewe weight is approximately 1.5 kg for singles and 2 kg for twins (Wheeler *et al*, 1971). This corresponds well with our findings. Although ewes did weigh almost the same at pre-lambing compared to pre-mating, they all put on weight during the last trimester of pregnancy, as observed from the scanning to pre-lambing data. The twin ewes gained approx. 15 % of their body weight and the single-carrying ewes less than 10 %.

Our data suggests that the weight gain due to the growing foetus overshadows the management effects. However, it should be noted that the treatment effect will not affect every individual ewe, but just the ones who would be selected differently in the two systems. Therefore, the treatment effect for the overall flock will be lower. We will analyse the data collected from these animals in more detail in the future.

The implementation of the first TST approach was successful and showed that it can be done on a commercial hill farm. The actual amount of wormer saved does not necessarily contribute a great extent to improved farm economics. However, this approach should be considered in the light of the growing problem of anthelmintic resistance in sheep flocks, with all the associated negative impacts on farm economics. In addition, there may also be an environmental benefit when less wormer is used. The first trial did not show any negative effects on growth rates for drenched and non-drenched lambs, but this needs to be further investigated as the experiment progresses.

## Conclusions

Overall, the project is a demonstration of how to integrate EID into a hill sheep system and to manage the resources more viably. This is both in terms of feed and wormer inputs and of number of lamb outputs. Anthelmintic use could be optimised, thus, helping to maintain the efficacy of current products. In conclusion, the implementation of the new management system is so far successful, with the preliminary results showing great promise and benefits for more sustainable management of hill sheep.

## Acknowledgements

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# Session 12

# Posters

## Preliminary testing of off-the-shelf sensors to detect a swarm of bees in a bait box

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### Abstract

Australia is currently free from a number of significant bee pests that might enter the country by cargo movement at sea and airports. Bait boxes (i.e. baited empty hives) at Australian ports are intended to attract exotic swarms of bees and are currently manually inspected by apiary officers. An electronic sensing method for a swarm of bees in a bait box is required to enable more timely monitoring of bait boxes. A review of electronic sensing techniques for beehives was conducted and a bait box was instrumented with cameras and temperature and weight sensors for the purpose of identifying which sensors would be the most effective at detecting the presence of a swarm. An original methodology was developed to manipulate a swarm of bees into the instrumented bait box for controlled testing. Preliminary results indicate that the camera images were the most reliable indicator of the presence of a swarm. This study has informed the format and instrumentation of further controlled testing such that an automatic algorithm for swarm presence can be developed.

**Keywords:** Remote monitoring, temperature, image, surveillance, honeybees, biosecurity

### Introduction

The Australian honeybee industry is at risk from bee pests (e.g. the Varroa mite) that have devastated honeybee populations around the world. Bait boxes at Australian ports are intended to attract and intercept pest bee species that have entered the country via cargo movements. Monitoring of bait boxes is a manual task that is labour intensive, time consuming and sometimes, irregular. Electronic detection of a swarm of bees in a bait box would enable more timely identification of a possible pest incursion at an Australian port.

The aim of this research was to identify sensor technologies that were potentially suitable for detecting a swarm of bees in a bait box, and ultimately for deployment to a port. Off-the-shelf sensors were desirable to expedite the development time for the bait box remote monitoring system.

## Review of existing technologies

<u>Beehive monitoring</u>

Beehive attributes that are typically monitored in commercial systems are hive weight, temperature and flight activity (BeeWise, 2013; Hivemind, 2013). Commercially-available sensing systems are specified for working hives and are not expected to have the measurement sensitivity required for swarm detection in a bait box. For example, a working hive will vary in weight with the daily activity of several thousand bees and honey production whereas a small swarm arriving in a bait box might only number a few hundred bees (Table 1). Sound analysis of beehives is not available as a commercial system but has been reported in the research literature for prediction of swarming events in a working colony (Ferrari *et al.*, 2008; Bencsik *et al.*, 2011). Research of image analysis systems for bee activity at the hive entry have been reported (Campbell *et al.* 2008).

Table 1: Differences between bait box swarm detection and commercial beehive monitoring

| Hive attribute | Bait box | Commercial hive |
|---|---|---|
| Weight | Normally empty bait box (<10kg) and possibly hundreds or thousands of bees (each 0.1g) when a swarm arrives | Hive (<10kg), honey production up to 2kg per frame and several thousand bees (each 0.1g) |
| Bee activity | Normally none with occasional scout bee/s and other insects/small animals and possible swarm arriving in bait box | Thousands of field bees leaving and returning to the hive each day |
| Location | Ports and possibly remote apiary sites within 200km of ports | Apiary sites in remote and centralised locations |

<u>Electronic insect traps</u>

Commercially-available electronic insect traps are capable of reporting trap data remotely. The RedEye (Mi5 Security, 2013) was used to capture and transmit images of insect traps at an Italian port for surveillance of wood-boring beetles (Chinellato *et al.* 2012). Images uploaded to the server required manual review to identify the contents of the trap. The Z-trap (Spensa Technologies, 2013) reports insect counts automatically by sensing the change in resistance in an electrical coil as an insect passes over the coil, where bigger insects have bigger resistance. The traps classify insects by size but are not designed for use with a swarm of insects arriving. Hence, currently available systems are not suitable for specific use in identifying the presence of a swarm of bees in a bait box.

**Assembly of instrumented bait box**

Beehive attributes that provide bee activity information for commercial beekeepers are weight, temperature and flight activity. It was determined that off-the-shelf sensors would be assembled for initial instrumentation of a bait box to assess which sensors were capable of achieving swarm detection in a bait box. The effectiveness of each sensor would be evaluated in controlled testing at an apiary site. The most accurate, robust and cost-effective swarm detection system is intended for deployment to a port. A bait box was instrumented with the following sensors, which are further described below:

- temperature inside and outside of the bait box;
- button load cells to measure the weight of a top bar inside the bait box;
- platform load cell to measure the overall weight of the bait box; and
- camera and infrared lights inside the bait box, for flight activity.

Temperature sensor

The in-line temperature sensor (Melexis MLX90614) is a small barrel probe that measures ambient temperature and in-line temperature from a non-contact infrared sensor. The in-line temperature sensor was mounted directly underneath the top bar so that temperature changes resulting from a cluster of bees suspended from the top bar was measured. The temperature sensor was expected to detect the characteristic thermoregulation of bees to 34°C.

Weight sensors

The bait box was seated on a platform weigh scale consisting of a load cell with 20kg capacity and 1g resolution (PT2000, PT Limited). It was expected that the load cell would measure the increase in weight that occurred when a swarm of bees arrived in the bait box. Bees were expected to favour clustering onto a top bar in the bait box so the weight of the top bar in the bait box was measured as a possible alternative to the platform load cell. A button load cell (FC22, Phidgets, rated at 0-4.5kg) supported each end of a top bar in the bait box (Figure 1). The top bar was located centrally in the bait box to reduce the likelihood of bee clusters forming with support from both the top bar and the side wall of the bait box.

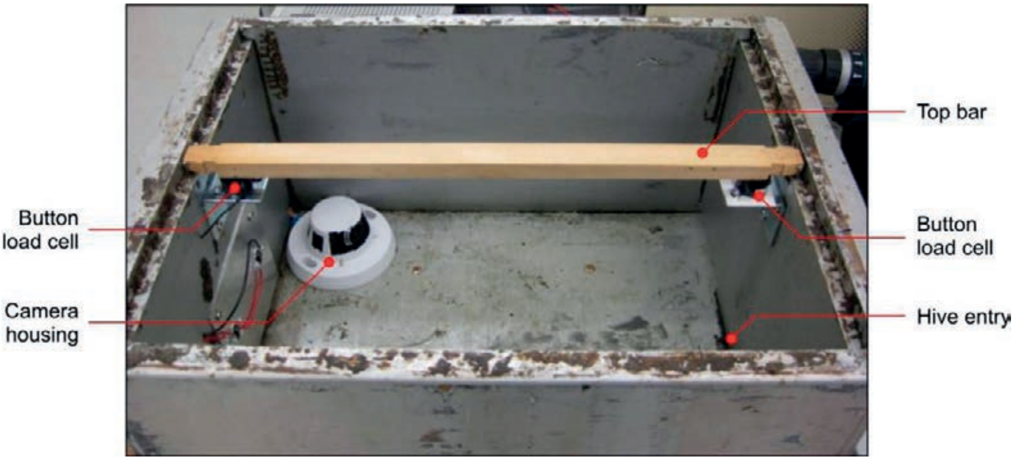
Camera

A day/night camera (SuperHAD CCD, Sony) was installed in the bait box to provide a visual indicator of the bait box occupancy and to assist in interpretation of the measurements from the temperature and weight sensors. The camera was mounted in a housing in the bottom corner of the bait box opposite to the bait box entry and with a 2mm wire mesh in front of the camera. The camera was mounted at the base of the bait box so that bees could not cluster underneath the camera. The camera was fitted with a fisheye lens (focal length 1.78mm) with a view angle of 106° that enabled a view of the bait box encompassing the bait box entry, lid, base and three sides of the bait box. Two infrared LEDs (850nm, 1W) were mounted inside the bait box (Figure 1) to provide illumination for the camera image in addition to the ambient daylight entering the bait box from the bait box entry.

Sensor datalogging components

A sensor conditioning and logging unit was assembled to record the sensor data and was housed in a weather-resistant enclosure (Figure 2). The top bar and platform load cells each had an analogue output that was stored to a small form-factor desktop computer (fit-PC, CompuLab) via an 18-bit analogue-to-digital converter (ADC) (U6, Labjack Corporation). The platform load cell had an additional conditioning unit (PT100LC, PT Limited) before the ADC input. The camera was connected to an analogue-to-USB digitiser for input into the computer. The in-line temperature sensor was read by the I2C bus on the ADC.

Custom software was written in Visual Studio 2008 to read in the digitised sensor data and to capture an image from the camera at a user-defined logging interval. The logged sensor data was saved in a textfile for postprocessing. The fully assembled instrumented bait box with datalogging components is presented in Figure 2 and was powered by a 12V car battery.



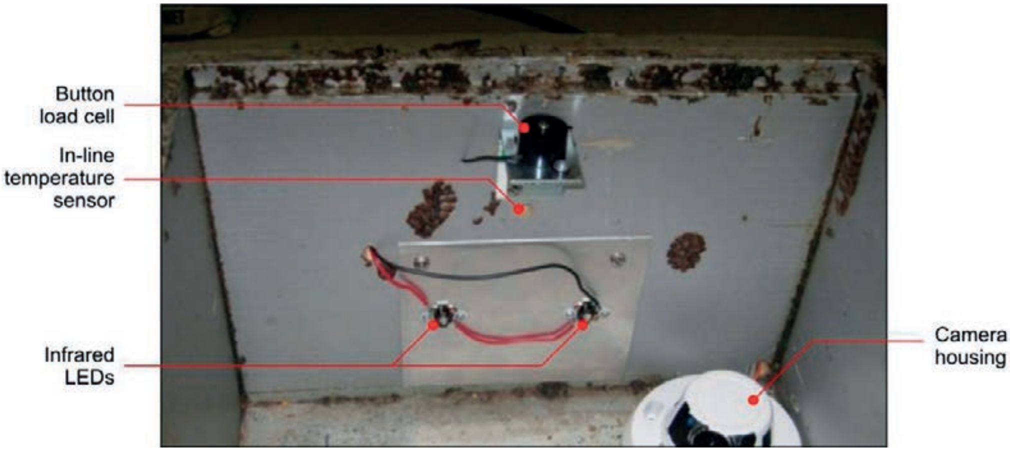



Figure 1: Instrumented bait box with the top bar in position (top); and the top bar removed (bottom), showing the positions of the sensors


Figure 2: Fully assembled bait box ready for controlled testing.

**Swarm manipulation into instrumented bait box**

Controlled testing of the instrumented bait box was required to enable comparison of sensor data for a bait box while empty, and then while occupied by a swarm. It was expected that the controlled testing would facilitate identification of sensor data thresholds that reliably indicated the presence of a swarm.

A method was established to manipulate a swarm into the bait box at an apiary site. The method involved moving a working hive at least fifty metres while the field bees were out foraging and to position the instrumented bait box in its place. Returning field bees would then find the instrumented bait box instead of their own hives and enter the instrumented bait box in the manner of a swarm.

The instrumented bait box was trialled at a site in Cabarlah on 12 January 2012. The day was sunny with a temperature of 26°C when the trial began at 9am. Three palettes, each containing four working hives, were moved using a forklift to a new location (Figure 3). The field bees returning to the original position of the palettes instead found and entered the instrumented bait box. After one hour, the trial was concluded and the occupancy of the bait box was manually inspected.

There were an estimated 2000 bees in the bait box at the end of the hour (Figure 4). It was observed that the bees did not form a single cluster inside the bait box, but were dispersed on all the interior surfaces of the bait box, including on the camera housing in the bottom corner of the bait box. A small group of bees were suspended in a cluster from one end of the top bar. The palettes of hives were then returned to their original location and the instrumented bait box was removed after being smoked and having the bees shaken out.

**Results and discussion**

<u>Sensor response</u>
The measurements made by the temperature and weight sensors for the controlled test are included in Figure 5, with a sequence of images captured by the camera presented in Figure 6. Observations when the swarm arrived were:

- the temperature inside the bait box increases and appears to stabilise;
- the temperature outside the bait box continually increases;
- the weight of the top bar and of the whole bait box increases; and
- the camera images clearly indicate the presence of bees on the interior surfaces of the bait box and eventually the images are completely obscured by bees on the camera lens.

Further trials are necessary to examine the diurnal variation in sensor data when there is no bee activity, activity from other sources (e.g. ants or geckos) and the effect of size of swarm (e.g. small swarms) on the sensor data. There is potential for swarm detection to be based on motion detection in the camera images. It is expected that the image quality will need to be improved to enable colourings on the bees to be identified.

Figure 3: Instrumented bait box placed next to working hives (left) and working hives being moved away (right)

Figure 4: Bees arriving at the instrumented bait box (left) and dispersed throughout the hive at the end of the test (right)

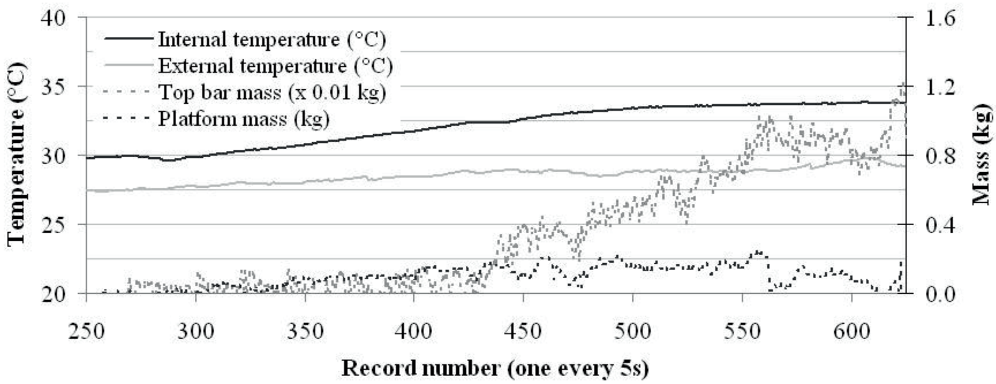



Figure 5: Sensor data for the controlled test, with bees swarming into the bait box at Record #270 (0930h) and the bait box lid being removed at Record #625 (1000h)

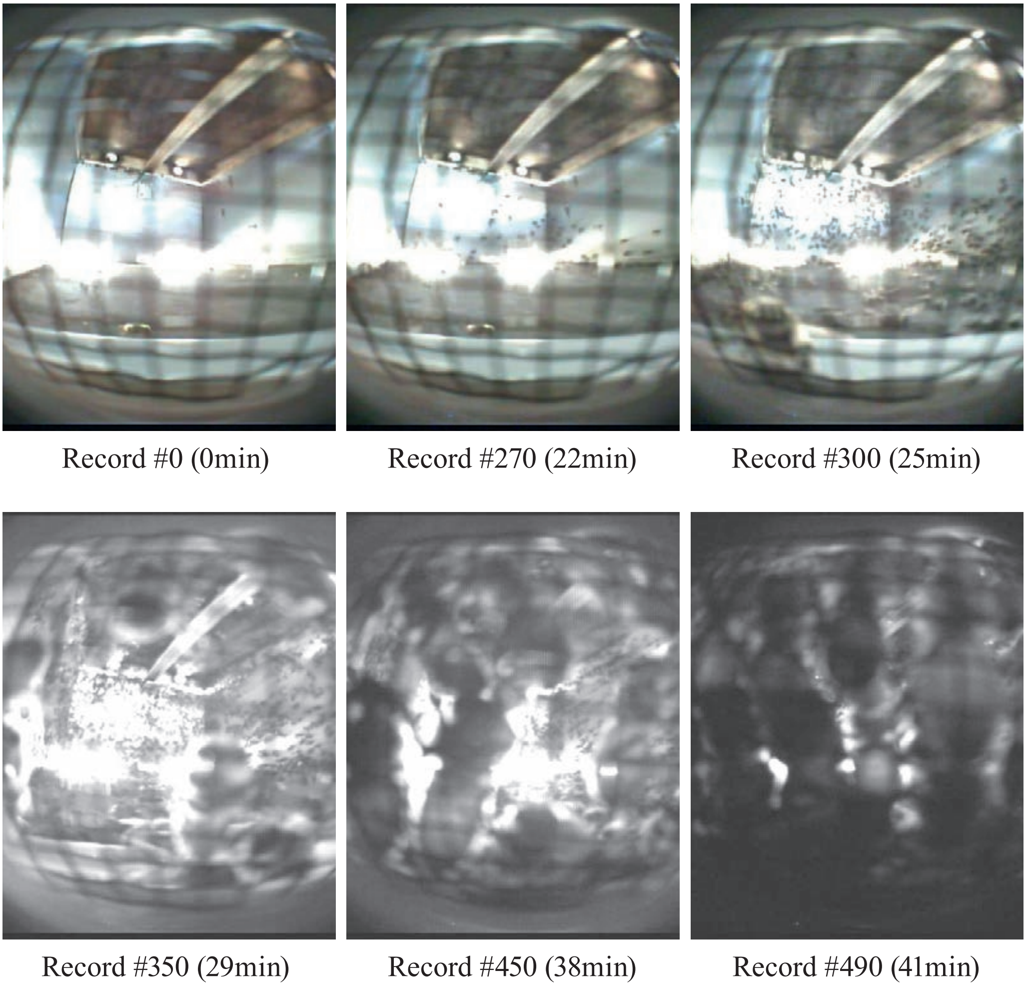



Figure 6: Image series captured from a camera in the bait box as the swarm of bees arrives, with the camera facing the hive entry and the top bar visible in the top half of the image.

Comparison of different sensor technologies in the context of port deployment

Table 2 summarises expected benefits and limitations of each of the evaluated sensor technologies for remote installation at a port. Bait boxes at Australian ports are typically seated on, or suspended from, an existing structure (e.g. a shed or tree) so **ease of mounting** for the sensor in the bait box is a significant factor. Hence, the platform mass sensor is ranked as poor for this factor. **Low false positive** rate is desirable to prevent unnecessary callouts for the relevant authorities to perform a follow-up manual inspection of a bait box. Mass sensing rates poorly for false positives because disturbance to the bait box (e.g. by mobile vehicles or heavy machinery at the port) are expected to influence the mass measurements. Temperature sensing is rated as poor for **weather sensitivity** because detection of a swarm by its thermoregulation would require a temperature differential (i.e. a cooler ambient climate).

Camera images obtain a good rating for each of the factors listed, including the potential for low false positive rates. The camera images can be visually inspected to identify what species, if any, are present in the bait box.

Table 2: Comparison of factors that influence selection of swarm detection sensors

| Factor | Camera image | Temperature | Top bar mass | Platform mass |
|---|---|---|---|---|
| Low false positives | Good | Fair | Poor | Poor |
| Sensor accuracy | Good | Good | Fair | Good |
| Weather sensitivity | Good | Poor | Good | Good |
| Ease of mounting | Good | Good | Good | Poor |
| Sensor cost | Good | Good | Good | Poor |
| Overall ranking | 1 | 2 | 3 | 4 |

## Conclusions

A preliminary investigation of a swarm detection system for bait boxes has been presented. Off-the-shelf sensors for weight, temperature and camera imagery were determined to be more suitable than commercial technologies for beehive and electronic insect trap monitoring for controlled testing of an instrumented bait box. Controlled testing of the instrumented bait box at an apiary site of was effective for emulating swarm entry into the bait box. Replicated testing for different swarm sizes is required before thresholds in sensor data can be identified that reliably indicate the presence of a swarm. Electronic sensing by camera images is a promising method, particularly in the context of remote port installation.

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**Range measurements of a Radio Frequency Identification System for registering growing-finishing pigs near a feed trough**

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**Abstract**

A High Frequency Radio Frequency Identification (HF RFID) system was tested and validated for its use as a registration system for pigs' feeding patterns. A HF RFID antenna was installed around the hopper and above the feed trough of a commercially available wet/dry pig feeder. Using a wooden board with RFID transponders at fixed positions, the range of the RFID system was measured at different distances from the RFID antenna. The range was found to cover the feed trough very well, up to a certain distance from the antenna. This system could therefore be used to register feeding pigs, which brings the possibility to measure feeding patterns and develop a health monitoring system based on changes in feeding patterns of pigs.

**Keywords:** growing-finishing pigs, feeding, radio frequency identification, range, validation

## Introduction

A pig farmer aims towards a profitable and sustainable business and simultaneously providing good care of the animals. In today's larger herds and complex markets and legislations, this requires of the pig farmer to turn to management tasks next to the animal caretaker tasks (Frost *et al*, 1997). Since individual visual monitoring of large groups of pigs is difficult, there is a need for automated detection of problems in the pig herd. Indeed, timely detecting, solving and treating disease and welfare problems can

prevent decreased health, decreased growth and finally economic losses (Jensen *et al,* 2007; Maes *et al,* 2004; Maes *et al,* 2001).
In case of stress situations or upcoming illness, pigs are thought to alter their behaviour before any physiological signs can be seen (Hart, 1988). So, automated registration of animal based behavioural variables could provide the necessary information to detect problems in pigs. Alterations in pigs' feeding patterns are particularly promising warning signals for welfare-, health- and production problems (Brown-Brandl *et al,* 2011b; Cornou *et al,* 2008; Hessel & Van den Weghe, 2011). Feeding pigs can be registered using Radio Frequency Identification (RFID) (Artmann, 1999; Eradus & Jansen, 1999; Ruiz-Garcia *et al,* 2011), which is a collection of different techniques for contactless transfer of data between a data-carrying device and a reader using (electro) magnetic fields (Finkenzeller, 2010).

By integrating a LF RFID system in a commercially available feeder, Brown-Brandl et al (2011a; 2011b) have already achieved good results in determining individual animal feeding patterns in an industry type feeder. However, most commercial feeders provide access to multiple pigs, while today's LF RFID does not have the possibilities to read multiple tags at the same time. RFID systems of higher frequencies often incorporate anti-collision algorithms to avoid losing data when multiple tags are in read-range. Using passive High Frequency (HF) RFID antennas incorporated in the feed trough, feeding piglets were successfully identified in a semi-commercial group-housed situation (Hessel & Van den Weghe, 2011; Reiners *et al,* 2009).
In this paper a HF RFID system is presented where the antenna is placed above the feeding pigs. Since the measurement range of an RFID system depends on numerous factors - such as the operating frequency, the type of tags used, the type of reader used, influences in the environment, etc. - the theoretical range of an RFID system can differ from the achieved range in a real-life situation (D'hoe *et al,* 2011; Finkenzeller, 2010). Therefore, the range of the presented RFID system is measured in a pig stable and there is determined whether it is suited for detecting feeding pigs or not.

## Materials and methods

RFID system

To register transponders near pig feeders, HF RFID antennas (Custom-made, DTE Automation GmbH, Enger, Germany) were designed and attached to 8 pig feeders (Swing MIDI, Big Dutchman Pig Equipment GmbH, Vechta, Germany) above the trough. The feeders were placed in a pig barn at the ILVO (Institute for Agricultural and Fisheries Research, Melle, Belgium). The Swing MIDI feeder had a round metal trough with a diameter of 45 cm and an edge with height of 11 cm from the ground. The underside of each antenna is 50 cm from the ground and the theoretical range of the RFID antenna is 30 cm. Each antenna was connected to one of two HF long range readers (ID ISC.LR2500-A, FEIG ELECTRONIC GmbH, Weilburg, Germany) with the use of 2 multiplexers (ID ISC.ANT.MUX-A, FEIG ELECTRONIC GmbH, Weilburg, Germany). Data communication between the readers and a desktop PC was through RS232 standard with the use of a USB-RS232 adapter for interface with the PC where all the RFID registrations were logged. The tags used were IN Tag 300 I-Code SLI tags (ISO 15693, HID Global Corporation, California, USA) with a diameter of 30.0 mm, a thickness of 2.5 mm and an enlarged hole of 7.8 mm. These RFID tags fitted onto the pin of standard pig ear tags and had approximately the same diameter as the ear tags.

Figure 1: Testing equipment for RFID range measurements.

Testing equipment

The testing equipment is shown in figure 1. To measure the range of the RFID system a portable wooden frame (height 50 cm, width 100 cm, depth 50 cm) was placed around one half of the feeder. The presence of metal in the close neighbourhood of an RFID antenna or tag has negative effects on the performance and range, therefore the wooden frame was made entirely out of wood and glue. The frame could hold a wooden board of size 100 cm x 50 cm horizontally at 7 different heights: from 15 cm till 45 cm with 5 cm in between. A semicircle cut-out with radius 11 cm was made in the board to make room for the hopper of the feeder. On each board 48 ear tags were placed in the centre of each 10 cm² of the board. These ear tags could then hold 48 transponders of choice on the board.

Experiment

The experiment was aimed at measuring the range of the RFID system for different distances from the antenna. Therefore, the designed board is placed at every height of the wooden frame during minimum 10 s. This is done for five different, random distributions of the transponders on the board. Each test is also repeated five times, giving in total 25 measurements of the same position. Start and stop time were recorded for each test and the RFID tags registered during the tests were logged. Afterwards there is determined for each test if the transponders on the different positions were registered during the 10 s of the test or not.

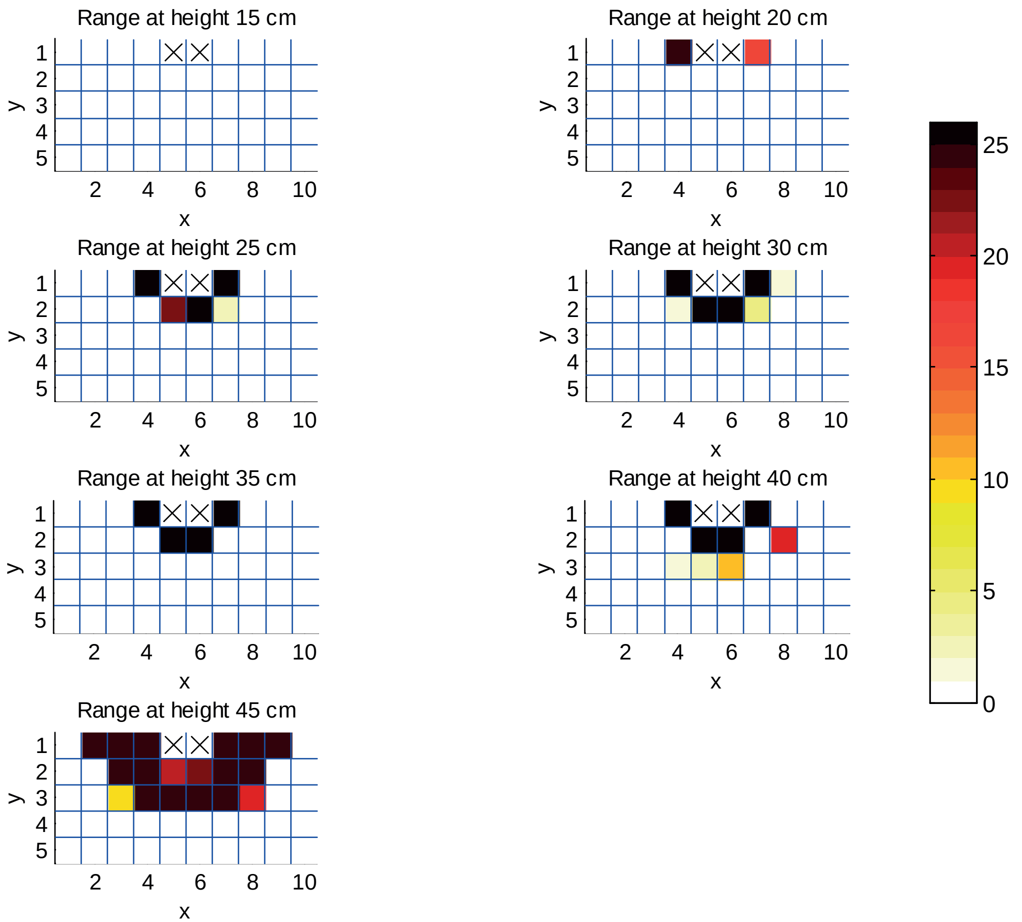


Figure 2: Registered positions at all heights of the experiment. The colormap represents the number of repetitions during which the RFID tag at that position was registered minimum once (5 different tag distributions were tested 5 times each). Top side of each plot is in the direction of the feeder. Due to the semicircle cut-out in the wooden board there was no tag at (x,y)-positions (5,1) and (6,1).

## Results and discussion

In figure 2 the results of the experiment can be seen. Every plot represents one height of measurement and the top side of each plot is in the direction of the feeder. Every square block represents a 10 cm² area containing one tag. At the (x,y)-positions (5,1) and (6,1) no tag is present due to the semicircle cut-out in the wooden board.

At a height of 15 cm from the ground, no transponders are registered during the 25 repetitions. For measurements with pigs, the transponders will be placed in the ears of the pigs and they will often be higher from the ground. A pig will also not bring its snout to the ground all the time but often lift its head to look around or chew its food, bringing its tag thereby closer to the antenna. For small pigs in the beginning of the fattening period (see for example figure 3), this lack of registrations at 15 cm might cause problems however. This can be avoided by lowering the antenna at the beginning of a fattening period to a height of 46 cm. This will not be a sufficient comfortable height for larger growing-finishing pigs (> 60 kg) and will mean that the antenna height has to be changed to 50 cm during the fattening period.

Figure 3: Example of a feeding pig at the beginning of a fattening period.

In figure 2 we see that at a height of 20 cm from the ground, 2 positions are often registered. At the heights of 25, 30, 35 and 40 cm the same 4 positions are (almost) always registered. When looking at these positions (at a radius of 15 - 16 cm from the centre of the feeder) relative to the edge of the trough (at a radius of 22.5 cm), we

can conclude that these tags are in the area above the feeder trough. The positions a bit further away ((4,2) and (7,2)) are approximately on the edge of trough and are practically not registered.
Closer to the antenna, at a height of 45 cm, the range of measurement is a lot larger. The registered tag positions cover also an area outside of the feeder trough area. This will only be the case when a tag is less than 5 – 10 cm away from the antenna in the vertical direction and less than 10 – 15 cm away from the edge of the feeder trough in the horizontal direction. These range measurements are necessary to be able to know the range of an RFID system in practical circumstances. It is clear that the theoretical range of 30 cm is not achieved in all directions. The resulting range shows where we can expect transponders to be registered and what limitations we have to take into account when using this RFID system to register feeding pigs. A suggestion is to adapt the height of the antenna to the size of the pigs to ensure the transponders to be close enough to the antenna. To be able to know the range of the RFID system when for example the orientation of the transponders versus the antenna is changed, further experiments need to be performed. Also to be able to evaluate the consequences of the limitations of the RFID system on the registrations of real pigs, validation of the system has to be done using transponders attached to pigs.

## Conclusion

This paper presents a HF RFID system designed to register growing-finishing pigs feeding from a commercially available feeder using an antenna above the heads of the pigs. To validate the system for the intended purpose, an experiment is performed to measure the range of the RFID system for horizontally placed transponders at different heights. The results show that close to the ground no transponders are registered, while close to the antenna the area spanned by the registered transponders is larger than the area covered by the feed trough. In between these heights, the range was found to cover the area of the feed trough very well. Taking into account the limitations, this means the presented RFID system can be able to register feeding pigs, although further validation is necessary.

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## The use of Ultra High Frequency (UHF) tags for fattening pig identification

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### Abstract

On the pig research farm Varkens Innovatie Centrum (VIC) Sterksel, The Netherlands, 430 fattening pigs were identified with UHF ear tag transponders. In the used tag the UHF transponder is integrated in the male part, applied to the outside side of the right ear. In a 2x2 experiment two different pin diameters were used. A normal sized pin (215 pigslets) and a smaller sized pin ear tag were applied (215 piglets) on the day of birth (214 piglets) or on the seventh day after birth (216 piglets). Wound recovery (inflammation), irritation, ear tag hole size and physical and functional loss rate were scored at weaning, at transfer to the fattening house and before transport for slaughter. Inflammation and irritation were scored on a scale of 1 (no inflammation/irritation) to 5 (serious inflammation/irritation). Hole size was also scored on a scale of 1 to 5 (hole size 1 = diameter pin; 2 < 0.5 cm; 3 < 1 cm; 4 < 2 cm; 5 > 2 cm). Functional loss rate was detected when reading the tags with a portable UHF reader. The time needed for reading a group of animals (different group sizes) with a portable reader was recorded. Reading performance of a static UHF reader was evaluated for 5 different groups (with 10 or 11 animals per group). The physical and functional loss rate during the slaughtering process was recorded in the slaughtering line at the position were the carcass is attached to the slaughtering hook and  just before carcass classification.
Physical loss rates in the slaughtering line was best for the tags that were applied seven days after birth and for tags with a small pin diameter, functional loss rate was not impacted by application day or pin size. Normal pin diameter and day one application scored better on wound recovery. Handheld reading of tags of a group of pigs took averagely 4.1 s per animal. Static reading performance score was 89.6% while 4.2% of numbers read belonged to animals that did not pass the antenna but were housed in pens close to the reader.

**Keywords:** UHF, transponder, pigs, identification, reader

### Introduction

During decennia the average pig farm size is increasing and it is expected this will also be the tendency during the coming decennia. Despite the increased farm size the farmer insist in a more individual animal orientated working method. In case of illness for instance the farmer prefers a treatment of individual animals affected above the treatment of the whole group of animals. In this setup an adequate identification of the individual animals is required for the needed data registration and sensor recording of behaviour and performance of the individual animal. Resulting in better tools for managing and controlling e.g. animal wellbeing, animal health and farm efficiency. With dedicated measurements and registrations it is possible to give consumers access to what production methods are being used and good farming practises guaranties can be provided. The ideal image, as mentioned by sector representatives, is that the animal itself has the possibility to adjust the circumstances for getting an optimal result. The individual animal has a central place. To speed up these important developments the farmers organizations NVV and LTO and the product board livestock and meat have challenged trade and industries in bring forward innovative ideas that can be developed and tested at the Pig Innovation Centre (VIC) Sterksel. One of the initiatives which has been evaluated in 2012/2013 is the use of UHF (Ultra High Frequency) ear tag transponders for identifying the animals individually. In general mostly LF (Low Frequency) identification devices are being used for identifying animals. There are a couple of projects in the world evaluating the use of UHF ear tags for identifying animals, e.g. Pigtracker project in Denmark (Baadsgaard, 2012) and the pathfinder project in New Zealand (Pugh, 2013). The LF identification devices have a reading range of maximum over 1 meter and produce a robust signal that is not influenced by the body tissue of the animal. UHF identification devices can be read from a bigger distance (up to 8 meters), have an anti-collision protocol (possibility of reading ID's while having several RFID transponders in the field of the reader) and are possibly a little cheaper because less material is needed for the manufacturing. A drawback of the UHF technology is that the signal is strongly impacted (damped) by body tissue or moisture. This paper reports the results of an experiment with UHF ear tags used for identifying meet pigs. In the experiment the impact of ear tag pin thickness and tag application age on wound recovery and physic and functional ear tag loss rate (on farm and during slaughter) was studied. Reading speed with a handheld device and reading with stationary reading equipment were tested on farm and during slaughter.

## Material and methods

Piglets and application of ear tags

On the pig research farm Varkens Innovatie Centrum (VIC) Sterksel, The Netherlands, 430 fattening pigs, all born in the period from 25$^{th}$ of August to 2$^{nd}$ of September 2012, were identified with UHF ear tag transponders. In the used ear tag type the UHF transponder is integrated in the male part of the transponder. Both the male and the female part are of the button type (diameter male part 28.5 mm and diameter female part 27.1 mm), total weight of the combination 3.3 grams. The UHF male part was applied to the outside side of the right ear. Two different pin diameter sizes were used. In total 215 piglets were identified with an ear tag with a normal sized pin diameter (NORMAL) and also 215 were identified with an ear tag with a smaller as usual pin diameter (SMALL). The tags were applied on the day of birth for 214 piglets (ONE) or on the seventh day after birth for 216 piglets (SEVEN). The identification method used was the same for all piglets of a one litter. All tags were applied by the same person. The piglets were weaned at an age of 27±4 days. At an age of 63±4 days the pigs were transferred to the fattening house and the animals were slaughtered at an age between 5 and 5.5 months.

Observations

Wound recovery (inflammation), irritation, ear tag hole size and physical and functional loss rate was scored at weaning, at transfer to the fattening house and on the day before transport for slaughter. Inflammation and irritation was scored on a scale of 1 (no inflammation/irritation) to 5 (serious inflammation/irritation). Hole size was scored on a scale of 1 to 5 (hole size 1 = diameter pin; 2 < 0.5 cm; 3 < 1 cm; 4 < 2 cm; 5 > 2 cm). The scoring was performed by one person. Functional loss rate was detected when reading the tags with a portable UHF reader. The time needed for reading a group of animals with a portable reader was recorded for several groups. Reading performance of a static UHF reader was recorded for 5 different groups (with 10 or 11 animals per group). Slaughter line loss rate of tags was recorded in a slaughtering house in Helmond. The physical and functional loss rate during the slaughtering process was recorded at two spots in the slaughtering line: 1. At were the carcass is attached to a slaughtering hook and 2. just before carcass classification.

Data analyses

Qualitative characteristics with 2 possible outcomes (functional and physical loss) were GLM (Generalized Linear Model) with binomial distribution analysed. Ordinal characteristics with more than 2 possible outcomes (inflammation, irritation and hole size) are analysed with a threshold model also belonging to the GLM's. In this case the distribution is multinomial. Analysed effects in both models were the factors pin diameter and application age and their interaction. The analyses were performed using the statistical package GenStat for Windows 15th Edition (Genstat, 2012).

## Results and discussion

Inflammation

Inflammation results scored at weaning are presented in Table 1 and scores at transfer to the fattening house in Table 2. At weaning and at transfer to the fattening house a significant better wound recovery is found for NORMAL pin and for application at day

ONE. Before slaughter there was only one animal (NORMAL pin and applied on day ONE) with a 'serious inflammation', the rest of the animals had 'no inflammation'. No significant impact of 'Pin diameter' or 'Day of tag application' on inflammation score was found on the day before transport for slaughter.

A SMALL pin has higher impact on the wound because the surface of the ear (wound) to support the pin is smaller. This higher impact results in slower wound recovery. On day SEVEN the ears of the animals are more dirty (more bacteria) as on day ONE. This explains why wounds heal easier for tags applied on day ONE.

Table 1: Percentage of different inflammation scores at weaning 1 (no inflammation) to 5 (serious inflammation).

| Inflammation | Pin diameter | | Day of tag application | |
|---|---|---|---|---|
| Score | NORMAL (%) | SMALL (%) | ONE (%) | SEVEN (%) |
| 1 | 60.3 | 42.3 | 67.1 | 35.6 |
| 2 | 26.2 | 31.2 | 23.9 | 33.3 |
| 3 | 12.1 | 23.3 | 8.5 | 26.9 |
| 4 | 1.4 | 3.3 | 0.5 | 4.2 |
| 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | $p < 0.001$ | | $p < 0.001$ | |

Table 2: Percentages of different inflammation scores at transfer to the fattening house 1 (no inflammation) to 5 (serious inflammation).

| Inflammation | Pin diameter | | Day of tag application | |
|---|---|---|---|---|
| Score | NORMAL (%) | SMALL (%) | ONE (%) | SEVEN (%) |
| 1 | 97.1 | 88.4 | 96.7 | 88.9 |
| 2 | 1.0 | 7.2 | 2.9 | 5.3 |
| 3 | 1.0 | 3.9 | 0.5 | 4.3 |
| 4 | 1.0 | 0.5 | 0.0 | 1.4 |
| 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | $p = 0.002$ | | $p < 0.001$ | |

Table 3: Percentages of different irritation scores at weaning 1 (no irritation) to 5 (serious irritation).

| Irritation | Pin diameter | | Day of tag application | |
|---|---|---|---|---|
| Score | NORMAL (%) | SMALL (%) | ONE (%) | SEVEN (%) |
| 1 | 68.2 | 60.5 | 78.9 | 50.0 |
| 2 | 15.4 | 15.8 | 13.1 | 18.1 |
| 3 | 11.2 | 20.0 | 7.0 | 24.1 |
| 4 | 4.7 | 3.3 | 0.9 | 6.9 |
| 5 | 0.5 | 0.5 | 0.0 | 0.9 |
| | $p = 0.076$ | | $p < 0.001$ | |

Irritation

Results of the irritation scored at weaning are presented in Table 3 and at transfer to the fattening house in Table 4. At weaning and at transfer to the fattening house significant less irritation is found for application at day ONE (no impact was found for pin diameter). On the day before transport for slaughter there was only one animal (NORMAL pin and application at day ONE) with a irritation score of '4' the rest of the animals had 'no irritation'. No significant impact of 'Pin diameter' or 'Day of tag application' on irritation score on the day before transport for slaughter.

Table 4: Percentages of different irritation score at transfer to the fattening house 1 (no irritation) to 5 (serious irritation).

| Irritation | Pin diameter | | Day of tag application | |
|---|---|---|---|---|
| Score | NORMAL (%) | SMALL (%) | ONE (%) | SEVEN (%) |
| 1 | 98.6 | 96.1 | 99.0 | 95.7 |
| 2 | 0.5 | 2.4 | 0.5 | 2.4 |
| 3 | 0.5 | 1.4 | 0.5 | 1.4 |
| 4 | 0.5 | 0.0 | 0.0 | 0.5 |
| 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | $p = 0.253$ | | $p = 0.013$ | |

Higher contamination of the ears is most likely the explanation for the higher percentage of irritations for the tags that are applied on day SEVEN.

Hole size

Results of the hole size scores at weaning are presented in Table 5, at transfer to the fattening house in Table 6 and the day before transport for slaughter in Table 7. At weaning, at transfer to the fattening house and on the day before transport for slaughter a significant bigger hole size is found for NORMAL pin size tags (e.g. day before transport for slaughter for the NORMAL pin size tag 12.8% of the holes > 2cm versus 0% for the SMALL pin size tags) and for application of the tags at day ONE (e.g. day before transport for slaughter for the day ONE applied tags 10.9% of the holes > 2cm versus 2.2% for the day SEVEN applied tags).

Table 5: Percentages of different hole size score at weaning 1 = diameter pin; 2 < 0.5 cm; 3 < 1 cm; 4 < 2 cm; 5 > 2 cm.

| Hole size | Pin diameter | | Day of tag application | |
|---|---|---|---|---|
| Score | NORMAL (%) | SMALL (%) | ONE (%) | SEVEN (%) |
| 1 | 1.9 | 14.4 | 9.4 | 6.9 |
| 2 | 33.2 | 56.3 | 36.2 | 53.2 |
| 3 | 55.1 | 27.9 | 46.0 | 37.0 |
| 4 | 9.8 | 1.4 | 8.5 | 2.8 |
| 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | $p < 0.001$ | | $p = 0.004$ | |

Application of SMALL pin ear tag stamps a smaller hole and because the hole in the ear grows along with the size of the ear itself the NORMAL pin size ear tag results in a bigger hole. Application after one week has the advantage of one week less hole in the ear growth, explaining the smaller hole for the tags applied at a higher age.

Table 6: Percentages of different hole size score at transfer to the fattening house 1 = diameter pin; 2 < 0.5 cm; 3 < 1 cm; 4 < 2 cm; 5 > 2 cm.

| Hole size | Pin diameter | | Day of tag application | |
|---|---|---|---|---|
| Score | NORMAL (%) | SMALL (%) | ONE (%) | SEVEN (%) |
| 1 | 0.0 | 1.0 | 0.0 | 1.0 |
| 2 | 4.3 | 23.4 | 6.7 | 20.9 |
| 3 | 45.5 | 65.4 | 52.4 | 58.3 |
| 4 | 50.2 | 10.2 | 40.9 | 19.9 |
| 5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | $p < 0.001$ | | $p < 0.001$ | |

Table 7: Percentages of different hole size score on day before transport for slaughter, 1 = diameter pin; 2 < 0.5 cm; 3 < 1 cm; 4 < 2 cm; 5 > 2 cm.

| Hole size | Pin diameter | | Day of tag application | |
|---|---|---|---|---|
| Score | NORMAL (%) | SMALL (%) | ONE (%) | SEVEN (%) |
| 1 | 0.0 | 0.6 | 0.0 | 0.6 |
| 2 | 0.5 | 6.2 | 2.2 | 4.4 |
| 3 | 5.9 | 46.3 | 22.8 | 28.2 |
| 4 | 80.9 | 46.9 | 64.1 | 64.6 |
| 5 | 12.8 | 0.0 | 10.9 | 2.2 |
| | $p < 0.001$ | | $p < 0.001$ | |

On farm use of portable reader

The time needed to scan a group of animals (age ~4.5 months) with a portable psion UHF reader was recorded. In total 39 groups of animals, with an average group size of 8.2 animals (minimum group size 2 and maximum group size 12 animals) were scanned. The average reading time per animal of all groups was 4.1 s (minimum average reading time per animal of a group was 1.0 s and the maximum 13.1 s).

Tags could be read with a portable reader within a reasonable time frame, but a marker had to be used to indicate animals being read. The reading distance had to be set to a few decimetres to eliminate the change of reading animals from a different group.

On farm use of static reader

The static reading performance was evaluated with an Impinj multi antenna reader. The 4 antennas of the reader were installed in a 2.0 m broad hallway at a height of 1.1 m in a squire of 2.0 by 2.0 meters. Five groups of animals (3 groups with 11 animals and 2 groups with 10 animals) passed the antennas 6 times. Of the 318 possible readings 285 times (89.6%) once or more a RFID number was recorded. During the reading of those animals 14 times (4.2% of the numbers read) a RFID number was recorded of an animal of a closely housed group.

No optimization, tuning and shielding of the reader was done while doing this experiment. The reading performance is reasonable for a first trail. Reading numbers of non-passing animals is a serious issue that shall be solved.

Loss rate on farm

At weaning no tags were lost and all tags were readable, at transfer to the fattening house 3 tags (0.7%) were lost and 4 of the tags (1.0%) were not readable, before transport to the slaughterhouse 6 tags (1.6%) were lost and 6 tags (1.6%) were no longer readable.

‘Pin diameter’ and ‘Day of tag application’ had no significant impact on physical and functional loss rate.

The physical and functional loss rate during the on farm fattening period was low. ‘Pin diameter’ and ‘Day of tag application’ have no impact on the on farm losses.

Table 8: Percentage of physical loss rate recorded in the slaughtering line after the scrapper.

| Physical | Pin diameter | | Day of tag application | |
|---|---|---|---|---|
| Lost | NORMAL (%) | SMALL (%) | ONE (%) | SEVEN (%) |
| Yes | 12.9 | 5.1 | 14.4 | 3.9 |
| No | 87.1 | 94.9 | 85.6 | 96.1 |
| | $p = 0.009$ | | $p < 0.001$ | |

<u>Loss rate during slaughter</u>

At the slaughter line connection point a significant lower loss rate was recorded for the tags with the SMALL pin size (5.1% versus 12.9% for the NORMAL pin size tags) and also the tags applied on day SEVEN showed significant lower loss rates as the tags applied on day ONE (3.9% versus 14.4%), result are presented in Table 8. Of the present tags 5.5% were not readable (no impact of pin size or application day). Of the tags that were still present at the slaughter line connection point 5.3% was no longer present at the carcass classification point (no impact of ‘Pin size’ or ‘Day of tag application’ on loss rate).

In slaughter line loss rates at the slaughter line connection point of the SMALL pin size ear tags and of the tag applied on day SEVEN are promising. From this point in the slaughtering line the sequence of carcasses does not change (under normal conditions), so in principle an official slaughterhouse reading can be performed at this point in the slaughter line. The functional loss rate recorded at this point is quite high. During the remaining part of the slaughter line until the classification point further physical ear tag losses were recorded so for slaughterhouse reading the point where the carcass is connected to the slaughtering line is the best point for UHF ear tag reading.

## Conclusion

The physical and functional on farm loss rate of the UHF ear tags for fattening pig was low. Day of ear tag application (day ONE versus at day SEVEN) and diameter of the ear tag pin (NORMAL versus SMALL) has no impact on the on farm ear tag losses. Wound recovery and irritation show better results for NORMAL pin diameter and ear tag application at day SEVEN. In general UHF ear tag wounds recover quite quickly and the number of irritations are limited and also recover quickly. The in-slaughter line loss rate strongly depends on the pin size and the moment of application. Ear tags with a SMALL pin diameter and application at day SEVEN show better slaughter line physical loss rate results. The best position for reading the UHF tags is the point where the carcasses are connected to the slaughtering line. The physical loss rate is at this point (for the tags with small pin and for the tags applied one week after birth) reasonably low, but the functional characteristics of the UHF tags shall be improved because a to high percentage of tags is unreadable at this point in the slaughtering line.

On farm reading with a portable UHF reader can be performed within a reasonable time frame, but it is unwieldy that the read animals have to be marked. Although a promising reading percentage was achieved for static readings, further developments are needed especially because the reader picks up signals of tags of animals housed in pens near the reading point.

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# Measurement of floor space covered by standing and lying pigs during the rearing period

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## Abstract

Space allowance is one of the most disputed criteria in modern pig production. The legal framework is provided by the EU Directive 2008/120/EC. However, little is known about the real floor space covered by the body of a pig. This study describes how to measure the floor space covered by standing and lying pigs during the entire rearing period by the colour contrast planimetric method “KobaPlan” which had originally been developed to calculate the surface of chicken. The planimetric survey gives an allometric measure for the development of calculation models defining an animal based minimum floor area for suckling piglets and weaners.

**Keywords:** piglet, floor space, planimetric method

## Introduction

In the EU, 148.5 million pigs are kept for breeding or fattening (Eurostat, 2011). From birth throughout the suckling period of at least 21 days, the piglets are usually kept in pens where the sows are placed in farrowing crates. After weaning, the piglets are moved to rearing pens which are mostly unstructured flat decks. The legal framework for the space requirements of these animals is provided by the EU Directive 2008/120/EC. Each weaned piglet deserves a certain unobstructed floor area, according to its live weight. However, the numbers given in the directive are based on about 22 years old estimates which can also be found in the EU Directive 91/630/EEC. There are no defined values for piglets that are less than 10 weeks old. In order to obtain current and accurate readings, the floor space covered by pigs was measured during the entire rearing period. For this purpose the colour contrast planimetric method “KobaPlan” was used which had originally been developed to calculate the surface of chicken (Briese & Hartung, 2009).

## Animals, material and methods

Animals and housing

The study was carried out on the research farm "Ruthe" of the University of Veterinary Medicine Hannover, Germany. About 90 sows and their piglets (genetics: German national breeding program "BHZP") are kept there under practical conditions in a conventional housing system. After weaning at the age of 35 days, the piglets are raised for 6 weeks in flat decks where they are kept in groups of 12 animals per pen providing space allowance of 0.3 $m^2$ per animal. After this period, the piglets are sold for fattening.

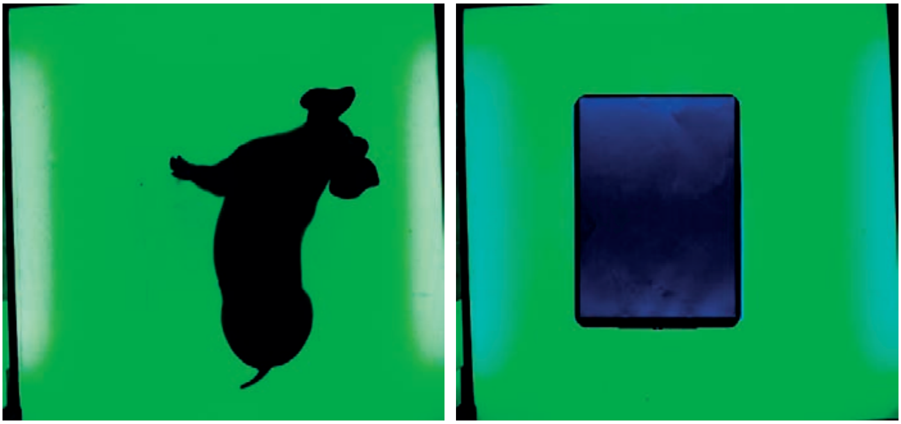

Figure 1: Pictures of the reference area (A 4 sheet, left column) and of a piglet (right column) taken in the box from top view

Planimetric survey of suckling piglets and weaners

The photographs of the piglets in this study were taken from the 1st week of life to 10 weeks at regular intervals of eleven days.

In order to measure each piglet individually, it was weighted and photographed digitally from top view in a special box. Therefore a camera was fixed to a metal frame that was 1.40 m above the ground of the box. In addition to these images, a reference area (= standard, placed at back level of the animals) with known surface (A 4 sheet = 623.70 $cm^2$) was photographed with the same camera settings (Figure 1). Subsequently, all images were transferred to a personal computer and analysed using the KobaPlan software. To obtain accurate data interpretation by the program, the box was fitted with a fluorescent floor and black lights to provide a high contrast background. The KobaPlan program counts the number of dark pixels of each picture resulting in a continuous area within the photograph (= surface of the top view photographed piglet). Using the known surface and number of pixels of the reference area, the KobaPlan software calculates the number of pixels of the photographed piglet and thus the floor space covered by the animal's body. Due to their size, pigs older than six weeks and with an average body weight over 10 kg could not be photographed in the box described above. Therefore a mobile planimetric equipment was developed that could be mounted on standard animal barn scales. As ground, a wooden plate coated with fluorescent paint, was used. The black lights were attached laterally to the barn scale. The camera was fixed to a 1.85 m high metal frame which could be placed on the scale. In this case the reference area was an A 3 sheet (= 1247.40 cm²).

Body positions of the pigs

In order to obtain exact results by the method described, it was important to distinguish between two body positions. Since the back level of a standing pig differs from that of a lying pig, a standard photography for each of these two postures had to be taken. For example, the A 4 sheet as a reference area for piglets with an average body weight of 8.95 kg was photographed at a height of 23 cm. Concerning lying pigs of the same average body weight, the standard height had to be 14 cm. By this arrangement, it was ensured that the distances were approximately identical in both from the piglets' surface, as well as from the standard to the camera. Thus, distortions could be virtually eliminated.

Processing of data

Since the colour contrast planimetric method had originally been developed for measurements in chicken, the digital images of the pigs had to be modified prior to processing with the KobaPlan software. Due to the highly reflective surface of the piglets it was not possible to achieve a sufficiently strong contrast by the methods described (black lights, fluorescent floor area). This affected especially the areas of the extremities and rooting discs of the animals. Therefore the pictures were retouched by the software Photoshop (Adobe Systems). Contrast and brightness were adjusted manually and the reflecting areas were filled in black with the airbrush tool. The digital photographs prepared in this way were processed as follows:

- Recording and calculation of the floor area covered by the piglets using the software KobaPlan;
- Transferring the data to Microsoft Excel;
- Assigning the calculated floor spaces (in cm²) to the collected live weights (in kg) of individual animals (based on the numbering of the pictures). For clear presentation the calculated surfaces of the pigs were assigned to weight classes. Such a weight class was formed by animals with similar body weights which differed by less than 0.50 kg. Subsequently the mean floor space covered by pigs of each weight class was calculated.

## Results

In total 448 images of piglets from top view were taken from the 1st week of life to 10 weeks at regular intervals. Thereof, 167 photographs showed lying pigs; 281 times standing pigs were depicted.

Floor space covered by lying suckling piglets and weaners

Figure 2 presents the increase of the floor space (in cm²) covered by lying pigs during the rearing period (1st to 10th week of live). In this study lying pigs with a body weight from 0.50±0.25 kg to 22.50±0.25 kg were measured. It was shown that with increasing body weight, the surface covered by lying pigs increased almost linearly (linear regression with a correlation coefficient of $R^2 = 0.93$). From weight classes over 20 kg a high scatter was observed which apparently occurs because of the smaller sample size in this weight range. The mean floor space covered by piglets in the 1st week of life (body weight 1.50±0.25 kg) was 242±18 cm². The calculated surface of lying piglets with a body weight of 5.00±0.25 kg was 519±35 cm². At weaning (about 9.00±0.25 kg body weight) this value increased to 830.00±140 cm². With a live weight of 20.00±0.25 kg lying pigs covered a floor area of 1607±28 cm². The heaviest pigs measured lying in this survey weighed 22.50±0.25 kg and covered 1615±31 cm².

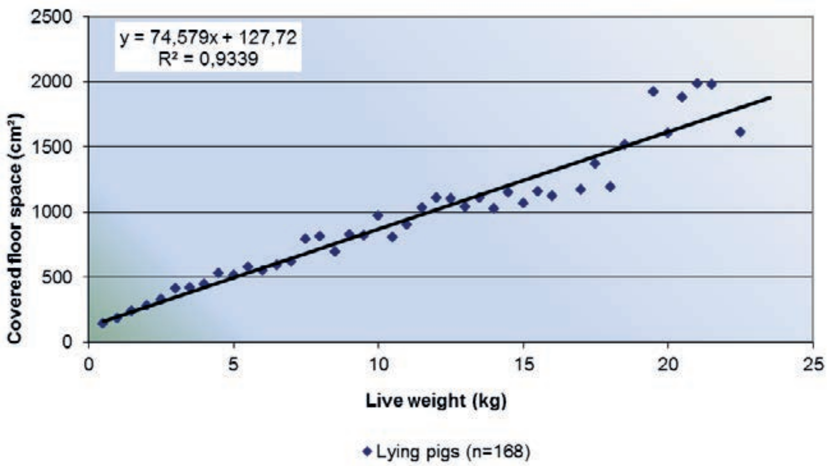


Figure 2: Mean floor space (cm²) covered by lying pigs depending on the live weight of the animals

Floor space covered by standing suckling piglets and weaners

The planimetric data of standing piglets were summarized in weight classes according to the covered floor space (in cm²) of lying pigs. Standing pigs comprised a weight range of 1.00±0.25 kg to 23.50±0.25 kg. Figure 3 presents the increasing mean floor space (cm²) covered by standing pigs during the rearing period (1st to 10th week of live). There is also a linear increase in the surface covered by standing piglets as a function of live weight (correlation coefficient $R^2 = 0.94$). As with the data of lying pigs, a high scatter in the upper weight classes of standing pigs can be seen in Figure 3. Again, this was mainly due to the small sample size in this weight range. The mean floor space covered by piglets in the 1st week of life (body weight 1.50±0.25 kg) was 227±26 cm². The calculated floor space of piglets weighing 5.00±0.25 kg was with 509±36 cm² slightly smaller than the area covered by lying pigs of the same weight. Also at weaning (9.00±0.25 kg body weight), pigs in standing position required less floor space (788±36 cm²) than in lying position. With a weight of 20.00±0.25 kg, the calculated surface of standing weaners was 1377±269 cm². Older weaners (23.50±0.25 kg body weight) covered 1992±270 cm².

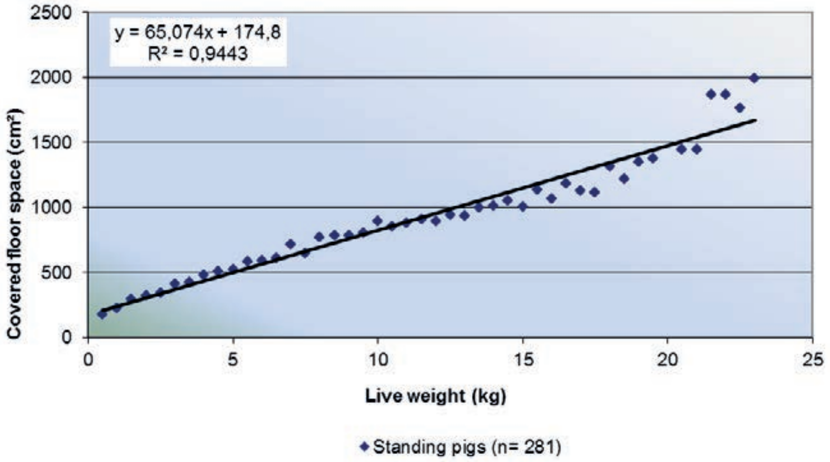


Figure 3: Mean floor space (cm²) covered by standing pigs depending on the live weight of the animals

**Discussion**

The aim of this study was to measure the floor space covered by a piglet depending on its weight and body position. As a basis for the discussion of values on the minimum space requirements in the legislation, it is important to know the exact area that an animal covers by its own body. The issue of adequate space allowance in livestock housing is very complex, since biological, ethological but also economic parameters must be considered. Petherick (1983) defined three different kinds of space. First, the area required by an animal due to its size and shape (body space), further the space that is necessary to carry out various maintenance behaviours (behavioural space) and finally the space that is needed for interactions between the animals (social-interaction space).

The planimetric study particularly focuses on the first definition (body space), even if some authors worked on the measurement of space-occupying behaviours (e.g. Bogner *et al.*, 1979; Spindler *et al.*, 2012). In the field of poultry, various planimetric methods have been developed. Bogner *et al.* (1979) photographed laying hens from top view. They measured the contours of the hens in the pictures and calculated their surfaces using the cage area as known reference area. Freeman (1983) also took photos of laying hens from above. From these photographs, the contours of the animals were cut out. Subsequently the weight of each cut-out was compared to the weight of a photo of a reference area. In order to calculate the floor space covered by turkeys, Ellerbrock (2000) used a digital planimeter. The contours of the animals were retraced in a photograph from which the device calculated and displayed the animal area using a predetermined reference area. The KobaPlan technique applied in the present study was used in an earlier version by Briese and Knierim (2006) for the measurement of turkeys and ducks and by Briese and Hartung (2009) for planimetric studies in laying hens. This method is based on the fact that digital images consist of pixels and that each of these pixels has a constant surface. The number of pixels associated to the animal in the picture was detected using Photoshop (Adobe Systems). Based on the known number of pixels of a reference area, the animal area was calculated (in cm²).

By using the KobaPlan software it was possible to calculate the floor space covered by the animal largely automatically. Thus, Spindler *et al.* calculated the surfaces of broiler chickens (2011) and pullets (2012). There are numerous studies dealing with space requirements of piglets and weaners (e.g. Pearce & Paterson, 1993; McGlone & Newby, 1994; Hyun *et al.*, 1998; Turner *et al.*, 2000; Wolter *et al.*, 2000; Jensen *et al.*, 2012). However, these investigations primarily treated the effects of space allocation on the pigs' production performance, health and behaviour. In contrast, Petherick (1983) referred to the physical dimensions of an animal as main factors for its space requirements.

He developed allometric equations which allow an estimate of the required space of pigs in various body positions. The present study was focused on the calculation of the "body space", i.e. the floor space that a pig covers due to its size and shape. It is obvious that there was an almost linear relationship between the covered floor space and the body weight of the piglets in both lying and standing position ($R^2$= 0.93 and 0.94). The floor area covered by lying pigs increased almost linearly from 186±37 cm² (body weight 1.00±0.25 kg) to 1615±31 cm² (22.50±0.25 kg). Standing pigs required an area of 180±37 cm² to 1992 ± 270 cm² (1.00±0.25 kg and 23.50±0.25 kg). Comparing these results with the minimum space allowance required in the EU Directive 2008/120/EC, it becomes clear that lying piglets with 5.00±0.25 kg body weight covered 34.7 % and standing piglets of the same weight class covered 34.0 % of the mandatory floor area (0.15 m²). On top of this weight range (10 kg) the animals already required 64.7 % of the given floor space lying and 53.3 % standing due to their body dimensions. Thus, 35.3 % (0.053 m²) and 46.7 % (0.071 m²), respectively are available for space-occupying behaviours and social interactions. However, these numbers describe the amount of space per animal. Pigs kept in groups have the possibility to time-share the available space to carry out maintenance behaviours (Petherick, 1983). In contrast, social interactions can only occur simultaneously between animals and thus the amount of space must also increase with increasing group size (Petherick, 1983). The next higher weight class (10-20 kg) described in 2008/120/EC needs a minimum area of 0.2 m² for pigs. Thereof, lying piglets (10.00±0.25 kg body weight) covered 48.5 % and standing piglets 40.0 %. Older and heavier weaners (20.00±0.25 kg) covered lying 80.5 % of the statutory defined minimum floor space and 69.0 % in standing position. In this case, the free space available to lying pigs is lowest with 19.5 % (0.038 m²) and close to an A 5 sheet (0.031 m²). The heaviest animal in this study weighed 23.50 kg and is therefore assigned to the weight range of 20 to 30 kg, according to 2008/120/EC. It covered 56.9 % of the minimum area of 0.35 m².

It should be noted that the collected biometric data, strictly speaking, only apply for hybrid pigs of BHZP genetics because animals of other breeds may show a different growth in terms of proportions and the associated body weight. This may result in different data concerning the floor space covered by the pigs depending on their body weights. Furthermore, the results provide only the floor area covered by the pigs' bodies. To offer the bare surface, which is covered by an animal's physical body dimensions, will not be sufficient in livestock husbandry (Hughes, 1983). There is still a need for research which space-occupying behaviours are essential to pigs kept in intensive housing and which amount of additional space has to be provided to perform these behaviours. Moreover, the use of space by the pigs is influenced by the position of pen features, such as the feeder, drinker and slatted floor. For example a pen measuring 2 m x 2 m will be used in a different way from a pen 8 m x 0.5 m, though both have the same area (Petherick, 1983).

## Conclusion

This study indicates that the colour contrast planimetric method KobaPlan which has originally been developed for measurements in chicken also provides reliable results regarding the floor space covered by piglets of 0.50±0.25 kg to 23.50±0.25 kg live weight. Since this method is feasible and repeatable under practical conditions, further data on the floor space covered by pigs of higher weight ranges or different genetics could be collected in this way. The present planimetric survey gives an allometric measure for the development of calculation models defining an animal based minimum floor area for piglets and weaners. This may be a first step for the optimization of current livestock housing and it could also be a useful basis for planning new environmental enrichment structures or elements in piggeries.

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**Repeatability of, and correlation between, force and visual stance variables measured by a system for automatic lameness detection in sows, SowSIS.**

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**Abstract**

This paper describes the repeatability of, and correlation between, force and visual stance variables measured by SowSIS, an objective method to detect lameness in sows. In total, five consecutive measurements were carried out on each of twenty-one hybrid sows. Within-animal coefficients of variation were calculated to evaluate repeatability whereas Spearman correlation coefficients were used to examine if stance variables are interrelated. Results reveal that SowSIS allows adequate registration of stance variables with high repeatability in sound sows. When kicking, sound sows shift their weight mainly towards the contralateral and ipsilateral leg and, to a lesser extent, towards the cross-related leg. The absence of clear correlations between force and visual stance variables implicate that both should be included in future research.

**Keywords:** posture, weight distribution, Spearman correlation, repeatability, sow

## Introduction

Lameness in sows is an important issue from a welfare (FAWC, 1992; Fernàndez de Sevilla *et al*., 2008) and economic point of view (Dewey *et al*., 1992; Jørgensen, 2000; Rowles, 2001; Stalder, 2004; USDA, 2006; Schuttert, 2008; Anil *et al*., 2009). The prevalence of lameness in sows ranges from 8% to 15% (Gjein & Larssen, 1995a; Bonde *et al*., 2004; Heinonen *et al*., 2006; Kilbride *et al*., 2009; Pluym *et al*., 2011a) with a higher percentage in group housed sows compared to sows kept in individual stalls (Gjein & Larssen, 1995b; Anil *et al*., 2003). Group housing became obligatory in the EU member states since 2013. Hence, early and accurate detection of lameness is required to impede unnecessary distress of sows and to avoid financial losses. Visual assessment of gait and posture is inexpensive and easy to perform, but prone to observer error and limited to detection of severely lame sows. (Krebs *et al*., 1985; Main *et al*., 2000; Petersen *et al*., 2004; Tiranti & Morrison, 2006; Fan *et al*., 2009). Increasing farm size and housing pregnant sows in groups will impede sufficient monitoring of the individual sow by the farmer (Estienne *et al*., 2006; Cornou *et al*., 2008; Chapinal *et al*., 2010). Automated and objective assessment will become crucial to enable early and accurate detection.

Recently, a detection system based on force stance variables derived from force plate analysis and visual stance variables derived from image processing was developed: SowSIS (Sow Stance Information System) (Pluym *et al*., 2011b). The system consists of an aluminium box and is constructed to be a transportable walk-through device. The two main measuring systems are incorporated in the bottom plate (a platform with four balances) and the rotatable arm with a camera. Force plate measurements start after a sow has entered the measurement box and lasts at least 5 min at 10 Hz (total of 3000 measuring points). While the sow is standing in the device, a lateral view of the left and right hind leg is taken with the digital camera. Before pictures are taken, the position of the stifle joint, the tibiotarsal joint and the middle of the region of the metatarsophalangeal joint and the coronary band viewed from the lateral side are marked. Data processing is automated in Matlab 7.13 (R2011b, MathWorks Inc, Natick, USA). Calculated force stance variables are: absolute and relative weight on each leg, number and duration of kicks on each leg, number, duration and magnitude of weight shifts between legs and leg weight symmetry. Visual stance variables derived from the digital pictures included the claw angle, the pastern axis and the angle of the hock. This paper describes repeatability of both force and visual stance variables as well as the correlation between these variables.

## Materials and Methods

<u>Animals and housing</u>

Twenty-one hybrid sows (Rattlerow Seghers) were selected *at random* from ILVO's (Institute for Agricultural and Fisheries Research) research farm. All sows were at least four weeks pregnant and were housed in individual stalls on partially slatted, concrete floors. Sows were checked for lameness during walking using visual assessment performed by the first author. A lame sow was defined as a sow unable to use one or more limbs in a normal manner varying in severity from reduced ability to bear weight, to total recumbency. None of the sows were clinically lame.

<u>Measurements</u>

The device was placed in front of the entrance to the gestation stable and sows were guided into the measurement box. After each single measurement the sows left the device, and entered the central corridor of the gestation stable through a loop to re-enter the measurement box for the next replication. Five consecutive measurements of every

sow were carried out within a time frame of one hour.
To examine the correlation between weight distribution related variables and conformation related variables, a single measurement of each of 21 sows was carried out with SowSIS. In this paper only the relationship between the force stance variables and the visual stance variables of the left hind leg will be described.

Statistical analysis

To assess repeatability of the force stance variables and visual stance variables, the mean within-animal coefficient of variation (SD/mean × 100%) was calculated. Coefficients of variation were first calculated over all five consecutive measures 'within sow' and then averaged across the twenty sows to obtain a mean within-animal coefficient of variation. Repeated measures ANOVA was performed with consecutive measurements (categorical) as within subject variables using IBM SPSS Statistics 19 (SPSS Inc., Chicago, IL, USA).
The Spearman correlation test was used to identify associated force and visual stance variables. Analysis was performed in IBM SPSS Statistics 19 (SPSS Inc., Chicago, IL, USA).

## Results and Discussion

The results of the repeatability study indicate that SowSIS allowed adequate registration of force and visual stance variables with a high level of precision in sound sows. All force stance variables showed a low (< 10 %) to moderate (≤ 20 %) mean within-animal coefficient of variation, except for number and duration of both kicks and weight shifts (> 20%). No significant differences were found between consecutive measures of force stance variables within a sow except for the number of weight shifts between left fore and left hind leg ($P = 0.043$), duration of weight shift between left fore and left hind leg ($P = 0.009$) and between right fore and right hind leg ($P = 0.004$) and for the magnitude between left fore and left hind leg ($P = 0.007$). Mean within-animal coefficients of variation for all three visual stance variables were low to very low with a coefficient of 6%, 11% and 3% for the claw angle, the axis of the long pastern bone and the angle of the hock, respectively. The high repeatability of the three visual stance variables demonstrates their potential use as an objective assessment of the posture of a sow.
Both the absolute and relative weight on the left hind leg were positively correlated with the variable leg weight symmetry (table 1). In sound sows, more weight (58% of total body weight) is carried by the fore legs (Sun *et al.*, 2012). When more weight is carried by the hind legs, the leg weight symmetry will increase and even might become equal to one, indicating an even distribution of weight between fore and hind legs. The more kicks on the left hind leg, the higher the number of weight shifts between the left legs ($\rho_s = 0.81$, $P < 0.001$) and between the hind legs ($\rho_s = 0.75$, $P < 0.01$). Kicks are defined as a short lifting of a leg in the air so that the absolute weight exerted on the leg value

falls below 10 kg. A weight shift, from one leg to another (lateral, anterior-posterior or diagonal), is considered when the shift of absolute weight for each of both legs differed by more than 10 kg from the mean weight of the leg during the whole measurement period. Therefore, the number of weight shifts may include the number of kicks and this might explain the positive correlation between the number of kicks and the number of weight shifts. A higher number of kicks on the left hind leg decreased the duration of the weight shifts between the left legs and increased the magnitude of the weight shifts between the hind legs. In addition, diagonal weight shifts (i.e. between the left hind leg and the right fore leg) are significantly correlated with weight shifts between the hind legs and between the left legs. These relationships indicates that, when a sow kicks, the weight of this leg is shifted towards the ipsilateral leg, the contralateral leg and, to a lesser extent, towards the diagonal.

The significant negative correlation between absolute weight and pastern axis ($\rho_s = -0.44$, $P < 0.05$) was the only significant correlation that could be found between the force and visual stance variables indicating heavier sows may have more sloping pasterns. Visual stance variables were not significantly interrelated in this study. This is in contrast with the results of a study by Barczewski *et al.*(1990). In that study, the hind pastern angle and the angle to the hock were positively correlated (0.23, $P < 0.01$). Absence of a similar significant correlation in this study may be due to the lower number of investigated sows (21 versus 288 in the study of Barczewski *et al.*(1990)) and the different method used for calculating the angles. In their study, Barczewski *et al.* (1990) measured the angles of both fore and hind legs from a film made as the sows walked on a treadmill whereas in this study angles were calculated from a picture taken when a sow was standing still. Notwithstanding, it can be concluded that the relationship between force stance variables at the one hand and visual stance variables at the other hand are rare and, if present, correlation coefficients are low. As a consequence, both force and visual stance variables will have to be included in future research.

Table 1: Significant Spearman correlation coefficients ($\rho_s$) for all force and visual stance variables.

| | Abs | Rel | nK | dK | WS le | WS di | WS hi | dWS le | dWS di | dWS hi | mWS le | mWS di | mWS hi | LWS left | LWS Hind | Claw angle | Pastern axis | Angle hock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abs | | 0.72** | | -0.73** | | | | | | | | | | 0.77** | 0.46* | | -0.44* | |
| Rel | | | | | | | | | | | | | | 0.93** | 0.63** | | | |
| nK | | | | | 0.81** | | 0.75** | -0.53* | | | | | 0.72** | | | | | |
| dK | | | | | | | | | | | | | | | | | | |
| WS le | | | | | | | 0.69** | -0.55* | | | | 0.46* | 0.48* | | 0.58** | | | |
| WS di | | | | | | | | -0.44* | | | | 0.47* | | | | | | |
| WS hi | | | | | | | | -0.69** | | | 0.46* | | | | | | | |
| dWS le | | | | | | | | | | 0.67** | | | | | | | | |
| dWS di | | | | | | | | | | | | | -0.46* | -0.45* | | | | |
| dWS hi | | | | | | | | | | | | | | | | | | |
| mWS le | | | | | | | | | | | | | | | | | | |
| mWS di | | | | | | | | | | | | | | | | | | |
| mWS hi | | | | | | | | | | | | | | | | | | |
| LWS le | | | | | | | | | | | | | | | | | | |
| LWS hi | | | | | | | | | | | | | | | | | | |
| Claw angle | | | | | | | | | | | | | | | | | | |
| Pastern axis | | | | | | | | | | | | | | | | | | |
| Angle hock | | | | | | | | | | | | | | | | | | |

[1]absolute weight on left hind leg (Abs), relative weight on left hind leg (Rel), number of kicks (nK), duration of kicks (dK), weight shifts (WS) between left feet (le), left hind and right front (di), hind feet (hi), duration of weigth shifts (dWS), magnitude of weight shifts (mWS), leg weight symmetry (LWS).

[2] Significance: * < 0.05; ** < 0.001

## Conclusions

The low to moderate mean within-animal coefficients of variation for all force and visual stance variables, with exception of kicks and weight shifts, revealed sufficient repeatability of the measurements of stance variables measured with SowSIS. The high significant Spearman correlation coefficients between the number of kicks and the number, duration and magnitude of weight shifts indicated a lateral, anterior-posterior and, to a lesser extent, a diagonal weight shift when a sound sow kicks, as would be expected. This indicate that SowSIS is able to detect physiological changes in sound sows. Visual stance variables were not significantly interrelated in this study.

The negative correlation between absolute weight and the pastern axis was the only relationship found between force and visual stance variables. Future research is needed to evaluate whether SowSIS is able to detect incipient lameness, especially at an earlier stage than visual assessment. The limited correlation between force and visual stance variables imply that both types of stance variables should be taken into account when performing further research.

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## Analysis of energy consumption in robotic milking

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### Abstract

This study aims to document the energy consumption of an Automatic Milking System (AMS) as operated within a grass based seasonally calved dairy production in Ireland. The data and information collected will be used to i) describe the energy consumption of the AMS, ii) examine consumption of individual energy consuming components within the milking system, iii) compare energy consumption of AMS and conventional milking systems. Energy consumption in AMS milk production is a topical issue because these systems are becoming more popular worldwide (more recently even in grazing systems), however there has been little analysis of how on-farm energy use changes when a farm adopts an AMS in place of a conventional herringbone type milking system. Our objectives, therefore, were to document electricity used per litre (l) of milk sold as a farm makes the transition from milking in a herringbone milking parlour to milking in an AMS and to identify the relative share of energy consumption among the energy consuming components of the milk harvesting process.

**Keywords:** energy use, milk production, automatic milking

### Introduction

Recent data shows that there are approximately 10,000 commercial farms worldwide using automatic milking systems (AMS) to milk their cows. This figure is expected to grow rapidly in the coming years (De Koning, 2011). Therefore, the energy consumption of AMSs will become increasingly important. Studies by Bijl *et al,* (2007), and Artmann & Bohlsen, (2000), showed that electricity costs were greater with AMSs compared to conventional milking systems. However these studies focused of indoor dairy herds and did not give detailed component breakdown information.

The removal of the milk quota system in the European Union in 2015 is likely to increase milk production per farm and to decrease milk price (Bouamra-Mechemache *et al*., 2008; Lips *et al*., 2005). In Ireland, for example, milk production per farm is expected to increase by 50% by 2020 (DAFM, 2010), whereas milk price is expected to decrease by 33% (Lips *et al*., 2005). Milk production systems in Ireland, therefore, will focus on cost control and maximising the amount of milk that is produced from grazed grass. The potential of Irish soils to grow grass throughout the year and efficiency in utilizing grass are key factors affecting output and profitability of dairy production systems (Shalloo *et al*., 2004).

Efficient use of energy is one way to improve the cost competitiveness of the Irish dairy sector. At this moment, electricity costs on Irish farms are around 4% of variable on-farm costs (Upton *et al*., 2011), but they are expected to increase because of rising global energy costs and the introduction of a dynamic electricity pricing structure for 80% of electricity consumers in Ireland by the year 2020. Thus, reducing electricity consumption will reduce production costs, but it also has an environmental benefit, because electricity consumption has been shown to represent 25% of total primary energy use on pasture-based dairy farms in New Zealand (Wells, 2001). Hence understanding electricity consumption among varying milking systems will contribute to the debate on robotic versus conventional milking and help farmers and advisors to make informed decisions. There is a plethora of social and economic reasons why a farmer would choose to install a robotic milking system, however this paper will focus on electricity consumption running costs alone.

The aim of this study was to document electricity used per litre of milk sold as a farm makes the transition from milking in a herringbone milking parlour to milking in an AMS and to identify the relative share of energy consumption among the energy consuming components of the milk harvesting process.

## Materials and methods

### Farm system description

This study was carried out on a dairy research farm at Teagasc Moorepark in Ireland. Data collection was undertaken from May to October during 2010, 2011 and 2012. Over these periods all relevant inputs and outputs were recorded using a combination of wireless data transfer and manual recording. Data recorded included milkings per cow per day, milk yield and milk quality parameters such as total bacteria count (TBC) and somatic cell count (SCC). The energy consumption of the milking systems was monitored using Sinergy Escot energy monitoring equipment and software. The Escot data-logger can measure power consumption of multiple electrical circuits using clip-on AC current transducers. The logging software records cumulative kilowatt-hour (kWh) readings every 15 minutes. Measurement equipment was calibrated and accurate to ±1% of reading. This equipment allowed for measurement of the following individual components in the dairy: milking robot, vacuum pump, air compressor, milk cooling and water heating.

### Experimental measurements

In year one of the study, prior to installation of the AMS and herd of 107 cows were milked in a 20 unit herringbone parlour equipped with automatic cow identification, milk metering technology and automatic cluster removers. This milking machine had two 4 kW vacuum pump motors. Water heating was provided by two 3 kW 300 l electrical water heaters. Milk was pre-cooled using a plate heat exchanger supplied with well water and subsequently cooled in a 10,000 l direct expansion bulk milk tank. Vacuum level was controlled by a standard regulator. Cows were milked twice per day and yielded 3,566 l per cow over the monitoring period.

In years 2 and 3 of the study the spring calving herd (herd size of 63 and 72 cows, respectively) was milked from pasture using a Merlin AMS*. Data presented here pertains to the period from May to October of both years. Cows were milked on average 1.78 times per day in 2011 and 1.87 times per day in 2012. Average milk yield over the period was 3,079 l and 3,388 l per cow over the 26 week periods in 2011 and 2012, respectively. The AMS was washed with hot water 3 times per day during 2011 and twice per day in 2012. Water heating was provided by electrical water heaters. Milk was pre-cooled using a Packo tubular cooler (model TT2) supplied with well water and subsequently cooled in a 5,000 l ice bank tank. The vacuum pump was a vane pump with a 3 kW motor. Vacuum level was controlled by a standard regulator from weeks 1-6 of 2011, while a variable speed drive (VSD) controlled pump with 1.1kW motor was used thereafter. Compressed air was supplied by a 2.2 kW compressor.

Data analysis

Raw data from the electricity monitoring system were exported to spreadsheets, and subsequently used to compute the electricity consumption of individual components as well as total dairy electricity usage. To determine electricity costs of individual items, electricity data was combined with day and night rate pricing tariffs (day tariff was 0.18 €/kWh; night tariff was 0.08 €/kWh from 00:00 to 09:00).

## Results and discussion

Energy consumption of the AMS

Total energy use of the AMS was 105.63 Watt-hours per litre of milk produced (Wh/l) during its first lactation (range 68.58 - 178.15 Wh/l) and 84.27 Wh/l in its second lactation (range 52.88 – 113.39 Wh/l). further data on the performance of the milking systems over 3 years is presented in Table 1.

Table 1: Description of main system characteristics over the three year duration of the study

| | Conventional 2010 | AMS[1] 2011 | AMS 2012 |
|---|---|---|---|
| Milking frequency (Milkings/cow/day) | 2 | 1.78 | 1.87 |
| Milk production per cow | 3566 | 3079 | 3388 |
| Energy consumption (Wh/l)[2] | 46.90 | 105.53 | 84.27 |
| Energy costs (€ c/l)[3] | 0.79 | 1.36 | 1.09 |

[1] AMS = Automatic Milking System
[2] Wh/l = Watt-hour per litre of milk produced
[3] € c/l = Euro cent per litre of milk produced (excludes taxes)

Water heating accounted for the largest portion of energy use (39% and 30% in 2011 and 2012). Reducing hot water wash cycles from 3 times per day to twice per day in 2012 reduced energy consumption by the water heating system by 38% (from 40.77 to 25.44 Wh/l). This requirement is a consistent fixed cost irrespective of the volume of milk produced because wash cycle scheduling is time based. The average TBC results were 18,000 cells/ml across both the 2011 and 2012 milking seasons.
Changing from a standard vacuum regulator controlled vacuum pump system to a VSD vacuum pump in week 6 of the 2011 season reduced vacuum pump energy use by 63% (from 19.19 to 7.09 Wh/l).
The energy consumption of the milk cooling system, air compressor, vacuum pump and robot in 2011 and 2012 are presented in Table 2. Miscellaneous items such as wash pumps and an office consumed 15.53 and 12.66 Wh/l in 2011 and 2012 respectively. When the relevant tariffs were applied, the average cost of electricity was 1.36 Euro cent per litre of milk (c/l) in 2011 (range 0.84 – 2.42 c/l) and 1.09 c/l in 2012 (range 0.68 – 1.58 c/l).
The average AMS running costs of 1.36 c/l (2011) and 1.09 c/l (2012) were high compared to an audit of conventional milking systems (0.43c/l) on 21 commercial dairy farms (May-October 2010) by Upton *et al.* (2011). This may be due to either reduced milk output from the AMS during the start-up years, (when milk yield is expected to be reduced by 10-15% (Wade *et al*, 2004)) and/or under utilization of the AMS. Sixty three and seventy two cows were milked in this grazing based study in the first two years of operation, whereas the possibility to extend capacity to 112 is considered achievable (Jago *et al.*, 2006).

Energy consumption of the conventional milking system
Total energy use in the conventional 20 point herringbone milking plant from 2010 was 46.9 Wh/l (range 34.38 to 65.00 Wh/l). The water heating system was the largest energy user (29% of total). Other major energy users were the vacuum pumps (26%), milk cooling system (25%) and lighting (13%). There was no air compressor used during

milking on the conventional system. This is a key difference between the two systems as the energy consumption of the air compressor alone was 17.13 Wh/l on the AMS in 2012. Average energy costs were 0.79 c/l (range 0.55 – 1.02 c/l). The average costs are higher than the average figures presented by Upton *et al.* (2011) (0.43 c/l) from a study of 21 commercial farms with an average herd size of 106 cows.
However the cows milked in the convention milking parlour in year one of this study had extended milking times due different experimental treatments in the research centre farm, which may have lead to higher energy consumption.

Table 2: Breakdown of electricity consumption per litre of milk produced including cost of electrical energy consumed during three 26 week periods i) May-October 2010 with a conventional herringbone milking system, ii) May-October 2011, 1st lactation with an AMS, iii) May-Oct 2012, 2nd lactation using an AMS

| | Conventional 2010 (Wh/l)[1] | AMS[2] year 1 2011 (Wh/l) | AMS year 2 2012 (Wh/l) |
|---|---|---|---|
| Vacuum pump | 12.38 | 11.54 | 7.41 |
| Cooling | 11.54 | 15.39 | 16.75 |
| Lighting | 6.26 | 2.74 | 2.23 |
| Air Compressor | na[3] | 16.41 | 17.13 |
| Water Heating | 13.65 | 40.77 | 25.44 |
| Other | 3.07 | 15.53 | 12.66 |
| Robot | Na | 3.25 | 2.64 |
| Total | 46.90 | 105.63 | 84.27 |

[1] Wh/l = Watt-hour per litre of milk produced
[2] AMS = Automatic Milking System
[3] na = Not applicable

## Conclusion

Average electricity consumption of the AMS tested with 63 and 72 cows in 2011 and 2012 milking seasons were 105.63 and 84.27 Wh/l respectively. These figures were higher than the conventional herringbone milking system used on this farm in 2010 prior to the AMS installation. Largest energy consuming processes associated with milk harvesting in the AMS were heating water, compressing air and cooling milk. It is likely that the energy use of the AMS will reduce further as cows become familiar with the AMS and optimum herd size/milk output for the AMS is reached. The suitability of a heat recovery system (designed to recover waste energy from the milk cooling system) and cold detergent wash cycles, in place of hot water wash cycles, will be investigated in 2013 to moderate running costs further.
* Merlin AMS supplied by Fullwood Ltd

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# Gold standards concepts for automatic lameness assessment systems in dairy cows

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## Abstract

Lameness is an important welfare problem in modern dairy farms. In order to support lameness control in dairy farms, several concepts to develop a reliable automatic lameness assessment systems (ALAS) have been undertaken. Golden standards methods used for ALAS development are discussed based on a literature review. 16 out of 18 articles related with automatic lameness assessment systems used locomotion scores as gold standard. Main advantages of locomotion scores as gold standard lie on their practical application. Locomotion scores are easy and cheap to use in practice. Disadvantages of locomotion scores as gold standard are related with validity and repeatability of the method. Locomotion scores as tool for pain and hoof lesions (potential source of pain) seems limited because, cows seems to present an important tolerance to pain and locomotion is also impaired by the practical conditions in which it is assessed. Repeatability for locomotion assessment showed a large variation between and within observers. The main factor in the variation of repeatability seems to be the subjectivity associated to locomotion scores. Poor validity and repeatability hinders the interpretation of what is finally being assessed by LSs and ultimately by ALAS. Hoof and painful lesions are also used as gold standard for ALAS development. As LS diagnosis of hoof and painful lesions are also subjective and may present poor repeatability. In conclusion, currently there is not an optimal gold standard for the development of ALAS.

## Introduction

Lameness has been defined as the deviation in gait resulting from pain or discomfort from hoof or leg injuries (Flower and Weary, 2009). Lameness is associated with impaired productive and reproductive performance (Garbarino *et al.*, 2004; Archer *et al.*, 2010), increased risk of culling (Booth *et al.*, 2004) and impaired animal welfare (Whay, 2002). These effects leads to increased production costs (Bruijnis *et al.*, 2010).

In order to support lameness control in dairy cows, several concepts have been devised for the development of a reliable automatic lameness assessment system (ALAS). The ALAS collects data from cows in a barn using several types of sensors which are analysed using mathematical algorithms in order to make a classification of cows regarding their level of lameness (de Mol *et al.*; Chapinal *et al.*, 2009; Viazzi *et al.*, 2013) (Figure 1).

The development of ALAS requires a gold standard for lameness assessment to be used as reference for model development. A gold standard is defined as a test or procedure that is valid and truly reliable (Dohoo *et al.*, 2003). Under practical conditions, however, the gold standard becomes the best diagnostic method available for the evaluation of a certain condition (Dohoo *et al.*, 2003).It is commonly stated that an algorithm cannot be more accurate and precise than its gold standard. Therefore, selection gold standard, is one of the critical points in the development of ALAS (Figure 1).

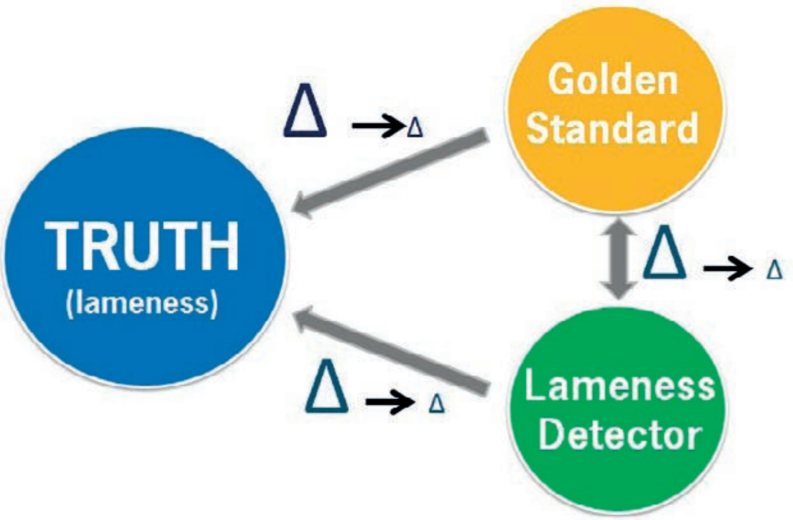


Figure 1: Relation truth (lameness), gold standard, lameness detector

Since the gold standard is an important factor in the development of ALAS, the objective of this review was to point and analyse different methods used as a gold standard for the development of ALAS.

**Gold standards used in ALAS development.**

From 18 different reviewed articles related with ALAS development, 12 articles used LS as unique gold standard (de Mol *et al.*; Viazzi *et al.*, 2013), four articles used a mixed gold standard in which uses LS and/or hoof lesions (total or specific lesions) or LS and hoof lesions (Liu *et al.*, 2009; Pastell *et al.*, 2010). One article used painful lesions (Bicalho *et al.*, 2007)and another used veterinary treatment applied for hoof lesions as a gold standard (Kramer *et al.*, 2009).

**Locomotion scores and lameness assessment**

Lameness assessment by means of LSs is based on the assumption that cows with affected hoofs/limbs change their way of walking in order to relieve pain or discomfort. The alterations in locomotion are perceived as changes in specific gait and posture traits of cows. Observers assess these gait and posture aspects in order to judge locomotion and finally classify cows in different lameness degrees according to a scale (Whay, 2002). Under this assumption, lameness is the visible indicator of the underlying problem which is pain or discomfort.

It is common practice that lameness assessment is performed using LSs with five (Sprecher *et al.*, 1997) or nine levels (Flower *et al.*, 2006). Later data are transformed into a two- level score classifying cows as lame or not lame. In this regard, most LSs include a lameness threshold, which is an arbitrary point from which a cow is considered as being clinically lame, and consequently in pain or having discomfort. The lameness threshold in most of LSs is considered to be score ≥ 3 (Figure 2).

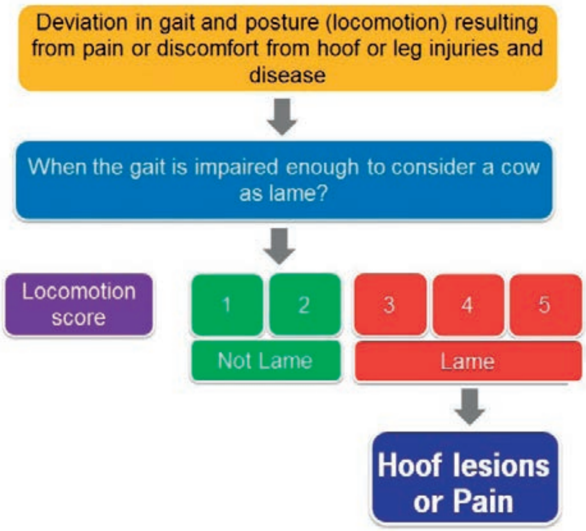


Figure 2: Lameness assessment process with locomotion scores.

In 16 articles where a LScM (including articles with mixed gold standard) was used as gold standard, measurements were performed by a single experienced observer or veterinarian..
The advantage of LSs lies on their practical application. They can be conducted quickly on-site, require no technical equipment and allow evaluators to provide an overall assessment of locomotion in large number of animals in a short time (Whay, 2002).
Disadvantages, on the other hand are related with the validity and repeatability of the methodology.

As stated previously it is commonly assumed that impaired locomotion is associated with pain and discomfort. Therefore the validity of lameness assessment lies in its usefulness to detect pain and discomfort. Pain assessment is a difficult, however some methodologies have been developed
The first method of pain and discomfort assessment is related to the amount of force (applied on the claws) to induce a reaction in a cow. In this regard, Dyer *et al.* (2007) proposed that cows presented a great tolerance to pain since 37% of cows classified as having painful claws did not display lameness (LS $\geq$ 3).
A second approach assumes that since lameness is an expression of pain, the use of analgesics/anaesthetics should improve locomotion. Significant, small improvements (a decrease in 0.3 and 0.25 points of locomotion score) were found after the injection of lidocaine and ketoprofen to lame cows (Rushen *et al.*, 2007; Flower *et al.*, 2008).
A third validation method determines the capability of LSs to detect hoof lesions (as potential source of pain). Bicalho *et al.* (2007) reported sensitivity = 67.1% and specificity = 84.6% for detection of painful hoof lesions. Similar values were obtained by Chapinal *et al.* (2009) (sensitivity = 54.0%, specificity = 70.0%) for sole ulcer detection.
Taking into account the information stated in this section, the validity of LSs as a tool for pain/discomfort or lesion detection appears to be limited. In addition, locomotion is not only affected by pain but also by external factor such as the surface on which cows walk (Haufe *et al.*, 2009), anatomical conformation (Boettcher *et al.*, 1998), number of lactations and days in milk (Chapinal *et al.*, 2009) among others. Poor validity and repeatability hinders the interpretation of what is finally being assessed by LSs and ultimately by ALAS.

## Repeatability of locomotion scores

Repeatability is an important indicator of the quality of the measurement (Martin and Bateson, 1993). Two types of repeatabilities can be distinguished: a) between-observer repeatability (BOR) indicating the repeatability between two or more observers recording data (Martin and Bateson, 1993) and b) within-observer repeatability (WOR) indicating the repeatability of a single observer recording data at different times (Martin and Bateson, 1993). Since LSs are widely used as gold standard for ALAS it is

important that observers assessing lameness attain the high BOR and WOR as possible. BOR and WOR values found in literature displayed considerable variation. BOR values ranging from 46% to 95% for BOR with a five levels LS (March *et al*., 2007). The major source of variation in the BOR and WOR values arises from the individual variation of the observers (Engel *et al*., 2003; Channon *et al*., 2009). Some factors associated to individual variation that can potentially affect repeatability of lameness assessment are level of experience of the observers, memorization of individuals (especially in small herds), awareness of the observer of being assessed for repeatability, expectations of the observers regarding the cow's behaviour and the feedback that observers receive from the researcher in relation to a behaviour (Kazdin, 1977).
Improvement of BOR and WOR can be obtained by transforming the whole LS into a lame/not lame classification. Channon *et al*. (2009) reported and increment in the BOR values from 33% with a nine levels LS to 88% for lame/not lame classification. Similar trend was obtained with WOR with values increasing from 30% with a nine levels LS to 87% for lame/not lame classification (Channon *et al*., 2009).

**Hoof lesion, painful lesions and treatment**

The biggest advantage of using hoof and painful lesions as a gold standard is that, unlike LS, they do not require further validation.
Hoof lesions detection consist on perform hoof trimming to cows and later diagnose the lesions presents in every claw. Methods for recording hoof lesions consist mainly on a scoring sheet with the draw of a claw divided in different zones. The specialist must mark the zone in which the lesion is located in addition with the final diagnosis of the lesion e.g. white line disease, sole ulcer, digital dermatitis (Bergsten, 1993; Leach *et al*., 1998). The diagnosis of hoof lesions is commonly carried out by a veterinarians or claw trimmers. Once the diagnosis of specific lesions is done, they can also be used as gold standard (Pastell *et al*., 2010).

Painful lesions assessment consist on apply digital pressure hoof lesions. A lesion is considered painful when the cow react to the digital pressure or when a lesions was obviously painful (Bicalho *et al*., 2007).
Since the hoof and painful lesions are diagnosed by different individuals, there is the possibility that different observers disagree in the presence or absence of different lesions (Holzhauer *et al*., 2006). In addition, specific and painful lesions are far less common than lameness assessed with LS. Therefore a larger number of animals may be required to meet the statistical requirements (Amory *et al*., 2008)
A final lesser extended method used as gold standard for ALAS is the utilization of the registers for treatments for hoof lesions, consisting basically on claw trimming. The disadvantage of this method is that there is not an standard that indicate when a cow must be treated. This criteria may vary depending on the management plan of the farm.

## Conclusions

The LSs are the most used gold standard for the development of ALAS. This may be explained because of LSs are easy and cheap to perform under farm conditions. However, it is important to consider important limitations associated to LScMs before select them as gold standard. First, the LSs presented a limited validity to detect pain or hoof lesions. In addition there is large variation in repeatability and overall performance between different observers performing LSs. This is reflected in the wide range of the repeatability values reported in the literature. Poor validity and repeatability hinders the interpretation of what is finally being assessed by LSs and ultimately by ALAS. Hoof/painful lesions detection are also been used as gold standard for the validation of different ALAS concepts. Although the utilization of hoof/painful lesions as gold standard are focused on detect the problem without intermediate indicators (e.g. LS) , they are still subjective diagnosis tools that may suffer poor repeatability. Currently, there is not an optimal gold standard for the development of ALAS.

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# Video pre-processing for the improvement of an automated lameness detection system for dairy cows

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## Abstract

Computer vision and image analysis are techniques with potential for use in animal health and welfare monitoring systems, since they are relatively inexpensive and do not interfere with the animals' environment. In an automatic lameness detection system for dairy cows, in particular, the performance of the model relies on the quality of the 3D input videos and therefore video pre-processing is required. This paper describes video pre-processing routines for automatic filtering of "video quality" and "cow's walking speed". Decision tree algorithms J.48 were used to classify model performance. The results show that the "video quality" filtering model correctly classified 75.7% of cases while the "cow's walking speed" achieved 91.3% accuracy. Detailed results are quantified in the form of a confusion matrix. Further optimisation of the 3D automated lameness detection system through pre-processing is needed before it can be used on commercial dairy farms.

**Keywords:** filtering, 3D image, cow's features extraction, video quality, system implementation

## Introduction

Livestock management decisions in the past were based on audio-visual observations, judgments and experience of farmers (Frost *et al.*, 2003). The increase in the scale of farms and the correspondingly high number of animals has reduced the farmer's ability to monitor animals by audio-visual scoring. Nowadays, on dairy farms, a diagnosis of lameness relies on visual locomotion scores for the cow's gait and posture parameters such as gait asymmetry, head bobbing and back curvature (Schlageter-Tello *et al.*, 2011). A veterinarian with expertise in lameness is currently able to visually attribute a locomotion score for a normal walking cow or severely lame cow.

The ongoing intensification and automation processes on dairy farms involve the use of on-line tools for fully automatic and continuous monitoring of cows throughout their life (Berckmans, 2008). Recent approaches to the automation of lameness detection have used a variety of techniques such as force plates (Ghotoorlar *et al*., 2012; Liu *et al*., 2011; Pastell *et al*., 2008), pressure mats (Maertens *et al*., 2011), accelerometers (Chapinal *et al*., 2011; Pastell *et al*., 2009) and image processing (Pluk *et al*., 2010; Poursaberi *et al*., 2010; Van Hertem *et al*., 2013; Viazzi *et al*., 2013a). The latter technique is relatively inexpensive, since it requires only a camera and a computer, and it does not interfere with the animals' environment. However, an important issue for any computer vision or image-based solution is video pre-processing. In particular, for the automated lameness scoring algorithm based on 3D videos of cow gait developed by (Viazzi *et al*., 2013b) the performance of the output system depends on the quality of the 3D input videos. Hence, video pre-processing is of fundamental importance for the optimisation of such systems by excluding videos of cows which are of unsuitable quality or contain an undesirable walking pattern. Therefore, the objective of this study is to develop two automated video pre-processing routines for the purpose of video filtering. Videos with imprecise depth measurements and videos with changes in the cow's walking pattern or cows which stopped during the recordings were classified as unsuitable for further video processing and excluded from the dataset. Optimisation of the 3D automated lameness detection system through pre-processing is needed before it can be used on commercial dairy farms and in further product development stages.

## Material and methods

### Experimental farm

Video data were collected on a commercial dairy farm with 951 lactating Israeli-Holstein cows located in Yifat, Israel. Video recordings were carried out during three consecutive evening milking sessions, starting at 19h00. All cows were milked three times a day in a 2 x 32 side-by-side parallel milking parlour. A narrow corridor, 0.7 - 1.1 m wide, was built at the exit of the milking parlour and all cows passed through it just after milking.

### Data acquisition system

When walking through this corridor, each cow was recorded for about 4 s by a top view 3D Kinect™ Xbox camera (Microsoft, Washington - USA). The camera was positioned in top down perspective, 3.2 m above ground level and at a distance of approximately 2 m from the cow's back, providing a depth image size of 640 x 480 pixels with 1 cm resolution and an acquisition rate of 28 fps. The field of view of the 3D camera covered about 2.5 m of the corridor. The 3D camera was connected via a USB-port to a desktop computer where the depth videos were stored for further analysis.

Automated lameness detection system

The video acquisition system was installed on the experimental farm with the aim of developing the automated lameness detection system based on image analysis proposed by Viazzi *et al.* (2013a). The system is able to detect lame cows by recording videos of walking cows by means of image processing techniques using MATLAB Runtime Compiler (Matlab® R2011b, The MathWorks©, Inc, Natick, MA, United States) software. The mathematical algorithm developed uses the curvature of the cow's back to automatically extract 4 parameters which are used to classify lameness posture into the three different lameness classes "Not Lame", "Lame" and "Severely Lame". A detailed description of the back curvature algorithm procedures can be found in (Poursaberi *et al.*, 2010; Viazzi *et al.*, 2013a). The input to the lameness software is 3D video of a walking cow and the output is the cow's lameness status. Therefore, the performance of the automated lameness detection system described above relies on the quality of the 3D input videos. Consequently, video pre-processing and video filtering techniques were applied to improve the performance of the overall system.

Video pre-processing principles and algorithms

Two main automated pre-processing routines were developed for proper video filtering, as described below.

1. *Video quality*

When the depth information generated by the 3D camera sensor was imprecise, it gave rise to black spots on the segmented images of the cow's body as well as noise on the contour line of the cow's body. Both the number of black spots and contour roughness were automatically quantified and used for filter categorization.

2. *Cow's walking speed*

Cows which stopped walking or did not walk smoothly during the video recordings were filtered out from the video dataset and were not used for further analysis in the lameness detection system. A smooth walking pattern under the 3D camera was required in order to achieve accurate lameness detection.

Labelling procedure

Two different video datasets captured on the experimental farm described above were used as a reference for testing and validation of the filtering algorithm. Each video was carefully watched, labelled and categorised in a binary format (Yes/No); the video was then excluded from or included in the final dataset according to the classification obtained by video labelling, as follows:

- Video quality: the total number of videos used to build up the dataset was 313,consisting of 223 poor quality 3D videos (71%) and 90 videos (29%) considered as good quality.

- Cow's walking speed: the final dataset consisted of a total of 276 videos with 227 videos (82%) of cows walking smoothly and 49 videos (18%) of cows which stopped walking or did not walk smoothly

<u>Classification method</u>

Data mining techniques were used to classify each video into one of the two filtering targets, resulting in exclusion or inclusion of the video. The J48 decision tree induction algorithm (Quinlan, 1986) was chosen to classify the parameters extracted from the videos using the software WEKA 3.6.9 (Hall *et al.*, 2009). The decision tree learning classifier was applied to the dataset, using a 10-fold cross validation. The outcome of the classification by the automated filtering algorithm can be positive (videos to be filtered and excluded) or negative (videos to be included in further analysis), predicting that the videos are of good quality or the cows do not change their walking pattern. The results of the analysis fit into one of the following categories:

- True positive (TP) = correctly filtered
- False positive (FP) = incorrectly filtered
- True negative (TN) = correctly included
- False negative (FN) = incorrectly included

The relationship between the performance measures was presented in the form of a confusion matrix as shown in Table 1.

Table 1: Performance measures used to evaluate the classification results

| | | **Classified by video labelling** | | |
|---|---|---|---|---|
| | | Condition Positive Filtering: YES (Exclude) | Condition Negative Filtering: NO (Include) | |
| **Classified by the automated filtering algorithm** | Test Outcome Positive Filtering YES | True Positive<br>TP | False Positive<br>FP | PPV Positive predictive value TP/(TP+FP) |
| | Test Outcome Negative Filtering NO | False Negative<br>FN | True Negative<br>TN | NPV Negative predictive value TN/(FN+TN) |
| | | Sensitivity TP/(TP+FN) | Specificity TN/(FP+TN) | |

## Results and discussion

The decision tree used with the J48 classification algorithm revealed two classification criteria and their respective thresholds for both "video quality" and "cow's walking speed", with one parameter extracted from the videos. Figure 1 presents the results graphically, allowing visualisation of the rules, and is commonly used in supervised learning.

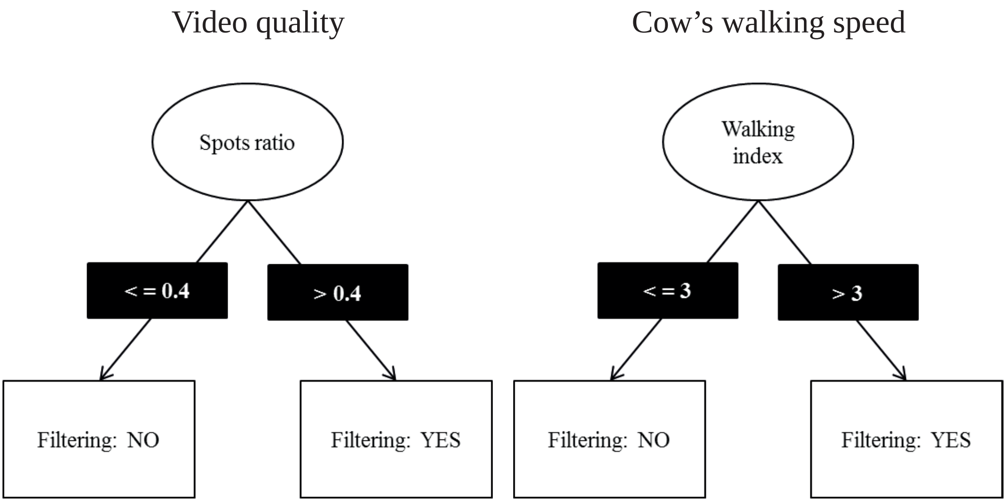


Figure 1: J48 pruned decision tree model with 2 leaves and specification of the thresholds for the most powerful classification criteria for both "Video quality" and "Cow's walking speed"

The relationship between the performance measures for the classification models is presented in the form of the specific table layout of a confusion matrix. Tables 2 and 3 show the results of the decision tree classification models.

Table 2: Confusion matrix of the decision tree classification model for “Video quality” using 10-fold cross validation.

| | | Classified by video labelling | | |
|---|---|---|---|---|
| | | Filtering: YES (Exclude) | Filtering: NO (Include) | |
| **Classified by the automated filtering algorithm** | Filtering YES | 166 | 19 | PPV 89.7 % |
| | Filtering NO | 57 | 71 | NPV 55.5 % |
| | | Sensitivity 74.4 % | Specificity 78.9 % | |

Table 3: Confusion matrix of the decision tree classification model for “Cow’s walking speed” using 10-fold cross validation.

| | | Classified by video labelling | | |
|---|---|---|---|---|
| | | Filtering: YES (Exclude) | Filtering: NO (Include) | |
| **Classified by the automated filtering algorithm** | Filtering YES | 30 | 5 | PPV 85.7 % |
| | Filtering NO | 19 | 222 | NPV 92.1 % |
| | | Sensitivity 61.2 % | Specificity 97.8 % | |

Each column of the matrices presented in Tables 2 and 3 represents the instances in an actual class, according to the classification by video labelling, while each row represents the instances in a predicted class classified by the filtering algorithm.

In the confusion matrix presented in Table 2, the objective of the algorithm is to exclude poor quality videos and include good quality videos. Of a total of 223 poor quality 3D videos, the classification algorithm correctly predicted the filtering for 166 instances and 57 videos were wrongly categorised as good quality. Table 2 also shows that 19 good quality videos were incorrectly filtered out, while 71 videos were correctly included in the final dataset for further image analysis.

The results shown in Table 3 correspond to the confusion matrix for the classification of videos relating to “cow’s walking speed”. A total of 30 videos were correctly filtered while 19 videos which should have been filtered out were misclassified and therefore incorrectly included. For a total of 227 videos of cows walking smoothly, the classification model correctly predicted 222 and made wrong predictions for only 5 videos.

More detailed statistical measurements of the performance of the two decision tree classification models developed are presented in terms of sensitivity and specificity values. Sensitivity relates to the ability of the classification algorithm developed to identify positive results for filtering, meaning exclusion of the videos due to poor 3D quality or an incorrect walking pattern. The lowest sensitivity value is around 61% and corresponds to the identification of cows that stop or do not walk smoothly.

The reduced performance observed is mainly linked to the fact that the 3D camera has a limited range of view, covering the total length of the cow's body in approximately 2.56 ± 0.9 frames per video. With this low average number of frames, the velocity calculation presents a higher probability of errors, since velocity indexes were extracted from the differences in positions between two consecutive frames. With regard to the issue of 3D video quality, the main limitation of the camera is the influence of natural light which increases the number of black spots. The specificity value is related to the ability of the algorithm developed to identify negative results, meaning the inclusion of the videos for further image processing by the automatic lameness detection system. Both decision tree classification models shown in Figure 1 presented relatively high values for specificity, e.g. 79% for "video quality" and 98% for "cow's walking speed".

The results indicate that the proposed models do not generally miss negative outcomes, meaning that few videos were incorrectly included in the final dataset. A false positive error, commonly called a "false alarm", indicates that the videos fulfilled the filtering condition for exclusion when in fact the condition had not been fulfilled. False positive rates were around 21% and 2% for video quality and cow's walking speed, respectively. Further investigations in the dataset also showed correlation between cow walking speed and neck direction, with 72% of stopping cows turning their necks. Since the performance of the proposed 3D lameness detection system is based on parameters extracted from the curvature of cow´s back around the spine line neck angles play an important role. Those results evidence the importance of low false positive rates of the developed filters.

## Conclusion

Since the objective of this study was to investigate an interesting issue relating to the pre-processing of videos of cows in order to determine their suitability for further use in the lameness detection system proposed by Viazzi et al (2013), the results presented are sufficient to state the following: 1) The "video quality" filtering model correctly classified 75.7% of cases while the "cow's walking speed" achieved 91.3% accuracy; 2) The decision tree classification models developed are easy to implement in practice as only a single criterion is used resulting in less computational efforts; 3) Sensitivity and specificity related values provided quantitative results for first verification of the models developed; 4) Further investigation of the misclassification instances is required for filtering optimisation; and 5) Validation of the developed models is required to evaluate the filtering effects on the overall system performance.

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## Biomarkers of weaning stress at housing in beef calves

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### Abstract

The study objective was to elucidate the physiological effects of weaning at housing on beef calves and profile a panel of biomarkers in circulation that may aid in the early identification of stress-susceptible animals. On the day (d) of weaning (d 0), calves were assigned to one of two treatments: 1), Housed (Control; n = 8; mean weight (s.d) 292.0 (36.5) kg; mean age (s.d.) 228 (22.1) days), these animals were housed with their dam, 2), Weaned (n = 8; mean weight (s.d.) 296.5 (59.5) kg; mean age (s.d.) 242 (32.8) days), these animals were abruptly separated from their dam and housed. Blood was collected by jugular venipuncture on d -4, 0, 1, 2, 3, 7, and 14 relative to weaning (d 0). Neutrophil number increased in weaned calves on d 1 ($P < 0.05$), d 2 ($P < 0.001$) and d 3 ($P < 0.01$) relative to baseline, and in control calves on d 3. Plasma haptoglobin was elevated ($P < 0.05$) from baseline in weaned calves on d 2 and 7. Plasma cortisol concentration increased from baseline in weaned animals on d 2 ($P < 0.05$) and d 3 ($P < 0.01$) and remained elevated throughout the study ($P < 0.05$). This study identified plasma CXCL8 as a highly suitable biomarker for stress in calves. When coupled with the increase in CXCL8, the fact that haptoglobin and total neutrophil number were also elevated suggests that weaning stress triggers an inflammatory response in calves.

**Keywords:** Cattle, weaning, stress, haematology, cortisol, CXCL8

### Introduction

Weaning is a multifaceted stressor that usually involves numerous husbandry practices, including the abrupt separation of the beef calf from its dam, a nutritional adjustment to a non-milk diet and social reorganisation and, additionally, is often associated with housing (Lynch *et al*., 2010; Enriquez *et al*., 2011). Housing has been reported to alter the neutrophil and lymphocyte immunophenotype of calves, along with the acute phase response (Lynch *et al*., 2010), with a more pronounced stress response occurring in calves weaned at housing compared with those housed with their dams (Lynch *et al*., 2010; 2011). Alterations in calf immunity following weaning stress are of great importance as these changes are thought to be associated with increased incidence and severity of respiratory disease (Duff and Galyean, 2007).

The objective of the present study was to characterize changes in specific blood components in beef calves subjected to either, weaning at housing, or housing, with the aim of identifying the best biomarkers for the corresponding stress. In the present study we also hypothesized that plasma CXCL8 protein levels would increase concurrently with blood neutrophils.
The identification and characterisation of novel, specific biomarkers and biomarker profiles of patho-physiological states will be an important step towards the early detection of disease susceptible animals.

## Materials and methods

Care and Use of Animals
All animal procedures performed in this study were conducted under experimental licence from the Irish Department of Health and Children in accordance with the Cruelty to Animals Act 1876 and the European Communities (Amendment of Cruelty to Animals Act 1876) Regulation 2002 and 2005.

Animal model
Sixteen clinically healthy, spring-born, single-suckled, Blonde d'Aquitaine sired beef crossbred bull calves were used in this study. Prior to housing, cows and their calves were rotationally grazed on a predominantly perennial ryegrass (*Lolium* perenne) based sward from early April until housing on the 9$^{th}$ November. Calves were immunized 28 days prior to weaning against bovine respiratory syncytial virus (BRSV) and infectious bovine rhinotracheitis (IBR) virus using *Rispoval-3* and *Rispoval-IBR* vaccines (Pfizer Animal Health, Co. Cork, Ireland), respectively. On the day (d) of weaning (d 0), calves were moved to a handling yard and assigned to one of two treatments: 1), Housed (Control; n = 8; mean weight (s.d) 292.0 (36.5) kg; mean age (s.d.) 228 (22.1) days), these animals were housed with their dam, 2), Weaned (n = 8; mean weight (s.d.) 296.5 (59.5) kg; mean age (s.d.) 242 (32.8) days), these animals were abruptly separated from their dam and housed.

Sample collection
Calves were blood sampled via jugular venipuncture on d -4, 0, 1, 2, 3, 7, and 14 relative to weaning (d 0). For this procedure, they were moved gently to a holding pen with a squeeze chute facility and were blood sampled with minimal restraint. Blood sampling was carried out by the same experienced operator on each occasion and the time taken to collect the blood samples was less than 60 s/calf. Blood samples were collected into 1 × 6 mL $K_3$Ethylenediaminetetraacetic acid ($K_3$EDTA) tube (Vacuette, Cruinn Diagnostics, Ireland) for haematological analysis and 1 × 8 mL lithium heparin tubes for cortisol, acute phase protein and CXCL8 analysis.

Haematology variables

Unclotted whole $K_3EDTA$ blood samples were analysed using an ADVIA haematology analyser (AV ADVIA 2120, Bayer Healthcare, Siemens, UK) equipped with software for bovine blood. Total leukocyte, neutrophil, lymphocyte were measured.

Acute phase proteins, cortisol and CXCL8

Plasma was harvested from the lithium heparin anti-coagulated blood tubes following centrifugation at 1600 × *g* at 4˚C for 15 minutes and stored at -80˚C until analysis. The concentration of plasma haptoglobin was measured using an automatic analyzer (spACE, Alfa Wassermann, Inc., West Caldwell, NJ, USA) and commercial assay kit (Tridelta Development Ltd., Wicklow, Ireland) and serum amyloid A using the SAA ELISA kit (Phase Range SAA ELISA kit, Tridelta Development Ltd., Co. Kildare, Ireland). The intra and inter assay CV for haptoglobin were 6.3 % and 4.1 %, respectively. SAA had an intra assay CV of 5 %. Plasma CXCL8 was quantified using the Quantikine IL-8 Immunoassay (R&D Systems Europe, Ltd., Abingdon, UK) according to the manufacturers' instructions. CXCL8 had an intra and inter assay CV of 7.8% and 11.6%, respectively.

Statistical analysis

Haematological, acute phase protein, CXCL8 and cortisol data were tested for normality using PROC UNIVARIATE and the Shapiro-Wilk test and, values that were not normally distributed were log transformed prior to statistical analyses. Haematological physiological were analysed as repeated measures using the PROC MIXED procedure of SAS (Version 9.1, SAS Institute, Cary, NC). The first sample (d -4; sample 1) was used as the baseline covariate in the statistical analysis of the data. Animal was the experimental unit and was specified as a repeated measures effect, and the dependence within animal was modelled using an unstructured covariance structure. Data subject to transformation were used to calculate P-values. The corresponding least squares means (Lsmeans) and SE of the non-transformed data are presented to facilitate interpretation of results. Differences between treatments were determined using the Tukey-Kramer test for multiple comparisons. Lsmeans were considered significantly different at the $P < 0.05$ probability level.

## Results and discussion

Rectal body temperature

There was no treatment × sampling time interaction ($P > 0.05$) for rectal body temperature.

Haematological responses

There was no effect ($P > 0.05$) of treatment, sampling time or their interaction on lymphocyte, monocyte or basophil number. For total leukocyte number, there was a treatment × sampling time interaction ($P < 0.01$) whereby total leukocyte number was greater ($P < 0.05$) in weaned calves than control calves on d 1 and d 2. Similarly, there was a treatment × sampling time interaction for neutrophil number ($P < 0.05$) and N:L ratio ($P < 0.001$). In weaned calves, neutrophils increased on d 1 ($P < 0.05$), d 2 ($P < 0.001$) and d 3 ($P < 0.01$) relative to baseline, resulting in higher levels compared to control calves on d 1, whereas in control calves, neutrophil number did not increase ($P > 0.05$) from baseline until d 3 ($P < 0.05$) (Fig. 1). As a reflection of alterations to total neutrophil number, the N:L ratio was elevated ($P < 0.01$) from baseline in weaned animals at sampling on d 1, d 2 and d 3, whereas an increase in control calves was not evident until d 3

Inflammatory responses

There was no effect of treatment or treatment × sampling time interaction ($P > 0.05$) for serum amyloid A (SAA) (Table 1), whereas there was a treatment × time interaction for haptoglobin. Haptoglobin was significantly elevated ($P < 0.01$) from baseline in weaned calves on d 2 and d 7, with no alterations in control calves. A treatment × sampling time ($P < 0.01$) interaction was identified for circulating plasma CXCL8 concentrations whereby CXCL8 concentration increased ($P < 0.001$) in both treatments following either housing or weaning at housing but was higher ($P < 0.05$) in control calves than weaned calves on d 1 and d 3 (Fig. 2).

Weaning typically combines a number of physical and psychological stressors which have the potential to alter the immune state and increase susceptibility to bovine respiratory disease. Additionally, because stress can manifest as a variety of interrelated physiological, metabolic, endocrinological, and behavioural processes, which in turn, can impair immune defence, the search for biological measures to provide an objective assessment of animal welfare status is warranted. It is thus important to fully characterise the weaning process in order to assess the potential health and animal welfare implications that weaning can have when combined with housing and social reorganisation. This will permit adaptation of herd management practices in order to alleviate stress in livestock and avoid compromising their immune system response.

Table 1: Effect of weaning induced stress at housing on the acute phase proteins haptoglobin and serum amyloid A (SAA) in weaned beef calves. The values are expressed as least squares means (Lsmeans) ± s.e.

| | | Days Post Weaning | | | | | | *P*-Values | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | | 0 | 1 | 2 | 3 | 7 | 14 | T | S | T×S |
| **Haptoglobin** | C | 0.57 ± 0.09 | 0.52 ± 0.043 | 0.66 ± 0.072 | 0.79 ± 0.104 | 0.74 ± 0.115 | 0.67 ± 0.038 | NS | ** | * |
| (mg/mL) | W | 0.54 ± 0.09 | 0.46 ± 0.043 | $0.72^{b}$± 0.072 | 0.64 ± 0.104 | $0.78^{a}$± 0.115 | 0.64 ± 0.038 | | | |
| **SAA** | C | 104.3 ± 16.0 | 101.8 ± 15.5 | 98.9 ± 15.9 | 116.3 ± 13.8 | $53.7^{b}$ ± 16.5 | $46.4^{a}$ ± 11.2 | NS | ** | NS |
| (µg/mL) | W | 62.1 ± 17.5 | 89.4 ± 16.9 | $119.5^{a}$± 17.4 | 105.8 ± 15.0 | 62.5 ± 18.1 | 32.8 ± 12.3 | | | |

T = treatment, S = sampling time, T×S = treatment × sampling time interaction, NS = not significant ($P > 0.05$). * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$. [a,b,c]Within rows, Lsmeans differ from pre-weaning baseline by $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

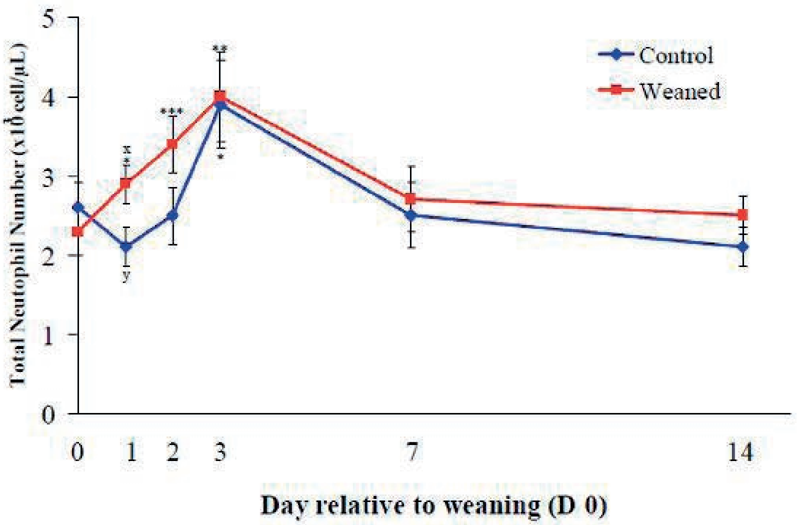


Figure 1: The neutrophil response to housing and weaning stress. Total neutrophil number increased immediately following abrupt weaning at housing while there is a delay is a delayed neutrophilia in housed calves on d 3. * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$. Lsmeans differ relative to baseline (d 0). [X, Y] Lsmeans differ between treatments ($P < 0.05$).

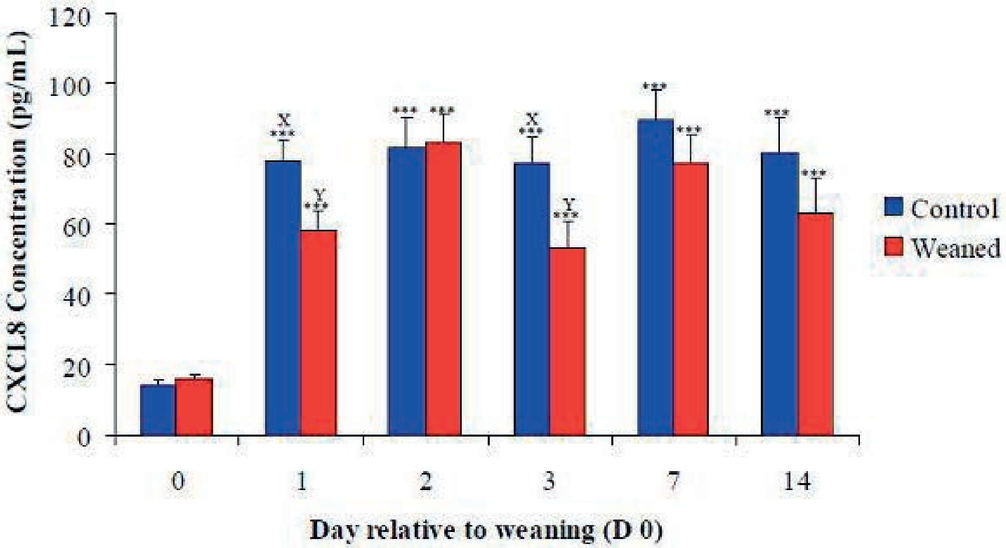


Figure 2: The circulating plasma CXCL8 response to housing and weaning stress. Following either housing or weaning, CXCL8 concentration increased significantly and remained elevated at sampling throughout the course of the study. * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$. Lsmeans differ relative to baseline (d 0). $^{X, Y}$Lsmeans differ between treatments (P < 0.05).

**Conclusions**

Weaning is a multifaceted stressor, with calves that were weaned at housing showing a stronger physiological stress response than those that were not weaned but housed with their dams. This study confirmed that neutrophil number is a robust biomarker of stress and additionally that plasma CXCL8 is a sensitive indicator of stress in weaned and housed calves. In future studies, these two biomarkers should be central to the characterisation of stress responses and offer potential as point-of-care tests for stress diagnostics. Bioanalytical technologies now provide us with the means to study the molecular patterns of tissue function that are associated with particular physiological or pathophysiological conditions. It is possible that using more advanced technology, for example biosensor technology, it should be possible to measure CXCL8 in real time. This study was focused on using advances in biomolecular science to enhance animal health care and aid the identification of robust biomarkers of stress.

Integrating high-dimensional molecular and physiological data with precision livestock farming (PLF) data promises to allow us to define the molecular systems that respond to genetic and environmental perturbations of physiological functions in animals.

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# Oestrus detection in beef and dairy cattle

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**Keywords:** Wireless communications, oestrus detection, beef cattle

## Abstract

Precision Livestock Farming (PLF) is core to satisfying the increasing world-wide demand for sustainable food products. This paper reports on the evaluation of a decision support platform which uses an accelerometer activty monitoring collar to detect changes in animal behaviour patterns that can be related welfare conditions. The performance of the system is assessed within the context of a dairy farm in relation to milk progesterone sampling. A further evaluation on free roaming beef herds is also reported.

## Introduction

Precision Livestock Farming (PLF) is core to satisfying the increasing world-wide demand for sustainable food products of good quality and the increasing societal concerns over animal welfare and health. Real-time animal monitoring systems will play an increasing part in delivering precsion farming solutions (Kwong 2009). This paper reports on an animal monitoring platform that has been designed to support the optimisation of on farm fertility by detecting the onset of oestrus in cattle and generating alerts for farm operatives. The system was initially designed for dairy application but recent evaluations within a free roaming beef context have shown that the technology is equally applicable in this context. Within the beef context additional complications arise due to the fact that animals are less constrained in their movements. Hence field depolyable wireless relay stations are required in order to give round the clock coverage of the herd. The performance of the system is two beef herds located on Scottish hillsides is reported.

Silent Herdsman Collar

The Silent Herdsman[R] (Andonovic 2012) platform is a collar based sensor which records neck movements continuously using a 3-axis accelerometer. The measured activity is processed to identify changes from normal activity behaviour which can be related to welfare conditions e.g. the onset of heat. Events are downloaded to a computer wirelessly when cattle are within range of a base station and are displayed on graphical user interface. We report on the differences in operation between dairy and beef environments.

## Material and Methods

Progesterone sampling is a recognized benchmark within the industry for determining the fertility status of cattle (Friggens, 2008). Progesterone levels are high during times where the cow is not ovulating. A fall in progesterone (to below 3 ng/ml) level is associated with the point in time when an egg is released.

50 Holsteins cows, within a herd of 200 located within SRUC's Dairy Research Centre, Dumfries, were fitted with Silent Herdsman Collars. The cows were milked thrice daily and fed using a total mixed ration. The forage component of the complete diet consisted of grass silage, maize silage and whole crop. Milk samples were taken on Mondays, Wednesdays and Fridays and progesterone analysis performed in laboratory. The Silent Herdsman collar outputs were recorded during this time and later correlated with the progesterone sampling records.

Figure 1 shows the output from the Silent Herdsman collar. The blue trace represents a measure of the overall restlessness of the animal. This is not a simple calculation of activity level but it is a representation of how much the behavior is changing over a period of 1.5 hours. This is scaled against the left hand axis of the graph which shows a general Restlessness Measure in arbitrary units. A normal routine level of behavior is visible along with a change in restlessness around oestrus.

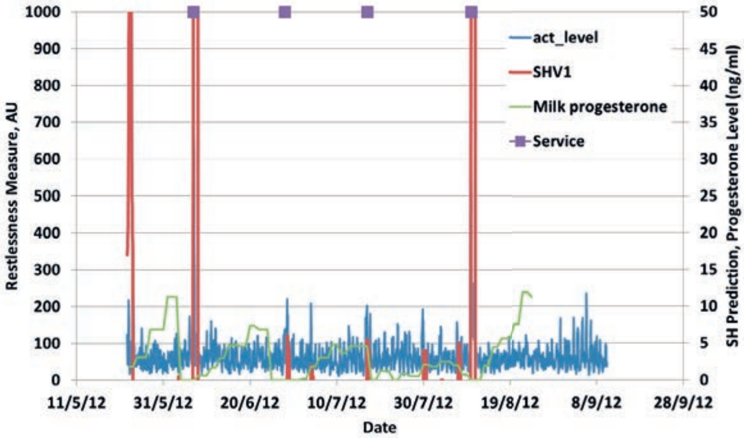


Figure 1: Measurement of Cow Data

Figure 1 also shows the prediction algorithm from the Silent Herdsman (shown in red against the right hand axis). The performance of the Silent Herdsman was evaluated with respect to the progesterone signatures. Predictions that followed a drop in progesterone level were concluded to be a True Positive. If the progesterone level was measured to fall in the absence of a Silent Herdsman prediction this was considered a False Negative. Instances with high progesterone level accompanied with a Silent Herdsman prediction were considered as False Positive. Generally the Silent Herdsman system is set such that if the red trace, the prediction exceeds a nominal value of 5 then an alert is generated. If this alert coincides with a fall in progesterone, then it was considered to be a true positive. The graph also shows dates represented by a square, where the cow was served by the stockman on the basis of observation alone. The timings of these services, and the progesterone measurements were taken independently of the Silent Herdsman predictions and were only related to each other at the point of analysis.

The outcome of this analysis is shown below in Table 1.

Table 1: Silent Herdsman Oestrus Detection in Dairy Cattle

| | |
|---|---|
| Sensitivity *TP/(TP+FN)* | 90.3 % |
| Positive Predictive Value *TP/(TP+FN)* | 93.3% |
| Accuracy *(TP+TN)/(TP+TN+FP+FN)* | 90% |
| Specificity *TN/(TN+FN)* | 85-90% |
| False Alarm Rate *FP/(TN+FP* | 10.5% |

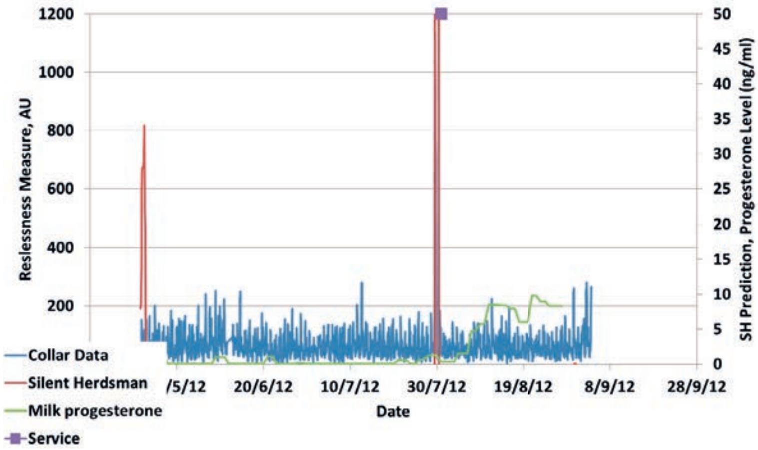


Figure 2: Silent Herdsman Prediction

Figure 2 shows an interesting observation. Despite the fact that progesterone is widely regarded as being a robust metric for determining the onset of oestrus, it is not without issues. In Figure 2 the progesterone level is observed to remain at a low level for an extended period of time prior to the 29th July 2012. The cow can therefore be concluded to be not cycling. A change in the behavior pattern, detected by the collar on 29th July, was highlighted as being a strong indication of oestrus. This prediction was also in close agreement with the stockman's observations and this is reflected by the fact that that cow was served. The progesterone level was then observed to rise and the cow was confirmed PD+ on 1st September. Progesterone sampling alone would not have detected this heat.

## Results and Discussion

Monitoring beef cattle represents a greater challenge due to the fact that beef herds are free to roam over significant distances. Mobile, battery/solar panel powered base stations were deployed within the grazing area to receive the signals from cow collars and to relay the information over a separate wireless infrastructure to the central base station and display area. The cattle grazing area was approximately 1.5 km from the central base station unit. 802.11 (wi-fi) interfaces were used to relay signals to the central base station.

50 steer were fitted with Silent Herdsman collars that permit on collar signature analysis and also can relay un-processed data back to the central base. The cattle were synchronized  Since these cattle were not milked, progesterone data was not available,

therefore service records were used for evaluating the presence or absence of heats.

Significant differences in the overall activity levels between dairy and beef cattle were observed. Figure 3 shows the output restless activity screen taken from the Silent Herdsman showing the detection of an oestrus event in a dairy cow. The right hand scale represents an arbitrary measurement unit of restless behavior. The maximum scale value is 1000 and generally the restless behavior index sits around100. The exact readings are not important, only their evolution over time. The solid red line on the graph is an output from the collar that indicates the likelihood that the cow is in heat. If this red line crosses the dotted red line then an alert is generated. On the left hand of the graph, the scale represents the likelihood that the cow is in heat. Generally any level above 5 is a useful starting point although this is adjusted by the farm operative according to the cows behavior. In this case the heat generation threshold value is set at 5. Cows can be sorted into different groups and different thresholds applied according to their nature.

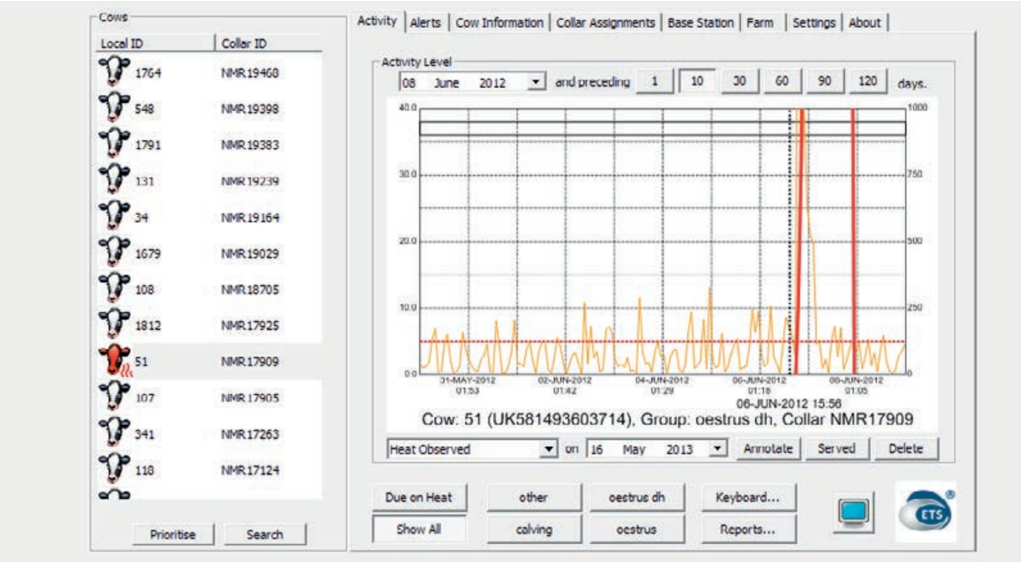


Figure 3: Typical Oestrus Signature from Dairy Cow

In the case of beef cattle, the general activity level is higher and the recorded 'restlessness' is also higher. This is evidenced in Figure 4 where the general restless scale (on the right hand side of the graph) has been increased to 2000. The overall restless nature is not dissimilar to dairy cattle but the oestrus events are significantly stronger. Note that the detection threshold in this beef signature has been increased to 50 and that the oestrus prediction line (the red solid line) greatly exceeds this value.

All 50 animals were removed from the hill side two to three days before insemination for removal of the progesterone CIDR. This resulted in a significant activity increase within the activity data however this was of relatively short duration (1 to 2 hours depending on the degree of movement and handling required). Median filtering was implemented to alleviate its influence. Oestrus predictions were made by the collar within 12 to 36 hours of removal of the CIDR. The indication of oestrus was accompanied by a strong change in behavior that was sustained in almost all cases for a period of 6 to 8 hours.

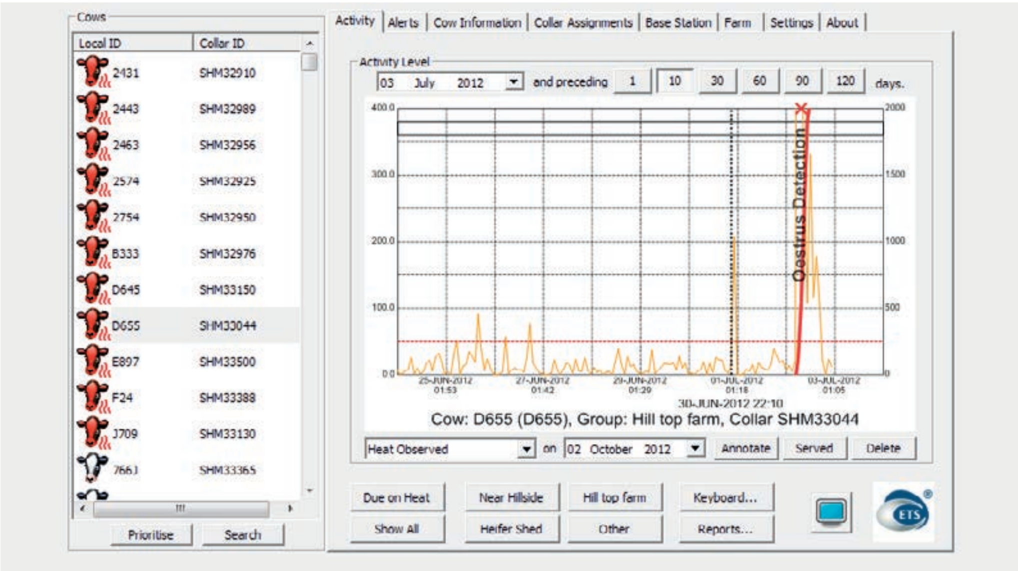


Figure 4: Beef Cow Activity Trace

Despite the increase in activity observed within the free ranging cattle, the strength of the oestrus signature was such that it was easily differentiated. More than 85% of the oestrus events were detected within 48 hours of the CIDR being removed.

## Conclusions

We have evaluated the performance of a decision support platform, designed to detect oestrus in dairy cows within a free roaming beef environment. Similar performances are obtained with over 85% of heats being accurately detected. Beef oestrus signatures are significantly stronger.


## Acknowldgements

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## Focal sampling of cow lying behaviour for automated welfare assessment

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### Abstract

The objective of the current study was to determine the number of focal animals required to represent the daily lying behaviour of a herd of lactating dairy cows. The study was carried out at 3 commercial dairy farms. The lying time (h/d) and number of lying bouts (n/d) of 15 ± 3 focal dairy cows, continuously recorded by electronic recording devices, were analysed using a resampling method for sample size determination. Estimates of lying behaviour based on five or six cows per focal group provided an accurate estimate of the overall means for each focal group monitored. An accurate estimate of the daily lying behaviour on commercial dairy farms might be generated using continuous recording of at least 40% of the cows in the herd. The sampling methods applied to the automated monitoring systems are time- and labour-saving tools that can be used to assess cow comfort and welfare in relation to lying behaviour.

**Keywords**: Dairy cow, Lying behaviour, Automated measurement, Focal animal, Sampling

### Introduction

Behaviour is one of the most commonly used and sensitive indicators of animal welfare (Haley *et al*., 2001). Measures of lying behaviour are important measures of cow comfort and welfare, providing valuable information on how cows interact with their environment (Tucker *et al*., 2004; O’Driscoll *et al*., 2008). The duration and frequency of lying behaviour (particularly the time spent lying down, the frequency of lying bouts, the duration of individual lying bouts and the laterality) have been identified as sensitive measures of stall comfort and can be used as indicators to assess the welfare of lactating dairy cows (Fregonesi and Leaver, 2001). On-farm monitoring of cow behaviour can be time consuming and labour intensive, particularly when the number of animals per pen is high. Large numbers of animals per pen (the usual experimental unit) make it difficult to sample the entire herd continuously. Focal sampling – which involves observation of one or more sample individuals for a specified period of time – requires less effort when studying groups of animals than continuous monitoring of the entire population (Martin and Bateson, 2007). Methods of assessing behavioural activity have changed in recent years in favour of automatic sampling techniques (Rushen *et al*., 2012). Recent developments in sensor technology have created new opportunities for automatic monitoring and recording of animal behaviour. Electronic data loggers can be used to measure lying behaviour accurately, including the total time spent lying down, the number of lying bouts (Müller and Schrader, 2003; McGowan *et al*., 2007), the duration of each lying bout for individual cows (O'Driscoll *et al*., 2008) and the laterality of their lying behaviour (Ledgerwood *et al*., 2010). These devices can be quite inexpensive, although this depends upon the particular device being used (size of memory storage and power options). However, since at least one device is needed per animal, the total cost can be high when there is a large number of animals, which will create pressure to reduce sample sizes during a welfare assessment (Rushen *et al*., 2012). The accuracy of focal-group sampling depends on group size, cohesiveness, animal activity, and design and management factors, and potentially introduces biases into data collection. Therefore, focal animal sampling should be validated and selected according to the objectives of a specific study. The objective of the current study was to determine the number of focal animals required to represent the daily lying behaviour of the herd mean of lactating dairy cows, using a resampling-based procedure (jackknife).

## Materials and methods

### Farms and animals

This study was conducted at 3 commercial dairy farms between April 2010 and July 2011. Two dairy farms (A and B) were located in Friesland (Netherland) where animals were milked in an automatic milking system (AMS) and feeding was carried out by an automatic feeding system (AFS). In both farms, barns were E-W oriented and featured a loose-housing layout with a total of 141 and 129 cubicles with rubber mats covered with sawdust, and 61 and 85 feeding places, for Farm A and B respectively. The milking area, in both barns, consisted of two AMS units and a closed waiting area in front of the unit entrance. One-way gates provided selectively guided cow traffic. At the time of the study, barn A housed 107 lactating Holstein-Friesian cows (parity 2.4 ± 1.3, milk yield 33.0 ± 6.6 kg/d, days in milk 187 ± 99.7; mean ± SD) during the first monitored period (focal group 1) and 109 lactating Holstein-Friesian cows (parity 2.7 ± 1.5, milk yield 31.5 ± 10.5 kg/d, days in milk 138.3 ± 110.9; mean ± SD) in the second monitored period (focal group 2). Ninety-seven lactating Holstein dairy cows, 45 primiparous and 52 multiparous (parity 2.1 ± 1.4, milk yield 28.3 ± 11.2 kg/d, days in milk 188.4 ± 128.0; mean ± SD), subdivided into two homogeny groups (focal group 3 and 4) were used in the study at farm B. The third commercial dairy farm (C) was located at the Institute of Animal Sciences of the Volcani Center in Bet-Dagan (Israel). The cows were housed in a loose-covered pen, milked 3 times a day and fed twice daily. At the beginning of the data collection period, the barn housed a group of 92 lactating Israeli Holstein cows (focal group 5) with 215.4 ± 167.4 days in milk (mean ± SD).

<u>Behavioural recordings</u>

The lying behaviour of 73 focal dairy cows, randomly selected and subdivided into focal groups 1 to 5 (14.6 ± 3.2; mean ± SD, ranging from 11 to 19 cows; see Table 1), was continuously recorded for 3 to 16 days by electronic recording devices (Afimilk Pedometer Plus tag, Hobo Pendant G data logger, IceTag 2D). The data loggers, previously validated for recording standing and lying behaviour in dairy cows (McGowan *et al.*, 2007; Ito *et al.*, 2009; Higginson *et al.*, 2010) were programmed to record daily lying time (h/d) and number of lying bouts per day (n/d).

Table 1: Parity, milk production and days in milk of 5 focal groups monitored

| Farm | Focal Group | Cow (n) | Day (n) | Parity mean ± SD | Milk Yield mean ± SD | DIM mean ± SD |
|---|---|---|---|---|---|---|
| A | 1 | 12 | 3 | 2.7 ± ١,٤ | 33.6 ± ٥,٦ | 191 ± ١٠٧ |
| A | 2 | 11 | 16 | 3.0 ± 1.7 | 31.3 ± 11.5 | 213 ± 130 |
| B | 3 | 15 | 16 | 2.4 ± 1.1 | 29.6 ± 12.1 | 177 ± 121 |
| B | 4 | 16 | 16 | 2.4 ± 1.7 | 31.8 ± 10.8 | 200 ± 150 |
| C | 5 | 19 | 11 | 2.3 ± 1.5 | / | 218 ± 163 |

The HOBO Pendant G (Onset Computer Corporation, Pocasset, MA) is a waterproof 3-channel data logger. This data logger uses an internal 3-axis accelerometer with a range of ± 3 g. The data loggers were attached to the lateral side of the left or right hind leg of the cows using Vet-flex such that the x-axis was perpendicular to the ground and pointing towards the back of the cow (dorsal direction). The data loggers were programmed to record g-force at 1 min intervals following the procedure of Ito *et al.*, (2009). The g-force readings from the x-axis were used to evaluate lying and standing behaviour (Ledgerwood *et al.*, 2010).

The IceTag 2D (IceRobotics, Edinburgh, UK) is an electronic sensor device based on accelerometer technology that measures and determines the percentage of time the cows spent lying and standing for each recorded second (McGowan *et al.*, 2007). IceTag was attached to the lateral side of the left or right hind leg above the fetlock by means of a strap with a buckle. Lying behaviour, per-minute basis, was classified for each recording following the IceTag-recorded intensity thresholds for lying and standing (Trénel *et al.*, 2009). For both data loggers (Hobo Pendant G data logger and IceTag 2D) we followed the approach by Endres and Barberg (2007) and ignored lying bouts shorter than two minutes.

The Pedometer Plus tag (afimilk, Kibbutz Afikim, Israel) provides information relating to lying time and lying bouts by means of a posture sensor including an omni-directional tilt switch to sense a tilt in orientation above an operating angle. From this information, the device calculates a number of behavioural parameters, including the rest time (the time that the cow is lying down) and the rest bout (the number of lying bouts). The Pedometer Plus tag was attached with a strap to the lateral side of the leg above the fetlock, between the knee and the hoof. The recorded data were analysed by the Afifarm software which calculates daily lying time (h/d) and number of lying bouts per day (n/d) for each cow monitored.

Data analyses: sample size determination using the visual jackknife

To determine how the sample size in focal sampling affects the estimates for lying behaviour of cows in each of the five focal groups, the lying time and number of lying bouts were analysed using a sample size determination method, derived from a resampling-based procedure (namely, jackknife). This approach is based on intensive use of the sample data by systematically taking sub-samples of the original data set, and calculating mean and standard deviation for each of subsamples. The software (SISSI – Shortcut In Sample Size Identification, ver. 1.01; Confalonieri *et al.*, 2007) was used to generate virtual samples and matrices of the means and standard deviations for the lying time and number of lying bouts for each of 5 focal groups. When analysing the trends in the means for increasing values of $N$-$k$ ($N$ is the total number of observations; $k$ is the number of observations not used by the jackknife), the optimum sample size is considered to be the $N$-$k$ value for which the variability between the means does not significantly decrease with increasing sample size (Confalonieri *et al.*, 2007). Specifically, four weighted linear regressions are performed for the generated means (the first uses the highest values of the $N\text{-}k \leq (N\text{-}k)'$; the second uses the lowest values; the third uses the highest values of $N\text{-}k \geq (N\text{-}k)'$; and the fourth uses the lowest values). A global index ($SR^2$) is calculated by summing the coefficients of determination of the four regressions. By repeating the steps for all the possible $(N\text{-}k)'$ it is possible to identify the optimum sample size, i.e. $(N\text{-}k)'$ where $SR^2$ is the highest. The process stops when the next sample size does not produce an $SR^2$ that is larger than 5% of the previous value.

## Results

Means and standard deviations were obtained for all the generated virtual sub-samples for each of five focal groups and were plotted on two charts, with the values of (N-k) on the X-axis and the means and standard deviations on the Y-axis. This allows a visual representation of how the means and standard deviations for the samples generated vary with increasing sample size of focal group (Figures 1 and 2, for lying time and number of lying bouts, respectively).

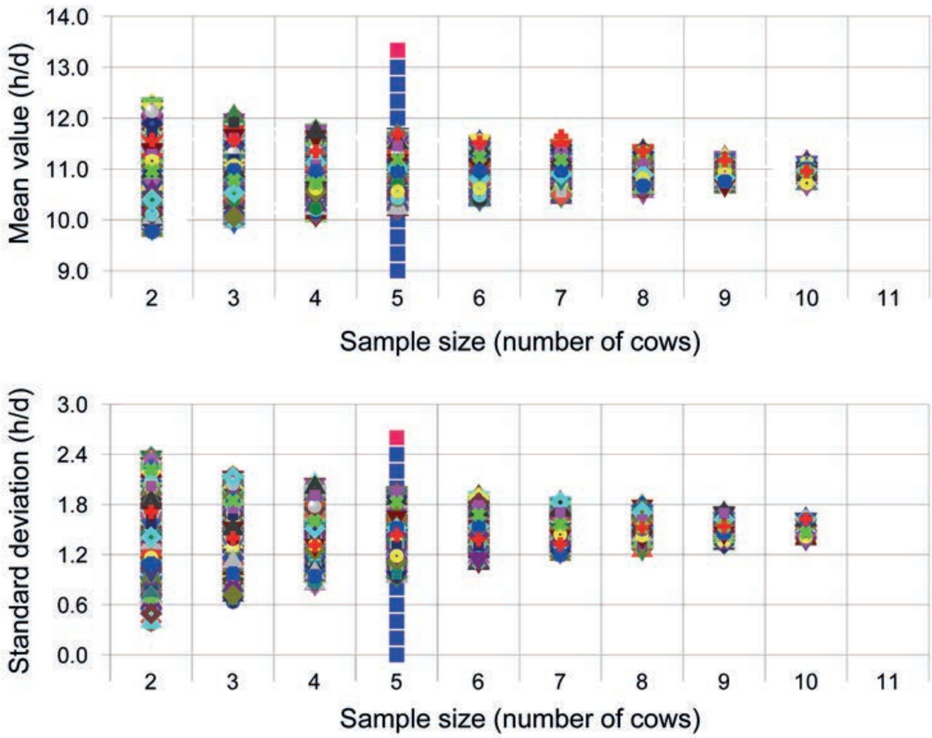


Figure 1: Daily lying time (focal group 1) – Means (h/d) and standard deviations (h/d) of the generated populations of subsamples (various symbols and colours) when the jackknife is applied for different k values. The sample size (*N*-*k*) values are shown on the X-axis, with *k* from (*N*-*2*) to 1. *k* is the number of observations not used by the jackknife; *N* is the total number of observations (12 cows). The automatically computed sample size is indicated by the vertical series of blue dots

Figure 1 shows that the differences between the means and standard deviations for daily lying time in the populations of subsamples generated for focal group 1 decrease for a sample size of up to five cows. These differences, obtained with this resampling method, continue to slightly decrease with larger sample sizes (more than five cows). For this focal group, five cows can be considered the optimum sample size, obtained by an automatic sample size determination procedure, based on the variability between the means.

The same considerations apply to the number of lying bouts in focal group 4 (Figure 2). The mean values chart shows that the range of the plot is similar for sample sizes larger than six cows, while differences in standard deviation are greater in samples smaller than six cows. The accuracy of estimates of daily lying time (Figure 1) and lying bouts (Figure 2) decreased when estimates were based on fewer cows per focal group.

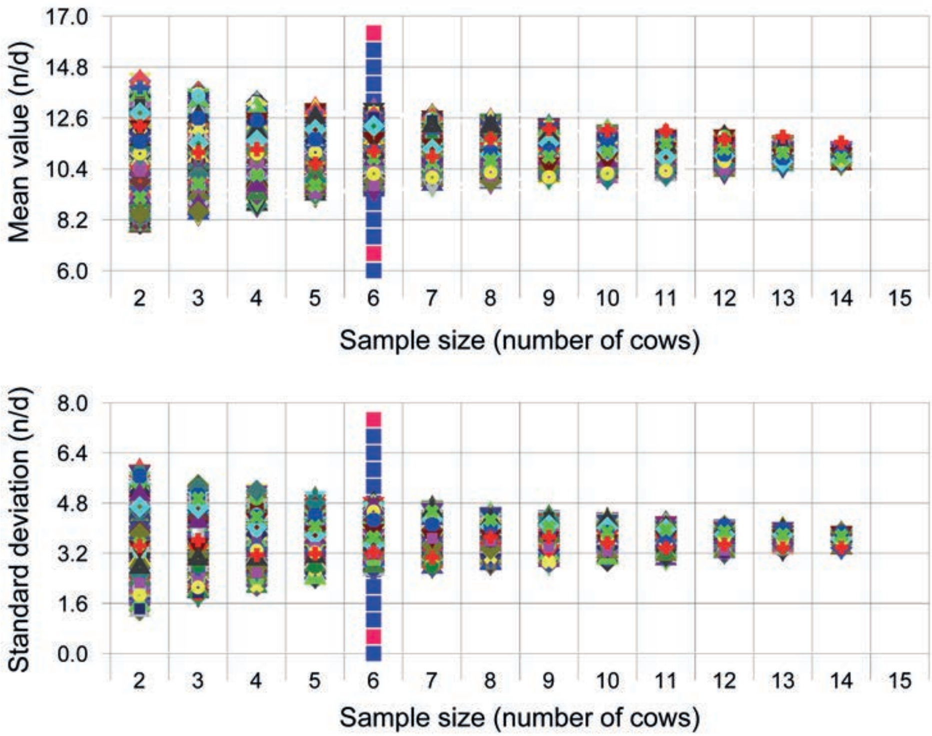


Figure 2: Number of lying bouts per day (focal group 4) – Means (n/d) and standard deviations (n/d) of the generated populations of subsamples (various symbols and colours) when the jackknife is applied for different k values. The sample size (*N*-*k*) values are shown on the X-axis, with *k* from (*N*-2) to 1. *k* is the number of observations not used by the jackknife; *N* is the total number of observations (16 cows). The automatically computed sample size is indicated by the vertical series of blue dots

The mean values, standard deviations, range of variability (CV) and sample size for lying time and number of lying bouts for each focal group are reported in Table 2. Estimates of lying time (h/d) and number of lying bouts (n/d) based on five or six cows per focal group (*N* – *k* value for which the variability between the means and standard deviations does not significantly decrease with increasing sample size) provided an estimate of the overall means.

Table 2: Means, standard deviations, range of variability (CV) and sample size[1] for daily lying time and number of lying bouts per day for each focal group (five) monitored

| Focal Group | Lying time (h/d) mean ± SD | CV range < CV (%) < | | Sample Size[1] $N-k$ value |
|---|---|---|---|---|
| 1 | 10.94 ± 1.55 | 9.63 | 17.35 | 5 |
| 2 | 11.89 ± 1.83 | 10.78 | 18.36 | 5 |
| 3 | 11.32 ± 1.92 | 11.75 | 20.89 | 6 |
| 4 | 12.14 ± 1.86 | 10.5 | 19.67 | 5 |
| 5 | 9.07 ± 1.94 | 12.25 | 28.65 | 6 |
| | Lying bout (n/d) mean ± SD | CV range < CV (%) < | | Sample Size $N-k$ value |
| 1 | 9.8 ± 3.7 | 28.64 | 41.88 | 7 |
| 2 | 9.4 ± 2.5 | 21.11 | 30.9 | 5 |
| 3 | 9.5 ± 2.1 | 14.46 | 27.56 | 5 |
| 4 | 11.1 ± 3.7 | 24.61 | 41.99 | 6 |
| 5 | 11.8 ± 2.5 | 14.43 | 25.8 | 5 |

[1]Automatically computed sample sizes ($N-k$ value) were obtained using a resampling-based procedure (jackknife)

**Discussion and conclusions**

Mitlöhner *et al.* (2001) showed that estimates of the percentage of time spent lying based on one to nine animals out of a group of ten were all similar, indicating that one focal animal for every ten was sufficient to estimate the group mean. However, Cook *et al.* (2005) sampled ten focal cows from a pen containing approximately 85 cows and found some differences between behavioural indices calculated from only the focal cows and the same indices based on all cows. Furthermore, most of the studies that have utilized automated devices to measure behaviour have sampled focal animals. Ito *et al.* (2009) established that 30 cows per farm provided a reasonable sample to detect variations in lying behaviour with approximately 90% accuracy, but that accuracy dropped to less than 60% when the sample size decreased to ten cows.

Endres and Barberg (2007) placed activity monitors on the legs of at least 15% of the cows in each herd to represent the entire group. Considering all possible combinations of cows for each group monitored, we found that a sample of at least six cows (40%) is necessary to provide an accurate estimate of lying behaviour for a group with an average size of 15 cows. In the present study, cows differed greatly in terms of lying time and number of lying bouts both between focal groups and among cows within each focal group, and it is necessary to sample and select cows to obtain a representative measure of the herd. The accuracy of focal-group sampling depends upon group size, cohesiveness, animal activity and management operations, thus potentially introducing biases into data collection. Several farm conditions contribute to and affect the social behaviour of a dairy herd, including the type of housing, the number of cows and the space allowance per cow. These factors largely explain the differences in automatically computed sample size (*N–k* value) obtained for the five focal groups monitored, for lying time and number of lying bouts. The number of cows in the group, the variability of lying behaviour among the cows and the different environmental and farm conditions may play a part in determining the sample size for focal sampling. Furthermore, the different aspects of lying behaviour (lying time and number of lying bouts) can also affect the sample size for focal sampling. Group definition and the method of selecting the animals in the "focal group" are crucial for valid behavioural sampling. Some authors have limited their selection to only high-yielding cows or systematically selected the cows based on the order they entered the milking parlour; other authors have selected the cows by limited random selection or on the basis of parity, stage of lactation, locomotion score, and/or health problems.

Regardless of the cause, individual lying behaviours of cows housed together can be highly variable. In small and non-homogeneous groups, the behaviour of each individual cow has a greater effect on the total behaviour of the group (in terms of weighting), whereas in large groups or synchronized subgroups each individual cow has a smaller effect on the total behaviour of the group. This relationship was confirmed in the results of this study, where the number of cows required to estimate the behaviour of a focal group consisting on average of 15 cows was 40% (six cows), whereas Ito *et al.* (2009) found that for a group of 44 cows, the number of focal animals required to obtain a reasonable estimate of lying behaviour was approximately 25% of the herd (ten cows).

In conclusion, estimates of the daily lying behaviour of the herd mean can be generated using continuous recording of at least six focal cows out of 15. The sampling methods applied to the automated monitoring systems are time- and labour-saving tools that can be used to assess cow comfort as exemplified by lying behaviour.

**Acknowledgements**

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# Development of an accurate vacuum control system for quarter individual milking systems

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## Abstract

A problem of the currently available milking technology is that the teat-end milking vacuum always falls as the liquid flow increases. With large flows of milk, however, a higher teat-end vacuum is required for removing the milk than with small flow rates. A recently developed system for the quarter individual control of the teat-end vacuum therefore constitutes the focus of this paper, which compares the vacuum behaviour at the teat end of the cow in a Multilactor® milking system with and without the mentioned vacuum control system. As a result, the following differences with and without the control system were observed: In low-flow milking stages, the milking vacuum is set to 8 kPa (release) and 17.5 kPa (suction) with the vacuum control system in both pulse-cycle phases. By contrast, the milking vacuum reaches values of 29 kPa (release) and 33.5 kPa (suction) without the control system. In high-flow milking phases the milking vacuum remains relatively high at approximately 31 kPa, in both settings, with and without using the vacuum control system, allowing for speedy udder stripping in both cases. However, a low vacuum applied to the teat in the case of small liquid flows often can have a positive effect on the udder tissue.

**Keywords:** Vacuum control system, fluctuation, reduction, liquid flow rate, teat-end

## Introduction

The milking technology development is an important section of the agricultural technology (Ströbel *et al*., 2013). Relating to the vacuum application in milking systems it can be stated that stabile vacuum conditions are the very important precondition for successful machine milking with milking systems. That was stated by different authors in the field of milking technology (Hoefelmayr and Maier, 1979; Nordegren, 1980; Schlaiß, 1994). Meanwhile, almost all new installed milking systems produce stabile vacuum conditions at the teat ends of the cows, but despite that fact, frequently there can be observed udder tissue damages of different levels after the milking process. The discussion about the exact adjustment of the teat-end vacuum is still very intensive until today (Ströbel *et al*., 2013). Hamann (1987) and other authors found out that the teat-tissue around the teat end should be kept clean and healthy. Important are the findings of Reinemann *et al*. (2001). These authors found out that low teat-end vacuum has a positive effect on the teat condition, but that during milking on low mean teat-end vacuum level the machine-on-time increases, what again can partly increase the stress on the teats and teat ends, because the teat cups are longer connected to the teats.

A careful treatment of the teats and an optimisation of the vacuum application in modern milking systems is necessary and is supported by many statements in the literature. Even when the focus of research in milking technology was not so much on that topic, within the last few years (Ströbel *et al*., 2013).

## Materials and methods

In the measurements which were carried out, the effect of a vacuum control valve (VCV) setting in the control system and the effect of changes in the liquid flow rate on the vacuum change at the teat end was measured. The VCV was the actor in the control system and in that test-series and was inserted in one of the four quarter individual milk tubes (Fig. 1-No.4). With that new developed actor (the VCV), it was possible to adjust the cross-sectional area within one of the quarter individual milk tubes of the used milking system (Ströbel *et al*., 2013).

The milking system, where VCV was inserted was used for wet-tests. These tests were performed according to the wet-test-method (ISO 6690, 2007) in the laboratory milking parlour of the Leibniz Institute for Agricultural Engineering in Potsdam, Germany. The wet-tests were performed with artificial teats, which were produced by the standard of ISO 6690 (2007). Water at room temperature was used to simulate the effects of the liquid flow (ISO 6690, 2007). The adjusted flow rates were set between 0.0 and 1.1 l/min/quarter, because up to that level a requirement for vacuum reduction at lower flow rates was expected by the experience of other pre-tests (Ströbel *et al*., 2013). For the simulation of the liquid flow, four flow meters (Parker Hannifin Corporation, Cleveland, USA), were used. These flow meters were prepared on a board. At each flow meter, the flow can be adjusted by the help of a water tap in a range of 0.0 and 2.0 l/min/quarter, where the measuring deviation was ± 2%. In detail the measurements were performed for the following flow rates: 0,0; 0,3; 0,4; 0,5; 0,6; 0,8; 0,9; 1,0 and 1,1 l/min/quarter (Ströbel *et al*., 2013).

At each measurement the liquid flow rate was on the same level in each quarter at each performed test. In the wet-tests the vacuum was measured using a MilkoTest MT52 measuring system (System Happel® GmbH, Friesenried, Germany) sampling with 500 Hz, with an accuracy of ± 0.1 kPa while the measuring accuracy of ± 0.6 kPa is required, as defined in ISO 6690 (2007). The vacuum at the end of the artificial teat, in the pulse chamber and in the main vacuum line, was measured and eight repetitions were performed. The pressure sensor 1 of

MT52 was connected to the machine vacuum. Pressure sensor 2 was connected to the pulse chamber through a T-piece. The T-piece was placed at a distance of 30 mm under the end of the teat cup's pulse tube. The connection of sensor 3 was performed by a 30 mm long low-inner-diameter tube (2 mm) to the end of the artificial teat.

The measurements were conducted in the tubes of the quarter individual milking system Multilactor® (MULTI). Figure 1 shows the pipe and tube length and the inner diameters of the duct system in MULTI, including the vacuum control valve (VCV) and the artificial teat, which are given for one of the four individual quarter milk tubes. The other three quarters were not equipped with VCV in this series of tests. Nevertheless, during the wet-tests the other three quarters were also in operation and connected to artificial teats.

The milking system Multilactor® was fabricated by Siliconform GmbH & Co. KG, Türkheim, Germany. The most important technical innovation in MULTI is the quarter individual milk tube guidance, available for milking parlours, within that system. Furthermore, the system is equipped with sequential pulsation. The milk tube length from the teat cup to the junction point was 3095 mm and the inner tube diameter was 10 mm. MULTI was installed in 2009 in the laboratory milking parlour, the machine vacuum was adjusted to 35 kPa and the adjusted pulsation ratio (for all performed measurements) was 65:35. MULTI's mode of operation is different in comparison to conventional milking clusters. To attach the teat cups, a pneumatic holder for the cups moves under the udder. Afterwards the teat cups are attached manually. The removal of the teat cups occurs automatically (Rose and Brunsch, 2007). The location in the technical design of MULTI, where the vacuum control valve (VCV) was added to MULTI's construction is given in Figure 1. For the purpose of the development of the complete vacuum control system, three different prototypes of VCV were developed a fabricated.

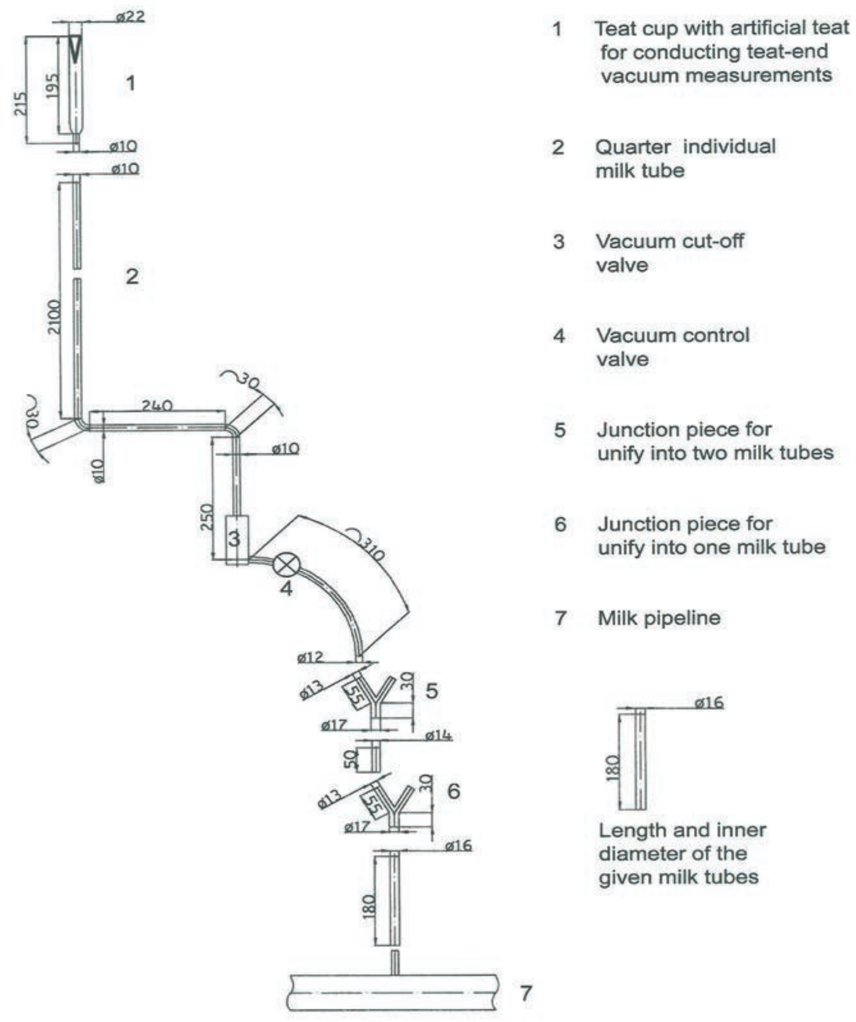


Figure 1: Schematic drawing of the test set-up: The duct system of the Multilactor® milking system, with inserted vacuum control valve (VCV) (Ströbel *et al.*, 2011)

During the whole development process, the purpose was to produce a technical device (VCV) that is able to adjust different cross-sectional-area in the valve and to have a variation possibility for adjusting the cross-sectional-area in milk tubes, with that device. The speedy change of possible cross-sectional-area positions was also a requirement for the VCV. The twelve adjustable cross-sectional-areas which could be adjusted in the VCV ranged from 0.0 to 78.5 mm². To have a comparison: A milk tube with inner diameter of 10 mm has a cross-sectional-area of 78.5 mm² (Ströbel *et al.*, 2013).

The calculation of the mean teat-end vacuum for the different pulsation phases was performed according to ISO 6690 (2007). With this calculation method, the correlation between teat-end milking vacuum und the liquid flow rate was found. All in all, each possible combinations out of 9 liquid flow rates and 12 adjustable cross-sectional-areas in the VCV were tested. Therefore 108 different settings has been tested with 8 repetitions. Thus, 864 single short-time measurements has been performed. From the pool of different adjustment combinations, via comparing the impact on the teat-end vacuum for each liquid flow level a fitting VCV adjustment was assigned manually. The combinations were chosen manually with the objective to produce an increasing teat-end vacuum, when the liquid flow is increasing (Ströbel *et al*., 2013).

**Results and Discussion**

The effect of the vacuum control system is explained in Figure 2. In that Figure 2, it can be seen that the vacuum can be lowered, to a level of approx. 16 kPa in the suction and approx. 7 kPa in the release phase, when the control system is active. In the case when the control system is inactive, very different vacuum conditions were measured at the same flow rate of 0.2 l/min/quarter: mean teat-end vacuum levels of 34 kPa in the suction phase and 29 kPa in the release phase were found (Ströbel *et al*., 2012b). Therefore, with an active control system the vacuum level can be decreased to approx. half the level in comparison to the inactive control system. That could be an advantage for the teat condition, but this correlation can only be tested in a farm experiment.

The comparison of both diagrams shows that the developed control system results in a marked reduction in teat-end vacuum at low liquid flow rates. This is practical in that no great amount of vacuum is required for the transport of the milk. The low vacuum during such phases prevents high pressures on the teat tissue and enables a “gentle” milk withdrawal (Ströbel *et al*., 2012a).

In the suction phase at a high liquid flow rate the vacuum was measured as similar high as the machine vacuum in the system. With the high vacuum a rapid milking-out effect is possible. In the release phase, on the other hand, a reduction of vacuum on the teat, seems to be desirable from the knowledge out of the literature, because a controlled teat-end vacuum, depending on the liquid flow, could help to protect the sensitive udder tissue of the cows (Ströbel *et al*., 2012a).

With the new vacuum control system the vacuum can be precisely adjusted with the expectation of positive effects on the udder health. It can therefore be assumed that there’s a possibility of reducing udder diseases in this way. The application of the gentler quarter-individual milking technique can therefore probably lengthen dairy cow’s service life. It also could increase performance potential of the cow. Thereby, positive effects on the total energy balance in milk production could be expected: increased dairy cow longevity means rearing energy inputs are spread over a longer production period (Ströbel *et al*., 2012a).

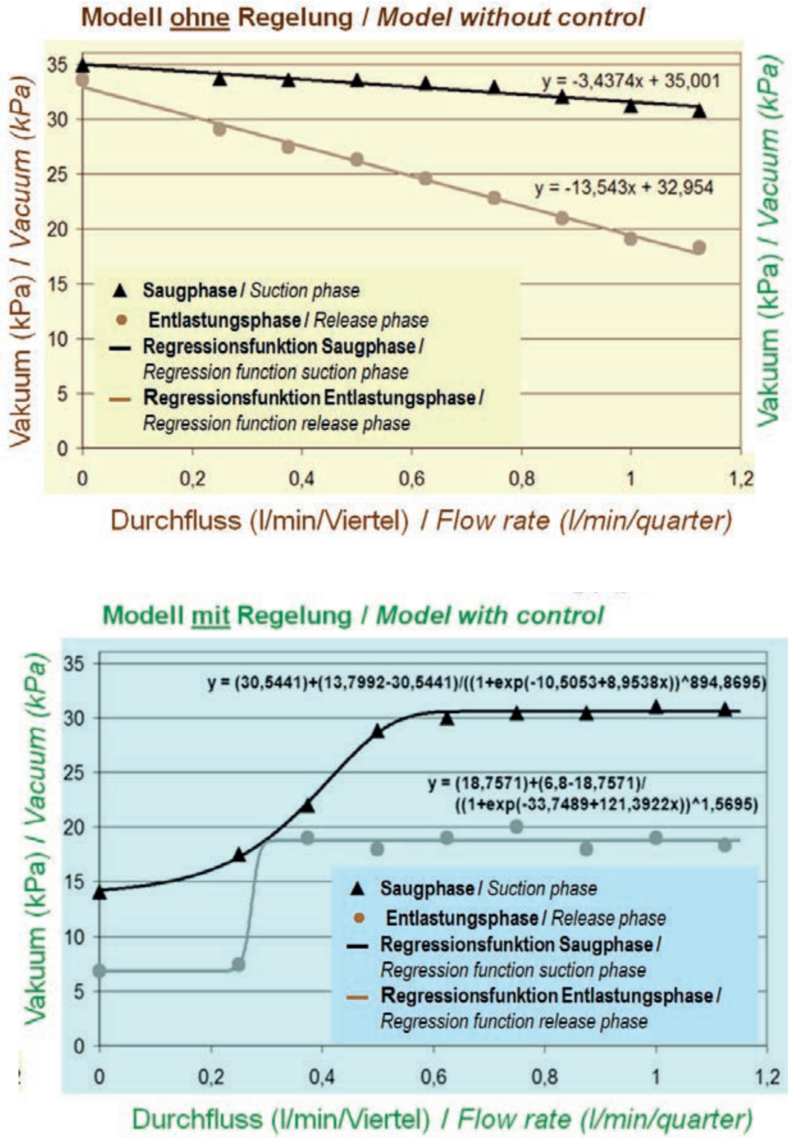


Figure 2: Effect of the vacuum control system on the teat-end vacuum depending on the liquid flow rate (Ströbel *et al.*, 2011)

## Conclusions

The vacuum control system described here, achieved the desired effect, through which the teat-end milking vacuum during the release phase, and in phases with low liquid flow rate, could be markedly reduced (Ströbel *et al.*, 2012b). Many further innovations on the milk technology equipment market show, that further development of quarter individual milking systems represent considerable animal welfare oriented potential in milking. Also the situation of the milkers could be improved by the mentioned technologies (Ströbel *et al.*, 2012a).

The required electronic module groups for improving the milking process are, in principle, available right now. It is now the role of agricultural engineering and of research in milking technology to take the available electronic components and adjust them to suit the operational conditions in livestock farming and develop a suitably robust technology (Ströbel *et al.*, 2012a). In future the comprehensively tested vacuum control system should be further tested under practical conditions to see, if it can deliver the required positive effect in protection of udder tissue and udder health (Ströbel *et al.*, 2012b).

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## An early warning system for dairy farms based on tank milk quality analysis

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### Abstract

In this study a tool was developed to monitor bulk milk somatic cell count (BMSCC) which is a parameter available on every dairy farm due to mandatory analysis. An adapted cumulative sum control chart was elaborated into a self-learning system with a dynamic individual target value. The control chart was validated online, where it detected a case of clinical mastitis and a case of subclinical mastitis. As it is based on the already available BMSCC measurements and answers to famers' requirements for a monitoring tool  low false alarm rate , this control chart is has high potential for practical use as an added value to manage and control udder health and overall efficiency of the milking process.

**Keywords:** health monitoring, Bulk Tank Milk, protein feeding, management support

### Introduction

Tank milk is sampled at every collection to measure the protein and butterfat content, the amount of bacteria and somatic cells, and to detect residues of antibiotics. While these analyses are imposed by the government to determine the correct price and acceptability to the market for human consumption, it can also provide valuable feedback to the farmer with respect to his management.

On 53% of the professional dairy farms in Flanders BMSCC is the only parameter to control the subclinical mastitis status in the herd (CRV, 2012). Moreover, most farmers only focus on the somatic cells and bacteria count to avoid negative financial consequences crossing the statutory regulation of 400.000 cells/ml. However, progressive dairy farmers, veterinarians and feed consultants have started to it as a feedback with respect to the health and nutrition status of the dairy herd (Jayarao *et al*., 2004)and to understand the relationship between different bacterial groups that occur in bulk tank milk. One hundred twenty-six dairy farms in 14 counties of Pennsylvania participated, each providing one bulk tank milk sample every 15 d for 2 mo. The 4 bulk tank milk samples from each farm were examined for bulk tank somatic cell count and bacterial counts including standard plate count, preliminary incubation count, laboratory pasteurization count, coagulase-negative staphylococcal count, environmental streptococcal count, coliform count, and gram-negative noncoliform count. The milk samples were also examined for presence of Staphylococcus aureus, Streptococcus agalactiae, and Mycoplasma. The bacterial counts of 4 bulk tank milk samples examined over an 8-wk period were averaged and expressed as mean bacterial count per milliliter. The study revealed that an increase in the frequency of isolation of Staphylococcus aureus and Streptococcus agalactiae was significantly associated with an increased bulk tank somatic cell count. Paired correlation analysis showed that there was low correlation between different bacterial counts. Bulk tank milk with low (<5000 cfu/mL. Analyzed at least 4 times a month, BMSCC has a clear correlation with the subclinical mastitis situation, expressed by the percentage of cows above 250.000 cells/ml (Lievaart *et al.*, 2009). This makes BMSCC a potential and inexpensive parameter for monitoring and controlling udder health and providing feedback on the total process of milk production on the farm.

While visual inspection of these data can provide valuable information, it is a tedious task and the success largely depends on the expertise of the evaluator. Detecting process deviations in an early stage is the aim of Statistical Process Control (SPC), which is widely used in the process industry. However, an important difference between monitoring process parameters of industrial processes (e.g. chemistry), where SPC has become common practice, and BMSCC is the fact that the milk production process cannot be stopped when it is out of control. The milk production will continue and the farmer has to search for the problem as soon as possible. Even after detecting a problem, it can take a substantial time before the quality has returned to its normal level, which makes that a parameter can be out of control for a longer period. In this case it is important for practical use that the farmer does not keep getting alarms for the same problem, as these would make him insensitive for the generated alarm and as a consequence for alarms related to a new process shift or problem (Mollenhorst *et al.*, 2012). Moreover, the seasonal pattern in the BMSCC hampers the direct use of the popular tools of SPC such as Shewhart- or Cumulative Sum control chart, as these tools can only be used on stationary data, fluctuating around a constant value. A possible solution to achieve stationary data is by modeling the seasonal trend with a non-linear trend model, which leads to stationary residuals (Mertens *et al.*, 2009). The major challenge in modeling the trends in BMSCC is, however, that it is influenced by many animal and production parameters such as parity, stage of lactation, type of housing, access to pasture, management and environmental factors as temperature and humidity (Lievaart *et al.*, 2010; Olde Riekerink *et al.*, 2007)herd characteristics, season, and management practices determined in a previous study that quantified the contribution of each factor for the HSCC. The LME model was tested on a new data set of 101 farms and included data from 3 consecutive years. The farms were split randomly in 2 groups of 50 and 51 farms. The first group of 50 farms was used to check for systematic errors in predicting monthly HSCC. An initial model was based on older data from a different part of the Netherlands and systematically overestimated HSCC in most months. Therefore, the model was adjusted for the difference in average HSCC between the 2 sets of farms (from the previous and current study. Lievaart *et al.* (2010) succeeded in developing a model to predict the next month somatic cell count, based on seasonal, herd and management characteristics. However, as the herd characteristics in the model contain information on the individual cows, it can only be used by farmers participating in an individual milk recording program. Moreover, the quality of the model prediction is highly dependent on the data collection, entering and feedback by the farmer (Lievaart *et al.*, 2010). Lukas *et al.* (2008b;a) tried to predict the change of exceeding the statutory regulation. However, this procedure only gives valuable information to farmers with problems meeting the quality goals and not to the more successful herd managers with low BMSCC which are also interested in small process shifts in the BMSCC (e.g. 50.000 cells/ml).

To fill this gap, an intelligent system for monitoring the bulk milk somatic cell count based on an SPC control chart was elaborated in this study. The self-learning dynamic control chart was based on the Cusum control chart, because it is sensitive to small process shifts (Montgomery, 2009) and provides a concept which is clear and intuitive for the farmer.

## Material and methods

<u>Cusum control chart</u>

The cusum control chart consists of two calculations: the first accumulates the deviations above the target value *T* that exceed a certain reference value *K* and is named the upper cusum $C^+$. The lower cusum $C^-$ accumulates the deviations below the target *T* that exceed *K*. They are computed as follows:

$$C_t^+ = \max(0, x_t - (T + K) + C_{t-1}^+) \quad (1)$$

$$C_t^- = \max(0, (T + K) - x_t + C_{t-1}^-) \quad (2)$$

with starting values ==0;  the observation at time *t*; and *T* the target value; *K*=*k*. the reference value and  the in control standard deviation of the time series. The process will be out-of-control when the upper or lower cusum crosses the control limit. *H*=*h*. with *h* the decision interval.

Apart from non-stationarity of the BMSCC , the large amount of alarms for one problem makes that there was an adaption needed of the Cusum before it could be used as a practical BMSCC monitoring tool. For example, in Figure 1 the application of a cusum control chart on BMSCC data is shown. On this farm there is clearly a problem with the udder health at measurement 29, which is alarmed. However, the BMSCC is again fluctuating around the mean value from measurement 36 on, which indicates that the farmer has noticed the problem and solved it. However, the farmer keeps getting alarms. In this case the farmer was alarmed twice by the Milk Quality Centre of Flanders (MCC-Vlaanderen) that he had crossed the statutory regulation of 400.000 cells/ml. The farmer started searching for the problem, but due to the fact that the milk production process cannot be stopped it took a substantial time before the quality was back in control. In this case the farmer would have been only interested in the alarms at measurement 29 and 30, making him aware of the problem.

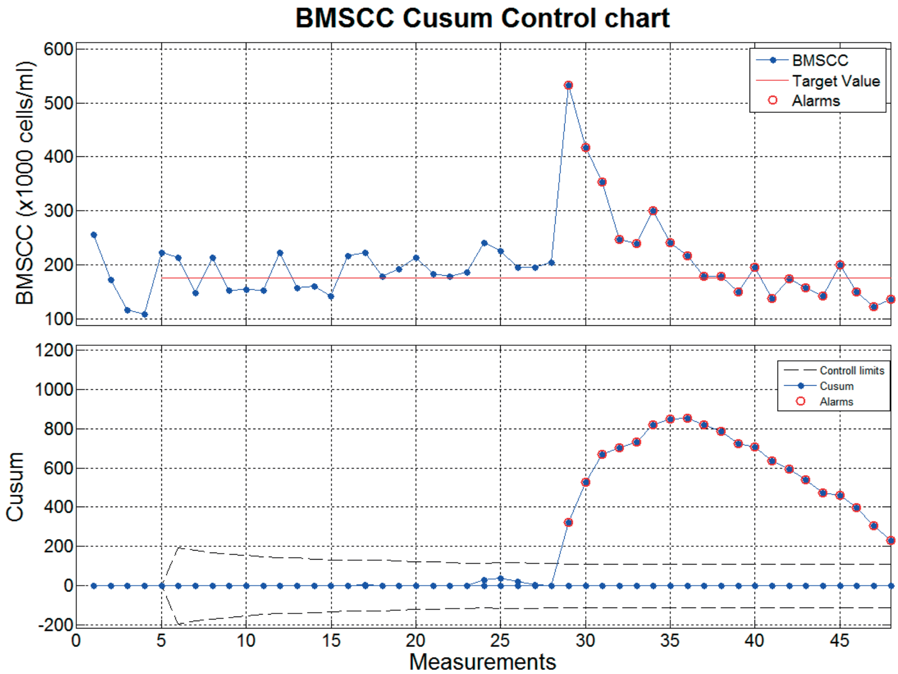


Figure 1: Original Cusum on BMSCC-data

<u>Adapted Cusum control chart</u>

To solve the problem that traditional control charts face when applied on processes not varying around a fixed mean it was suggested to update the local mean level (Box and Paniagua-Quiñones, 2007) . In this case there are 2 types of chart needed: a typical control chart, in this case a Cusum control chart, and an adjustment chart, the exponentially weighted moving average (EWMA) chart. In the latter chart there is no fixed mean value, but an individual target value. This target value starts with a mean based on an initialization period, which could be in the past as every farm has already a historical dataset. The Cusum control chart works with residuals (measurement – target value) and $k=0.5$ and $h=5$. This leads to an ARL0 or the time between of 38, equal to

10 months for normal sample frequency or 5 months for high frequency (every milk collection). As such it fulfills the need of a low amount of false alarms.
The adjustment chart is a EWMA chart and is defined as:

$$Z_t = (\lambda Y_t) + (1-\lambda)Z_{t-1} \qquad (3)$$

with $Z_t$ and $Z_{t-1}$ the EWMA on respectively time *t* en *t-1* , $Y_t$ is the observation on time *t*. is de weighting factor (Montgomery, 2009).
The adjustment chart is the chart that adjusts the target value after an alarm has been given by the control chart. The EWMA is calculated on the residuals with= 0.20. In this study, it was chosen to adapt the target value after three consecutive aberrant BMSCC measurements. The target value is adapted by the value of the EWMA. In a normal sample frequency for BMSCC 3 consecutive alarms means correspond to an average time of 14 days between the first and the third alarm. This means that the farmer was not able to directly solve the problem. Due to the fact that he is aware of this problem by two alarms, there is no need to continue giving alarms. The adjustment of the target value makes the residuals stationary, while retaining the possibility to detect new shifts in the BMSCC.

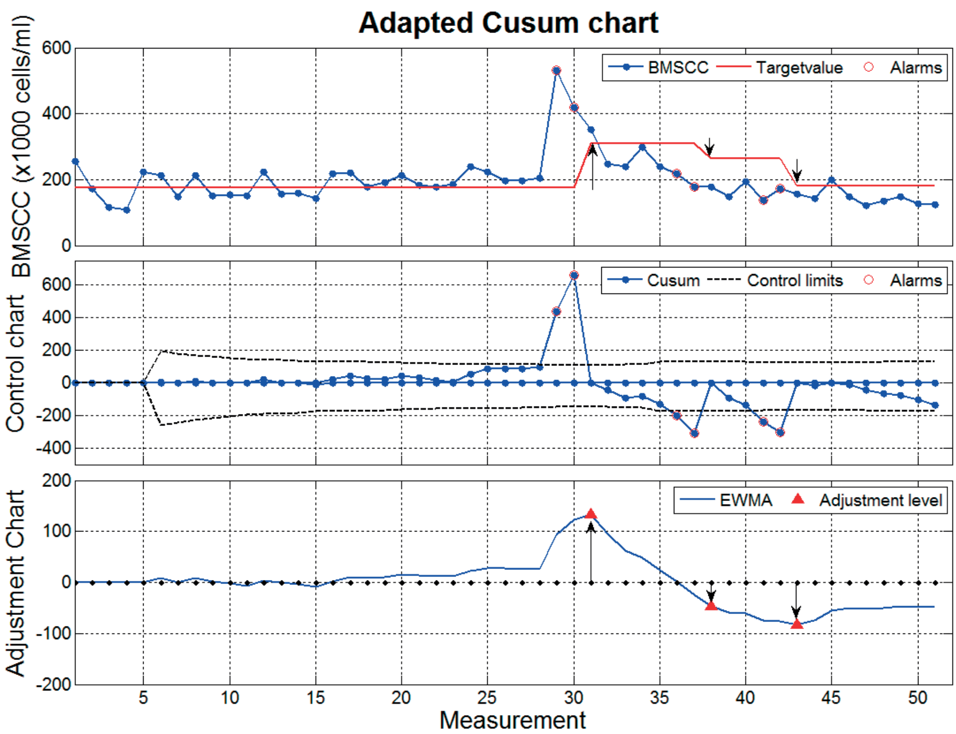


Figure 2: Adapted Cusum control chart with Control chart and Adjustment chart

Individual monitoring

As aforementioned, the accurate farm managers are already interested in small shifts in contrast to the herd managers with high BMSCC which are only interested in high shifts or shifts that may lead to financial consequences. The preferable shift to detect by the cusum control chart depends on the reference value K. K depends on the parameter $k$ which is multiplied by the common cause variation . As such, it was investigated how the common cause or normal variation differ as a function of the mean BMSCC. In Figure 3 a good relationship between the BMSCC and can be observed. This was also reported by Lievaart *et al*. (2009), who found an even a stronger correlation ($R^2$=0.648). Due to the general relation between $k$ and the desirable shift, which is given by:

$$\Delta = 2k\sigma_0 \tag{4}$$

it is not needed to build something artificial in the control chart. The accurate herd managers will be able to detect small shifts (< 50.000 cells/ml), while the farmers with a high BMSCC will only be alarmed for a higher shift between 50.000 – 100.000 cells/ml.

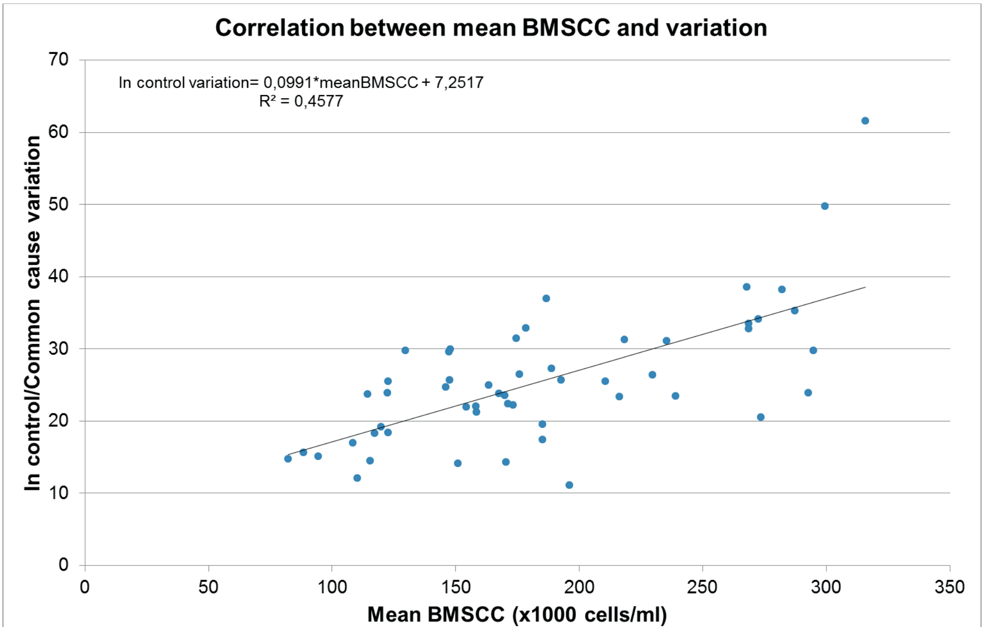


Figure 3: Correlation between mean BMSCC and in control variation

Test cases

The algorithms were calibrated offline on a set of historical BTSCC data of 5 Flemish dairy farms for the period from January 2008 until September 2012. The criteria for the alarms were defined by the dairy farmer. They were only interested in an increase of the BTSCC parameter. The shift to be detected was highly dependent on the average performance level of the herd. The accurate herd managers, with BTSCC below 200.000

cells/ml, are already interested in small process shifts (50.000 cells/ml), while the farms with higher mean BTSCC are only interested in shifts of 100.000 cells/ml or shifts which might lead to crossing the statutory regulation of 400.000 cells/ml.
The developed system was validated in practice on the same 5 farms by monitoring the BTSCC level in the period from 14 February 2013 until 30 April 2013. Each day, as new lab analysis values became available these were entered in the monitoring system. When the system gave an alarm the farmer was contacted and asked for feedback.

## Results and Discussion

In this short online validation period there were alarms 10 alarms divided over 3 farms. Two cases or 6 alarms which could be related to known udder health problems. The other 4 alarms, occurred on one farm in a period of 1 month but the reason of this elevation could not be discovered.

<u>Clinical mastitis case</u>
In Figure 4 the BMSC control chart of one of the farms is shown. On March 7 the control chart reported a shift in the BMSCC. When contacted the farmer could give no explanation for the elevation of the BMSCC. The next day the shift was persistent and the farmer found a clinical mastitis in a fresh high yielding cow. Due to the fact that this farm is rather small (50 cows) and the high yield cow had an infection which lead to clinical mastitis, this event was detected in the BMSCC. After milk separation and treatment of the sick cow the BMSCC returned to its original level.

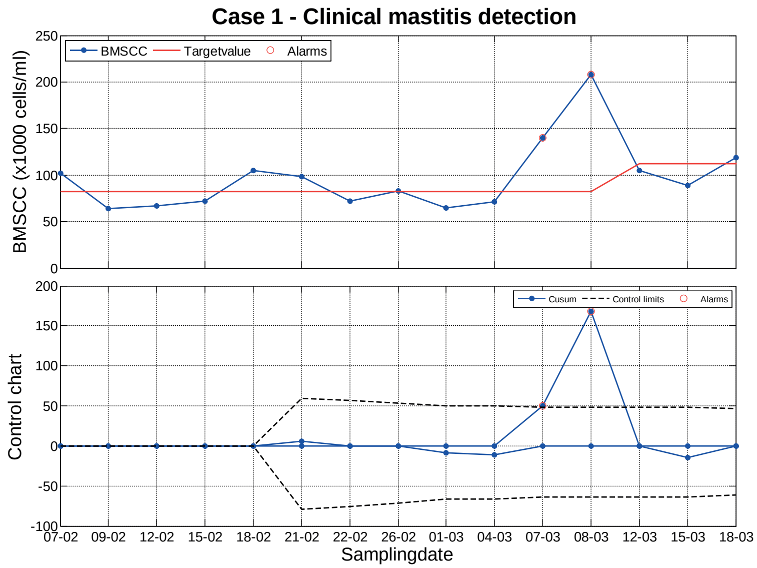


Figure 4: Detection of clinical mastitis by monitoring BMSCC

Subclinical mastitis case

In Figure 5 the control chart for another farm is shown. The control chart detected a shift on March 1st, which persisted and lead to a new target value. The farmer did not observe anything. On March 21st a new shift was detected by the control chart. The farmer started separating the milk of a cow he suspected to have a high somatic cell count based on historical information. The individual milk control on April 3rd confirmed that there were two cows (nr.6624 and nr. 4014) with high somatic cell count, who contributed 18% together of the total BMSCC (Table 1). For subclinical infections it is known that the amount of bacteria and SCC can fluctuate (Harmon, 1994). As a consequence, it is probable that these two fresh cows were also responsible for the first two alarms in the beginning of March. To confirm this hypothesis their individual SCC should have been measured on these days, but this was unfortunately not done.

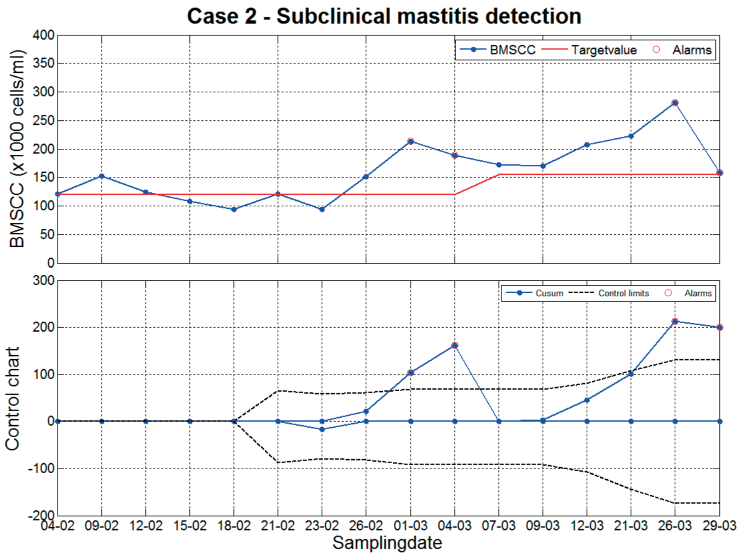


Figure 5: Detection of subclinical mastitis by monitoring BMSCC

Table 1: Results of the individual milk recording (Par.=Parity, DIM=Days in Milk, %BMSCC= % of BMSCC produced by this cow)

| | | | | Individual Somatic Cell count (x 1000 cells/ml) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Animal | **Par.** | **Calving date** | **DIM** | **25 Oct** | **4 Dec** | **14 Jan** | **21 Feb** | **3 Apr** | **% BMSCC** |
| 5 | 1 | 25 March 2013 | 9 | | | | | 295 | 2 |
| 6624 | 4 | 20 February 2013 | 42 | 115 | 63 | Dry | | 568 | 5 |
| 4014 | 3 | 14 February 2013 | 48 | 19 | 137 | Dry | 33 | 1322 | 13 |
| 4026 | 3 | 28 October 2012 | 157 | Dry | 13 | 33 | 109 | 320 | 3 |

## Conclusions

An online monitoring tool for the bulk milk somatic cell count has been elaborated in this study and validated in practice on 5 farms. During this short online validation period the system showed clear potential with the detection of a clinical mastitis one day before the detection by the farmer. It also suggested two cases of subclinical mastitis, which could not be verified as individual somatic cell count recordings were not available. As such, this system should not be seen as a replacement for the individual milk recording, but rather as a complementary tool which gives feedback between individual recordings. Today, many farms maximize the interval (6 weeks) between the individual milk recordings to reduce the cost. When the control chart detects a shift in the BMSCC, the farmer could, however, decide to advance the next individual control. As such, the presented monitoring tool extracts useful additional information from the analyses imposed by the government. The technique involving two charts, the control chart and the adjustment chart, could also be used on other milk parameters like the ratio of protein and urea.


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## Analysis of test-day milk and milk components yield records by using an interactive system to visualize multivariate data

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### Abstract

In many research fields, the amount of collected data surpasses the ability of the domain expert to analyze these data directly. One approach to overcome this data-analysis challenge is by using visual analytics that employs a visual metaphor to represent the data to detect patterns or simply identify outliers. In this paper, an integrated system for visual analysis of test-day milk and milk components yield records. Data collected in Ragusa province (Italy) from several herds were used to identify trends and between-breed differences in milk production curves. Besides common multivariate data visualizations, the developed system provides techniques for time-varying and seasonal data analysis. Scatter plots with interactive filtering allow users to highlight the correlation between milk, fat, and protein production changes over time with different coefficients depending on the breed of the cow, the parity and the season of calving. Histograms are used to explore density of data sampling for different dairy farms. Multiple line charts show time varying data pointing out distinct behavior for different months or seasons. A user friendly environment allows animal researchers to dynamically produce several kinds of plots to reveal well-known properties as well as find out new interesting characteristics in data, predict individual production for a specific animal at a particular parity and test-day, and identify possible outliers. It could be shown how graphically reproduce the effect of correlation between milk components according to the lactation curve and how to make clear production differences for different breeds.

**Keywords**: Lactation curves, Time-dependent data, Test-day model, Visual analytics, Statistical graphics

### Introduction

Farm management aimed to maximizing milk production in the dairy industry is commonly supported by information from monthly-collected measurements of milk and milk components production and events regarding health, reproduction, etc. The information can be used by the producer for making decisions for the improvement of on-farm management practices. However, the benefits only come about if the farm manager and/or the advisor spend a considerable amount of time in analyzing the incoming information. This process can be time consuming and complex due to the large amount of information. The number of information increases rapidly with number of cows. Furthermore, sometimes information has to be combined with information on management practices, such as feed availability and health status of the herd. To extract all the information to support management decisions is, therefore, not a trivial process. For this reason, it is necessary to develop analytical tools which will accelerate and improve these analyses. Such tools should not only filter and pre-process the data, but also present the results in a way that they are easy to use by the producer. The tool should allow the farmer and/or the advisor to determine rapidly management decisions that will lead to improvement of performance in technical and financial terms. The first objective of the present study is to develop a model of analysis of production data that provides very reliable predictions. The second objective is to develop a user-friendly and easy-to-use system that helps farmers to identify abnormalities in production data to early detect problem animals.

## Material and methods

### Data

The developed system was applied on a dataset provided by the Dairy Herd Improvement (DHI) agency of Ragusa (Italy). Data used for our study are used by animal researchers and extension people to assist farmers in the management of dairy herds. The first dataset contained 85,279 records for milk, fat and protein yield and somatic cell count on 4,824 cows from 29 commercial herds. Samples were taken monthly at the test-day, for over 10 years. In the dataset, records from 6 parities are included with days-in-milk ranging from 5 to 365. The dataset also contained information on pathologies occurring immediately before the test-day. This dataset was processed using a test-day model described in the following section.

The second dataset contained data collected from one commercial herd. At this farm, production data are collected in the parlour equipped with an Afimilk® milking system. Production data and events are collected daily. Data records regard a single herd of 90 high producing cows.

### Test-day model

Production test-day records for the first dataset were processed using a multiple-lactation, single-trait random regression test-day model, as described by Caccamo *et al.* (2008):

$$y_{dijklmnoprs} = pd_i + pysd_j + pay_k + pcipr_l + yw_m + htd_n + \\ + \sum_{q=0}^{4} z_{oq}\left(hcur_{qs} + ag_{qrs} + pe_{qrs} + \begin{Bmatrix} 0, & \text{if } p < 3 \\ ls_{pq}, & \text{if } p \geq 3 \end{Bmatrix}\right) + e_{dijklmnoprs}$$

where $y_{dijklmnoprs}$ = yield record (milk, fat or protein yield, or somatic cell score) of the cow s on DIM d of parity p within herd test-day (HTD) effect n and belonging to fixed effect class i, j, k, l, and m defined as follows; $pd_i$ = ith class of parity (7 levels) × class of DIM; $pysd_j$ = jth class of parity × year of calving × season of calving × class of DIM; $pay_k$ = kth class of parity × age at calving × year of calving; $pcipr_l$ = lth class of parity × calving interval × stage of pregnancy; $yw_m$ = mth class of year of test × calendar week of test; $htd_n$ = random herd × test date n; $z_{oq}$ = order q Legendre polynomial for DIM o, where o = min{d,365}; $hcur_{qr}$ = random herd curve (HCUR) effect of herd × year of test corresponding to polynomial q of parity r, where r = min{p,3}. In this manner, each herd gets a regression curve for parity 1, 2 and ≥3; $ag_{qrs}$ = random additive genetic effect of cow s  corresponding to polynomial q of parity r; $pe_{qrs}$ = random permanent environmental effect of cow s corresponding to polynomial q of parity r; $ls_{pq}$ = lactation-specific permanent environmental effect of lactation p corresponding to polynomial q. Only TD records from lactations with parity ≥3 are assigned to a lactation specific permanent environmental effect. In this manner, lactations with parity ≥3 have one common permanent environmental curve and one specific curve for each lactation; $e_{dijklmnoprs}$ = residual belonging to observation $y_{dijklmnoprs}$.

Unknown parents were assigned to 259 phantom pedigree groups based on their selection path (sires to breed sons, sires to breed daughters, dams to breed sons, and dams to breed daughters), breed, country of origin, and birth year. Random effects were HTD and HCUR, animal additive genetic effect, and permanent environmental effect modeled using fourth-order Legendre polynomials. The random and permanent environmental regression curves were modeled using fourth-order Legendre polynomials.

For each record in the dataset, predictions for milk, fat and protein yield and somatic cell count were estimated by adding the solutions of all effects estimated from the model.

Visual analytics tool

An integrated system was developed to help animal researchers in analyzing the large amount of raw data obtained during the test-day in both datasets and the output from the test-day model. The goal of this system is to allow researchers to find insights, anomalies and abnormal production in the collected data. Furthermore it is possible to explore and analyze data from DHI agencies for hypothesis building.

## Results and discussion

Test-day model

In this study a model that exploits test day information (TD model) for management purposes was developed for Sicilian dairy herds. Everett *et al.* (1994) suggested using results of TD models for monitoring genetics and management in dairy cattle. TD models have been further improved and today represent one of the most advanced and sophisticated mathematical tools to process DHI data with very high reliability (4 to 8% more accurate genetic evaluations of cows compared to evaluations from 305-d yields; Schaeffer *et al.*, 2000). For management purposes, several solutions based on TD models have been proposed in the literature also. Estimation of fixed, genetic, environmental and herd effects can be used to predict future productions of individual cows. Deviations between predicted and actual production could be used to detect a disease at an early stage, i.e. before the cow shows clinical signs. Halasa *et al.* (2009) used the difference between actual and predicted production to model production loss due to subclinical mastitis. Records from cows with clinical mastitis were excluded in order to use predicted production based only on healthy cows. A multiple-trait mixture model was successfully applied to TD milk yield, fat-to-protein ratio and somatic cell score to detect sub-clinical mastitis in dairy cattle (Jamrozik and Schaeffer, 2012). Fat-to-protein ratio, easily available, highly heritable and relatively independent from milk and somatic cell score, could serve as an additional indicator for indirect selection against mastitis in dairy cattle.

The difference between real and predicted milk and milk components production estimated from the test-day model allows farmers to identify problem cow when, or even before, clinical signs of pathologies appear.

Visual analytics tool

A visual system was designed aimed to help farmers and technicians to handle production data and draw conclusions in management decision process. The system was tested by technicians working at the extension group of CoRFiLaC and was recognized as a good means to easily produce graphs to show analysis results to the farmers.

The developed system integrates a simple tool for editing input data and several methods to visualize them.

Data can be provided in a tab-separated values format (.txt) or in a comma-separated values file (.csv) that can be simply exported from a spreadsheet application.

Loaded data are shown in a tabular form. Edit functions can be used for a data cleaning phase: data can be ordered or filtered and complete columns and rows can be removed. The numbers of entries and data fields are shown accordingly. The system has been designed to support and handle any kind of multivariate dataset containing at least a date (or time) data field to make available all the developed view functions.

This particular field is recognized automatically, and then the user is asked to choose

what template he prefers to convert this information, by choosing from a list of common date and time formats.
After the preliminary phase of data conversion and pre-processing, the user can choose from a list of four different views. The views share user settings and parameters. Each time a parameter changes, all the views are updated maintaining all the settings used for the previous view, so that it is easy to compare distinct outputs. In the visualization panel, a window to access the raw data through a table is always available. The user can hide the raw data table or visualize the data view in full-screen mode.
The visualization functions were designed to manage multivariate data (i.e. data collected on several variables for each sampling unit), mainly focusing on trivariate data (milk, fat and protein yield values).
Multivariate data visualization, as a specific type of information visualization, is an active research field with numerous applications in different areas (Chan, 2006).
One of the visualization methods proposed is based on scatter plots. This kind of diagram is one of the most important tools for revealing the structure of bivariate data and can also be extended to display time-varying bivariate data.

The user is asked to choose which data fields have to be used as *X-axis* and *Y-axis.* By default field containing temporal information (date or time) is used as *X-axis.* Each data-point can be colored according to a third data field used as a *category.* The user have to choose a different color for each value if the *category* field contains labels (categorical data); then data belonging to a class only can be shown and not interesting data are removed from the view. Otherwise, if the field chosen contains continuous values, data-points are colored automatically using a color scheme selected by the user from a list of 18 different color schemes.
The chosen data field can be used also to filter data points on the plot. A slider with two handles allows the user to decide the interval of values to show in the plot. It is possible to set the wideness and the bounds of the range of values. By moving the handle on the slider the view will interactively update the plot, pointing out differences in data according to the changing values.

If data points tend to aggregate in the same area of the plot, overlapping, it could be difficult for the user to understand the scatter plot; in those cases transparency can be used to reduce the information occlusion. The user can simply increase or decrease the transparency value of data points.
The second view offered to the user adds a line chart of mean values and standard deviation. Those line charts can be plotted on the scatter plot diagram described before. Besides, a histogram of the density of data samples in the dataset is shown, giving the user information about the quality of the original data. An overview is shown in Figure 1. A low-pass filter can be used to smooth the line plots and density plots. The user can increase or decrease width of the low-pass filter interactively.

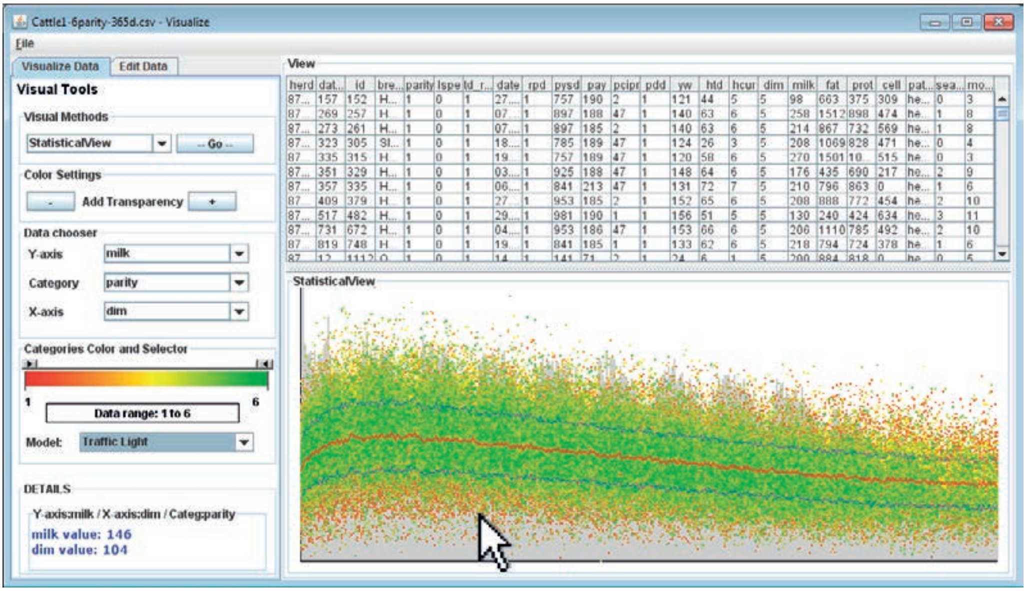


Figure 1: Main window for statistical data visualization. In this view the production of milk for each day-in-milk is shown. Colors are used to identify data points belonging to different lactation period (parity). For this example, the traffic light metaphor has been used as a color scheme. First parity is colored red, next parities are colored with an orange-to-yellow color gradient and the last parity is colored green. The curve of density of samples in the dataset is represented in gray. The density of data samples varies over time following a regular pattern, more samples are collected in certain days of the month. The red line curve indicates the mean value of quantity of milk and the blue lines the standard deviation. In the box at the bottom details on data beneath the mouse pointer are dynamically shown. In the upper part of the window, raw data are shown in tabular form.

Then, two methods to show and analyze the dual nature of time, with respect to the linear and cyclic time behavior are provided. In our datasets, parities have a "cyclic time" behavior because they progress similarly, while, within a single parity data follow a "linear time" behavior. The first method uses a stacked view of several scatter plots, one for each period of the absolute timeline. The scatter plots share the same *x-axis* representing the relative timeline. A list of time periods can be used to aggregate data and create different plots. It is possible to visualize data points for each season, month, or year. In Figure 2 the scatterplots for several months are shown.

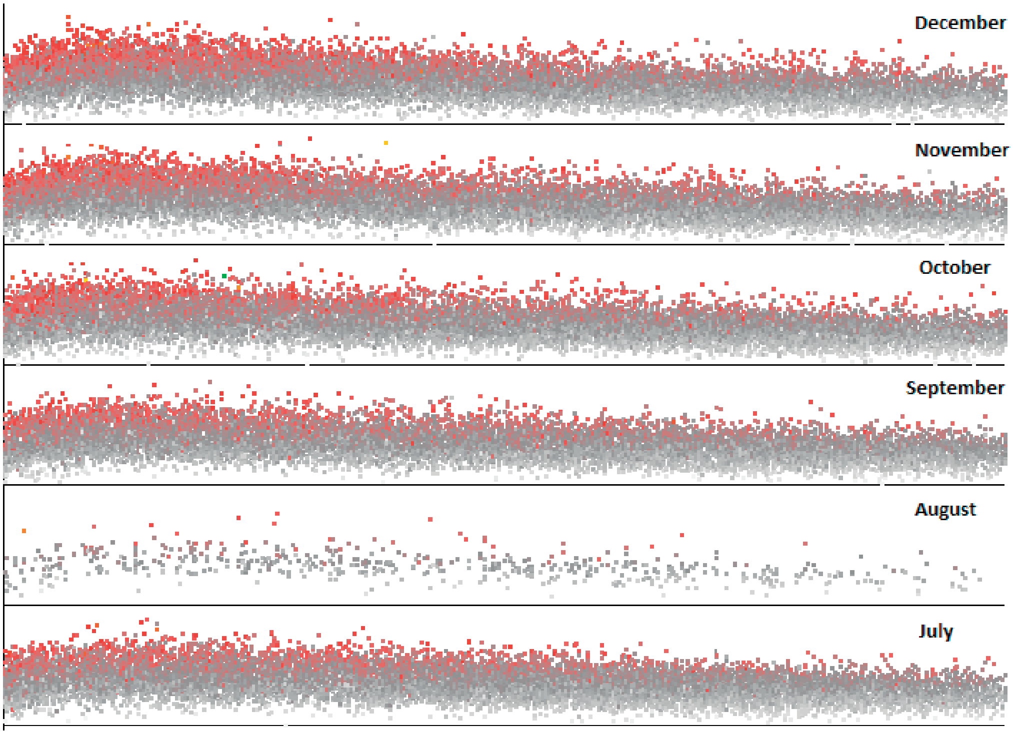


Figure 2: Multiple time lines. The production of milk is shown and the data points are colored according to the percentage of fat contained in milk samples. By plotting stacked data points for each month, only some data points in the August plot are shown, which identifies an anomaly in data recording. That reflects the lack of data sampling during summer.

This method helps identify frequent patterns in data points or highlight cyclic behavior, but it is difficult to draw a comparison between data values at the same relative time point in different plots. To help the analyst in this task, a second visualization method is designed. Different line charts are drawn in the same plot. Each line chart represents the mean value curve for aggregated data on the same time intervals proposed in the previous view. It will be simpler for the user to compare the curves because the line plots share the same coordinate system. Furthermore this method can also be used to show curves for different breed or parity (see Figure 3). The line charts can be smoothed as in the statistics view described above.

For each view method proposed, the mouse pointer can be moved over the plot, on data points to retrieve details on represented data. These details on demand are shown in a small window next to the main view.

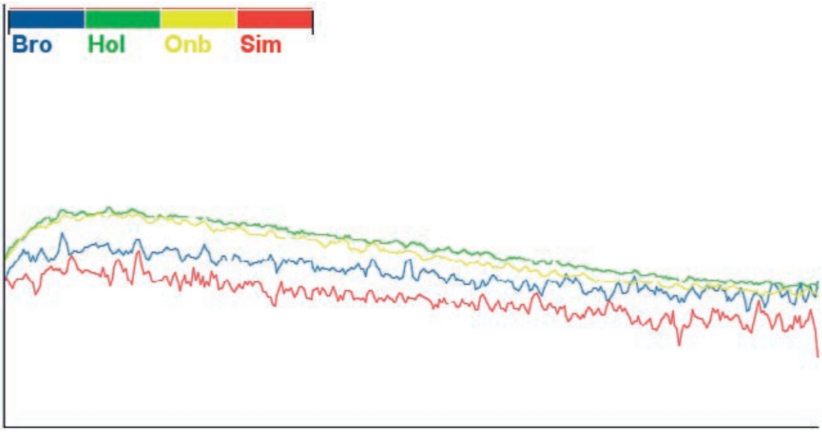

Figure 3: Average milk production for different breeds (Bro = Brown Swiss; Hol = Holstein Friesian; Onb = Crossbreed; Sim = Simmenthal).

The software could handle both datasets, thus representing a flexible visual analytics tool for production time-dependent data collected using any time interval between test days. The system allowed also to plot real, predicted and deviations of real from predicted values using different colors. The user can then easily identify problem cows by clicking on outliers points in the scatter plots in order to get information such as cow number, herd and test-day. However, many false positive and false negative deviations were found (data not shown). One possible reason could be that the date a pathology appears does not correspond to the test-day where the production is measured and recorded, therefore the day the milk is measured is not necessarily affected by the pathology. Another reason could be that the model was applied a dataset that included all records, including also problem cows, thus affecting the correct estimation of all effects. Future work will focus on the application of a test-day model on individual daily-recorded milk and milk components yield from healthy cows.

## Conclusions

Milk and milk components records were used to design a user-friendly and easy-to-use system that helps farmers and animal researchers to handle production data and draw conclusions in management decision process. The system was tested and recognized as a valuable means to easily produce graphs to show analysis results to the farmers.

## Acknowledgements

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**Distributed computing as a new opportunity for stakeholders in dairy cattle management and breeding**

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**Abstract**

Currently the uses of on-farm computers and of centralized performance-recording based tools are considered as two opposite models for dairy management. However, dividing the problem into complementary tasks, each of which is optimally solved, is an opportunity that should also be considered by stakeholders. Recent development solved data exchange issues allowing the use of adapted distributed computing algorithms. As example milk yield and composition are given. Different research projects and several commercial companies are focussing on the development of on-farm tools, mostly Near InfraRed (NIR) based, other projects are developing and implementing tools based on Mid InfraRed (MIR), available only through performance recording. Both are complementary, as NIR based measurements are easier and less expensive, available at every milking, but MIR based measurements are more precise, however only obtained every 4 weeks. Numerous advantages arise when combining both types of measurements. It will be shown that statistical theory exists to base advanced modelling on, using optimally the longitudinal data generated by this type of setting. This will open different novel opportunities to optimize currently used on-farm and off-farm management and breeding tools.

**Keywords:** Milk recording, Data exchange, Central database, Distributed computing, Hierarchical modelling

**Introduction**

The use of direct milk yield meters and similar sensors in robotic milking units and fully computerized milking parlours associated to farm computers running adapted on-farm herd management system, is often seen as a classical case of "precision livestock farming" in dairy cattle. In opposition to many other species and production systems, dairy farming has also another, well-developed historic dairy herd management approach which relies on classical performances recording, mostly supervised by technicians, on centralized milk testing and on centralized data bases. This data is then used to generate herd and cow reports that, until recently on paper nowadays often by the Internet, are send back to help manage associated herds. Basic principles of milk recording are harmonized across countries by the International Committee for Animal Recording (ICAR, 2012). This data is also the primary source of dairy cattle data used in animal breeding (INTERBULL, 2012). Currently the uses of on-farm computers based systems and of centralized performance-recording based tools are considered as two opposite “models” for dairy cattle management. The objective of the present report is to show an alternative integrative approach currently under development presenting the different layers and how by dividing the problem into complementary tasks. By optimizing each task and achieving its optimal solving at the adequate level, dairy herd management can then be optimized. Additionally the statistical background of this approach will be explained and some practical examples will be given.

## Material and Methods

Current status of interaction between on-farm and off-farm systems

Use of sensors available on-farm is increasing. This includes a wide range from classical milk yield meters and conductivity sensors, over sensors directly measuring on the animal as pedometers up to very advanced sensors as those for LDH (Lactate Dehydrogenase), urea, BHB (Beta Hydroxy Butyrate) and progesterone becoming commercially available in the Herd Navigator (developed by Danish Lattec A/S, a jointure venture company of Delaval International and FOSS Analytical: Mazeris, 2010). Classically all these tools were conceived as stand-alone products or potentially linked by a common on-farm infrastructure but only if provided by the same manufacturer. Despite some efforts especially from milking parlour manufacturers common standard “languages” for data exchange are still sparse (i.e., TAURUS Standard Interface).

Very early with the first sensors (classical milk yield meters) becoming available performance recording agencies have started to develop ways to import data. Basically two strategies were pursuit. The first strategy is the development of own on-farm management systems, the PCDART program (Dairy Records Management Systems, Raleigh, NC, USA) being an example. Unfortunately this limits the choice of herd owners and is considered not necessarily optimal by them because of their choice of other systems. Therefore manual transfer of data was often needed. A second strategy was to develop methods to export the data from the farms to central databases independently from the manufacturers of the different on-farm systems. Again the natural limit that appeared was the need or, unfortunately, the lack of common exchange standards. An innovative idea was developed by Valacta (Dairy Production Center of Expertise Quebec-Atlantic, Canada) in its Trans-D software that was from the beginning on multi-manufacturer and pluged-in directly into on-farm data bases (Saunier *et al*, 2012). Based on this principle, in collaboration France Conseil Elevage (FCEL) and Valacta developed Ori-Automate a bi-directional interface tool that links farm management software to performance-recording databases. Only this interface is installed additionally on-farm. The XML format is then used to communicate with the central milk recording databases (Saunier *et al*, 2012). In the Walloon Region of Belgium the Walloon Breeding Association (AWE) is currently implementing Ori-Automate. In other countries alternative tools are under development or already deployed. There are two other hidden advantages in a bi-direction approach. First all on-farm sensor-based tools need to access basic animal data in order to operate. By linking up with the recording agencies farmers no longer need to enter this information, potentially even several times, as it is readily available in the central databases. Also as described above current on-farm systems when provided by different manufacturer are seldom designed to exchange data. By communicating with Ori-Automate or similar systems the exchange between on-farm tools is, indirectly, established.

<u>The next step: distributed computing</u>

Having this exchange architecture in place, the development of distributed systems is the next logical step. With the steady increase of computing power current desktop PC, as routinely used on-farm, are underused. The quantity and quality of data produced by on-farm sensors is also increasing, potentially overwhelming centralized data bases. A way to address these issues is by developing adapted distributed computing algorithms dividing the problem into complementary tasks. By optimizing each task and achieving its optimal solving at the adequate level, dairy herd management (and breeding) can then be optimized. The quantity and quality of milk produced will be used as practical example to show the statistical and modelling background of this approach.

**Results and Discussions**

<u>Modelling</u>

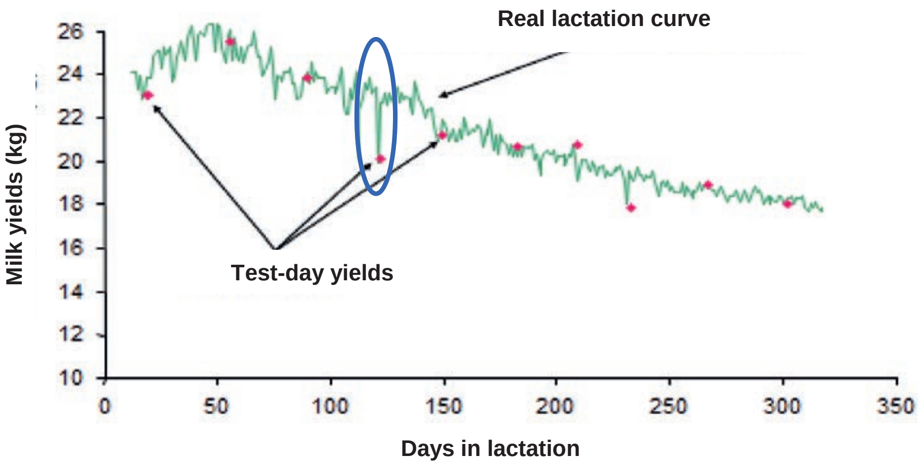


Figure 1: Evolution of the real lactation curve (daily yields) and yields recorded at specific test-days (for clarity only three indicated by an arrow); an outlier is highlighted.

A typical lactation curve for milk yield is shown in Figure 1. Numerous mathematical models were developed for this type of data (e.g., Wood, 1967), an overview was given by Gengler (1996). The natural limitation of all method was the limitation of data to few (between 8 and 11) test-day records available over a standard lactation period of 305 day yields. More advanced computational methods became available as Vallait Concept implemented by AWE based on the study by Mayeres et al (2004). One of the specific features of this method is that the lactation curve modelling included all information known of this cow including the specificity of her herd, her breed and her genetics. The used equations were set-up as mixed model equations (Henderson, 1984; Robinson, 1991), but can also be interpreted in a Bayesian setting (Blasco, 2001). Other mathematical approaches were proposed as the Kalman Filter (Van Bebber *et al*, 1999), but these were only useful when applied to daily data. With on-farm meters the limitation on the availability of data was replaced by that of finding adequate methods to limit the burden at a central database level. An adequate solution is to consider this as a two step process (Gengler, 2002) adopting adequate solving algorithms (Gengler *et al*., 2000) where herd-individual and population levels are seperated. Statistically this can be written in a more formal context using a Bayesian hierarchical modelling approach (e.g., Jamrozik *et al,* 2001). Also extending this to use more data on a farm level exchanging only specific lactation parameters (e.g., Gengler, 2002) is also straightforward.

<u>New opportunities</u>

An example for current developments leading to new opportunities is the detection and use of fine milk composition. Different research projects (e.g., MILKINIR: Nguyen *et al*., 2011) and several commercial companies are focussing on the development of on-farm tools for milk quality that are mostly based on Near InfraRed (NIR). Other projects (e.g., RobustMilk: Soyeurt *et al,* 2012; OptiMIR: Massart, 2011) are developing and/or implementing tools based on Mid InfraRed (MIR), available only through performance recording milk laboratories. Both are complementary, as NIR based measurements are easier and less expensive, available at every milking, but MIR based measurements are more precise, however only obtained every 4 weeks. If both sources of information are combined MIR will also help improve quality of NIR measurement, which can be used to make management decision on a short term. Advanced modelling of this longitudinal data generated by this type of setting combining optimal both levels: population for the performance recording and herd-individual on a herd level. This type of interactions will open numerous opportunities to optimize currently used tools. A few examples are first on an on-farm level that these tools would be near real-time during or shortly after milking but still allowing benchmarking and comparison to other farms. On an off-farm level, it would also allow quality control on the performance recording side as outliers (cf Figure 1) linked to a specific event (e.g. heat) could be more easily detected. Also, following the proposal by Gengler (2002) alternative parameters could be transmitted to the central database. These parameters would then generate new phenotypes (i.e., stability of records as an indicator of animal robustness). Boichard & Brochard (2012) gave many other opportunities created by the linking on Precision Livestock Farming and performance recording, especially for animal breeding and genetics.

## Conclusions

Recently and also through the generalisation of Internet access and the development of "cloud computing ", the development of distributed systems is becoming a reality. For Precision Livestock Farming, especially after the solving of the data exchange problem this gives numerous new opportunities on-farm but also off-farm. In particular, theory exists to develop distributed computing. It is therefore a real new opportunity for stakeholders in dairy cattle management and breeding. Given the positive interaction between performance recording agencies and manufacturers of equipment recently establish for data exchange, by adding adapted research the practical development of such systems will become a reality. This paper gave first indications what can be done, but many other opportunities exist.

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## Effect of single tube guiding milking system and periodic air inlet on the concentration of free fatty acids in conventional milking parlour

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### Abstract

Free fatty acids reduce the quality of milk and dairy products by generating a rancid and soapy taste. Their origin is the spontaneous or induced enzymatic hydrolysis of milk-fat. In this study the influence of a single tube guided milking system (MultiLactor®) on the concentration of FFA was examined. It could be shown that milking with the MultiLactor® causes an increase of the concentration of FFA in fresh milk. The FFA increase was higher for a flow rate of 1 l/min compared to a flow rate of 3 l/min.

**Keywords**: free fatty acids, quarter milking, conventional milking parlour, milk composition

### Introduction

A moderate amount of free fatty acids (FFA) is natural in milk. Jensen (1964) named an average of 0.2 – 0.6 mmol/100 g fat and 0.4 – 0.8 mmol/100 g fat FFAs in normal milk, depending on the method used for analysis, respectively. An increase of FFA caused by lipolysis reduces the quality of milk and other dairy products. High FFA can change the milk's flavour and reduce the suitability for processing (Pillay *et al*., 1980).
The concentration of FFA is dependent of three types of lipolysis, which can be spontaneous, induced or microbial (Suhren *et al*., 1981). The spontaneous lipolysis is caused by cow individual factors like for example mastitis, stage of lactation, feeding etc. The microbial lipolysis has no high importance if the plate count is under $10^6$–$10^7$ per ml. The induced lipolysis has its origin in mechanical stress for milk like milking process and pumping of milk (Suhren *et al*., 1981). The reason for induced lipolysis is a damage of the fat droplet's membrane. By destroying the membrane of fat droplets, the barrier which protected the fat from lipolysis is lost and the lipase is able to bind at the triglycerides and start lipolysis (Suhren *et al*., 1981). Mechanical stresses and changes of temperature can be a reason for this damage (Slaghuis *et al*., 2004).
Previous studies had shown that different milking systems had a changing effect on the content of FFA in milk (Slaghuis *et al*., 2004). When automatic milking systems (AMSs)

were introduced De Koning *et al.* (2003) observed an increase of FFAs concentration from 0.39 mmol/100 g fat to 0.57 mmol/100 g fat at farms in the Netherlands. An increase of FFA was confirmed by Abeni *et al.*, 2005; Klungel *et al.*, 2000; Salovou *et al.*, 2005.
A higher milking frequency could be shown as one important reason for a higher FFA level (Abeni *et al.*, 2005; Klei *et al.*, 1997; Slaghuis *et al.*, 2004; Suhren *et al.*, 1981; Wiking *et al.*, 2006). Slaghuis *et al.* (2004) saw the frequency of milking as a more important influence on the FFA content in milk than technical parameters of the milking system itself. Depending on the management system in AMSs, the cows can choose the milking frequency themselves to some extent; this can result in an increase of milking frequency in AMSs (Abeni *et al.*, 2005; Klungel *et al.*, 2000).

Slaghuis *et al.* (2004) mention the higher air intake in AMSs by attaching the cluster as well as the higher air to milk ratio of 8 : 1 to 10 : 1 in comparison to 3 : 1 in conventional milking systems as technical factors for the higher concentrations of FFA found in those milking systems. The single tube guided milking system MultiLactor® combines characteristics of both, the conventional and the automatic milking system. The attachment of the cluster is done manually in a milking parlour. Each udder-quarter is milked like in AMSs. The system works without a claw and is equipped with silicone liners, provides periodic air intake by employing the Bio-Milker®-system and applies a sequential pulsation (Rose-Meierhöfer *et al.*, 2010).

The objective of this study was to investigate the influence of the single tube guided milking system (Multilactor) on the concentration of FFA in a conventional milking parlour.

## Material and Method

<u>Sampling and milk analysis</u>
The study to investigate the influence of the MultiLactor® as well as the influence of different milk flows on the contents of FFA in Milk was carried out in the milking laboratory of the Leibniz Institute for Agricultural Engineering Potsdam Bornim (ATB), Germany. The experimental construction for the simulated milking process is shown in Figure 1. Milk samples were taken at flow rates of 1 l/min and 3 l/min. For each flow rate 20 repetitions were made. The milk was fresh raw milk taken directly from Holstein cows being milked in the milking parlour directly connected with the lab. During the experiment the machine vacuum was set to 35 kPa. The experiment was carried out on four subsequent days. The milked cows could have been different between these days. The raw milk in the tank of the milking laboratory was kept at a temperature of 30°C and was slowly stirred during the measurements to avoid the separation of fat. The milk was taken from the tank into a reservoir (FFA-1) that enabled

the regulation of flow rates. The flow was regulated by a counter vacuum regulated to 29-30 kPa for a flow of 1 l/min and to 21-22 kPa for a flow of 3 l/min. The reason for that is to reduce the mechanical stress by pumping or using flow meters. The reservoir was filled completely before every repetition to avoid vacuum fluctuations. Starting the simulated milking process, the milk passes the complete MultiLactor® milking system with the adjusted flow rate. The MultiLactor® was equipped with long milk tubes with a length of 2100 mm and diameters of 10 mm. The milk was collected in a milk can after passing the MultiLactor® (FFA-2). Duplicate samples were taken for each repetition from the tank and from the milk can, respectively. Five duplicate samples for each flow rate were taken before and after passing the milking system per test day. The samples were cooled to 10-12 °C in a running water bath for one hour. After transport to a laboratory they were stored at 4 °C for 24 h before analysis. The FFA analyses were performed after ICAR Guidelines Section 11.1 (ICAR, 2011). In the first step the total fat content was determined for all samples with the butyrometer according to the method of Gerber (IDF, 2008). For the determination of FFA the method according to Deeth (Greiling, 2000) was used. The FFA concentration is given as mmol per 100 g fat.

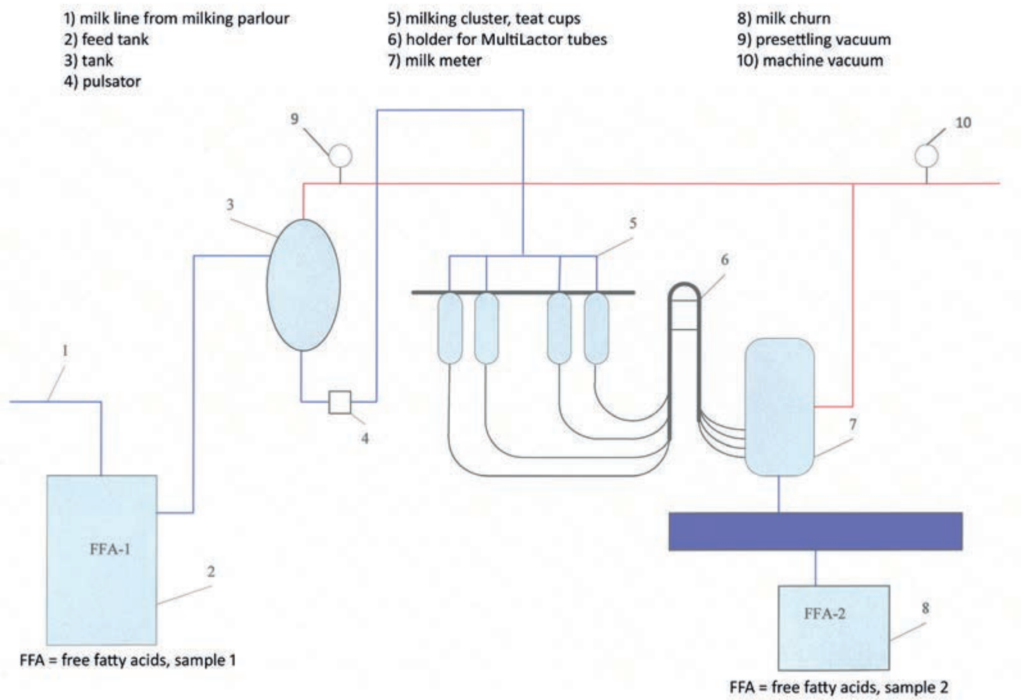


Figure 1: Experimental set up of the milking laboratory

Statistical analysis

The observed FFA values were analysed using the MIXED procedure (SAS Version 9.2, SAS Institute Inc., Cary, NC, USA). A forward stepwise modelling procedure was used with the HTYPE=1 option in the MODEL statement to add terms to the model that contributed to explaining FFA variability. Three fixed effects and their full interactions were considered in this process. The fresh milk used for each repetition per day was considered to be randomly assigned to the treatment combinations and thus was modeled as a random effect. Degrees of freedom were calculated using the Kenward-Roger method (Kenward and Roger, 1997). The significance level was defined as P < 0.05. This resulted in a mixed linear model as follows:

$$FFA_{ijkl} = \mu + DAY_i + MT_j + FLOW_k + (REP * FLOW * DAY)_{ikl} + e_{ijkl} \quad (1)$$

where $FFA_{ijkl}$ is the observed FFA concentration, μ is the general mean, $DAY_i$ is the fixed effect of test day I (1 to 4), $MT_j$ is the fixed effect of measuring time j (j = 0: before passing the milking system, j = 1: after passing the milking system), $FLOW_k$ is the fixed effect of milk flow rate k (1 l/min vs 3 l/min), $(REP*FLOW*DAY)_{ikl}$ is the random effect of milk sampled at DAY i at FLOW k during repetition REP l (1 to 5) and $e_{ijkl}$ the random error term.

Adjustments to keep the global significance level for multiple comparisons of factor levels were done using the ADJUST=SIMULATE option in the LSMEANS statement.

## Results and Discussion

During the modelling process test day, measuring time (MT) (implying the effect of the milking system) and flow rate were found to have a significant influence (P < 0.05) on FFA concentration (Table 1). The FFA values for the three significant influences are shown in Figure 2.

Table 1: Type I Test of Fixed Effects

| Effect | Num DF | Den DF | F Value | Pr > F |
|---|---|---|---|---|
| *DAY* | 3 | 18.88 | 17.29 | <.0001 |
| *MT* | 1 | 127.7 | 77.21 | <.0001 |
| *FLOW* | 1 | 86.48 | 4.02 | 0.0481 |

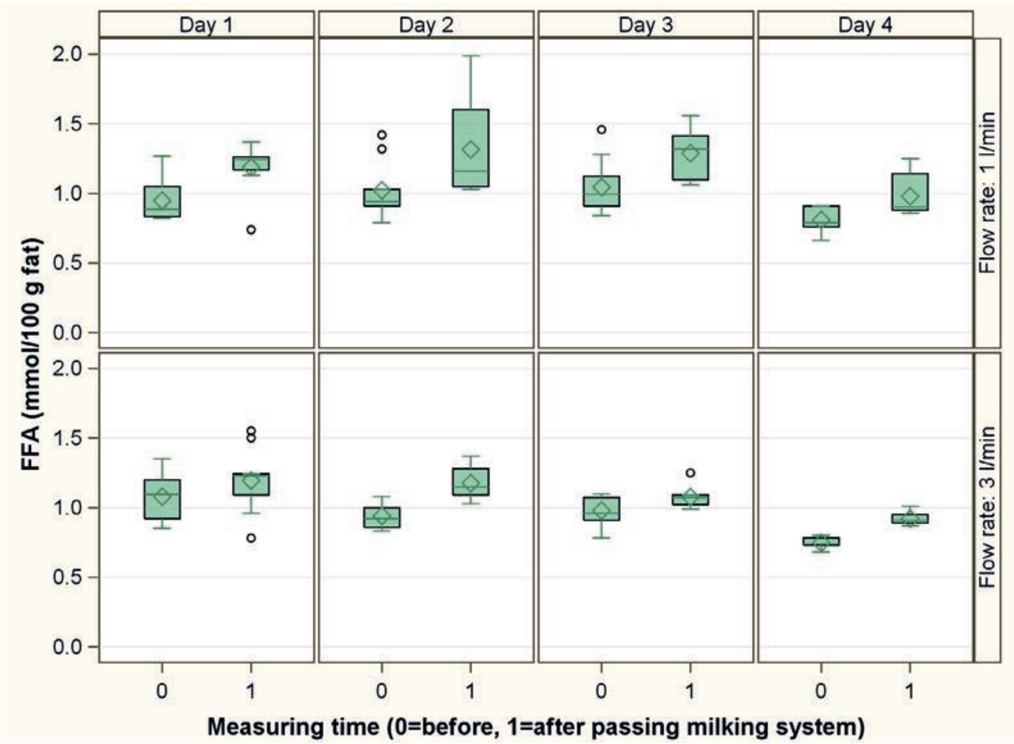

Figure 2: Free fatty acid values by block effect of test day, flow rate and measuring time

Passing the milking system led to an average increase of FFA concentration by 0.196 mmol/100 g fat compared to the tank milk. The principal results of the study were as expected. The mechanical stress induced by the milking system increased the FFA concentration from an average of 0.946 mmol/100 g fat before passing the milking system to an average of 1.142 mmol/100 g fats after passing the MultiLactor® milking system. Based on this study it could not be said which part has the most important influence on the increase of FFA caused by the MultiLactor®. Böhlen (1982) found a higher content of FFA after using the Bio-Milker®-system with periodic air intake compared to using a conventional two chamber teat cup. In contrast, Rasmussen *et al.* and Wiking *et al.*, (2006) found a positive correlation between the air intake at the teat cups and the FFA content. They detected a content of 0.77 mmol/100 g fat and 1.17 mmol/100 g fats without an air intake and an average of 1.02 mmol/100 g fats and 1.50 mmol/100g fat with an air inlet of 7 l/min in two herds, respectively. Needs *et al.* (1986) measured an increase of 21% FFA by milking with a high air intake compared to milking with low air bleed. A reduced vacuum decreases the lipolysis by about 54 % (Needs *et al.*, 1986). By comparison of these studies it can be concluded that by milking with the MultiLactor® the periodic air inlet has an important influence on the increase of FFA.

Mean FFA content was lowest on day 4 with 0.864 mmol/100 g fat, compared to concentrations ranging from 1.097 to 1.113 mmol/100 g fat for days 1 through 3. Only day 4 differed significantly from the other days in this respect, between the other days no difference was found. This could be explained with the fact that the milked cows for the experiment were chosen freely by the order in which they came to the milking parlour on testing day. So animal individual factors, like milk yield, fat percentage and fat globule size, which influence the content of FFA could be a reason for differences (Rasmussen *et al*., 2006). A reduced intake of fodder influences not only the content of FFAs in blood serum (Grabherr *et al*., 2008), it can influence the FFA content in milk as well, which Thomson *et al*. (2005) found out by an experiment with fodder restriction.

The FFA content was about 0.070 mmol/100 g fat higher at a flow rate of 1 l/min than at the flow rate of 3 l/min. This finding agrees with the results of Escobar and Bradley (1990) and Slaghuis *et al*. (2004) that mixing milk and air may cause a damage of the fat droplets membranes. For a lower milk flow rate the relation of milk and air is less favourable, which can be the reason for damage of the fat droplets and thereby also for higher FFA concentrations.

## Conclusions

The results showed that the increase of FFA is lower by using the MultiLactor® than by using an automatic or conventional milking system. Altogether in all milking systems the process of milking increases the concentration of FFA in milk. Milking in a conventional milking parlour with quarter individual milking and periodic air inlet has no negative influence on FFA of the raw milk.

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# Application of trends in body weight measurements to predict changes in body condition score

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## Abstract

Body weight and body condition score (BCS) are both related to the physical condition of dairy cows. Body weight can be measured automatically; automatic measurement of BCS is under development but not yet common in practice. Body weight and BCS are related but this relation is not straightforward. Experimental data were used to explore the relation between body weight and BCS of dairy cows. Body weight measurements of 148 dairy cows on an experimental farm during one year were available. BCS recordings were available per cow every four weeks. The objective of this research was to detect unwanted changes in BCS (sharp decline after calving, excessive rise at end of lactation) based on measurements of body weight. The body weight values were modelled, per cow and lactation, by a local trend model by applying dynamic linear modelling. This resulted in estimates of the level and trend of the body weight combined with confidence intervals. The non-zero trends in body weight were used to detect level changes in BCS. This method might be used to detect a fall in BCS after calving; however it is not specific enough to detect an excessive rise in BCS at the end of a lactation.

**Keywords:** body weight, body condition score, dynamic linear model

## Introduction

The body condition score (BCS) of a dairy cow is an assessment of the proportion of body fat that is possesses, the BCS is an important factor in dairy management (Roche *et al*., 2009). The BCS is scored on a 1-5 scale; this 5-point system is standard for dairy cattle. The scoring includes both a visual and tactile appraisal. Automated body condition scoring is subject of research but not commonly used in practice yet. A BCS of 1 indicates emaciated, 3 is average and 5 is obese. A score of 3.5-4 is desired (McNamara, 2011). Extreme scores (1 or 5) should be avoided. The intercalving BCS profile is similar to an inverted milk lactation curve, declining to a nadir at 40 to 100 d after calving as milk production peaks, before replenishing lost body as the milk lactation profile declines (Roche *et al*., 2009). BCS values should be compared within-cow. The BCS loss after calving and before peak production should be no more than 1-1.5 units (McNamara, 2011) and should not fall below 2.5 (Roche *et al*., 2009). At the

end of a lactation and during the dry period, the BCS should not rise above 4.
Body weight and BCS are related but this relation is not straightforward. This relation has been subject of extensive research, e.g. Berry *et al.* (2006), Buckley *et al.* (2003) and Thorup *et al.* (2012). BCS is indicator of the fattiness of a cow, the presence of a calve influences the cow's body weight but not necessarily the BCS. The body weight fluctuates during the day due to several influences (e.g. drinking bouts, urinating, milking).
The objective of this research was to detect unwanted changes in BCS (sharp decline after calving, excessive rise at end of lactation) based on measurements of body weight. This method is advantageous as body weight can be measured automatically while BCS has to be recorded by visual observations.

## Material and methods

Measurements of body weight of 148 dairy cows at the Dairy research farm "De Waiboerhoeve", of Wageningen UR Livestock Research in Lelystad, the Netherlands during one year (May 2011–April 2012) were available. The cows were housed without grazing in a free-stall barn with individual cubicles and a concrete slatted floor. The cows were milked twice a day in a ten stands open tandem milking parlour with electronic cow identification and milk flow recording. Body weight was measured automatically on entrance to the milking parlour during lactation and furthermore twice a week in the dry period. BCS recordings were available per cow every four weeks. Cow calendar data and recordings of cases of oestrus and diseases were available from the farm management system.
The model used to describe the body weight reflected the fact that the weight on successive milkings was related but might change over time. A linear trend model was used, where the weight shows a certain level that is changing in the course of time due to a linear trend:

$$W_m = \mu_m + \nu_m, \qquad (1)$$

$$\mu_m = \mu_{m-1} + \alpha_{m-1} + \omega_{1m}, \qquad (2)$$

$$\alpha_t = \alpha_{t-1} + \omega_{2m}, \qquad (3)$$

where:
$W_m$ = observed weight at milking m;
$\mu_m$ = level at milking m;
$\alpha_m$ = linear trend at milking m;
$\nu_m$ = observational error;
$\omega_{im}$ = system error (i = 1, 2).

The parameters in the linear trend model were time-dependent to reflect that they might change with time. The values of the parameters in the linear trend model should be known to be able to use this model for detection purposes, therefore the parameters were fitted on-line with a dynamic linear model (DLM) as in de Mol *et al.* (2013). This resulted in fitted values of the level and trend (with confidence interval) per milking for each cow and lactation. An example of the available data and the fitted parameters is given in Figure 1. The cow in Figure 1 was in her third lactation after February 2, 2011 till the dry period starting on November 24. She calved again on January 16, 2012 (day 381 since 1/1/2011). The fitted values for the weight level with confidence interval are included in the top left graph, the fitted values for the weight trend with confidence interval are included the middle right graph. For the analysis it was assumed that the trend is positive when the lower boundary of the confidence interval was above zero (e.g. at day 300); it was negative when the upper bound of the confidence interval was below zero (e.g. at day 400).

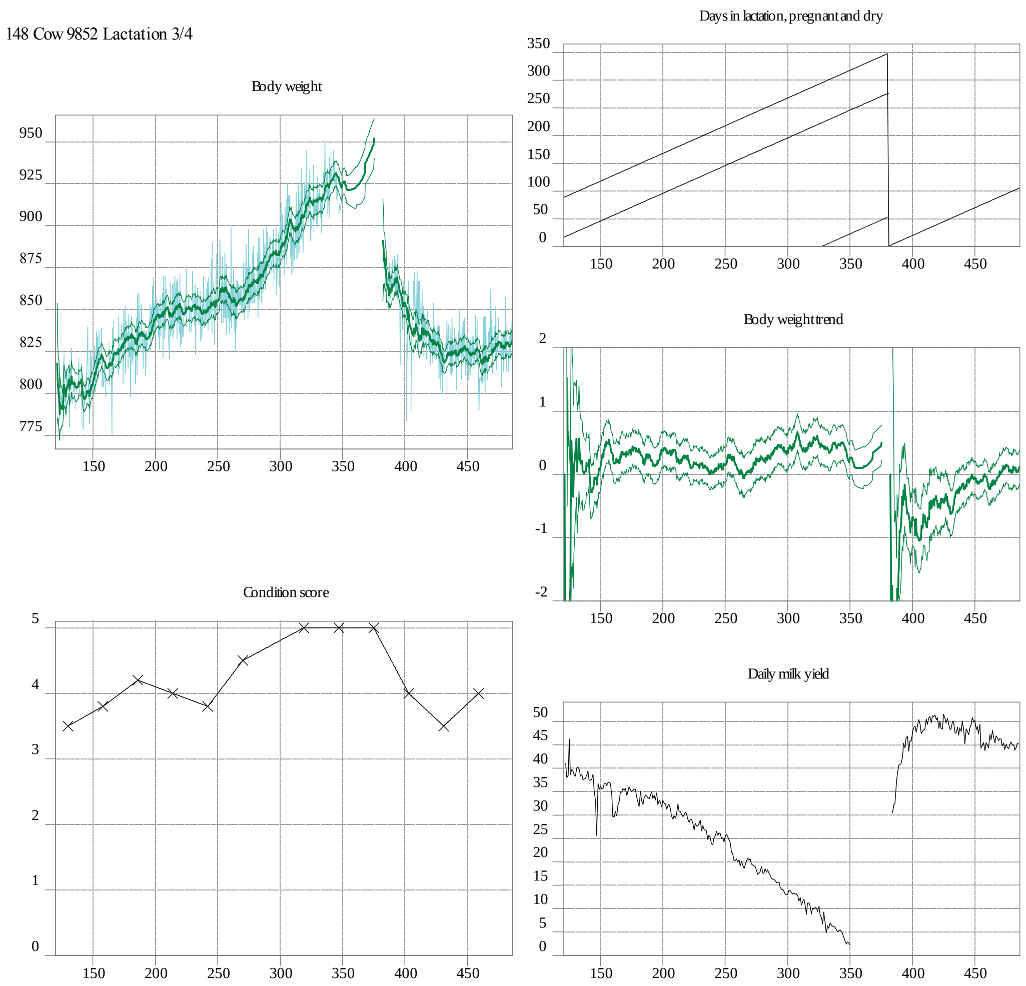


Figure 1: Example of the available data and fitted parameters for the 148th cow per milking (day since 1/1/2011 at horizontal axis), top left: body weight per milking with fitted level and confidence interval; bottom left: BCS; top right: cow status: days in lactation (solid line), pregnant days (striped) and dry days (dotted); middle right: fitted trend and confidence interval; bottom: right milk yield per day; further explanation in text

The analysis was focussed on cows with:

- more than 1 point decline in BCS after calving;
- excessive rise at end of lactation resulting in a BCS of more than 4.

These cows should be alerted and the farmer should keep an eye on them. The detection method was based on the number of successive days with a positive or negative trend and the maximum level of the trend during these days:

- a cow was alerted after calving when:
  - o the number of days with a negative trend was at least 14 or
  - o the number of days with a negative trend was less than 14 but at least 7 days and the minimum level was less than -1.
- a cow was alerted at the end of a lactation when:
  - o the number of days with a positive trend was at least 28 or
  - o the number of days with a positive trend was less than 28 but at least 14 days and the maximum level was more than -0.5.

The BCS of cow 9852 (Figure 1) rose up to 5 at the end of lactation 3, the model alerted for that as the number of successive days with a positive trend was 62 (with a maximum of 0.7). This cow had also more than one point decline in BCS in the beginning of lactation 4; the model alerted for that as the number of successive days with a negative trend was 18 (with a minimum of -3.6).
Each lactation with a decline in the beginning (or a rise at the end) was True Positive (TP) when the model generated an alert for it; otherwise it was False Negative (FN). A lactation without a decline in the beginning (or a rise at the end) was False Positive (FP) when the model generated an alert; otherwise it was True Negative (TN).

**Results and discussion**

Measurements of body weight and BCS of 148 cows during one year were available. These data included:

- 115 cows at the beginning of a lactation with the peak production included, of which 52 (45%) with a decline in the beginning;
- 137 cows at the end of a lactation, of which 41 (30%) reached a BCS level above 4.

The detection results are included in Table 1 (beginnings of lactation) and Table 2 (ends of lactation). Detailed results per cow are given in the annex.

Table 1: Analysis results for the 115 beginnings of lactation in the dataset

| | decline in BCS more than 1 | decline in BCS less than 1 |
|---|---|---|
| alert for decline | TP: 50 | FP: 37 |
| no alert for decline | FN: 2 | TN: 26 |

There were 52 lactations with a sharp decline in the beginning, 50 were detected, so the sensitivity (percentage of detected cases) was 96%. Also 37 of the 63 cases without a sharp decline were alerted, so the specificity (the percentage truly not detected cases) was rather low: 41%.

Table 2: Analysis results for the 137 ends of lactation in the dataset

| | level of BCS more than 4 | level of BCS not more than 4 |
|---|---|---|
| alert for increase | TP: 39 | FP: 81 |
| no alert for increase | FN: 2 | TN: 15 |

There were 41 lactations where the BCS became more than 4 at the end, 39 were detected, so the sensitivity (percentage of detected cases) was 95%. Also 81 of the 96 cases where the BCS became not more than 4 were alerted, so the specificity (the percentage truly not detected cases) was extreme low: 16%.

## Conclusions

A decline in BCS at the beginning of a lactation can be detected by a negative trend in body weight. An alert can be false positive, but a cow without an alert on weight has almost sure no problems with the BCS, An unwanted peak in the BCS at the end of a lactation is more difficult to detect by changes in the body weight because almost all cows do have a positive trend in this stage.


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## Annex: Per cow, left: analysis of end of lactation, right: analysis of begin of lactation

| number | cow | lactation | BCS from | BCS to | nr of days with positive trend | maximum level | alert | classification | lactation | BCS from | BCS to | BCS change | nr of days with negative trend | minimum trend | alert | classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1033 | 3 | 4.00 | 3.00 | 64 | 0.7 | 1 | FP | 4 | 3.00 | 1.25 | -1.75 | 46 | -6.8 | 1 | TP |
| 2 | 1180 | 6 | 2.50 | 2.50 | 0 | -0.3 | 0 | TN | 7 | 2.00 | 1.00 | -1.00 | 4 | -0.3 | 0 | TN |
| 3 | 2047 | 8 | 3.50 | 3.00 | 41 | 0.7 | 1 | FP | 9 | 3.00 | 2.00 | -1.00 | 17 | -12.3 | 1 | FP |
| 4 | 2124 | 3 | 4.00 | 5.00 | 99 | 1.3 | 1 | TP | 4 | 5.00 | 3.00 | -2.00 | 72 | -12.1 | 1 | TP |
| 5 | 2156 | 3 | 3.00 | 2.75 | 17 | 0.6 | 1 | FP | 4 | 2.75 | 2.00 | -0.75 | 14 | -3.4 | 1 | FP |
| 6 | 2165 | 4 | 3.00 | 4.00 | 50 | 0.8 | 1 | FP | 4 | | | | | | 0 | |
| 7 | 2200 | 2 | 3.50 | 4.25 | 36 | 0.6 | 1 | TP | 3 | 4.25 | 2.50 | -1.75 | 45 | -2.0 | 1 | TP |
| 8 | 2220 | 2 | 3.25 | 3.50 | 26 | 1.8 | 1 | FP | 3 | 3.50 | 1.75 | -1.75 | 51 | -1.9 | 1 | TP |
| 9 | 2238 | 2 | | | | | 0 | | 3 | 3.00 | 1.50 | -1.50 | 25 | -1.4 | 1 | TP |
| 10 | 2244 | 3 | 3.00 | 3.50 | 71 | 0.9 | 1 | FP | 4 | | | | | | 0 | |
| 11 | 2246 | 3 | 2.25 | 3.50 | 27 | 0.8 | 1 | FP | 4 | | | | | | 0 | |
| 12 | 2281 | 2 | | | | | 0 | | 3 | 2.25 | 1.50 | -0.75 | 12 | -3.1 | 1 | FP |
| 13 | 2544 | 3 | 3.75 | 4.50 | 53 | 0.7 | 1 | TP | 4 | 3.25 | 2.75 | -0.50 | 41 | -3.8 | 1 | FP |
| 14 | 3289 | 7 | 2.50 | 3.00 | 20 | 0.4 | 0 | TN | 7 | | | 0.00 | | | 0 | TN |
| 15 | 3478 | 5 | 2.00 | 3.00 | 50 | 0.6 | 1 | FP | 6 | 3.00 | 2.25 | -0.75 | 8 | -7.4 | 1 | FP |
| 16 | 3522 | 5 | 3.50 | 4.75 | 25 | 0.7 | 1 | TP | 6 | 3.75 | 3.00 | -0.75 | 10 | -9.1 | 1 | FP |
| 17 | 3527 | 6 | 2.50 | 3.00 | 86 | 0.8 | 1 | FP | 7 | 3.00 | 1.50 | -1.50 | 7 | -10.9 | 1 | TP |
| 18 | 3530 | 5 | 1.00 | 1.75 | 22 | 0.5 | 1 | FP | 6 | 1.75 | 1.00 | -0.75 | 16 | -4.9 | 1 | FP |
| 19 | 3604 | 5 | 1.25 | 1.50 | 10 | 0.5 | 0 | TN | 6 | 1.50 | 1.00 | -0.50 | 2 | -6.6 | 0 | TN |
| 20 | 3672 | 5 | 1.75 | 2.25 | 18 | 0.5 | 1 | FP | 6 | 2.25 | 1.25 | -1.00 | 4 | -13.0 | 0 | TN |
| 21 | 3675 | 4 | 1.75 | 3.00 | 43 | 1.2 | 1 | FP | 5 | 3.00 | 2.00 | -1.00 | 3 | -1.3 | 0 | TN |
| 22 | 3699 | 4 | 2.25 | 2.75 | 30 | 0.9 | 1 | FP | 5 | 2.75 | 2.25 | -0.50 | 23 | -1.2 | 1 | FP |
| 23 | 3707 | 5 | 3.25 | 4.00 | 81 | 0.8 | 1 | FP | 6 | 4.00 | 3.00 | -1.00 | 26 | -1.1 | 1 | FP |
| 24 | 3721 | 5 | 3.00 | 3.25 | 37 | 0.8 | 1 | FP | 6 | 3.25 | 2.00 | -1.25 | 25 | -1.9 | 1 | TP |
| 25 | 3727 | 4 | 1.50 | 2.00 | 4 | 0.3 | 0 | TN | 4 | | | | | | 0 | |
| 26 | 3740 | 4 | 2.50 | 3.00 | 37 | 0.6 | 1 | FP | 5 | 3.00 | 2.00 | -1.00 | 15 | -1.0 | 1 | FP |
| 27 | 3751 | 5 | 3.25 | 3.75 | 29 | 0.7 | 1 | FP | 5 | | | | | | 0 | |
| 28 | 3756 | 4 | 2.50 | 3.50 | 43 | 0.7 | 1 | FP | 4 | | | | | | 0 | |
| 29 | 3778 | 3 | 2.75 | 3.25 | 38 | 0.8 | 1 | FP | 4 | 3.25 | 1.25 | -2.00 | 26 | -2.3 | 1 | TP |
| 30 | 3833 | 3 | 3.50 | 4.25 | 42 | 0.6 | 1 | TP | 4 | 3.50 | 1.50 | -2.00 | 15 | -6.2 | 1 | TP |
| 31 | 3853 | 2 | 2.00 | 3.50 | 44 | 0.7 | 1 | FP | 3 | 3.50 | 2.00 | -1.50 | 20 | -6.7 | 1 | TP |
| 32 | 3857 | 3 | 2.25 | 3.00 | 24 | 0.5 | 1 | FP | 3 | | | | | | 0 | |
| 33 | 3872 | 2 | 3.00 | 5.00 | 94 | 0.7 | 1 | TP | 2 | | | | | | 0 | |
| 34 | 3874 | 2 | 2.00 | 2.00 | 52 | 0.9 | 1 | FP | 3 | 2.00 | 3.50 | 1.50 | 0 | 0.0 | 0 | TN |

| number | cow | lactation | BCS from | BCS to | nr of days with positive trend | maximum level | alert | classification | lactation | BCS from | BCS to | BCS change | nr of days with negative trend | minimum trend | alert | classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 3875 | 2 | 2.00 | 3.00 | 7 | 0.4 | 0 | TN | 2 | | | | | | 0 | |
| 36 | 3919 | 4 | 3.00 | 3.50 | 29 | 0.5 | 1 | FP | 5 | 3.25 | 3.50 | 0.25 | 7 | -1.8 | 1 | FP |
| 37 | 3920 | 2 | | | | | 0 | | 3 | 3.50 | 2.50 | -1.00 | 6 | -2.3 | 0 | TN |
| 38 | 3925 | 3 | 2.25 | 3.00 | 47 | 0.8 | 1 | FP | 4 | 3.25 | 1.75 | -1.50 | 36 | -3.1 | 1 | TP |
| 39 | 3926 | 4 | 4.50 | 5.00 | 25 | 1.5 | 1 | | 5 | 5.00 | 2.00 | -3.00 | 23 | -1.0 | 1 | TP |
| 40 | 3933 | 3 | | | | | 0 | | 4 | 2.75 | 1.75 | -1.00 | 10 | -3.5 | 1 | FP |
| 41 | 3940 | 5 | 2.00 | 2.50 | 6 | 34.0 | 0 | TN | 6 | 2.50 | 1.25 | -1.25 | 15 | -5.0 | 1 | TP |
| 42 | 3949 | 3 | 4.50 | 5.00 | 69 | 0.8 | 1 | TP | 4 | | | | | | 0 | |
| 43 | 3968 | 2 | 4.50 | 4.00 | 21 | 0.6 | 1 | FP | 3 | 4.00 | 2.75 | -1.25 | 51 | -6.7 | 1 | TP |
| 44 | 3975 | 2 | 2.50 | 3.00 | 17 | 0.9 | 1 | FP | 3 | 3.00 | 2.25 | -0.75 | 38 | -1.4 | 1 | FP |
| 45 | 3990 | 2 | 3.25 | 4.00 | 60 | 0.5 | 1 | FP | 3 | 4.00 | 3.00 | -1.00 | 5 | -2.5 | 0 | TN |
| 46 | 3993 | 2 | 2.75 | 3.50 | 89 | 0.8 | 1 | FP | 3 | 3.50 | 1.75 | -1.75 | 33 | -0.6 | 1 | TP |
| 47 | 4001 | 2 | 3.25 | 3.50 | 30 | 0.4 | 1 | FP | 3 | 3.25 | 2.25 | -1.00 | 37 | -7.8 | 1 | FP |
| 48 | 4008 | 4 | 3.50 | 4.00 | 9 | 0.3 | 0 | TN | 4 | | | | | | 0 | |
| 49 | 4038 | 4 | 3.50 | 4.50 | 50 | 0.5 | 1 | TP | 5 | | | | | | 0 | |
| 50 | 4199 | 4 | 1.00 | 1.50 | 59 | 10.7 | 1 | FP | 5 | 1.50 | 2.00 | 0.50 | 6 | -0.7 | 0 | TN |
| 51 | 4210 | 4 | 3.00 | 3.50 | 36 | 0.7 | 1 | FP | 5 | 3.50 | 2.25 | -1.25 | 26 | -2.3 | 1 | TP |
| 52 | 4276 | 3 | 2.50 | 3.25 | 41 | 0.5 | 1 | FP | 4 | 3.00 | 3.50 | 0.50 | 4 | -12.3 | 0 | TN |
| 53 | 4282 | 4 | 2.75 | 4.75 | 40 | 0.8 | 1 | TP | 5 | 4.75 | 3.50 | -1.25 | 19 | -1.4 | 1 | TP |
| 54 | 4298 | 4 | 2.75 | 3.25 | 35 | 1.1 | 1 | FP | 5 | 3.25 | 3.00 | -0.25 | 19 | -3.1 | 1 | FP |
| 55 | 4310 | 4 | 3.00 | 3.50 | 21 | 0.7 | 1 | FP | 5 | 3.50 | 3.00 | -0.50 | 15 | -12.7 | 1 | FP |
| 56 | 4332 | 3 | 2.50 | 2.25 | 21 | 2.3 | 1 | FP | 4 | 2.25 | 1.75 | -0.50 | 29 | -2.8 | 1 | FP |
| 57 | 4341 | 4 | 2.50 | 3.00 | 14 | 0.4 | 0 | TN | 5 | 2.75 | 2.00 | -0.75 | 5 | -20.1 | 0 | TN |
| 58 | 4359 | 4 | 2.00 | 3.25 | 32 | 0.9 | 1 | FP | 5 | 2.50 | 1.00 | -1.50 | 32 | -5.6 | 1 | TP |
| 59 | 4430 | 4 | 3.00 | 4.50 | 38 | 0.8 | 1 | | 4 | | | | | | 0 | |
| 60 | 4458 | 3 | | | | | 0 | | 4 | 3.25 | 2.50 | -0.75 | 2 | -11.2 | 0 | TN |
| 61 | 4647 | 3 | 3.00 | 3.50 | 40 | 0.7 | 1 | FP | 4 | 3.50 | 2.25 | -1.25 | 39 | -5.3 | 1 | TP |
| 62 | 4669 | 2 | | | | | 0 | | 3 | 3.00 | 2.00 | -1.00 | 29 | -1.3 | 1 | FP |
| 63 | 4674 | 3 | 2.50 | 3.25 | 28 | 0.5 | 1 | FP | 4 | 3.00 | 2.50 | -0.50 | 17 | -5.6 | 1 | FP |
| 64 | 4676 | 3 | 3.25 | 3.75 | 15 | 0.4 | 0 | TN | 4 | 3.25 | 1.50 | -1.75 | 29 | -1.0 | 1 | TP |
| 65 | 4682 | 3 | 3.25 | 4.25 | 15 | 0.5 | 1 | TP | 3 | | | | | | 0 | |
| 66 | 4694 | 3 | 4.50 | 5.00 | 54 | 1.0 | 1 | TP | 4 | 5.00 | 3.50 | -1.50 | 62 | -9.4 | 1 | TP |
| 67 | 4712 | 3 | 2.50 | 3.25 | 55 | 0.8 | 1 | FP | 4 | 3.25 | 2.00 | -1.25 | 36 | -6.1 | 1 | TP |
| 68 | 4714 | 3 | 4.00 | 5.00 | 122 | 0.8 | 1 | TP | 4 | 5.00 | 2.50 | -2.50 | 65 | -3.9 | 1 | TP |
| 69 | 4757 | 3 | 2.50 | 3.00 | 41 | 0.6 | 1 | FP | 4 | 3.00 | 2.25 | -0.75 | 23 | -2.7 | 1 | FP |
| 70 | 4774 | 3 | 3.75 | 5.00 | 42 | 0.6 | 1 | TP | 4 | 5.00 | 2.50 | -2.50 | 43 | -6.7 | 1 | TP |
| 71 | 4792 | 3 | 3.50 | 5.00 | 94 | 0.6 | 1 | TP | 4 | 5.00 | 2.75 | -2.25 | 38 | -9.0 | 1 | TP |
| 72 | 4797 | 3 | 2.25 | 2.50 | 3 | 0.3 | 0 | TN | 3 | | | | | | 0 | |
| 73 | 4801 | 2 | 2.00 | 2.25 | 18 | 0.4 | 0 | TN | 3 | 2.25 | 1.25 | -1.00 | 0 | 0.0 | 0 | TN |
| 74 | 4805 | 3 | 3.25 | 3.50 | 56 | 0.6 | 1 | FP | 4 | 3.25 | 2.00 | -1.25 | 38 | -2.4 | 1 | TP |
| 75 | 4825 | 3 | 2.25 | 2.75 | 15 | 0.5 | 1 | FP | 4 | 2.75 | 3.00 | 0.25 | 12 | -3.6 | 1 | FP |
| 76 | 4887 | 3 | 3.50 | 5.00 | 26 | 0.6 | 1 | TP | 3 | | | | | | 0 | |
| 77 | 4890 | 2 | | | | | 0 | | 3 | 3.00 | 2.00 | -1.00 | 43 | -1.7 | 1 | FP |
| 78 | 4894 | 3 | 3.00 | 3.50 | 20 | 0.7 | 1 | FP | 3 | | | | | | 0 | |
| 79 | 4903 | 3 | | | | | 0 | TP | 3 | | | | | | 0 | |

| number | cow | lactation | BCS from | BCS to | nr of days with positive trend | maximum level | alert | classification | lactation | BCS from | BCS to | BCS change | nr of days with negative trend | minimum trend | alert | classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | 4913 | 3 | 3.00 | 3.75 | 71 | 0.8 | 1 | FP | 3 | 3.50 | 2.50 | -1.00 | 27 | -1.7 | 1 | FP |
| 81 | 4914 | 2 | 3.00 | 4.00 | 106 | 0.8 | 1 | FP | 3 | 4.00 | 1.50 | -2.50 | 54 | -2.3 | 1 | TP |
| 82 | 4918 | 3 | 3.00 | 4.00 | 88 | 0.6 | 1 | FP | 4 | 3.25 | 1.75 | -1.50 | 26 | -1.6 | 1 | TP |
| 83 | 4919 | 2 | 3.75 | 3.75 | 35 | 1.8 | 1 | FP | 3 | 3.75 | 3.00 | -0.75 | 14 | -2.6 | 1 | FP |
| 84 | 4927 | 2 | 2.25 | 3.75 | 43 | 0.9 | 1 | FP | 3 | 3.75 | 2.00 | -1.75 | 39 | -7.2 | 1 | TP |
| 85 | 4946 | 3 | 5.00 | 5.00 | 27 | 0.8 | 1 | TP | 4 | 5.00 | 4.50 | -0.50 | 25 | -5.1 | 1 | FP |
| 86 | 4952 | 2 | 3.25 | 3.75 | 28 | 0.6 | 1 | FP | 3 | 3.75 | 3.00 | -0.75 | 22 | -1.6 | 1 | FP |
| 87 | 4953 | 2 | 2.75 | 3.75 | 51 | 1.2 | 1 | FP | 3 | 3.75 | 1.75 | -2.00 | 13 | -14.3 | 1 | TP |
| 88 | 4972 | 2 | 4.00 | 5.00 | 53 | 0.8 | 1 | TP | 3 | | | | | | 0 | |
| 89 | 4974 | 2 | 3.00 | 4.50 | 45 | 0.9 | 1 | | 3 | 4.50 | 2.50 | -2.00 | 54 | -4.9 | 1 | TP |
| 90 | 4978 | 2 | 2.00 | 2.25 | 30 | 1.0 | 1 | FP | 3 | 1.00 | 3.00 | 2.00 | 0 | 0.0 | 0 | TN |
| 91 | 4980 | 2 | 5.00 | 5.00 | 104 | 0.6 | 1 | TP | 3 | 4.00 | 2.25 | -1.75 | 57 | -4.5 | 1 | TP |
| 92 | 4981 | 2 | 2.25 | 2.00 | 13 | 0.6 | 0 | TN | 3 | 2.00 | 2.00 | 0.00 | 0 | 0.0 | 0 | TN |
| 93 | 4985 | 2 | 4.50 | 4.00 | 16 | 0.4 | 0 | TN | 3 | 4.00 | 4.00 | 0.00 | 1 | -7.1 | 0 | TN |
| 94 | 4986 | 3 | 2.50 | 3.25 | 36 | 0.7 | 1 | FP | 4 | 3.25 | 1.25 | -2.00 | 9 | -1.5 | 1 | TP |
| 95 | 4990 | 2 | 3.00 | 3.25 | 52 | 1.1 | 1 | FP | 3 | 3.25 | 2.75 | -0.50 | 4 | -1.0 | 0 | TN |
| 96 | 4992 | 2 | | | | | 0 | | 4 | 3.25 | 2.25 | -1.00 | 24 | -0.8 | 1 | FP |
| 97 | 4996 | 2 | 3.50 | 3.50 | 6 | 0.4 | 0 | TN | 3 | 3.00 | 2.75 | -0.25 | 17 | -2.2 | 1 | FP |
| 98 | 4998 | 2 | 4.50 | 5.00 | 113 | 0.6 | 1 | TP | 3 | 5.00 | 3.00 | -2.00 | 46 | -6.3 | 1 | TP |
| 99 | 5002 | 2 | 3.50 | 4.00 | 33 | 0.7 | 1 | FP | 3 | 4.00 | 2.00 | -2.00 | 40 | -5.8 | 1 | TP |
| 100 | 5008 | 2 | 3.50 | 4.00 | 29 | 2.4 | 1 | FP | 3 | 4.00 | 3.50 | -0.50 | 4 | -0.4 | 0 | TN |
| 101 | 5025 | 2 | 2.75 | 3.50 | 30 | 0.7 | 1 | FP | 3 | 3.50 | 1.50 | -2.00 | 33 | -2.0 | 1 | TP |
| 102 | 5040 | 2 | 2.00 | 3.50 | 74 | 1.1 | 1 | FP | 3 | 3.50 | 2.50 | -1.00 | 4 | -2.3 | 0 | TN |
| 103 | 5042 | 2 | 3.50 | 3.75 | 79 | 0.7 | 1 | FP | 3 | 2.50 | 3.00 | 0.50 | 3 | -10.0 | 0 | TN |
| 104 | 5045 | 2 | 3.75 | 5.00 | 58 | 0.7 | 1 | | 3 | 4.00 | 2.25 | -1.75 | 52 | -7.7 | 1 | TP |
| 105 | 5058 | 2 | 4.50 | 5.00 | 89 | 0.7 | 1 | | 3 | | | | | | 0 | |
| 106 | 5059 | 2 | 2.75 | 3.00 | 55 | 0.9 | 1 | FP | 3 | 3.00 | 2.25 | -0.75 | 6 | -5.0 | 0 | TN |
| 107 | 5067 | 2 | | | | | 0 | | 3 | 3.00 | 2.00 | -1.00 | 26 | -3.6 | 1 | FP |
| 108 | 5092 | 2 | | | | | 0 | | 2 | | | | | | 0 | |
| 109 | 5097 | 2 | 3.50 | 5.00 | 78 | 0.7 | 1 | | 3 | | | | | | 0 | |
| 110 | 5131 | 2 | 2.00 | 3.50 | 29 | 0.7 | 1 | FP | 3 | 3.50 | 1.25 | -2.25 | 34 | -5.9 | 1 | TP |
| 111 | 5133 | 2 | 4.50 | 5.00 | 110 | 0.7 | 1 | TP | 3 | 5.00 | 3.25 | -1.75 | 69 | -6.6 | 1 | TP |
| 112 | 5136 | 2 | 2.00 | 4.25 | 54 | 0.6 | 1 | TP | 3 | 4.25 | 1.75 | -2.50 | 30 | -11.3 | 1 | TP |
| 113 | 5141 | 2 | 3.00 | 3.50 | 86 | 0.7 | 1 | FP | 3 | 3.00 | 2.00 | -1.00 | 54 | -5.4 | 1 | FP |
| 114 | 5143 | 2 | 4.75 | 5.00 | 52 | 0.7 | 1 | TP | 3 | 3.50 | 2.25 | -1.25 | 21 | -0.9 | 1 | TP |
| 115 | 5153 | 2 | 3.25 | 4.50 | 25 | 0.4 | 0 | FN | 3 | 3.25 | 3.00 | -0.25 | 13 | -2.0 | 1 | FP |
| 116 | 5158 | 2 | 4.50 | 5.00 | 59 | 0.4 | 1 | TP | 3 | | | | | | 0 | |
| 117 | 5169 | 2 | 3.00 | 2.50 | 61 | 1.3 | 1 | FP | 3 | 2.50 | 2.00 | -0.50 | 4 | -13.9 | 0 | TN |
| 118 | 5173 | 2 | 2.00 | 3.00 | 50 | 1.1 | 1 | FP | 3 | 3.00 | 2.25 | -0.75 | 20 | -4.5 | 1 | FP |
| 119 | 5179 | 2 | 4.50 | 5.00 | 57 | 0.6 | 1 | | 3 | 5.00 | 4.00 | -1.00 | 30 | -12.8 | 1 | FP |
| 120 | 5183 | 2 | 3.00 | 4.25 | 22 | 0.6 | 1 | TP | 3 | 4.25 | 2.00 | -2.25 | 21 | -7.8 | 1 | TP |
| 121 | 5187 | 2 | 3.00 | 3.50 | 64 | 0.9 | 1 | FP | 3 | 3.50 | 3.00 | -0.50 | 1 | -0.8 | 0 | TN |
| 122 | 5198 | 2 | 2.00 | 3.00 | 30 | 0.7 | 1 | FP | 3 | 3.00 | 1.25 | -1.75 | 42 | -4.1 | 1 | TP |
| 123 | 5200 | 2 | 1.75 | 2.50 | 39 | 0.8 | 1 | FP | 3 | 2.50 | 1.00 | -1.50 | 3 | -8.5 | 0 | FN |
| 124 | 5201 | 2 | 3.75 | 5.00 | 84 | 1.0 | 1 | TP | 3 | 4.50 | 3.50 | -1.00 | 20 | -1.8 | 1 | FP |

| number | cow | lactation | BCS from | BCS to | nr of days with positive trend | maximum level | alert | classification | lactation | BCS from | BCS to | BCS change | nr of days with negative trend | minimum trend | alert | classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125 | 5204 | 2 | 4.00 | 5.00 | 92 | 0.6 | 1 | TP | 3 | 3.50 | 2.00 | -1.50 | 54 | -14.0 | 1 | TP |
| 126 | 5209 | 2 | 4.00 | 4.50 | 76 | 0.8 | 1 | TP | 3 | 4.50 | 2.75 | -1.75 | 22 | -0.7 | 1 | TP |
| 127 | 5216 | 2 | 2.25 | 3.25 | 36 | 0.7 | 1 | FP | 3 | 3.00 | 2.00 | -1.00 | 33 | -3.6 | 1 | FP |
| 128 | 5219 | 2 | 3.00 | 2.75 | 22 | 0.8 | 1 | FP | 3 | 2.75 | 2.50 | -0.25 | 32 | -1.3 | 1 | FP |
| 129 | 5228 | 2 | 2.75 | 3.50 | 70 | 0.9 | 1 | FP | 3 | | | | | | 0 | |
| 130 | 5235 | 2 | 2.00 | 2.75 | 25 | 0.9 | 1 | FP | 3 | 2.75 | 2.00 | -0.75 | 19 | -3.8 | 1 | FP |
| 131 | 5236 | 2 | 2.00 | 3.00 | 26 | 0.5 | 1 | FP | 3 | 3.00 | 3.25 | 0.25 | 0 | 0.0 | 0 | TN |
| 132 | 5256 | 2 | 4.50 | 5.00 | 20 | 0.4 | 0 | FN | 2 | | | | | | 0 | |
| 133 | 5272 | 2 | 1.50 | 2.25 | 3 | 0.2 | 0 | TN | 2 | | | | | | 0 | |
| 134 | 5275 | 2 | 3.50 | 5.00 | 103 | 0.9 | 1 | TP | 3 | | | | | | 0 | |
| 135 | 5276 | 2 | 3.25 | 3.50 | 57 | 0.8 | 1 | FP | 3 | 3.50 | 2.25 | -1.25 | 7 | -0.9 | 0 | FN |
| 136 | 5279 | 2 | 2.50 | 4.00 | 104 | 1.0 | 1 | FP | 3 | 4.00 | 2.25 | -1.75 | 17 | -2.9 | 1 | TP |
| 137 | 5289 | 2 | 2.25 | 3.50 | 47 | 0.5 | 1 | FP | 3 | 3.50 | 2.75 | -0.75 | 10 | -0.8 | 0 | TN |
| 138 | 5291 | 2 | 4.00 | 5.00 | 34 | 2.0 | 1 | TP | 2 | | | | | | 0 | |
| 139 | 5321 | 2 | 3.50 | 4.75 | 19 | 0.8 | 1 | TP | 2 | 3.00 | 2.75 | -0.25 | 9 | -0.6 | 0 | TN |
| 140 | 5340 | 2 | 2.75 | 4.00 | 29 | 0.7 | 1 | FP | 2 | | | | | | 0 | |
| 141 | 5384 | 2 | 4.50 | 5.00 | 64 | 0.7 | 1 | TP | 2 | | | | | | 0 | |
| 142 | 5402 | 1 | 2.50 | 2.75 | 33 | 0.9 | 1 | FP | 2 | 2.75 | 1.50 | -1.25 | 32 | -2.3 | 1 | TP |
| 143 | 5442 | 2 | 3.00 | 4.00 | 87 | 0.8 | 1 | FP | 2 | | | | | | 0 | |
| 144 | 5465 | 2 | 2.00 | 2.75 | 29 | 0.8 | 1 | FP | 2 | 3.00 | 1.75 | -1.25 | 11 | -1.2 | 1 | TP |
| 145 | 9286 | 3 | 3.50 | 3.50 | 64 | 0.7 | 1 | FP | 4 | 3.50 | 2.00 | -1.50 | 43 | -2.5 | 1 | TP |
| 146 | 9685 | 5 | 2.00 | 2.50 | 33 | 0.8 | 1 | FP | 5 | | | | | | 0 | |
| 147 | 9712 | 5 | 2.50 | 3.00 | 20 | 0.6 | 1 | FP | 5 | | | | | | 0 | |
| 148 | 9852 | 3 | 3.75 | 5.00 | 62 | 0.7 | 1 | TP | 4 | 5.00 | 3.50 | -1.50 | 18 | -3.6 | 1 | TP |

# Challenges and opportunities for reticulorumen temperature monitoring

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## Abstract

Automatic monitoring of core body temperature in dairy cattle could be useful for identification of illness, heat stress, general physiological stress, and estrus. In this paper, results from three recent studies using reticulorumen temperature monitoring systems are summarized. In the first study, using an automatic reticulorumen temperature recording device, ambient temperature, breed, milk yield, season, and time of day influenced dairy cow reticulorumen temperature. In the second study using controlled water intake, the time for reticulorumen temperature to return to pre-drinking baseline ranged from 20 to 63 minutes. Water temperature and quantity independently influenced the magnitude of change (°C) and time required for return to baseline temperature. In the third study, reticulorumen temperature responses around mastitis events were observed in 4 to 56 % of mastitis cases depending on the threshold used. Reticulorumen temperature monitoring devices provide interesting biological data; however, additional technology refinements are needed before they can be employed practically on commercial dairy operations.

**Keywords:** reticulorumen, temperature monitoring, water intake, mastitis

## Introduction:

Body temperature is the most common and useful indicator of the interaction between a dairy cow and her physical environment. Temperature monitoring technologies could detect fever before emergence of clinical symptoms. Reticulorumen temperature transponders provide a practical, non-invasive tool for temperature monitoring. The dramatic decrease in reticulorumen temperature (RT) following water intake has been well documented; however, estimates for time required for RT to return to pre-drinking baseline temperature (TIME) and the dynamic relationship of water intake and reticulorumen temperature in uncontrolled situations are needed. Mastitis detection garners most of the interest in on-farm temperature monitoring although the range of physiological response to infection may limit practical implementation.

## Materials and Methods:

Study 1

This research was conducted using 93 cows (65 Holstein, 18 crossbred and 10 Jersey) at the University of Kentucky Coldstream Research Dairy Farm. All cows were housed in freestalls with one hour of access to a pasture exercise lot each day. Reticulorumen temperatures were collected from SmartBolus® transponders (TenXSys Inc, Eagle, ID) every 15 minutes from November 06, 2009 to July 14, 2011. The SmartBolus® (TenXSys Inc., Eagle, ID) system uses an active electronic bolus (11 cm long, 3.3 cm diameter), which remains in the reticulorumen of the cow and transmits data back to a computer via radio using repeaters. The raw RT (n=1,646,145) data was edited to remove erroneous reads and temperatures potentially influenced by water intake by removing RT < 38.3°C which was based on previous experience with RT. The mean temperature among each day's 96 AT recordings was classified as the mean daily ambient temperature (DAT) and the average daily RT was classified as the mean daily reticulorumen temperature (DRT). Generalized linear models with repeated measures were constructed to describe DRT using the MIXED procedure of SAS 9.3® (Cary, NC). All main effects were kept in each model, regardless of significance level. Interactions were included in the models when significant at P < 0.05 using backward elimination.

Study 2

Sixteen mid-lactation (160 ± 45 DIM), multiparous (2.5 ±. 5), Holstein dairy cows producing 31.9 ± 8.7 kg of milk daily were equipped with SmartBolus® transponders (TenXSys, Eagle, ID) set to record RT at 2-min intervals. Mean SCC was 33,000 ± 24,550 cells/ml per most recent DHI test. Cows were housed in a tie-stall barn at the University of Kentucky Coldstream Dairy Research Farm from February 14 to February 19 2011 where feed and water intake were restricted from 8:30 until release for the PM milking at 15:30. Feed and water intake were restricted during the experimental period to isolate the impact and interaction of water quantity and temperature on the reticulorumen environment. A two-day acclimation period for tie stall and intake restriction adjustment was given to all cows before experiment. The time of daily water drench administration was from 11:00 to 12:00 on February 16 to February 19 2011. This time was selected between milking times to avoid effects of milking on reticulorumen temperature. Drenches were administered such that every experimental cow received only one water quantity per day. All times of drench administration were recorded per cow. Just one water quantity was assigned per cow daily. Cows were released from tie stalls for afternoon milking at 15:30. The average daily low and high temperatures were 2.78 °C and 4.44 °C, respectively (Bluegrass Airport LEX). In this experiment, water volume and temperature were controlled. Cows were not allowed to consume additional water and feed during the experimental period. Water was administered to each cow via drenching by Cattle Pump System® for four consecutive days (Springer McGrath Co., Mc Cook, NE) using a modified Latin Square design. All random selections were conducted using a random number table. Four cows were randomly selected as control models for the duration of the experiment. Each of the twelve active cows received a constant water quantity of 5.7 L, 11.4 L, or 22.7 L each of the four days. Water temperatures were randomly assigned at 1.7°C, 7.2°C, 15.6°C, and 29.4°C, such that no cow received the same temperature treatment twice. These temperatures were selected to represent a range of temperatures from almost freezing to summer water temperature. A cow-specific baseline temperature range (BTR) was calculated using the mean ± 2 SD of all RT recorded 48 h before the beginning of the study. These temperatures were recorded via SmartBolus® transponders (TenXSys, Eagle, ID) set to record reticulorumen temperature (RT) at 2-min intervals. This BTR was used to define the TIME when RT returned to baseline following water drenching. The MIXED procedure of SAS® (SAS, Cary, NC) was used to assess factors influencing TIME and DROP with RANDOM block and water quantity. The resulting regression equation was used to develop a conversion table for calculating water intake based on DROP and water temperature (Table 1).

Study 3

This study was conducted at the University of Kentucky Coldstream Dairy from September 15, 2011 to March 20, 2013. The DVM Systems, LLC (Boulder, CO) bolus system monitors RT using a passive RFID transponder (Phase IV Engineering, Inc., Boulder, CO) equipped with a temperature sensor queried twice daily by a panel reader placed in parlor entrances. Milkers recorded clinical mastitis events from physical evaluation of milk (flakes, clots, or serous milk). A composite milk sample was obtained from each cow in the herd every 14 days for SCC analysis (Fossomatic™ FC somatic cell counter, Foss, Hilleroed, Denmark). Subclinical mastitis events were established by SCC > 200,000 cells/mL. Data were analyzed using SAS® (SAS Institute, Cary, NC). A 30-day rolling mean baseline RT was calculated along with the number of SD from which each respective RT varied from this baseline. The maximum RT and number of SD among all RT within the previous 10 days were used as a baseline to assess whether a RT alert was observed for mastitis and high SCC events. A minimum of 14 reticulorumen temperatures were required to establish a baseline. Raw reticulorumen temperatures were edited to remove erroneous reads and temperatures potentially influenced by water intake by first removing temperatures < 37.8°C and then removing temperatures with Z-scores < -3 from the cow's 10-day rolling average baseline. Reticulorumen temperatures > 41.1 ºC and with Z-scores > 3 from the cow's 10-day rolling average baseline were also interpreted as erroneous reads and were eliminated from the data set. Cow days were removed for two weeks after a clinical or subclinical mastitis event. Cow days were removed the day before, of, and after an estrus event. Cow days were removed when DIM ≥ 400.

## Results and Discussion:

Study 1

Overall daily mean RT was 40.14 °C, ranging from 38.62 °C to 41.89 °C. The overall diurnal maximum and minimum RT were observed at 23:30 and 10:00, respectively (Figure 2). Spring, summer, fall, and winter maximum RT were observed at 18:30, 14:30, 07:15, and 07:30, respectively; while seasonal minimum RT were at 10:00, 09:45, 10:30, and 10:30, respectively. In the fall and winter, maximum RT was observed in the morning whereas in the summer and spring maximum RT was observed late afternoon or early evening. This difference likely reflects the greater influence of AT on RT with increasing AT. Mean (± SD) daily RT during spring, summer, fall, and winter were 40.10 ± 0.29, 40.39 ± 0.36, 40.09 ± 0.23, and 40.00 ± 0.21 °C, respectively. Physiological responses to ambient conditions are breed-specific because of body size, skin color, sweating rate, respiration rate, and heat production. Mean daily (± SD) RT of Holstein, Jersey, and crossbred were 40.17 ± 0.33, 40.04 ± 0.25, and 40.05 ± 0.29 °C, respectively. Crossbred DRT were lower than Holstein DRT ($P < 0.01$), although this relationship varied by MY and DAT ($P < 0.01$). Jersey DRT was lower than Holstein in summer ($P < 0.01$). These differences in RT are adjusted for differences in milk yield. These results suggest that crossbred cows may be more heat tolerant than Holstein cows, possibly indicative of hybrid vigor. Mean (± SD) daily MY was 33.85 ± 8.67 kg, ranging from 4.18 to 56.77 kg. Mean (± SD) MY of Holstein, Jersey, and crossbred were 35.27 ± 8.44, 23.25 ± 5.78, and 31.72 ± 7.80 kg, respectively. Milk production did not affect DRT directly ($P = 0.23$). The effect of MY on DRT depended on breed, season, or DAT ($P \leq 0.01$). Mean (± SD) daily AT was 12.20 ± 10.61°C, ranging from -10.55 to 30.07 °C. Mean (± SD) AT for spring, summer, fall, and winter were 17.52 ± 6.36, 24.71 ± 2.58, 8.15 ± 7.85, and 1.45 ± 5.99 °C, respectively. Daily ambient temperature affected DRT directly ($P < 0.01$, Figure 1). As DAT was not related with DRT linearly, the increasing rate of DRT was more sensitive as AT increased, cows' DRT kept stable until DAT exceeded upper critical temperature (UCT). The result demonstrated that cows were more sensitive in warmer conditions. The impact of DAT on DRT varied by breed and MY. Generally, high-producing cows had greater DRT than low-producing cows; and cows under warm environment (greater than UCT) had greater DRT than cold environment (Figure 3). The DRT differences between high-producing cow and low-producing cow increased as AT increased ($P < 0.01$).

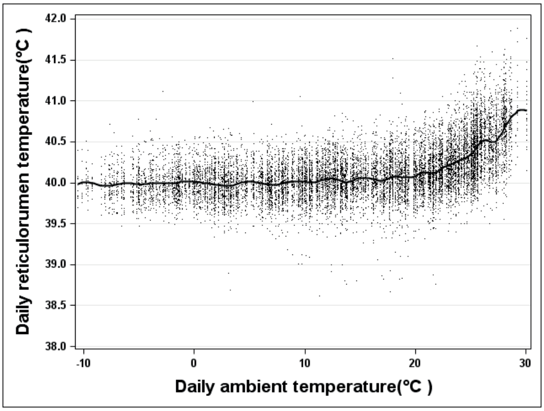


Figure 1. Relationship between daily ambient temperature (DAT) and daily reticulorumen temperature (DRT)

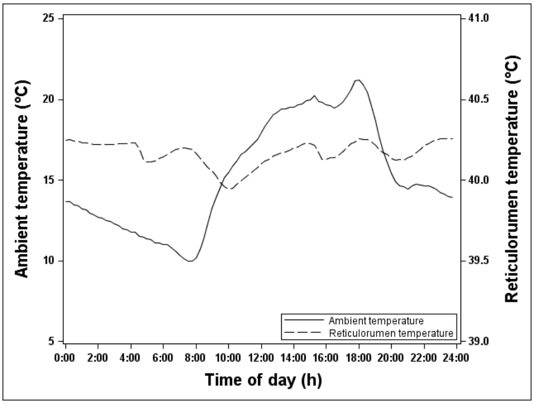


Figure 2. Overall diurnal rhythms of reticulorumen temperature relative to feeding and milking times

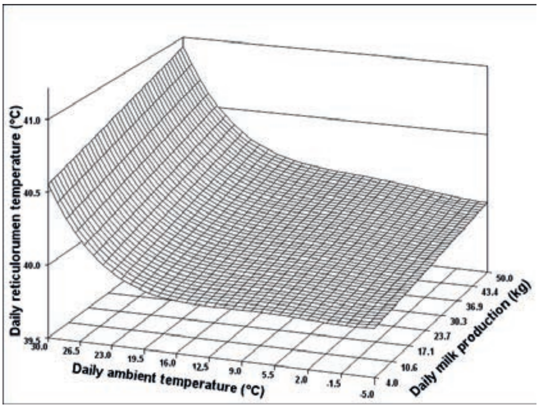


Figure 3. Relationships among daily ambient temperature (DAT), daily milk production (MY), and daily reticulorumen temperature (DRT).

Study 2

Water quantity ($P < 0.01$) and the interaction of water quantity and water temperature ($P = 0.05$) affected temperature decrease. Mean (± SD) TD was 4.7 ± 3.9, 9.0 ± 4.0, 11.1 ± 5.0, ° C for 5.7 L, 11.4 L, and 22.7 L, respectively (Table 3). Mean (± SD) temperature decrease was 12.8 ± 5.6 °C, 9.2 ± 4.3 °C, 8.5 ± 2.7°C, and 3.8 ± 2.7 °C for water temperatures of 1.7 °C, 7.2 °C, 15.5 °C and 29.4 ° C, respectively. These results are depicted in Figure 4. These results indicate both water quantity and water temperature influence degree of decrease °C. The study investigated not only effects of WT and quantity on RT, but also time required RT to return to baseline. Water quantity ($P < 0.01$) and the interaction of water quantity and water temperature ($P < 0.01$) affected time to return to baseline. Mean (± SD) time (min) to return to baseline was 19.9 ± 15.1, 36.9 ± 14.6, 67.3 ± 36.5 for 5.7L, 11.4L, and 22.7L, respectively. Mean (± SD) time (min) to return to baseline was 62.6 ± 41.9, 49.6 ± 29.4,41.0 ± 19.7, 19.9 ± 11.8 for temperatures 1.7°C, 7.2°C, 15.5°, and 29.4°C respectively. These results are depicted in Figure 5.

As water quantity increased, Mean (± SD) time to return to BTR increased to 67.0 ± 38.0 min. As WT decreased, Mean (± SD) time to return BTR also increased to 63.0 ± 42.0 min. Impact of water intake on RT is considerable and impacted by both quantity and temperature of water consumed. The results from this study demonstrate how dramatic the effects of water intake can be. These findings suggest monitoring temperature via reticulum may prove cumbersome. A predicted water consumption conversion chart (Table 4) for varying water temperature and temperature decreases was developed using the following conversion equation: Water Quantity Consumed (L) = (Temperature Decrease - 2.79 + 0.08 × Water Temperature (°C)) / (0.31 - 0.006 × Water Temperature (°C)). The equations developed in this study may be used (1) to remove temperatures affected by water intake when using cattle reticulorumen temperature monitoring systems and (2) to estimate water consumption using decreases in reticulorumen temperature. These equations may potentially aid farmers utilizing these technologies to isolate and identify indications of illness by monitoring for raised temperature before symptoms develop.

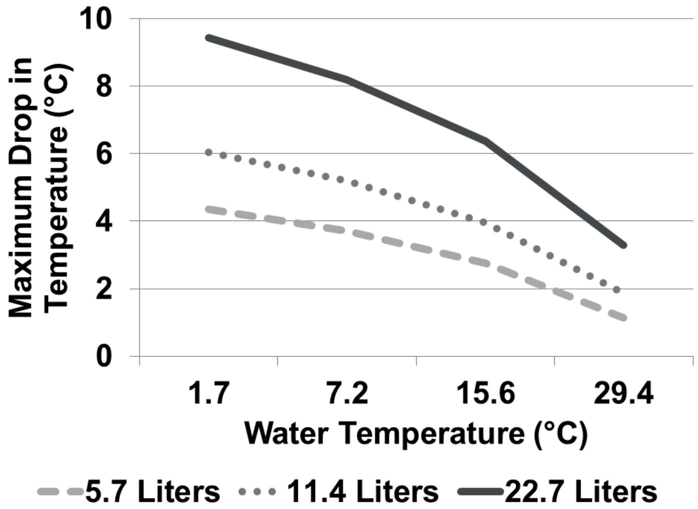


Figure 4: Temperature decrease (Experiment 2) following consumption of varying water quantity and temperature as predicted from the following mixed model: Temperature Decrease = 1.56 + (1.45×Water Quantity (L)) - (0.003 × Water Temperature (°C)) - (0.04 × (Water Quantity (L) × Water Temperature (°C)).

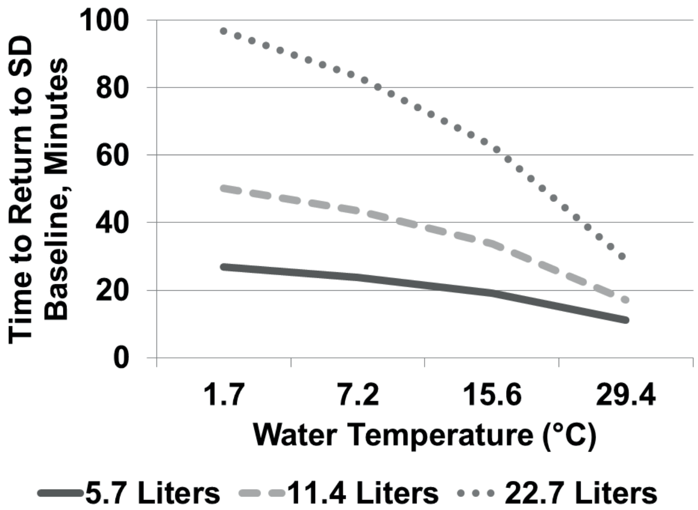


Figure 5: Time to return to baseline reticulorumen temperature (Experiment 2) following consumption of varying water quantity and temperature as predicted from the following mixed model: Time to Return to Baseline = 4.33 + (16.06×Water Quantity (L)) - (0.01 × Water Temperature (°C)) - (0.40 × (Water Quantity (L) × Water Temperature (°C)).

Table 1. Predicted water consumption conversion chart for varying water temperature and temperature decreases using the following conversion equation: Water Quantity Consumed (L) = (Temperature Decrease - 2.79 + 0.08 × Water Temperature (°**C**)) / (0.31 - 0.006 × Water Temperature (°**C**)).

| | | **Water Temperature (°C)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **5** | **10** | **15** | **20** | **25** | **30** | **35** | **40** |
| **Temperature Decrease (°C)** | **1** | | | | | | 1.4 | 5.0 | 11.1 | 23.3 |
| | **2** | | | 0.1 | 1.9 | 4.4 | 7.9 | 13.2 | 22.0 | 39.7 |
| | **3** | 0.7 | 2.2 | 4.1 | 6.6 | 9.8 | 14.4 | 21.3 | 32.8 | 56.0 |
| | **4** | 3.9 | 5.8 | 8.2 | 11.2 | 15.2 | 20.9 | 29.4 | 43.7 | 72.4 |
| | **5** | 7.2 | 9.4 | 12.2 | 15.8 | 20.6 | 27.4 | 37.6 | 54.5 | 88.8 |
| | **6** | 10.4 | 13.0 | 16.3 | 20.5 | 26.0 | 33.9 | 45.7 | 65.4 | 105.1 |
| | **7** | 13.6 | 16.6 | 20.3 | 25.1 | 31.5 | 40.4 | 53.8 | 76.3 | 121.5 |
| | **8** | 16.9 | 20.2 | 24.4 | 29.7 | 36.9 | 46.9 | 61.9 | 87.1 | 137.9 |
| | **9** | 20.1 | 23.8 | 28.4 | 34.3 | 42.3 | 53.4 | 70.1 | 98.0 | 154.2 |
| | **10** | 23.4 | 27.4 | 32.5 | 39.0 | 47.7 | 59.9 | 78.2 | 108.9 | 170.6 |

Study 3

Observations included 73 clinical cases and 338 subclinical cases throughout the study. Mean RT (N = 223,672) among those recorded 2 days before mastitis events were 39.10 ± 0.75, 38.93 ± 0.71, and 38.96 ± 0.68 ºC for clinical and subclinical mastitis events and healthy cows, respectively. When a temperature threshold was used to determine sensitivity and specificity, the highest clinical and subclinical mastitis detection rates were obtained using a 39.4ºC threshold (Table 2). The lowest false positive rates were obtained using a 40.3 ºC threshold (Table 2). When a Z-score threshold was used to determine sensitivity and specificity, the highest clinical and subclinical mastitis detection rates were obtained using a 20 observation temperature observation window and 2 Z-score threshold (55.7% and 52.7% for clinical and subclinical detection, respectively; Table 1). The lowest false positive rates were obtained using a 4 temperature observation window and a 3 Z-score threshold (4.3% false positive rate; Table 1). Stricter thresholds increased specificity, but decreased sensitivity. However, the most practical application of technologies would retain both optimal sensitivity and optimal specificity. Maximum sensitivity with minimal specificity requires producers to check cows that do not require extra care. Maximum specificity with minimal sensitivity causes producers to miss cows that are sick and do require extra care, forcing producers to check all the cows often regardless of what the system results are. Both situations cost producers time and money. When temperature increases around mastitis events were observed, the spikes were dramatic, indicating some potential for dairy cattle temperature monitoring. However, failure to identify most subclinical and clinical mastitis events demonstrates limitations of an RT system. Even after considerable edits to eliminate the impact of drinking events, water intake may still limit RT application.

Table 2. Clinical and subclinical mastitis detection and false positive rates for varying alert thresholds.

| Z-score or Temperature Threshold | Observation Window | Clinical Mastitis | | Subclinical Mastitis | | Healthy Quarter | |
|---|---|---|---|---|---|---|---|
| | | % Above Threshold | % Below Threshold | % Above Threshold | % Below Threshold | % Above Threshold | % Below Threshold |
| 2 | 4 | 22.8 | 77.2 | 14.6 | 85.5 | 13.3 | 86.7 |
| 3 | 4 | 8.9 | 91.1 | 4.5 | 95.5 | 4.3 | 95.7 |
| 2 | 10 | 39.2 | 60.8 | 31.0 | 69.0 | 27.9 | 72.1 |
| 3 | 10 | 15.2 | 84.8 | 12.2 | 87.8 | 10.0 | 90.0 |
| 2 | 20 | 55.7 | 44.3 | 52.7 | 47.3 | 18.3 | 81.7 |
| 3 | 20 | 32.9 | 67.1 | 21.7 | 78.3 | 46.1 | 53.9 |
| 40.3ºC | 4 | 13.3 | 86.7 | 4.6 | 95.4 | 2.8 | 97.2 |
| 40.0ºC | 4 | 25.0 | 75.0 | 13.1 | 86.9 | 6.3 | 93.7 |
| 39.7ºC | 4 | 37.8 | 62.2 | 21.9 | 78.1 | 11.5 | 88.5 |
| 39.4ºC | 4 | 45.5 | 55.5 | 40.4 | 59.6 | 20.1 | 79.9 |

**Conclusions:**

Ambient temperature, milk production, and breed influence reticulorumen temperature. Crossbred cows may be more heat tolerant than Holstein cows, even after adjusting for differences in milk yield. Even small quantities of water affect reticuloruminal temperature in lactating dairy cattle. Colder water and greater quantities both independently affect the degree of change in reticulorumen temperature to the greatest magnitude. This research suggests that temperature monitoring via the reticulorumen is an effective means of monitoring a dairy herd for water intake but temperature readings must be examined with caution. The time required for reticulorumen temperature to return to baseline temperature is dependent upon water quantity and water temperature. The results from these studies can also potentially serve researchers and farmers monitoring reticulorumen temperatures by eliminating drinking bouts from automatically recorded reticulorumen temperature data. Dairy producers must consider both sensitivity and specificity when evaluating a disease detection technology. Differences among bacteriological cause of mastitis may explain variation in temperature responses with clinical and subclinical mastitis. More frequent reticulorumen temperature collection and multivariate combinations of reticulorumen temperature with other mastitis indicators (i.e. electrical conductivity, activity, color analysis) may improve mastitis detection. Alternative data mining algorithms (i.e. neural networks, fuzzy logic) may improve mastitis detection. Reticulorumen temperature may be an indication of subclinical and clinical mastitis, but natural variation may limit the utility of a reticulorumen temperature monitoring system.

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## Energy balance estimated real-time from automated on-farm live weights is associated with udder health

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### Abstract

Several technologically advanced dairy herds weigh cows automatically, but live weight fluctuates mainly due to feed and water intake, and milking. This daily fluctuation has been the largest obstacle in extrapolating meaningful physiological information from short term live weight changes, and in using these as an automated management tool. Mastitis and somatic cell count (SCC) are used as udder health indicators, the former has been associated with decreased energy balance. This study uses a standard function of body protein changes to separate live weight changes into protein and lipid changes, thereby enabling estimation of individual energy balance of cows from live weights alone. Energy balance was estimated from 7421 live weight time-series, of these 862 cows were treated for mastitis. SCC during the first 100 days in milk was calculated. Energy balance correlated negatively with both milk yield and SCC, thus low energy balance was associated with high yield and high SCC. Mixed model ANOVA showed that SCC was significantly affected by energy balance, mastitis treatment, ECM, parity and calving season. In conclusion, informative individual energy balance estimates can be obtained from automated live weights in commercial herds without measuring feed intake.

**Keywords:** Automation, energy balance, modeling, ruminant, standard body protein function

### Introduction

In many modern dairy herds cow live weights are automatically measured. Attempts have been made to utilise live weights to make inferences about cow health. However, large daily fluctuations in live weight caused by production and excretion of milk, urine, faeces, and not least water and feed intake mask changes in empty body weight (van der Tol & van der Kamp, 2010). These fluctuations have precluded the use of live weights as an automated management tool. Further, sparse or no knowledge of body condition score, the degree of fatness, has prevented the separation of empty body weight into lipid and protein, which is required to estimate energy balance based on changes in body lipid and body protein reserves (Coffey *et al.*, 2001). New research suggests a standard function of body protein changes over lactation, which enables estimation of energy balance without body condition scores, using only frequent live weight measurements (Thorup *et al.*, 2013). The present study utilizes this standard function to estimate energy balance from live weights alone. Mastitis and somatic cell count are both used as indicators of the cow's udder health status. Mastitis correlates genetically with decreased body condition score (Lassen *et al.*, 2003), the latter of which is often used as an indicator of energy balance. However, manual body condition scoring is time-consuming and objective, therefore a tool estimating energy balance real-time using only frequently and automatically measured live weights would be faster and more objective to apply on-farm. Thus, this study aimed to investigate the association between energy balance estimated from automated live weights and udder health indicators.

## Materials and methods

The project data set consisted of automated live weights from 72 Danish Holstein herds with Lely milking robots. Live weight time series from January 2011 to June 2012, and lasting 100 to 305 days from calving were selected, in total 7421 lactations. The live weights were measured at the end of each milking, removing the influence of milk on weight. Across lactation, weights were smoothed double exponentially and asymmetrically (by emphasising weight loss more than gain) to lessen the influence of water and food intake on weight. Also, the weights were adjusted for pregnancy and residual gutfill to derive the empty body weight. Applying the standard body protein function allowed body lipid and body protein changes to be derived and energy balance to be estimated (MJ effective energy/day). Across lactation energy balance was smoothed double exponentially and symmetrically, after which mean energy balance of days 10 to 100 in milk (EB) was calculated. Parity, calving, and recordings of mastitis treatments (made by the farmer or a veterinarian) and energy corrected milk yield were obtained from the Danish Cattle Database. Mastitis treatment (MAST) was recorded as treated or not treated during lactation, and mean somatic cell count (SCC) during days 0 to 100 in milk was calculated, as was mean energy corrected milk during days 0 to 100 in milk (ECM). Descriptive means and s.d. for the continuous variables are reported by parity (table 1).

Table 1. Descriptive means and s.d grouped by parity. Number of lactations, energy corrected milk yield during days 0 to 100 (ECM), energy balance during days 10 to 100 (EB), somatic cell count during days 0 to 100 (SCC), and log10-transformed SCC (LogSCC).

| Parity | Lactations | ECM, l/day | EB, MJ/day | SCC, 1000/ml | LogSCC |
|---|---|---|---|---|---|
| **1** | 2943 | 29.3±4.6 | -11.8±19.1 | 156±328 | 1.86±0.46 |
| **2** | 2117 | 37.5±6.1 | -9.0±22.1 | 261±470 | 2.03±0.56 |
| **3+** | 2361 | 40.3±6.6 | -15.7±23.3 | 379±600 | 2.19±0.59 |

Spearman correlations were calculated for continuous data. Before further analysis, SCC was log10 transformed. EB100 was grouped in 2 categories: low (<0), or high (≥0 MJ/day). ECM was grouped in 3 categories: low yield (12 to 31 l/d), medium yield (32 to 39 l/d) or high yield (40 to 66 l/d). SCC was analysed in the following mixed model using the lme4 package in R (R Development Core Team, 2013):

$$SCC_{ghijkl} = \mu + (EB \times MAST)_{gh} + ECM_i + P_j + C_k + h_l + e_{ghijkl}, \quad (1)$$

where μ was the overall mean. The fixed effects were the interaction between $EB_g$ (g=low, high) and $MAST_h$ (h=untreated, treated), milk yield $ECM_i$ (i=low, medium, high), parity $P_j$ (j=1, 2, 3+), and calving season $C_k$ (k=winter, spring, summer, autumn). The random effects were the effect of herd $h_l$ (l=1, …, 72) and the residual $e_{ghijkl}$. The interaction between ECM and parity was tested and found insignificant and therefore removed from the model.

## Results and discussion

This preliminary analysis revealed very large variation in EB and SCC (table 1). The number of cows treated for mastitis within the first 100 days in milk was 862 of 6559. Not surprisingly, EB and ECM correlated negatively and significantly, meaning that high yielding cows had low energy balance (Table 2). EB and SCC also correlated significantly and negatively, signifying that cows in low energy balance had high SCC.

Table 2. Spearman correlation coefficients (above diagonal) and P-values (below diagonal), n=7421.

| | ECM | EB | SCC |
|---|---|---|---|
| **ECM** | - | -0.30 | 0.07 |
| **EB** | <0.001 | - | -0.04 |
| **SCC** | <0.001 | <0.001 | - |

The ANOVA showed that EB×MAST, ECM, parity, and calving season all significantly affected SCC (Table 3, logSCC transformed back to SCC). Cows in low EB and treated for mastitis had the highest SCC, followed by cows in high EB treated for mastitis, followed by cows in low EB not treated for mastitis, and cows in high EB not treated for mastitis had the lowest SCC. Thus, cows in low EB had higher SCC than cows in high EB. The least square means for the ECM showed that SCC decreased with increasing milk yield, opposite to the results for the descriptive means, possibly indicating the large impact of including EB and MAST in the model. SCC increased with increased parity. Finally, SCC for cows calving during spring was higher than for cows calving autumn and winter.

Table 3. Least square means for SCC (1000/ml).

| **Mastitis** | **Untreated** | | **Treated** | | |
|---|---|---|---|---|---|
| **EB** | **Low** | **High** | **Low** | **High** | |
| | $97.7 \pm 1.0^{a}$ | $89.1 \pm 1.0^{b}$ | $234.4 \pm 1.0^{c}$ | $169.8 \pm 1.1^{d}$ | |
| **ECM** | **Low** | | **Medium** | **High** | |
| | $162.2 \pm 1.0^{a}$ | | $141.3 \pm 1.0^{b}$ | $112.2 \pm 1.0^{c}$ | |
| **Parity** | **First** | | **Second** | **Third+** | |
| | $85.1 \pm 1.0^{a}$ | | $141.3 \pm 1.0^{b}$ | $208.9 \pm 1.0^{c}$ | |
| **Calving season** | **Winter** | | **Spring** | **Summer** | **Autumn** |
| | $134.9 \pm 1.0^{ac}$ | | $144.5 \pm 1.0^{b}$ | $141.3 \pm 1.0^{ab}$ | $125.9 \pm 1.0^{c}$ |

[a,b,c,d)] Different superscripts signify that groups within a row differ significantly (P<0.05).

## Conclusions

Mean energy balance calculated from frequent live weights, somatic cell count, mastitis treatments, and mean milk yield during the first 100 days in milk are significantly interrelated. This analysis shows that informative energy balance estimates can be obtained for individual cows in commercial herds without measuring feed intake. However, this analysis cannot reveal the causal nature of low EB. Future analysis will examine the associations between additional energy balance traits and health traits.

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## Prediction of body condition scores in dairy cattle from daily measurements of body weights and milk composition

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### Abstract

Regression equations were developed to predict body condition scores (BCS) during the course of the lactation for individual dairy cows from automatically measured milk yields, milk components (fat, protein, lactose), and bodyweights. Data were from 321 lactating Holstein cows scored weekly throughout their lactation on a 1 to 5 scale with 0.25 increments at the University of Florida Dairy Unit. The average BCS in parities 1 and 2+ were 3.54 ± 0.49 and 3.30 ± 0.61, respectively. Trends showed the usual decrease in BCS after calving until a few months in lactation after which BCS increased again. Procedure glmslect in SAS was used to find best predicting regression equations from while protecting for overfitting. The best 5-parameter regression equation had an R-squared of 63% and a root mean square (prediction) error of 0.31 BCS units. Bodyweights and milk yields were important for accuracy of BCS prediction, but availability of milk components was not if bodyweights were measured. An actual BCS observed on each cow at day 70 further significantly improved the accuracy of the best equation throughout the lactation. In conclusion, milk yields and bodyweights were useful predictors for individual BCS of dairy cows.

**Keywords:** Dairy, body condition score, milk component, body weight

### Introduction

Body condition scores (BCS) of dairy cattle are useful measures of body fat stores and energy status of the animal. Cows with either too much or too little body condition at calving and cows that lose too much body condition after calving are at a higher risk of metabolic problems, reduced fertility and milk production (Roche *et al*., 2009). Frequent body condition scoring can aid management intervention (Bewley & Schutz, 2008), but scoring is typically performed visually by a person and therefore labor intensive on large dairy farms. Commercially available sensors such as bodyweight scales and milk composition analyzers might provide sufficient information to predict BCS at any stage of the lactation automatically. The objective of this study was to develop and compare equations to predict BCS for individual lactating dairy cows during their lactation from bodyweight, milk yield and milk composition measurements obtained for each cow twice per day around milking. A requirement was that the equations had simple functional forms so they could be easily understood and build into software.

## Materials and Methods

At the University of Florida Dairy Unit, 321 lactating Holstein cows (n = 123 parity 1, n = 198 parity 2+) were scored weekly (1 to 5 scale with 0.25 increments; Ferguson *et al.*, 1994) from calving until culling or dry off in 2011 and 2012 (n = 15,372). Scoring was performed by 3 different but trained people depending on availability. All lactating cows were fed one total mixed ration regardless of stage of lactation, parity, or reproductive status. The cows were housed in freestall barns. Milk yield, fat, protein, lactose, and bodyweights were obtained using commercial sensors during or immediately after each milking (milk meters, on-line milk composition analyzers, and walk through scales, were all obtained from Afimilk, Israel). Cows were milking twice per day at 12 hour intervals in a double 12 herringbone parlor. Weekly averages of all input variables were calculated. The net energy of lactation (NEL) (kg) was calculated as 0.0929 * fat% + 0.0547 * protein% + 0.2195 * lactose% (NRC, 2001). Daily energy in milk then was calculated as milk yield * NEL (kg).

Regression equations were fitted to predict BCS from the input variables for each cow. First, the weekly BCS per cow were smoothed with a loess smoother to average out the week to week random variation in scores. Forty-three variables were constructed, including, but not limited to, energy in milk, milk yield, bodyweight, metabolic weight, days in milk (DIM), and their logs, squares and reciprocals. Four-week moving changes for these variables were also calculated. All variables were in metric units.

SAS procedure glmselect was used to find the best fitting regression equations constrained to 1, 2, 3, 5, or 7 effects. Possible effects were limited to main effects, quadratic effects and 2-way interactions of the variables. Stepwise regression was used with the PRESS stop criterion. The glmselect procedure randomly partitions the dataset into training data (50%), validation data (25%), and test data (25%) to prevent over fitting. During the selection process, regression equations are fit on the training data, and the prediction error for the equations obtained is found by using the validation data. These prediction errors are used to select the best equation. Finally, once a selected regression equation has been obtained, the test data is used to assess how the selected equation generalizes on data that played no role in selecting the equation. Goodness of fit was expressed as the root of the mean squared error (RMSE), bias, and the R-squared of the equation obtained from the training data set. In addition, the RMSE of the test data is provided. The RMSE is a single measure of predictive power of a regression equation. Prediction errors were calculated as actual BCS minus predicted BCS.

## Results and Discussion

The average BCS in parities 1 and 2+ were 3.54 ± 0.49 and 3.30 ± 0.61, respectively. The mean ± SD of BCS at calving, 70, 140, 210, 280, and 350 DIM for parity 1 were 3.39 ± 0.27, 3.21 ± 0.44, 3.33 ± 0.40, 3.55 ± 0.39, 3.68 ± 0.38, and 3.96 ± 0.40, respectively (Figure 1). For parity 2+, corresponding results were 3.51 ± 0.29, 2.86 ± 0.57, 3.07 ± 0.54, 3.39 ± 0.52, 3.63 ± 0.43, and 3.86 ± 0.45. Average bodyweights in parities 1 and 2+ were 587 ± 73 kg and 678 ± 75 kg, respectively. Average daily milk yield was 28.9 ± 8.4 kg and 34.6 ± 12.6 kg, respectively. Daily energy in milk was 45.7 **± 13.0** Mcal and 54.0 ± 19.1 Mcal. Across all data, the correlations between BCS and bodyweight (0.44), milk yield (-0.52), and energy in milk (-0.50) were all significant.

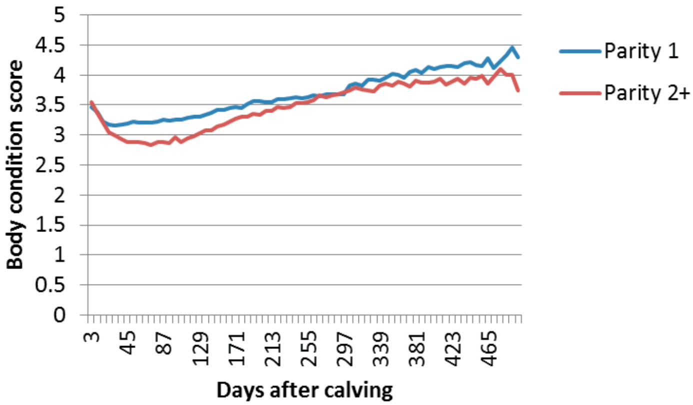



Figure 1: Average body condition scores for cows in parity 1 (n = 123) and parity 2+ (n = 198)

When only the mean herd BCS of 3.41 was included in the model (an intercept-only equation), the R-squared(train) was <0.001% and RMSE(train) was 0.51. The RMSE(test) at 70, 140, 210, 280 and 350 DIM were 0.54, 0.47, 0.40, 0.44, and 0.56 units BCS, respectively.

When the BCS at calving was fitted in addition to the intercept, the R-squared(train) was 1% and the RMSE(train) was 0.51. The RMSE(test) at 70, 140, 210, 280 and 350 DIM were 0.54, 0.47, 0.40, 0.43, and 0.55, respectively, with an average of 0.51. Therefore the fit improvement due to adding the BCS at calving was negligible compared to the intercept-only equation.

Further adding the BCS at 70 DIM to the equation resulted in an R-squared(train) of 35% and RMSE(train) of 0.41. The RMSE(test) at 70, 140, 210, 280, and 350 DIM were 0.39, 0.35, 0.26, 0.38, and 0.58 units BCS. The average RMSE(test) was 0.41. Although this equation was better than the one without BCS at 70 DIM, the bias (average of errors) varied from -0.32 at 70 DIM to + 0.51 at 350 DIM. Also, the BCS at 70 DIM is not available before 70 DIM.

A best 5-parameter equation with BCS at calving, parity (1 or 2) and the various transformations of DIM resulted in an equation with R-squared(train) of 41% with RMSE of 0.39. The RMSE(test) at 70, 140, 210, 280, and 350 DIM were 0.41, 0.40, 0.37, 0.34, and 0.29. The equation was: BCS = 2.52 + 0.26 * BCS at calving + 0.00052 * BCS at calving * DIM + 0.0010 * parity * DIM – 0.19 parity * log(DIM). Figure 2 shows the RMSE and bias by DIM of this 5-parameter equation.

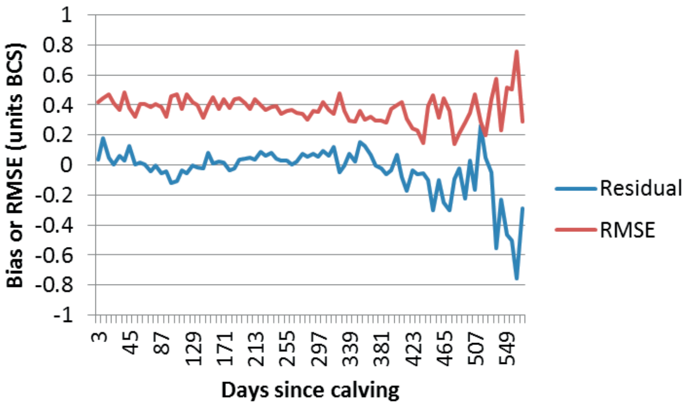


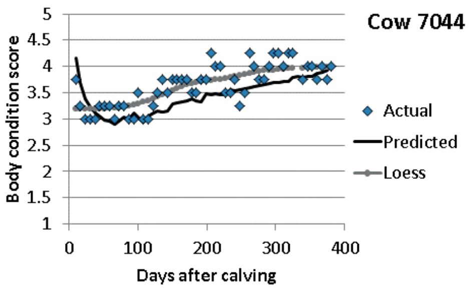

Figure 2: Bias and root of the mean squared error (RMSE) for all cows for the equation BCS = 2.52 + 0.26 * BCS at calving + 0.00052 * BCS at calving * DIM + 0.0010 * parity * DIM – 0.19 parity * log(DIM). Parity was either 1 or 2

Table 1: Fit statistics for the best 3, 5, and 7-parameter equations chosen from 43 variables and their interactions and squared terms

| Number of parameters | 3 | | 5 | | 7 | |
|---|---|---|---|---|---|---|
| R-squared (training) | 61% | | 64% | | 64% | |
| RMSE (training) | 0.32 | | 0.31 | | 0.30 | |
| RMSE (test) | 0.32 | | 0.31 | | 0.31 | |
| Correlation pred./actual | 0.77 | | 0.79 | | 0.79 | |
| BCS at specific DIM: | Bias | RMSE | Bias | RMSE | Bias | RMSE |
| 70 DIM | 0.039 | 0.39 | 0.042 | 0.37 | 0.048 | 0.37 |
| 140 DIM | -0.029 | 0.37 | -0.035 | 0.38 | -0.021 | 0.37 |
| 210 DIM | 0.027 | 0.30 | -0.038 | 0.28 | 0.041 | 0.28 |
| 280 DIM | -0.047 | 0.28 | -0.050 | 0.26 | 0.053 | 0.27 |
| 350 DIM | -0.037 | 0.28 | -0.027 | 0.27 | -0.043 | 0.28 |

The best 3-parameter model including the intercept, chosen from 43 variables and their interactions and squared terms, had an R-squared(train) of 61% and RMSE(train) of 0.32 (Table 1). The correlation between predicted and actual BCS was 0.77 with this equation. The best equation was BCS = 5.34 – 0.00067 * parity * daily milk yield – 1008 * (1 / bodyweight) * (1 / (bodyweight / bodyweight in week 1)). Here milk yield, body weight are measured at the same time as the BCS prediction.

The fit of the best equation improved slightly when a 5-parameter or 7-parameter equation was fit. The best 5-parameter equation was BCS = 4.54 + 0.24 * BCS at calving – parity * daily milk yield – 0.0077 * (1 / (DIM * DIM)) * log(bodyweight / bodyweight in week 1) – 1023 * (1 / bodyweight) * (1 / (bodyweight / bodyweight in week 1)). Here milk yield, bodyweight are measured at the same time as the BCS. The advantage of the 7-parameter equation over the 5-parameter equation was very small and is therefore not shown. The 7-parameter model included a variable based on the energy in milk calculated from milk components, but the 5-parameter equation did not include variables based on milk components. Figure 3 shows the actual, loess-smoothed, and predicted BCS of the best 5-parameter equation for 2 cows that represent the flexibility of the equation and the overall fit.



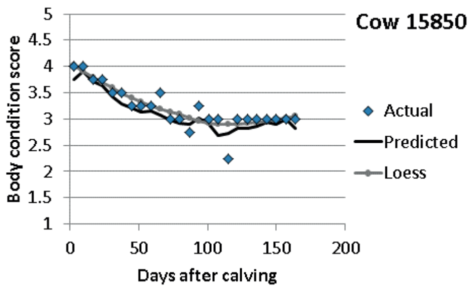




Figure 3: Actual and loess-smoothed body condition scores for 2 cows and their predicted scores from the best 5-effects regression equation

Table 2 shows that removing the BCS at calving from the available variables worsens the fit only slightly. Variables based on milk components are not chosen in the best 5-parameter model, but milk yield has some effect. Bodyweight variables were important for prediction of BCS, however.

Table 2: Value of BCS at calving, daily bodyweights, milk yields, and milk components on accuracy of the BCS prediction. Fit statistics for the best 5-parameter equation are shown

| All variables offered without the following: | R-squared | RMSE (train) | RMSE (test) | Correlation pred./actual |
|---|---|---|---|---|
| -[1] | 64% | 0.31 | 0.31 | 0.79 |
| BCS at calving | 61% | 0.32 | 0.32 | 0.79 |
| Bodyweight variables | 47% | 0.37 | 0.37 | 0.68 |
| Milk component variables | 63% | 0.31 | 0.31 | 0.80 |
| Milk component + milk yield variables | 59% | 0.32 | 0.33 | 0.77 |
| BCS at calving, milk components, yield | 57% | 0.34 | 0.34 | 0.77 |

[1] The best 5 parameter equation include BCS at calving and variables based on transformations of DIM, milk yield, and bodyweight.

The variables included thus far are either determined in the first week after calving or concurrent with the timing of the BCS prediction. No future variables, such as bodyweight at the nadir of lactation are included because they would not be available before the nadir is reached. Separate equations could be fit for different parities or parts of the lactation, for example for cows that are past 70 DIM and expected to have only increasing BCS afterwards. Further, including an occasional actual BCS to the equation, in addition to the BCS at calving, will further improve the fit. For example, adding the actual BCS at 70 DIM to the 5-parameter equation improved the fit greatly. The RMSE(train) reduced to 0.23 and the R-squared increased to 79%.

The prediction equations could be improved further with new variables that have not been tested, and should be validated with other BCS datasets. For example, adding reproduction variables, such as stage of gestation, might further improve the equations but this data was not available at the time of this analysis. We also did not investigate equations to prediction BCS into the future. For example, given all observations until the cow conceives, one might be interested in predicting the BCS at dry-off.

No attempt was made to compare the accuracy of the BCS predictions by these best equations with predictions by other techniques that automatically predict BCS. Both Bewley & Schutz (2008) and Roche *et al.* (2009) reviewed the literature concerning automation of body condition scoring where digital imaging takes an important place. Our best 5-parameter equation included parity, BCS at calving, daily milk yield, and daily bodyweight which would be readily available if automatic milk recording and a bodyweight scale are available.

## Conclusions

Bodyweight, milk yield, DIM, and a one-time BCS at calving were useful variables in an equation to predict BCS during the course of the lactation. The availability of daily milk components did not appear to increase the accuracy if bodyweights are available. The equations can be improved by adding occasionally scored actual BCS, for example around day 70. Further improvements in the accuracy of BCS predictions by unexplored equations using already collected data are anticipated.

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## Effect of sex on hatch time and correlation between hatch time and post-hatch weight and pododermatitis: a preliminary experiment

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### Abstract

Previous research has reported that incubation duration and hatch time are affected by pre-incubation and incubation conditions and by the sex of embryos. The aim of this experiment was: (1) to correlate embryo sex, egg weight and chick weight with hatch time; and (2) to study the effect of hatch time on the post-hatch body weight and pododermatitis up to slaughter age.

A total of 19,200 eggs from same ROSS 308 breeder flock (aged 40 weeks) were incubated in two standard incubators (Petersime N.V.) with a capacity of 9600 eggs each. Twenty eggs (focal eggs) were randomly selected per incubator. At transfer (Day18 of incubation), focal eggs were separated by mesh dividers. The hatch time of the focal chicks was labelled using video records taken by two analogue cameras placed 30 cm above the baskets. Of 40 focal eggs, 36 hatched and these focal chicks were marked with a non-toxic coloured spray.

At takeoff, each focal chick was weighed and sexed by a feather sexing expert. Focal chicks were divided into 4 pens (9 focal chicks per pen: 2 of males and 2 of females) with other chicks. The total number of chicks per pen was 241 males and 272 females in order to have a final density of 39 kg/m² at slaughter age. During the rearing period, the focal chicks were individually weighed at Day21 and Day28. Focal chicks were scored for pododermatitis at Day21 and Day28 according to the method developed by Michel *et al.* (2012) where scores range from 1 (no lesion) to 5 (severe lesion).

No significant effect of sex on the hatch time could be observed. However, hatch time was positively correlated with the weight of chicks at hatch, with heavy chicks hatching later than light chicks. There was no significant correlation between hatch time and weight or pododermatitis at Day21 and Day28 of rearing.

**Keywords:** hatching time, video, labelling, post-hatch performance, pododermatitis, broiler.

## Introduction

Previous research has reported that incubation duration and hatch time are affected by pre-incubation and incubation conditions and by the sex of embryos. In these previous studies, the methods of separating chicks according to their hatch time involved opening the incubator doors frequently to collect the hatched chicks: every 2 hours (Careghi *et al.*, 2005; Nielsen *et al.*, 2010; Tona *et al.*, 2005), 4 hours (Reis *et al.*, 1997) or 6 hours (Vieira *et al.*, 2005). However, opening the doors frequently may disturb the incubation conditions and may accelerate or delay the hatch time of the remaining incubated eggs; for instance, decreasing the temperature during the hatching process delays the hatch time (Swann and Brake, 1990).
In our experiment, new technologies (cameras and video recording systems) were used to determine hatch time without opening the incubator doors so as not to affect the hatching process. The aim of this experiment was: (1) to correlate embryo sex and chick weight with hatch time; and (2) to study the effect of hatch time on the post-hatch body weight and pododermatitis up to slaughter age.

## Material and methods

A total of 19,200 eggs from the same ROSS 308 breeder flock (aged 40 weeks) were used for this experiment. Eggs were collected on three days of laying and incubated in two standard incubators (Petersime N.V.) with a capacity of 9600 eggs each. Twenty eggs (focal eggs) were randomly selected per incubator. At transfer (Day18 of incubation), focal eggs were separated by mesh dividers. At hatch, the 36 focal chicks (hatched chicks from the 40 focal eggs) were sexed by a feather sexing expert and marked with a non-toxic coloured spray, then followed up to slaughter age (30 days). The 36 focal chicks were distributed into 4 pens (2 of males and 2 of females). There were 241 males and 272 females per pen in order to have the same final stocking density of 39 kg/m² at slaughter age. Broilers were reared in 12 m² pens with a litter of chopped straw. Feed and water were provided ad libitum. Light was provided by neon lamps. In agreement with the European Council Directive 2007/43/CE (Council of the European Union, 2007), chicks received 24 hours of light (24L:0D) at placement, then one hour of darkness was added each day from Day2 to Day7, to reach 6 hours of darkness (18L:6D), which was maintained until slaughter age.

The hatching time (HTH) of focal chicks was labelled using infrared analogue cameras RoHs (PIH-0022 P3.6) installed 30 cm above the hatching baskets. Videos were recorded using ECCTV-DVR 5008 and ECCTV-DVR 5004 recording systems. The chick was considered as ‘hatched’ when 50 % of its body had emerged from the eggshell. Hatch time was precisely labelled for 35 of the 36 focal chicks. Each focal chick was weighed at hatch (W00) and once a week during the rearing period, but only measurements at Day21 (W21) and Day28 (W28) are presented in this paper. Focal chicks were also scored for pododermatitis at Day21 (P21) and Day28 (P28). The right foot of the broiler was cleaned with smooth brush and scored according to the method developed by Michel *et al.* (2012) where scores range from 1 (no lesion) to 5 (severe lesion).

## Statistical analysis

Statistical analysis was performed using the package RVAideMemoire of R 3.0.1 (R Development Core Team, 2013). All data were examined by principal component analysis (PCA) in a data matrix of 35 chicks x 6 variables to analyse the possible variations of HTH with weight of focal chicks: W00, W21 and W28, and pododermatitis score: P21 and P28. Individual correlations between HTH and weight (W00, W21 and W28) were performed using a Pearson test. Individual correlations between HTH and pododermatitis scores (P21 and P28) were performed using a Spearman test. The non-parametric Kruskall-Wallis test was used to test the effect of sex on HTH.

## Results

The effects of sex on hatch time results are presented in table 1. The hatch time ranges between 486.7 and 514.0 hours. Chick sex did not have a significant effect on hatch time (P=0.895), body weight at hatch (P=0.589) or pododermatitis score at Day21 (P=0.644) and Day28 (P=0.747), but males were significantly heavier than females at Day21 and Day28 (P<0.001).

Table 1: Effect of sex on focal chick hatch time, weight and pododermatitis score

| Factor | Day | Sex | | Min | Max | P value |
|---|---|---|---|---|---|---|
| | | F | M | | | |
| Hatch time (hour) | 00 | 503,5±1,9 | 504,8±1,3 | 486.7 | 514.0 | 0.895 |
| Body weight (g) | 00 | 46,3±0,9 | 47,8±0,8 | 41.5 | 54.5 | 0.589 |
| | 21 | 842,6±17,3 | 997,4±14,8 | 654.0 | 1146.0 | <0.001 |
| | 28 | 1380,9±25,4 | 1699,5±25,0 | 1150.0 | 1900.0 | <0.001 |
| Pododermatitis score | 21 | 2,1±0,1 | 2,1±0,1 | 1.0 | 3.0 | 0.644 |
| | 28 | 2,4±0,2 | 2,4±0,2 | 2.0 | 4.0 | 0.747 |

Two principal components (PC) which accounted for 60.9 % of the total variation were extracted. The PCA showed a positive correlation between weight W21 and W28 (first dimension) which explained 36.07 % of variability. In the second dimension (which explains 24.83 % of variability) there was a positive correlation between HTH and W00 (Figure 1). Pododermatitis scores at P21 and P28 were not correlated with weight (W00, W21 and W28) or hatch time (HTH).
The Pearson test showed a significant (P=0.003) positive correlation (r=0.49) between HTH and W00 with a 95% confidence interval [0.183, 0.705]. An increase of 1 g in chick weight increased the HTH by 0.94 hour (56 minutes) as shown in equation 1 and figure 2.

$$HTH = 0.94(W00) + 460.26 \quad (1)$$

where:
HTH: hatch time in hours
W00: chick weight in grams
HTH was not significantly correlated with weight during the rearing period at W21 (P=0.711) or W28 (P=0.929). No significant correlation was observed between HTH and P21 (P=0.470) or between HTH and P28 (P=0.217).

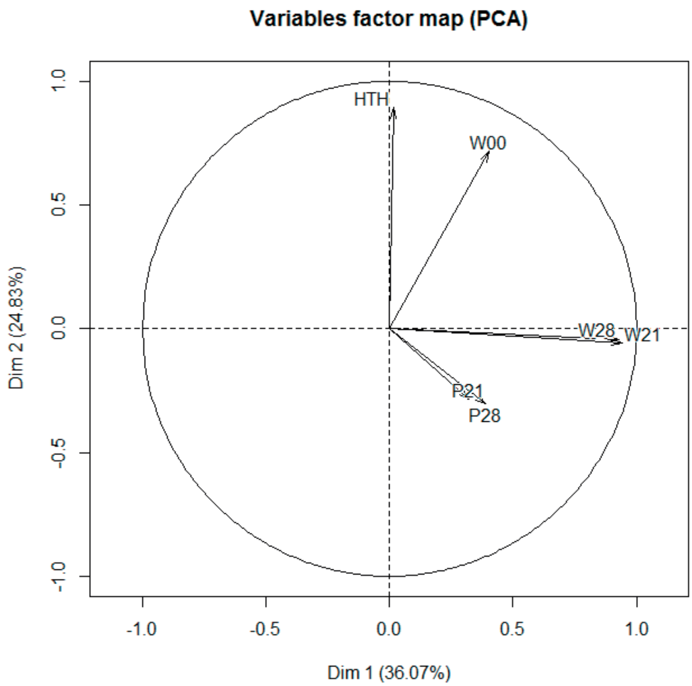


Figure 1: Variable factor map of principal component analysis.

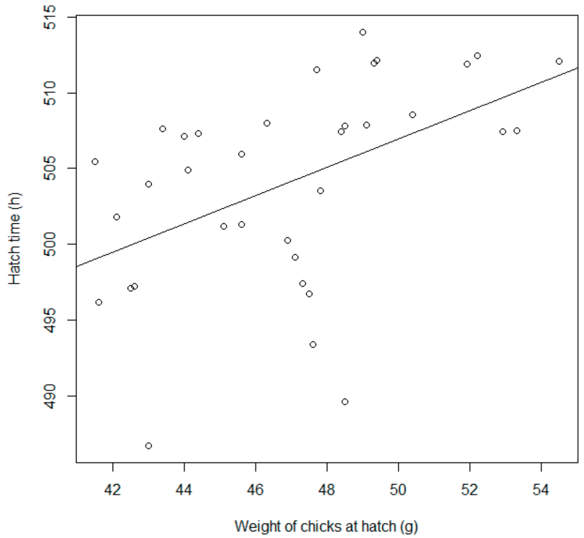


Figure 2: Hatch time correlation with day old chick weight.

**Discussion**

It has been suggested previously that females hatch earlier than males (Nielsen *et al*., 2010; van de Ven *et al*., 2011). Burke (1992) found that females hatch 2.7 to 3.3 hours earlier than males, and Reis *et al*. (1997) found that 62.1 % were hatched after 486 hours of incubation while only 48.1 % of males were hatched at the same time. In our study no significant effect of sex on hatch time was observed. The sex effect could not be observed because of the small number of chicks (35 chicks).

A positive correlation was found between the hatch time and day old chick weight, with light eggs hatching earlier. Using an interval of 6 hours to determine the hatch time, Vieira *et al*. (2005) suggested a positive correlation between egg weight and chick weight, and that light eggs initiated hatching earlier than heavy eggs. Careghi *et al*. (2005) did not find significant correlations between hatched chick weight and hatch time, but the egg weight of late hatched chicks (497 to 503 hours) was higher than that of early hatched chicks (476 to 482 hours). Raju *et al*. (1997) reported that there is a positive correlation between the egg weight and the body weight of the resulting chicks. Wilson's review (1991) clearly showed that the incubation time increases with egg weight. The average hatch time was 488 hours for eggs weighing 52 g and increased to 494 hours for eggs weighing 72 g (Burton and Tullett, 1985).

No significant correlations were observed between the hatch time and the weight at Day21 and Day28. These results confirm the results of Pinchasov (1991) who found no significant correlation between broiler weight at slaughter age (18 days) and their weight at hatch from Day5; he also reported that the main factor affecting final body weight is feed intake during the rearing period. Wyatt *et al.* (1985) found that broilers from large eggs were significantly heavier at 49 days of age than broiler, from small eggs, but feed efficiency was significantly better for broilers from small eggs.

Pododermatitis could develop early (less than a week), and where hyperkeratosis and necrosis of the epidermis could be observed histologically (Berg, 2004). Leg health and locomotion problems have been reported to be related to the incubation conditions (Oviedo-Rondon *et al.*, 2009). Some evidence of a possible relationship between hatch time and pododermatitis was presented by Kjaer *et al.* (2006) at the group level, when early hatched chicks remained in suboptimal conditions (temperature ~37 °C and relative humidity ~80 %) longer than late hatched chicks. This study aimed to study individual pododermatitis score in relation to the exact time of hatch but no significant correlations were found. This could be due to the small number of chicks and the small variability between scores (86 % of scores were 2 at Day21 and 72 % of scores were 2 at Day28).

## Conclusions

We conclude that the hatch time positively correlates with chick weight at hatch, with light chicks hatching earlier than heavy chicks. No significant correlations were observed between hatch time and sex, weight or pododermatitis at Day21 and Day28. Further studies are needed to identify other factors that may affect hatch time, such as initial weight and egg weight loss during incubation, and how they correlate to post-hatch performance.

## Acknowledgements

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## The use of renewable energy sources in poultry production

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### Abstract

The fast development of the Brazilian poultry industry, with special attention to the broiler sector, was mainly due to improvements in animal nutrition, genetics, health control and flock management, being the focus now given to barn indoor environment such as thermal comfort. This activity, in turn, consumes a considerable amount of energy, which is rather important to quantify. Energy sinks in a broiler barn are mainly lightening and maintenance of thermal comfort with mixing and/or exhaust fans and nebulizers. In this context, the need to develop and foment renewable energy generation technologies is a consensus among scientists and producers. Hence, the aim with this literature review work was to compile previously published data on technical and economic evaluation of novel renewable energy sources such as digesters, aero- and photovoltaic generators efficiency with respect to the total energy use in farms. It was observed that the use of digesters is the most feasible to poultry production. In contrast, the photovoltaic panels and aero generators are able to supply the energy demand for the activity but they are still dependent on government subsidies to be economically affordable.

**Keywords**: Broiler, biodigesters, clean energy

### Introduction

The accelerated development of the Brazilian poultry industry, highlighting the creation of broiler chickens on an industrial scale was mainly due to developments in the areas of animal nutrition, genetics, management and health including the importance of the ambiance of thermal comfort. These factors were relevant and decisive to make Brazil

as one of the largest producers and exporters of chicken meat in the world.
Thus the activity has a great economic importance in the Brazilian agricultural sector and great social responsibility as a generator of jobs and subsequent fixation of man in the field.
The viability and profitability of this activity is strongly influenced by parameters economic, environmental and social of brazilian market and international. The activity consumes a considerable amount of energy and it is used in these kind of confinement especially for feeding and maintaining the lighting and thermal comfort made by fans, extractor fans and nebulizers. It extremely matters in quantifying the production costs. The use of electricity on a large scale and rate adjustments included in this influences significantly the variable costs energy of the investor, an effect more noticed in large aviaries (NASCIMENTO, 2011).
According to data released by the Ministry of Agriculture, Livestock and Supply (MAPA, 2011), the domestic production of chicken meat tends to increase and reach a stake of up to 48.1% in the global meat market in 2020. This expected growth is accompanied by an increased energetic demand. In this context we have the need to develop and encouraging technologies that use renewable energy generation, enabling the creation of sources of supplies decentralized and small-scale (COLDEBELLa *et al.*, 2006). The technologies based renewable sources are attractive not only due of the environmental benefits, but also social and economic, implying the potential sustainable development, which is essential both in developed countries and in development countries. The waste of poultry production is important raw material for biogas production when subjected to anaerobic digestion, thus can be a promising source of energy. However, as occur with other agricultural activities, there is a small advantage of the enormous potential of energy from waste biomass, which remains as a co-product in various activities (PRATI, 2010). As biogas energy sources, the wind and photovoltaic are very promising and can be associated with poultry. It is common in Brazil the availability of solar radiation and wind resources in areas where the poultry business is located. Photovoltaic systems are distinguished from others by presenting a profile generation daytime, due to this limitation, feature low energy production on days with low solar radiation. According to Nascimento (2011), wind generator due to its mechanical rotating, requires an estimate 1-2% of the amount of initial investment to cover operating costs of maintenance throughout its life.

## Objective

In this context, this paper sought to compile data literary evaluation of the technical and economic feasibility of using renewable energy sources such as digesters, aero generators and photovoltaic generators with respect to the energy use within these farms.

## Results and Discussion

Use of Biogas Energy

Orrico et.al (2011) conducted a study which compared the main species of agricultural interest, about the potential of methane production from the fermentation of animal waste. For this, five species of animals were selected during the production phase: pigs, cattle, goats, laying hens and broilers. To estimate the parameter proposed was made anaerobic digestion of manure produced by the animals was used in batch digesters countertops, where it was accompanied by the volume and composition of the gas produced. After analysis it was found that the waste of the poultry industry was the third most promising waste as methane production, as a conversion of 421.7 l $CH_4$ $kg^{-1}$ of Volatile Solids, behind residues of pig and laying hens.

The values of methane production found for the residue of broilers can be variation according to the material used as poultry litter, density of animals and the number of reuse of litter. One advantage found in the droppings of birds in relation to others, is that these are under aerobic conditions which minimizes methane production, increasing its potential for methane production when subjected to digestion.

In case study by Prati (2010), the analysis of the feasibility of implementation of energy use using swine wastewater (ARS) for a property that has 2.000 pigs in the finishing phase. The analysis showed a daily production of 301 $m^3$ biogas (109,865 $m^3$ per year), which corresponds to the generation of 128 800 $kWh.ano^{-1}$. In further analysis, the author showed that in such a situation it is possible to supply the entire energy needs of the property, including the supply of poultry houses with 36.000 broilers and still have a surplus of 40% of the energy generated, which can be used in additional activities and increase producer income. According the calculations performed by Van Lier et. al (2008) an anaerobic reactor with 25 m high and 6 m in diameter is capable of treating 25 tons of Biochemical Oxygen Demand (B.O.D.) per day. These 25 tons of waste agricultural industries can be converted into 7,000 $m^3$ of methane $day^{-1}$ (assuming 80% recovery of $CH_4$ based on the average efficiency of large-scale treatment) with energy equivalent to about 250 GJ $day^{-1}$. If we use an engine that converts heat in energy, gas engine efficiency of 40%, a power of 1.2 MW useful electrical output can be achieved. The global recovery energy may be even higher (reaching up to 60%), if all the excess heat could be used on the premises of the company or in vicinity. Assuming that the same treatment was done by a procedure similar the aerobic efficiency would be required around 1KWh $Kg^{-1}$ B.O.D. removed, or 1 MW of electricity. Thus the total energy benefit from the use of the anaerobic reactor would be 2.2 MW. In addition to the power generation, the anaerobic system can generate carbon credits, which can be obtained by renewable generation of energy.

The generation of 1 MW of electricity emits about 20 ton of $CO_2$ $day^{-1}$. The carbon credit policy can therefore be considered as a subsidy to Western systems implementation

anaerobic waste treatment in developing countries (VAN LIER et. al., 2008).
The slaughterhouses are the sector of the poultry industry where anaerobic digestion is widespread. Salminene Rintala (2002) conducted a survey on the potential methane generation from waste of slaughterhouses and poultry and stressed the importance of the utilization of this waste with potential of production: 0.20 to 0.25 m³ $CH_4$.kg$^{-1}$ of poultry carcasses, from 0.10 to 0.15 m³ $CH_4$.kg$^{-1}$ of poultry litter, 0.05 m³ $CH_4$.kg$^{-1}$ of pens, 0.10 m³ $CH_4$.kg$^{-1}$of blood and 0.30 m³ $CH_4$.kg $^{-1}$ of visceral, feet and head. These data confirm the high potential of energy utilization of poultry waste, especially in the use within their own sheds and heating the chicks in the first days of life.
Thus, it becomes explicit the potential of harnessing energy from livestock waste and can result in significant reduction of cost of property , improved production quality and mitigation of environmental impacts.

<u>Photovoltaics and wind</u>
Nascimento (2011) conducted a study of economic analysis on the feasibility of using photovoltaic generators and aero generators connected to the grid to supply partially or fully loads installed in a dark house aviary located in the southwest region of Paraná. The work includes an analysis of the avian energy from data collected from the load curve and profile generation devices effectively wind-photovoltaic conversion under the influence of the spectrum of wind and solar irradiation site. To this the historical data for wind speed and solar radiation obtained from local government agencies and some universities were considered. Through a process of economic analysis the author found that use of photovoltaic generators and aero generators connected to the network in aviaries conditioned are not economically attractive in the current scenario, investments are viable for some configurations simulated from an optimistic scenario under the influence of adjustments tariffs, special tariffs and subsidies on acquisition of aero generators and photovoltaic modules.

Akyuz*et al.* (2010) analyzed data from solar radiation and wind speed in Balikesir in Turkey to assess the technique and economic feasibility of a hybrid energy system. We estimated the energy needed to meet the energy demand of a typical commercial poultry and designed a system to serve it. The Hybrid Optimization Model for Renewables (HOMER) software is used to simulate four respective cases: diesel, photovoltaic-diesel-battery, wind-diesel-battery and photovoltaic-wind-diesel-battery. As part of the results it was found that the hybrid system reduces $CO_2$ emissions from 21.8 to 10 t. And was also performed an analysis of the equilibrium point to determine the optimal distance at which the hybrid power system is more economical than the length of the transmission line, which had as an indication that the installation of the hybrid power system is more economical than conventional power grid, when the distance is greater than 3.21 and 3.13 km for PV-wind, diesel drums and wind-diesel-battery, respectively. Wind power systems depend on the availability of sufficient wind to produce electricity.

The lack of control over when and how much wind power is available makes this renewable energy not be feasible for some sectors. This feature is often decisive for the choice of photovoltaics as an alternative source of energy.

In case study company in Tennessee American poultry industry, Brazen and Brown (2009) evaluated the feasibility of solar PV farms in different company, situated in different municipalities. As a result it was found that the installation of photovoltaic panels would only be economically viable if they will be obtained with state and federal incentives.

## Conclusion

The use of digesters with energy recovery are indicated and appropriate in poultry production, due to the large amount of waste produced and also due to high energy consumption for production. Thus, according to the data presented, the anaerobic digestion is a technic economically viable for production of renewable energy in the poultry industry.
With regard to the production of photovoltaic and wind energy can observe the need of government subsidy for these sources of energy become economically feasible in most cases.

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## A relational study of gait score with resting behaviours of broiler chickens

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### Abstract

Technological developments have provided us with a variety of tools that can be used to monitor behaviour automatically, and these have great potential to improve our ability to monitor animal welfare indicators on-farm. In this study, a fully-automatic monitoring technique was developed to analyse the resting behaviours of broiler chickens with different gait score levels. Five experiments were carried out in order to assess the relationship between gait scores obtained by human experts and resting behaviours quantified by an automatic image monitoring system. Resting behaviours such as sitting were identified for all gait scores using an automatic image monitoring system. For this purpose, video monitoring images of broilers with five different predefined gait scores were analysed and classified. These classified behaviours were compared with manual labelling by experts. On average, 83% of the sitting behaviour of the 250 chickens during the experiments could be correctly classified. This research also demonstrated that there is a very high correlation between the gait score and resting behaviours of broiler chickens, with a correlation coefficient of 0.987. Further experiments are needed to establish whether the results are repeatable.
Overall, the results show that an automatic camera monitoring system can serve as an automatic tool for determining sitting behaviour in relation to gait score.

**Keywords:** Resting behaviour, broiler chickens, gait score, automatic monitoring

### Introduction

The most important broiler welfare issues that have arisen in the last two decades relate to the growing incidence of metabolic and locomotion problems due to fast growth rates and inactivity of chickens (Cangar *et al*. 2009).
Lameness is a broad term used for a range of injuries to broiler chickens of infective and non-infective origin (Sorensen *et al*., 2000). In some broiler houses it has been observed that at least 90% of the chickens experienced gait problems to some extent at slaughter age (Kestin *et al*., 1992). Investigating locomotion behaviours of broiler chickens in relation to gait score can serve as a measure of lameness (Bokkers *et al*. 2006, Aydin *et al*. 2010). Vision technology and associated image analysis, for example, make it

possible to assess animal movements to a certain extent. Automated methods of this type have been validated against traditional methods such as direct observation. The accuracy of data obtained automatically varies between methods but can be increased by combining data (Rushen *et al.* 2012).

Image analysis technologies have been widely used in behaviour analysis of different animals. The locomotion and posture behaviour of pregnant cows prior to calving was studied by Cangar *et al.* (2008). Similar studies have also been performed to detect lameness in dairy cattle (Song *et al.* 2008). Leroy *et al.* (2005) established a model-based computer vision system to study the behaviour of hens in furnished cages. Individual behaviours such as standing, walking and scratching could be recognised automatically and in real time. The use of video camera images to analyse individual behaviours is an emerging technology.

A major advantage of this type of automated behaviour monitoring is that it is non-invasive. A second important advantage is that the equipment is relatively cheap; for instance, relatively simple webcams were used successfully by Dawkins et al 2009.

Cheap and non-invasive techniques will facilitate the collection of more frequent data over longer time periods. The non-invasive nature of the equipment means that it can be used for long-term monitoring of animals without disturbing them. A third important advantage is that processing is carried out by an analysis algorithm in real time. There is therefore no need to store huge amounts of data.

The first objective of this study was to investigate resting behaviours of broiler chickens, such as sitting, in relation to their gait scores using an image-based monitoring system under laboratory conditions. Use of this system made it possible to automatically classify behaviours which are relevant to lameness assessment in broiler chickens. The second objective of this study was to serve as a preliminary step towards developing an automatic behaviour analysis tool for chickens with different gait scores. It is also applicable to on-line quantification and control of animal responses (Van der Stuyft *et al*, 1991, Bloemen *et al*., 1997, Frost *et al*., 1997). As concluded in the study by Rushen *et al*., (2012) if expanded further this type of automatic system may be combined with other monitoring tools to assess the behaviour and welfare of broiler chickens with higher accuracy.

## Materials and Methods

<u>Experimental design, video recordings and birds</u>

The experimental setup consisted of a wooden corridor measuring 2.40 m (length) x 1.00 m (width) x 0.50 m (height). A digital video camera, Guppy F036C equipped with a C30811KP 8.5 mm lens (Pentax) was mounted 3.0 m above the ground (floor) with its lens pointing downwards and directly above the centre of the experimental area in order to capture a top view of the entire walking area in the camera image (see Figure 1b). The camera was connected to a PC with a built-in frame grabber (E119932-U, AWM

20276, VW-1) using an IEEE 1394 firewire cable. Images were captured at a resolution of 1024 x 768 pixels and a sample rate of 3.5 frames per second. Video recordings were made during five experiments. A schematic overview of the complete setup is shown in Figure 1.

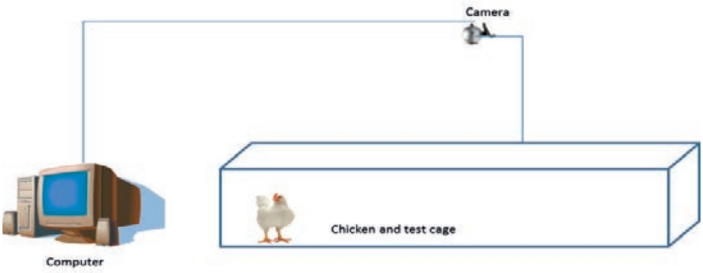


Figure 1. The test cage and the video recording equipment

Five experiments were carried out using a total of 250 broiler chickens which were obtained from the Provincial Centre for Applied Poultry Research, Province of Antwerp (situated in Geel, Belgium). The chickens were selected according to their gait score using the gait scoring method developed by Kestin *et al.* (1992). Based on Kestin *et al.* (1992), lameness in the chickens was ranked in increasing order from a gait score of zero (GS0) to a gait score of four (GS4), with GS0 being the healthiest. GS5 chickens were not used in the experiments as lameness in such birds is so severe that they are unable to walk.

For each experiment around 50 broiler chickens were chosen at day 39 such that there were enough samples from each gait score for accurate statistical analysis. Chickens were taken from a compartment of 1500 for each of the five experiments. In each experiment, 50 birds were used in total, with 10 birds belonging to each gait score group.

During the experiments, a chicken was placed at the starting point of the walking corridor and video images of the walking area were recorded while the chicken was walking from the start point to the end point of the walking corridor.

At the beginning of the rearing period, the animals were treated against infectious bronchitis (IB Primer, Poulvac) and Newcastle disease (NDW, Poulvac). On day 23, the birds were vaccinated again against Gumboro (Bursine 2, Poulvac) and Newcastle disease (Hipraviar NDV, Clone) in the poultry house via the drinking water. For the first 9 days, a pre-starter diet with 23% protein and 2890 kcal Amen/kg (apparent metabolisable energy) was provided. From day 10 to day 13 a starter diet with 22% protein and 2794 kcal Amen/kg was provided, and from day 14 to day 34 a grower diet with 20 % protein and 2899 kcal Amen/kg. Lastly, from day 35 to day 39 a 'finisher' diet was given with 19% protein and 2963 kcal Amen/kg. Drinking water was available on an ad libitum basis at all times.

Image analysis

Background subtraction for segmentation of the shape was used in the image analysis algorithms. This technique has been developed and used in studies due to the fact that the camera setup remains fixed during recording, so that the background remains constant over time. When segmentation is performed by subtracting a background image of the empty cage from each camera image of the cage with the animal, the pixels for which the difference is above a certain threshold are defined as the shape of the animal (Leroy *et al.* 2005). After this process, the shape of the animal could be characterised using a set of measurable parameters, such as the centre of mass of the shape mask, the area of the shape mask (Minagawaha *et al.*, 1994, De Wet *et al.*, 2003) or features calculated from the contour pixels (Tao *et al.*, 2000, Chi *et al.*, 2003, Ying *et al.*, 2003). In other studies, an image processing algorithm was developed by Leroy et al (2003a, 2003b, 2005) to extract the shape of the laying hen from a sequence of video images, and the fit of an elliptical shape around the animal in the images of hens in furnished cages was improved so that the, length and width of the animal in the image could be defined in real time in addition to its centre point and orientation.

Due to the capabilities discussed, the background subtraction technique was applied to the top view camera images taken at a frequency of 3.5 per second and the elliptical shape of the chicken was subtracted. Elliptical shapes are simple but widely applicable as an approximation of natural shapes (Birchfield, 1998) and their shape can be altered by varying only 5 parameters: $(xc, yc, \alpha, a, b)$, reducing the image processing time to such an extent that it can be used on-line (Leroy *et al.* 2005).

For initialisation purposes, the centre point, position, orientation and size of the mask derived from background subtraction of the chicken were calculated once in the first image of each video sequence and added to the program. For all other images, the optimal solution for one video image was used as the initial estimate for the next image. The optimum value of the shape parameters $(xc, yc, \alpha, r1, r2)$ for each image was labelled as posture parameters and stored for further processing (Leroy *et al.* 2005).When a certain type of behaviour showed up in the camera image, this caused a distinctive pattern in a number of successive values of the posture parameters. In each image, the posture parameters for the image were computed and the past values within a certain time window were considered, so that the window could hold the entire pattern (Leroy *et al.* 2005). To model the dynamic trajectories of the posture parameters within the time window, a first order transfer function (TF) model was used (Young, 1984, Aerts *et al.*, 2000). Fitting this function to the data within each time window resulted in a set of two dynamic parameters *a, b* for each posture parameter (Leroy *et al.* 2005).

The output resulting from the method consisted of the animal's position, orientation and body configuration as a function of time. These outputs were used for automatic classification of sitting behaviour. Table 1 summarises the dynamic variables that were extracted.

Table 1. Dynamic variables extracted from the video sequence of the chickens and their subsequent description.

| Variable name | Description | Units |
|---|---|---|
| x-y coordinates | x-y coordinates of the centre of the animal in the pen as a function of time | m |
| Walking trajectory | Subsequent positions of the animal's centre of mass as x and y coordinates | - |
| Orientation | Subsequent angles of the chicken with respect to the horizontal axis in the image as a function of time | ° (degrees) |
| Back surface | Top view area of the chicken | $m^2$ |

Classification of sitting behaviour

The classification procedure involved the variables: maximum radon, change in orientation, x–y coordinates and back surface area of the chicken. These variables were analysed using a sliding window approach. The chicken's behaviour was classified as sitting at a certain time if, during the past window size (3.5 frames per second):

1) The slope of the cumulative distance walked was below a certain threshold;
2) The x-y coordinates of the geometric centre of the animal were stable, meaning that fluctuations remained within a given stability range expressed as a percentage;
3) The filtered back area variable of the animal ($m^2$) exceeded a certain threshold (Cangar *et al.* 2008).

Different behaviours, such as sitting, were classified on the basis of the variables extracted from the images using an automatic real-time monitoring approach.

Table 2. Sitting behaviours that were classified using image analysis and the classification methods used.

| Behaviour | Classification method |
|---|---|
| Sitting | Classification of the sitting behaviour as a function of time, based on the x-y coordinates back surface area of chicken and the cumulative distance walked |

The decision that the bird was sitting was made if all three requirements were satisfied.

Statistical analysis

Statistical analysis was conducted on 50 data sets per experiment, with 10 data sets belonging to each different gait score group and 250 data sets in total, to investigate the differences in resting behaviours between the gait score groups. Friedman's test was used to analyse the effects of gait score on birds' resting behaviour. A Friedman's test, which is a non-parametric test that compares the columns without the row effects, was applied. In the test sample, size and dependencies did not affect the test results. After the Friedman's Test, a Dunn's test was used to define the statistical differences between the gait scores. Dunn's post test compares the difference in the sum of ranks between two columns with the expected average difference (based on the number of groups and their size).The calculations were performed using the Statistics Toolbox of Matlab (The Math Works, Massachusetts, USA).

## Results and discussion

Classification of sitting

An automatic continuous monitoring tool was applied to broiler chickens to automatically calculate some resting behaviours in a total of 250 broiler chickens with different gait scores. This fully automated monitoring tool made it possible to measure many body coordination variables (Table 1). In the experiments, the walking trajectory of chickens was measured using this automatic monitoring tool.

A change in orientation was a clear indication of activity by the animal. At certain times, the centre point of the animal did not change but its orientation did change, signifying a clear movement. X-y coordinates indicated the specific position of the chicken in the pen at a specific time. Fewer variations in x-y coordinates indicated limited movement by the chicken. During those periods the chicken was either standing and not moving or sitting down. Acceleration (m/s) was another means of investigating the chicken's movements. Not surprisingly, the speed was approximately zero during the sitting periods. Variations in the x-y coordinates over time combined with a speed greater than zero signified that the chicken was moving. This movement could be an indication of walking or could be indicative of lateral movements while in the sitting position.

The percentage of correctly classified sitting behaviours for 250 chickens is shown in Table 3. In particular, x-y position, back area and acceleration were strongly correlated with manual labelling of sitting behaviour. When the cumulative distance slope was highthe animal was moving. On the other hand, when the slope was close to zero, the chicken was sitting or standing still. Occasionally the cumulative distance increased slowly even when the chicken was sitting.

This could be due to the limited amount of noise that accumulated when measuring the position, or to real motion of the centre point of the animal while it was standing. The same conclusions could be reached by looking at the change in the back area of the animal. When the chicken was sitting, the back area was larger than when it was standing. These classified behaviours were compared with manual labelling by experts. On average, 83% of the sitting behaviour of the 250 chickens during the experiments was correctly classified.

Table 3: Sitting behaviours that were classified using image analysis and the classification methods used.

| Exp. No: | Correct assessment of sitting behaviour (%) |
|---|---|
| 1 | 84 |
| 2 | 81 |
| 3 | 80 |
| 4 | 88 |
| 5 | 82 |
| Average | 83 |

Assessment of resting behaviour in relation to gait score

The results of the algorithm were statistically analysed. As shown in Table 4, the prevalence of sitting in GS3 and GS4 (mean ± standard deviation) was significantly ($P<0.001$) higher than in GS0, GS1 and GS2 (Figure 2). Otherwise there are no significant differences in the prevalence of sitting among GS0, GS1 and GS2. The GS3 and GS4 groups are significantly different from each other. The results showed a clear correlation between the gait scores and the prevalence of sitting in broiler chickens, with a correlation coefficient of 0.894 (Figure 3).

Table 4. The prevalence of sitting by chickens.

| Gait Scores | NoS (Mean+Std) |
|---|---|
| 0 | $16{\pm}2^{a}$ |
| 1 | $17{\pm}1^{a}$ |
| 2 | $16{\pm}1^{a}$ |
| 3 | $34{\pm}2^{b}$ |
| 4 | $43{\pm}3^{c}$ |

* a,b,c Mean ranks, within a column, with no superscript in common differ significantly ($P < 0.05$).

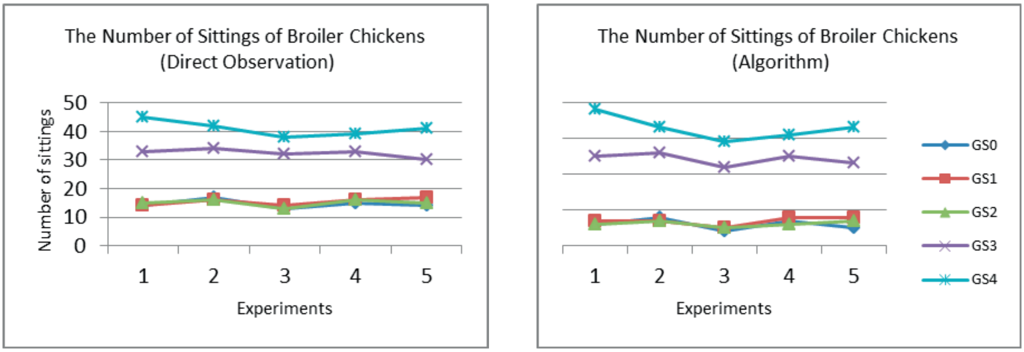


Figure 2. Prevalence of sitting in broiler chickens

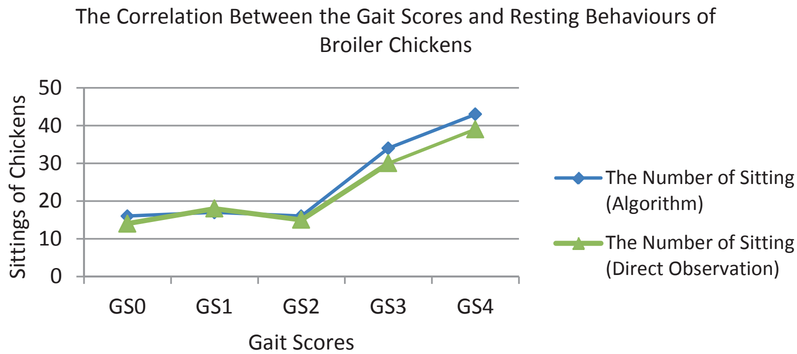


Figure 3. Correlation between gait scores and resting behaviours in broiler chickens.

There was no significant difference in the number of sitting results for the GS0, GS1 and GS2 groups. As concluded in the study by Weeks *et al.* (2000), a lame chick would spend a longer part of the day sitting and tends to sit down much more readily than a healthy one (the well-known 'latency-to lie test' is based on this fact).

In all experiments, there was a significant relationship between the gait score observed by experts and the resting behaviours monitored by image analysis. In all the experiments, GS3 and GS4 displayed significantly higher sitting behaviour ($P<0.001$). Overall, the results show that an automatic camera monitoring system can be used as an automatic tool to determine sitting behaviour in relation to gait score. In order to identify the effects of gait score on broiler behaviour more accurately, this automatically obtained sitting information can be combined with other automatic behaviour analysis systems such as tracking the activity levels of individual chickens and relating this to the degree of lameness (Aydin et al 2010).Since the same broiler breed Ross 308 was used in all five experiments, the above results only provide information about the behaviour of Ross 308, which is the most common breed in Europe. The resting behaviours of chickens with different gait scores may be different in other breeds.

## Conclusions

A technique was developed using computer vision for automatic monitoring of the body variables and coordinates of broiler chickens.

This research focused exclusively on the technical details associated with the development of an automatic real time resting and behaviour monitoring tool of this nature. However it requires further validation in different field conditions, using different type of chicken and a larger sample of broilers. When optimised in a future study, the automatic real-time resting and behaviour monitoring technique developed will prove a promising tool for analysing resting behaviour and relating it to the gait score in broiler chickens. In such cases, it will be possible to use this automatic activity monitoring tool as an indicator of high gait scores (GS4&GS5) under field conditions. As concluded in the study byRushen *et al.*, (2012) if expanded further, this type of automatic system may be combined with other automatic monitoring tools to assess the behaviour and welfare of broiler chickens with higher accuracy. The authors believe that a combination of this fully automated resting behaviour tool and the automatic activity monitoring tool described by Aydin *et al.* (2010) will allow researchers to conduct behavioural analysis studies of broiler chickens with greater accuracy. Therefore, in the future, experiments should be conducted to study the proposed combination of systems under field conditions.

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## Beak motion analysis of broiler chicks: preliminary studies

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### Abstract

To date, scientific studies into broiler feeding behaviour have been based on the productivity indexes and physiological responses of the birds, but little is known about the biomechanical features of the birds' jaw apparatus during this process. Chickens can use two different methods to manage the feed: the "catch-and-throw" (CT) and "slide-and-glue" (SG) techniques. This paper presents preliminary results for the feeding behaviour of five-day old broiler chicks using high-speed video footage and image analysis to determine the beak motion with respect to the two techniques used by the birds to handle the feed. The biomechanical variables considered in this study (opening and closing speeds and maximum beak gape) were significantly higher (P value < 0.05) in the catch-and-throw technique than in slide-and-glue.

**Key-words:** biomechanics; catch-and-throw, feeding behaviour, jaw apparatus; slide-and-glue.

### Introduction

The poultry industry has been considered one of the most active in the meat sector during recent years; this is explained by the strong increase in worldwide demand for chicken and turkey meat. Poultry production is important for the world economy. The United States, China and Brazil are the largest chicken meat producers, with Brazil and United States being the main exporting countries, and together accounting for two-thirds of global trade (FAO, 2012; USDA, 2012).

The domestication and selection of chickens for rapid growth did not make them lose the ability to distinguish different types of diets according to their energy and protein requirements, as their ancestors Red Junglefowl (*Gallus gallus*) used to do in natural environments (Emmans & Kyriazakis, 2001). Not all the birds' pecking actions result in a grabbed feed particle, and foraging behaviour (ground pecking) is highly associated with the feeding action (Yo, *et al*., 1997). Feed is an issue of great economic significance within commercial poultry production, not only because it is primarily accountable for the best bird performance, but mainly because it represents the largest cost in the productivity cycle (Ávila, *et al*., 1992). The influence of both chemical and physical characteristics of the feed on animal performance and, thus, the economic feasibility has been documented in a number of studies of feed processing methods (Thomas, *et al*., 1998; Perez & Oliva-Teles, 2002), feed particle size (Nir, *et al*., 1990; Nir, *et al*., 1994a; Nir, *et al*., 1995; Amerah, *et al*., 2007), feed physical form (Greenwood, *et al*., 2004; Nir, *et al*., 1994b; Skinner-Noble, *et al*., 2005; Zang, *et al*., 2009), and more recently the influence of feeder characteristics (Neves, *et al*., 2010; Roll, *et al*., 2010). To date, scientific research into the feeding performance and behaviour of broilers has been based on productivity indexes, physiological responses and the impact of environmental conditions, but little is known about the biomechanical features of the birds during feed consumption.

Chickens present cranial kinesis, which is characterised by movement of the upper jaw in relation to the skull and is a key factor in the feeding efficiency of all species of birds (Bock, 1964; Zweers, 1982; Bout & Zweers, 2001; Estrella & Masero, 2007). The mechanical feeding process in domestic chickens is similar to that of pigeons. Basically, a pecking session by those birds can be divided into different phases (Zweers, 1982; Bermejo, *et al*., 1989; Van Der Heuvel & Berkhoudt, 1998): fixation (the head is still and stable above the seed and eyes wide open; approach (bird moves its head uninterruptedly towards food); grasping (the beak tip touches and picks up the seed); withdrawal (food is retained in the beak tip and head is withdrawn in an upward motion); stationing (repositioning of the seed in the beak); transporting (transporting the seed from the beak tip into the pharynx level); swallowing (final transportation of the seed into the oesophagus). These phases can be performed differently according to morphological limitations as the birds are growing and can also be influenced by the feed particle characteristics, taking into account the time motion patterns (Martaresche, *et al*., 2000). Chickens can use two different motion techniques to manage the feed within the beak (Van Der Heuvel & Berkhoudt, 1998): catch-and-throw (CT), which is characterised by the repositioning the feed particle within the beak followed by head jerks and generally occurs with larger particles; or slide-and-glue (SG), which involves tongue movements to transport the feed into the pharynx and is generally used with smaller particles. A combination of both may occur in the same pecking scenario.

This paper presents some preliminary results for the feeding behaviour of 5-day old broiler chicks from the perspective of beak motion assessed through high-speed video footage and computational image analysis, and considers some initial findings relating to biomechanical characteristics during feeding by comparing the beak speed motion and maximum beak gape of the jaws for CT and SG techniques used by the birds.

## Material and methods

Birds and facilities

The experiment was carried out at the Ambience Laboratory in the School of Agricultural Engineering, State University of Campinas, Campinas-SP, Brazil. Eighty one-day old broiler chicks were reared in a climate chamber with tubular feeders and bell drinkers. Standard Brazilian husbandry methods were used. Four five-day old birds were randomly chosen from this group for the experiment.

Experimental procedure

The broiler chicks were placed individually in a rectangular glass box which contained a feed tray. Three birds received a mash-type ration and one milled corn. A high-speed camera (Microtron EoSens® with Nikon lens 50 mm/F 1.4) with an acquisition rate of 300 fps (frames per second) was set up and used to record the birds' intake behaviour. This acquisition rate resulted in a 0.003 s (3 ms) time delay between frames. With the aid of a tripod, the camera was arranged to fit the bird's head and the feed tray in a perpendicular-lateral direction into the field of view of the camera. A white paper sheet was placed in the background to provide a proper contrast between the bird and its surroundings and to assist with segmentation during image analysis (Estrella & Masero, 2007). No artificial light source was used, as the natural daylight was sufficient to illuminate the scene when acquiring the video footage. A laptop was connected to the camera to manage and store the data.

Biomechanical variables and image analysis

The biomechanical variables analysed were, (i) beak opening speed (measured in pixel $ms^{-1}$), (ii) maximum beak gape (i.e. inter-beak distance, measured in pixels) and (iii) beak closing speed (measured in pixel $ms^{-1}$). The movement sequence of each beak opening and closing event was defined as a "catch-and throw" (CT) or "slide-and-glue" (SG) movement type by manually checking and classifying the frame sequences. Both the opening and closing speeds were determined using the ratio between the displacement of the upper and lower jaw (at the beak tips) in respect to the time interval. The maximum beak gape was measured at its maximum aperture.

The feed tray diameter (47 mm) was used for calibration. In total, 96 sequences of opening and closing beak movements were analysed, corresponding to a total of 1905 frames (Table 1).

Table 1. The number of samples contained in each bird's opening and closing sequence and the number and percentage of the catch-and-throw (CT) and slide-and-glue (SG) feeding techniques identified in the samples.

| Bird | Ration type | CT | SG | Total samples |
|---|---|---|---|---|
| 1 | Mash | 7 (46.7%) | 8 (53.3%) | 15 |
| 2 | Mash | 9 (26.5%) | 25 (73.5%) | 34 |
| 3 | Mash | 17 (50.0%) | 17 (50.0%) | 34 |
| 4 | Ground corn | 2 (15.4%) | 11 (84.6%) | 13 |
| Total | | 35 (36.5%) | 61 (63.5%) | 96 |

Image analysis was carried out using Matlab (The MathWorks, Inc., Natick, Massachussetts, USA). To find the tip of the beak, Otsu's threshold was applied to the image to convert it to binary format (Otsu, 1979) (Figure 1b). The algorithm then commenced a search for the beak tips from the bottom left of the binary image (white dot; Figure 1b). If the beak was opened, the first non-zero pixel was identified as part of the lower tip of the beak. If the beak was closed, the first non-zero pixel was identified as part of the upper tip of the beak. Sometimes the feed particles occluded parts of the beak, making it difficult to detect the beak tip properly (Figure 1c) and so an algorithm was applied to remove the feed particle and facilitate correct beak-tip identification (Figure 1d). After removing the seed, a region of interest was defined around the beak (250x210 pixels) so that the beak gape could be determined. This gape was determined by identifying the two peaks along the boundary of the beak which corresponded to the end points of the beak (the beak tips). Then the Euclidean distance between these two points was measured (Figure 1e) and recorded. When the beak was closed only one beak tip was detected and the Euclidean distance was zero.

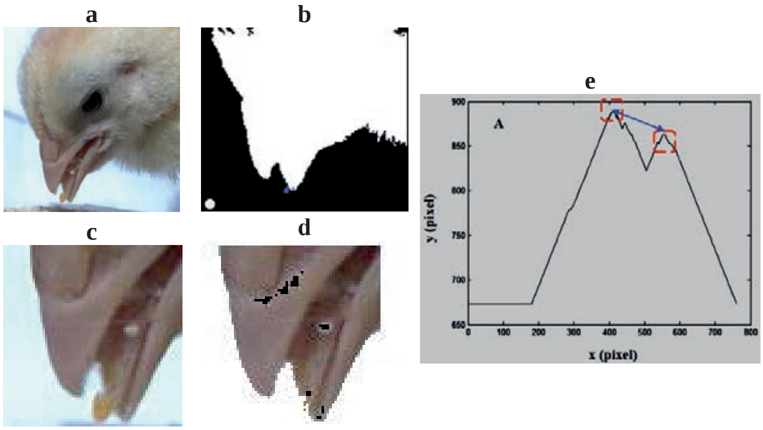


Figure 1. Illustrative pictures of processing stages of beak motion analysis: original frame (a and c); binarization process (b); feed particle removed (d); and determination of the inter-beak Euclidean distance (e).

Statistical analysis

Statistical analyses were performed using ANOVA procedures. For the differences between the techniques (CT and SG) and between individual birds, only data from those birds fed a mash-type ration (birds 1, 2 and 3) were considered. Data from bird 4 (fed milled corn) only were considered in the analysis to compare the differences between the types of ration. Minitab 15®software (Minitab Inc., Pennsylvania, USA) was used to carry out the analyses.

## Results and Discussion

The results (Table 2) show that the most relevant findings were the differences in the biomechanical variables in relation to the method used by the chicks to handle the feed within the beak, namely the catch-and-throw (CT) or slide-and-glue (SG) techniques. All the biomechanical variables (opening speed, closing speed and maximum beak gape) were significantly higher (P value $< 0.05$) in the CT than in the SG technique. Some significant variations were also found in relation to the ration type (mash and milled corn) and inter-individual differences between birds, although the ANOVA tests did not show a significant $R^2$.

These results were expected because the birds had to apply more physical effort to perform the CT technique, explained by a stronger beak motion and its larger aperture combined with more head jerks. On the other hand, less effort was required during the SG technique, in which less pronounced head and beak movements were evident and more tongue movements were used to hold the feed particles in place and transport them into the oral cavity, as previously described by Van Der Heuvel & Berkhoudt (1998).

Table 2. Descriptive analysis (mean ± standard error) and ANOVA results for biomechanical variables, for the catch-and-throw (CT) and slide-and-glue (SG) techniques, the differences between the birds (1, 2 and 3) and ration type.

| Biomechanical variable | | Factors | Mean ± SE | R-Square (%)/P-Value |
|---|---|---|---|---|
| Opening beak (pixel $ms^{-1}$) | Technique | CT | 5920 ± 505 | 49.60/0.000 |
| | | SG | 1774 ± 178 | |
| | Bird | 1 | 2424 ± 416 | 7.21/0.050 |
| | | 2 | 2963 ± 390 | |
| | | 3 | 4332 ± 621 | |
| | Ration type* | Mash | 3422 ± 318 | 0.97/NS |
| | | Ground corn | 2623 ± 547 | |
| Closing beak (pixel $ms^{-1}$) | Technique | CT | 6943 ± 427 | 42.12/0.000 |
| | | SG | 3399 ± 248 | |
| | Bird | 1 | 3348 ± 402 | 10.32/0.013 |
| | | 2 | 4560 ± 349 | |
| | | 3 | 5700 ± 567 | |
| | Ration type* | Mash | 4808 ± 295 | 6.31/0.014 |
| | | Ground corn | 2886 ± 393 | |
| Maximum beak gape (pixel) | Technique | CT | 126.0 ± 6.2 | 38.44/0.000 |
| | | SG | 72.0 ± 4.6 | |
| | Bird | 1 | 56.2 ± 4.8 | 30.85/0.000 |
| | | 2 | 84.2 ± 5.6 | |
| | | 3 | 119.2 ± 7.6 | |
| | Ration type* | Mash | 93.5 ± 4.7 | 8.80/0.003 |
| | | Ground corn | 57.1 ± 5.0 | |

*Bird 4 was included for ration type analysis only; NS = non significant (P-Value > 0.05).

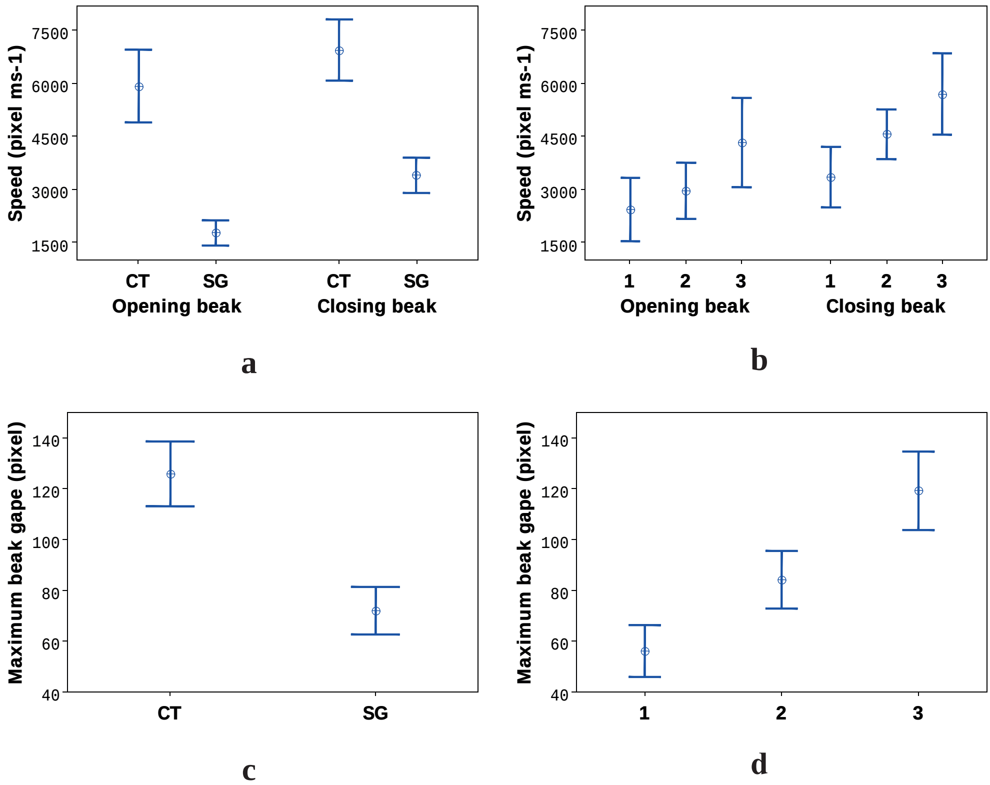


Figure 2.Interval Plot graphics of opening and closing speeds (a, b) and the maximum beak gape (c, d) in relation to the technique used by the birds to manage the feed within the beak ((catch-and-throw (CT) and slide-and-glue (SG)) and inter-individual comparison between birds (1, 2 and 3).

A significant difference was also found in the maximum beak gape between different birds fed with the same feedstuff, i.e. mash in this study (Figure 2b; 2d). More tests will be necessary to confirm the level of these inter-individual variations.
Refinement of the current image capture technique might also be important as birds frequently rotate the head, probably in order to identify the feed by vision cues (Turro-Vincent, *et al.*, 1995; Marples & Roper, 1996) and also to reposition the grabbed feed particle. This might create a distortion that could influence the results obtained by computational image analysis. In future experiments, it will be important to insert reference markers in both the upper and lower jaw to calibrate the measurements in order to obtain more accurate results. This is the reason why the unit presented in this specific study is pixel $ms^{-1}$ and not, for instance, mm $ms^{-1}$. The current objective was not to present the beak motion speed or aperture, but to show preliminary findings for comparisons between feeding techniques, individuals and rations.

Cranial kinesis is a key factor in the feeding efficiency of birds (Bock, 1964; Zweers, 1982; Bout & Zweers, 2001; Estrella & Masero, 2007) and a biomechanical approach has been reported for hens fed with peas (Van Der Heuvel & Berkhoudt, 1998). The authors classified pecking sessions during feeding into different phases and sub-phases from the point when the bird looks in the direction of the target particle until it is swallowed. The movements adopted to handle the feed particle could change in order to avoid dropping the grain, and some stereotyped patterns identified were explained by the anatomical limitations. Furthermore, different feed particle positions within the beak might excite different fields of tactile sensors and taste buds (Berkhoudt, 1985), which provides a series of sensory experiences, especially in chicks just after hatching (Fujita, 1973). These pecking session phases can be performed differently according to morphological limitations as the birds grow and can also be influenced by the feed particle characteristics (size and shape), taking into account the time motion patterns, as was previously described by Martaresche, *et al.* (2000).
The foraging behaviour is highly associated with the feeding process (Yo, *et al.*, 1997), in which the jaw apparatus plays a key role in identifying and selecting the feed particles. Additionally, the influence of both chemical and physical characteristics of the feed on the economic feasibility has been documented (Thomas, *et al.*, 1998; Perez & Oliva-Teles, 2002) and some studies have demonstrated the influence of feed particle size (Nir, *et al.*, 1990; Nir, *et al.*, 1994a; Nir, *et al.*, 1995; Amerah, *et al.*, 2007) and physical form (Nir, *et al.*, 1994b; Greenwood, *et al.*, 2004; Skinner-Noble, *et al.*, 2005; Zang, *et al.*, 2009) on animal responses. Thus, a biomechanical approach to evaluating feeding behaviour based on the characteristics of different feeds might play an important role in improving bird welfare and provide a new perspective on feed processing. Furthermore, it might be possible to develop a solid methodology for biomechanical assessment of feeding behaviour through high-speed video footage and computational image analysis which can be adapted for application to other livestock species.

## Conclusions

From this preliminary study, it can be concluded that the biomechanical features of the intake process differ significantly according to the technique used by the birds to handle the feed within the beak. A higher beak speed and larger maximum aperture were recorded for the CT technique than the SG. Inter-individual variations between birds were also found, but the statistical significance of these variations cannot be established using this relatively small dataset. Nevertheless, it is believed that different types of feed of different size, shape and hardness might also influence the birds' biomechanical motions. Future studies are necessary in order to understand the biomechanical processes involved in the feeding behaviour of broiler chickens, which in turn could offer new directions in feed manufacturing processes and insights for feed equipment design, leading to improvements in flock performance and welfare.

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## The variation of day-old chick beak tip lengths exposed to standard trimming gauges and its weak relationship to body weight

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### Abstract

Beak trimming is an elective surgery routinely performed on turkeys, layers and broiler breeder chickens to reduce the damage of abnormal feather pecking. It is often carried out on day-old poults and chicks at the hatchery or at the farm before 10 days old. Birds may also be beak trimmed a second time during the rearing period if a cannibalism outbreak occurs. Beak trimming can be a painful procedure linked to altered behaviour and may give rise to neuromas depending on the age and severity of trim. Since birds are processed in the hatchery using standardized 'one-size-fits-all' equipment, individual beak variation is not normally accounted for during beak trimming procedures. The purpose of this experiment was to quantify the variation in lengths of chicks' beak tips exposed to a pseudo hot-blade trimming gauge. The relationship between exposed beak tip length and body weight was also studied. After weighing, we placed 195 chicks' beaks snuggly through a custom made metal 4.35mm hole, modelled after commercially available day-old beak trimming gauges, and photographed from above. Beak tip length was analysed manually using image analysis software. Descriptive statistics showed that the exposed beak tips had a mean length of 3.43mm (± 0.44mm) with 2.56mm as greatest difference between two chicks' exposed beak tip lengths. The mean length was greater than the recommended maximum beak removal for day old chicks (3mm) while the tip length variation was too small to be individually accounted for even by experienced trimming operators in a commercial setting. Pearson's correlation gave a statistically significant positive correlation between exposed beak tip length and body weight at $r=0.261$. However, body weight was a weak predictor of exposed beak tip

length ($R^2$ =0.068), thus sorting chicks by body weight does not seem to be a good method to improve day-old beak trimming.

**Keywords:** chick welfare, beak trimming, image analysis, Precision Livestock Farming

## Introduction

The chicken beak is highly functional organ containing mechanoreceptors, themoreceptors and nociceptors for touch, heat and cold, and noxious stimuli perception. Only the very tip of the beak – up to 1mm from the end – is a hard corneum similar to a human fingernail; after which it is rich with nerves, connective tissues and blood vessels (Cheng, 2006).

Beak trimming is an elective surgery that typically removes $^1/3$ to $^1/2$ of the bird's beak without the use of analgesics. Beak trimming causing acute and/or chronic pain is widely documented in research through altered bird behaviour and the presence of neuromas and abnormal nociceptor discharge in trimmed beaks (Breward and Gentle, 1985; Duncan *et al*., 1989; Gentle, 1989; Gentle *et al*., 1990; Hughes and Gentle, 1995). Beak trimming at a young age, especially day old chicks, is strongly recommended due to a lessened behavioural impact, absence of neuromas and a quicker more complete healing process (Gentle *et al*., 1997; Cheng, 2006). Nonetheless, beak trimming may still be painful for day old chicks. During the first week post-trim, beak trimmed chicks rested more (sit/sleep behaviour) and preened less than untrimmed chicks (Gentle *et al*., 1997). Day old chicks that experienced cold trimming ate less and performed less beak related behaviours (Gentle *et al*., 1997) while turkey poults struggled and vocalised more during the hot-blade trimming (Grigor *et al*, 1995). Infrared beak trimming is considered more precise and a welfare friendlier method of beak trimming day old chicks (Dennis *et al*., 2009). It has been linked to greater beak uniformity and fewer irregularities at later ages (Carruthers *et al*., 2012). When assessing older chickens that were trimmed as day-old chicks, Carruthers *et al*. (2012) found differences in beak abnormalities between strains and hatcheries using similar equipment. These authors suggested that variation in day old chick size or intensity of trimming could account for differences between flocks and that new methods to improve trimming consistency were needed. Similarly, Glatz (2000) suggested that robotic beak trimming was unsuccessful in the past due to variation in chick weight and the inability for the current machinery to position chicks accordingly.

At embryonic day 14, the architecture of the chicken beak is well established in cartilage and bone; and by embryonic day 18, the majority of the beak is bone (Wu *et al*., 1996). An avian beak is formed by the growth effort of multiple facial prominences: lateral, maxillary and mandible prominences and a frontal nasal mass - where the size is determined by overall growth activities and the shape is determined by localised growth in different prominences (Wu *et al*., 2006). Differences in growth activity explain how the slightly curved and conical shape of a chicken's beak is formed differently than, for example, ducks' or hawks' beaks. Experimentally, Wu *et al.* (2006) were able to alter beak prominences to proportionately larger or smaller beak size and alter beak shape by modifying the growth of specific prominences through altering bone morphological protein pathways.

Given that beak development appears 'flexible', individual beak variation without trimming was studied. More specifically, it was investigated whether beak length variation had implications for beak trimming procedures using standardized 'one-size-fits-all' equipment. The purpose of this experiment was to see whether there was a difference in beak tip length when placed in a pseudo-hot-blade trimming gauge. We investigated whether exposed beak length correlated to body weight; and if so, whether body weight could be a reliable predictor for length and sorting index for improved beak trimming procedures.

## Materials and Methods

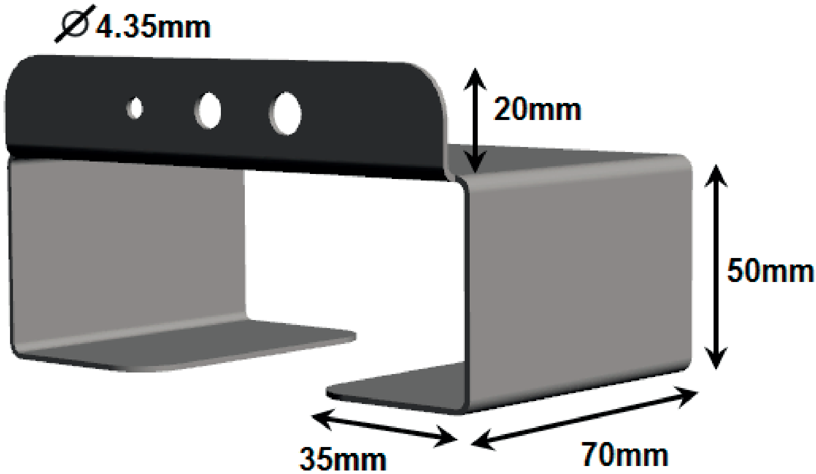


**Figure 1.** Custom-built beak trimming gauge. The smallest hole, measuring 4.35mm wide, was used in this experiment.

A total of 19,200 eggs (Ross 308, parent flock aged 45 weeks) were incubated through a standard commercial program in a custom-built Petersime machine in the hatchery lab of Anses (France). During processing (removal of shell debris, sorting and chick quality scoring), a total of 195 newly hatched chicks were selected for beak length analysis. The chicks were weighed using a Mettler PM2000 balance with 0.01g precision. After weighing, chick were held in a 'pistol grip' with their beaks fit snuggly and straight through a custom made metal 4.35mm hole, modelled after commercially available day-old beak trimming gauges, and photographed from above. The custom-made gauge had three hole sizes. The smallest hole measured 4.35mm wide and is the size commonly used for day-old chicks (Glatz, 2000; Lyon USA product catalogue). The medium and large holes (7mm and 8mm wide, respectively) were not used in our experiment. The gauge model was designed in SolidWorks software and constructed of steel (Figure 1). The gauge was secured onto the table with gaffer tape and beaks were photographed from a fixed distance using a Canon PowerShot SEM550 camera steadied at a 90$^{o}$ angle on a Manfrotto 190D tripod.  A 1mm x 1mm grid was taped to the gauge to serve as the beak photograph background and calibration scale (Figure 2a). Chicks were given individual numbers in the photograph in case a photo needed re-taking and to align the right chicks with their weight recordings afterwards. Artificial lighting was constant during image collection. Beak length was analysed manually using ImageJ software (Figure 2b).

Previous researchers have measured beak length from nares to beak tip using digital calibers (Carruthers *et al.*, 2012) or by photographing the beak profile against a scale (Fahey *et al.*, 2007). Our approach differed slightly from the latter by photographing birds from above in order to mimic the perspective of the operator during trimming and for potential automated image analysis technology. We also focused only on the length of the beak tip that would be exposed to hot-blade trimming. These broiler chicks were sub-sampled from a large scale field study as an additional measurement of flock uniformity. No birds were beak trimmed in this experiment and handling was kept to a minimum. The study served as a proof of concept trial to measure only the part of the beak potentially subjected to hot-blade trimming and as a conceptual design for automated image analysis.

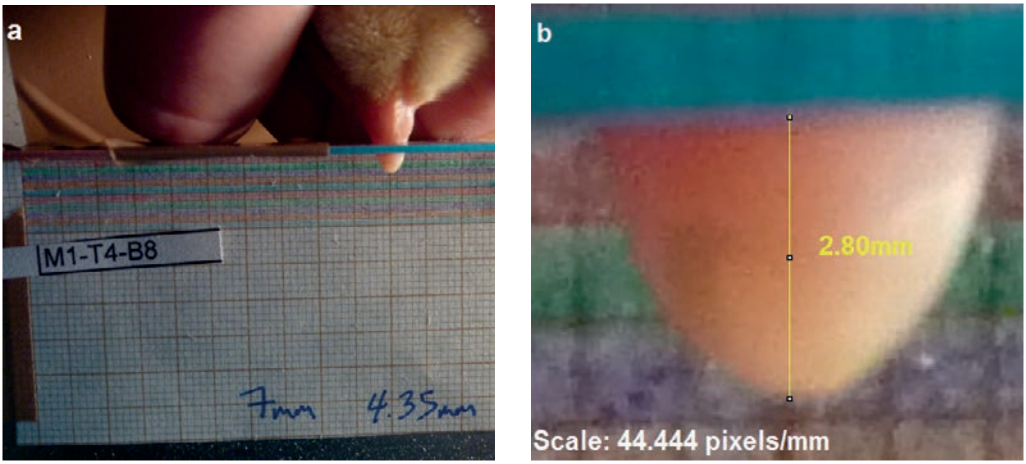


**Figure 2. (a)** Photograph of a chick's beak fit through the 4.35mm gauge hole. **(b)** Same photograph zoomed in 200% and measured using ImageJ software.

## Statistical Analysis

IBM SPSS Statistics 20 was used for data analysis. Exposed beak tip length and chick weight were normally distributed as evaluated by histograms and the one-sample Kolmogorov-Smirnov test. A Pearson correlation was chosen to assess the strength of the linear relationship between chick body weight and exposed beak tip length. Significant difference was evaluated at $P<0.05$. Linear regression was run to determine whether body weight could predict exposed beak tip length.

## Results and Discussion

In the *Beak Trimming Handbook for Egg Producers,* it is stated that day old chicks should have no more than 3mm of their beaks removed (Glatz and Bourke, 2006). In our study, the average beak tip length protruding from the gauge was 3.43mm ± 0.44mm, meaning that on average 3.43mm of the day old chick's beak tip would normally be subject to a hot blade beak trimming. In this average, 84% of chicks' exposed beak tips were over the recommended 3mm. This result suggests that the 4.35mm gauge may be too wide to optimally trim the majority of day old chicks and encourages trimming operators to assess the tip lengths per batch prior to trimming. Further research is needed into whether different breeds or strains vary in average beak tip length in order to select the optimal gauge size.

The variation between the chick beak lengths was less than half a millimetre (±0.44mm). On either end of the dataset, the difference between the largest exposed tip length (4.49mm) and the least exposed (1.93mm) was 2.56mm. Beak cutting precision depends on the quality of the equipment and the skill of the operator. Blades must be changed before becoming blunt or warped. The commonly used Lyon BC blade should be changed after trimming 5000 chicks (Glatz and Bourke, 2006). Accredited beak trimming operators must meet an accuracy standard of 85% of bird beaks trimmed within a 4mm range: either 1mm shorter or 2mm longer from the desired cut point. Of the remaining 15% of birds, only 1% are permitted to be trimmed beyond 1mm in severity from the optimal cut point (Glatz and Bourke, 2006).

Additionally, the hot-blade method itself creates some variability in the amount of tissue burned back from the blade cut point (Gentle *et al.*, 1997). We found that the variation in beaks tip length was small (SEM ±0.44mm) and within the optimal range of expected operator trimming precision (4mm). Whether small variation is worthy of welfare consideration depends on the degree to which these regions are innervated and responsive to painful stimuli; however, it is unreasonable to expect that an accredited trimming operator in a commercial setting could account for this variation. Future imaging technology may improve tip trimming accuracy on an individual basis.

Chick mean weight was 44.46g ± 3.35g. In Table 1, the Pearson's correlation coefficient (r) was 0.261 – showing a small positive correlation with significance ($P<0.01$) between body weight and exposed beak length.

**Table 1.** Correlation between chick weight and exposed beak tip length. Significant at $P< 0.01$.

| | | Length | Weight |
|---|---|---|---|
| Length | Pearson Correlation<br>Significance (2-tailed) | 1 | 0.261** |
| Weight | Pearson Correlation<br>Significance (2-tailed) | 0.261** | 1 |

**Table 2.** Linear regression model summary. [a.] predictor (weight); dependent variable (length).

| Model | R | R Square | Adjusted R Square |
|---|---|---|---|
| 1 | 0.261[a] | 0.068 | 0.063 |

**Table 3**. Linear regression coefficients output. Dependent variable (length).

| Model | | Unstandardized B | Coefficients Standard Error | Standardized Coefficients Beta | t | Significance |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 1.899 | 0.410 | | 4.638 | 0.000 |
| | Weight | 0.035 | 0.009 | 0.261 | 3.757 | 0.000 |

Table 2 shows the model summary of linear regression. The coefficient of determination (R square) is 0.068, meaning that only 6.8% of beak variance can be predicted by weight. Using the coefficient output in Table 3, the regression equation for predicted exposed beak length was 0.035*body weight + 1.899. Data is plotted with a linear fit line in Figure 3. Despite having significance, the low values of Pearson's r correlation (<0.3) and the low predictability value of $R^2$ suggest that body weight is not a practical way to sort chicks for tailored beak trimming. Fahey *et al.* (2007) classified chicks into weight categories (light, intermediate and heavy) and measured various beak features including the maxillary and mandibular tomias and anterior interamal and gonys. They found no correlations between beak features and weight in the light group but some statistically significant correlations between beak shape in the intermediate and heavy groups. While our study looked only to the beak tip that would be exposed to trimming, our work is in agreement that weight and beak correlations are too weak for practical application.

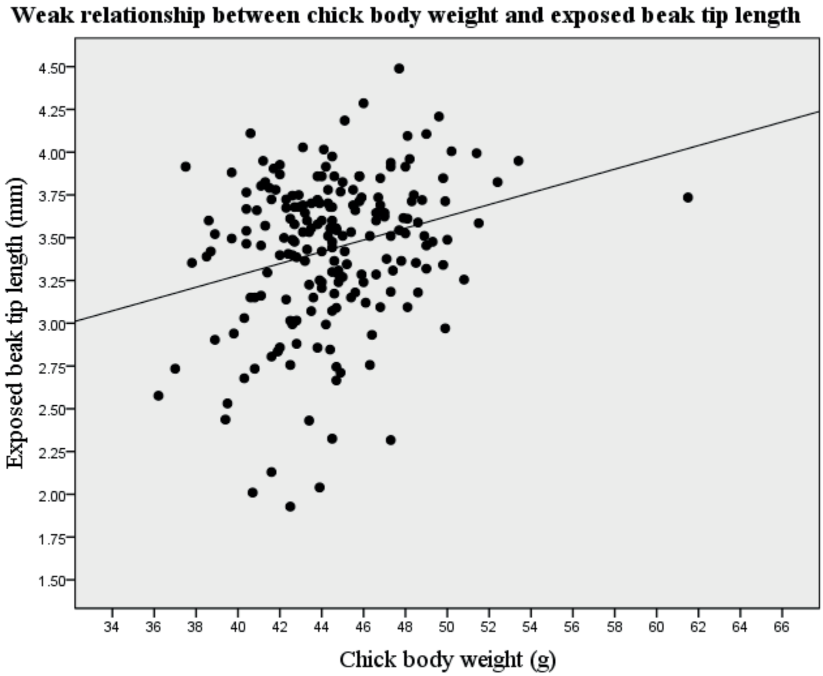


**Figure 3.** Scatterplot of chick body weight and exposed beak tip length with a linear fit line. R Square Linear = 0.068. Regression equation = 0.035x + 1.899

## Conclusion

A weak correlation was found between the exposed beak tip length (i.e. the beak that could be trimmed by a hot blade) and the weight of the day-old chicks. This suggests that sorting the chicks by weight does not have a considerable impact on the part of the beak that would be subject to hot-blade trimming. Variation was found between chicks' beak tip lengths but the differences were too small for operators to account for in a commercial setting. Further research into developing accurate imaging technology may help identify and adjust trimming for individual beak differences. More research is also needed into the beak differences between chicken breeds and strains to help select appropriate trimming tools and prevent excessive and non-uniform beak trimming. Our experimental design could be improved for automatic image analysis by increasing the contrast between the beak and gauge background.

## Acknowledgements

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**Enhanced efficiencies in the poultry industry via real-time monitoring and cloud-enabled tracking**

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**Abstract**
It is evident that for sustained production and enhanced efficiencies in the Agriculture and Food industries, continued development of Precision Livestock Farming (PLF) techniques will need to adapt to meet current technological and new-era wireless technology that is revolutionizing the way we live. Two key systems have been developed for the poultry industry, *BOSCA* and *CyberBar*. The focus of *BOSCA* is on real-time product visibility thus ensuring quality and integrity, empowering all stakeholders with decision support functionality. *CyberBar* is a track and trace system delivering a real time biological unit-level identification and traceability platform. It is based on three fundamental areas, individually tracked agri-food products coupled with remote environmental monitoring and diagnostic capability combined under cloud computing architecture made available to all stakeholders across the full supply network via modern telemetric smartphone delivery. Both systems are designed to provide real-time data which can be mapped against industry key performance indicators (KPI's), facilitating increased operational efficiency performance and improved food quality and safety. Both, truly unique systems will confer market advantage on the Irish food industry by enabling verifiable traceability in real time extending right down to the consumer level.

**Keywords:** Precision agriculture, telemetric traceability, environmental sensors, Big Data

## Introduction

<u>The key drivers of precision agriculture</u>
Agriculture is the world's largest industry. From a macro perspective it employs more than one billion people and generates over $1.3 trillion dollars' worth of food annually [1]. A number of recent reports have highlighted the need for new technology to play a leading role in developing strategies to improve food production and increase security [2].

Ten per cent of Europe's workforce are employed in the agricultural sector and generating 10 % of the European Union's total GDP. The EU food industry employs 4.4 million people, generates almost one trillion euro turnover annually and serves ca. 500 million consumers daily. From a poultry perspective the global market share has increased from 15% in the 1970's to 33.5% in 2010 [3] where Brazil produced almost 11 million tonnes of chicken meat in 2009, exporting 70%, which accounts for approximately 50% of the world market [4, 5]. At European level poultry accounted for a total of 22% of meat consumption per capita in the 27 EU member states in 2010 [6]. These statistics are some of the key drivers of *BOSCA* and *CyberBar* outlining the need to advance precision livestock farming.

In the current economic climate, there is increasing pressure being placed on poultry producers to increase value performance and output set against a backdrop of increasing feed and fuel costs. In previous years, some may have argued that poultry producers were in a price setting position, while now the market overwhelmingly defines the value of the produce given factors such as global competitiveness. The introduction of EU directives such as the 'Integrated Pollution Prevention and Control Directive' [7] further increases operating costs which is further exaggerated by variations in operating standards across the globe. Food standards agencies also exert price pressure on producers, as increased levels of food safety require ongoing implementation [8].

There is a global focus on sustainable, competitive and efficient agri-food production and processing, including the manufacture of safe, value-added foods. Both *BOSCA* and *CyberBar* are aimed at delivering enhanced operational efficiency across the sector, by aiding its smooth transition towards a knowledge-based data-driven sector. A combination of smart sensing technologies and data analytics play a key role in the development of both *BOSCA* and *CyberBar*. It is envisaged that increased productivity will help the poultry production industry to meet stricter environmental impact standards and consumer needs. It is estimated that it has the potential to enhance agri-food, including poultry production, output by approximately 30 % over a 5-year horizon, while also significantly reducing indirect economic and environmental costs.

In terms of basic functionality *BOSCA* (Gaelic for "Box") is a pre-processing smart networked sensing system with an agriculture poultry industry focus. It involves the development of a wireless-linked sensing unit to measure and control a vast array of critical performance related factors within broiler poultry production. Sensors currently in operation include temperature, light, ammonia, carbon dioxide and air speed with future sensing systems stated to include motion detection, video, vocalisations and thermal imaging. These systems have been found to provide real-time data which can be mapped against industry key performance indicators (KPI's), facilitating increased operational efficiency performance and improved food quality and safety.

*CyberBar* is a post-processing track and trace system delivering a real time biological [9]unit-level identification and traceability platform. It is based on three fundamental areas (1) individually tracked agri-food products coupled with (2) remote environmental monitoring and (3) diagnostic capability combined under cloud computing architecture which will be made available to all stakeholders across the full supply network. This is a world-first which will confer market advantage on the Irish food industry by enabling verifiable traceability in real time extending right down to the consumer level, via modern telemetric smartphone delivery. It also provides product integrity to all supply chain actors.

Modern day agri- food industries are beginning to focus less on tangible assets as a source of competitive advantage (buildings etc.) and are shifting their focus to intangible sources of competitive differentiation, such as data. It is for this reason that both *CyberBar* and *BOSCA* initiatives have tremendous game changing potential across a number of agri-food applications. These cloud-based platforms will also address the issues of dysfunctional and fragmented information systems and replace them with a user-orientated sensing systems delivering end-to-end production, supply chain integrity monitoring and product verification across agri-food networks. This is key to both the economic and social development of the knowledge based agri-food sector.

<u>Information as a resource</u>

A key strategic driver of sustainable precision agriculture is the availability of information at the correct time, place and in the correct format. As with every industry/sector, information is obtained from a number of sources and in a variety of formats. The true added-value comes in the ability to use this information, convert it to knowledge which can then be used to initiate proactive level responses and also generate organisational wisdom (Figure 1). In order for it to be both timely and beneficial it must firstly be gathered, stored, transmitted and converted to the correct format thereby making it meet the requirements of the end user facilitating the answering important management questions such as *what, when, where and how* relating to a particular product/ process. The availability of information across the organisation serves many purposes such as retrospective analysis, real time analysis and to develop strategies of future development. It can deliver details on a number of industrial indicators such as seasonal production outputs, animal welfare, quarterly sales comparisons, regional performance, and production performance or consumer trends. It is based on this information that each organisation provides all levels of managers the ability to review current status, respond to occurring incidences or pre-empt a variety of potential occurrence. State of the art systems such as *BOSCA* and *CyberBar* have been strategically designed to gather, store, and/or transmit this data in a form that is both useful and informative to all relevant stakeholders. It aims to deliver real time data to management thus enabling more informed and accurate decision making within the organisation forming the basis of sustainable differentiation across many industries and the agricultural industry is no exception.

Information communication technology (ICT) is an essential component of the progression of precision livestock farming. This is a discipline that has rightfully gained considerable acceptance and scale potential with the growing popularity of the internet. At wider levels it has formed the backbone of the ability of organizations to trade and function globally. The integration of ICT into the agricultural industry has made it a pivotal technology in the attainment of sustainable differentiation and also enhances an organization's ability to achieve global scale sustainable supply networks. Over the last number of years ICT based systems have transformed monitoring and traceability systems [10, 11] and revolutionised global supply chain trading. It is through the constant monitoring, gathering, analysis and interpretation of this information that organisations can compete in an ever changing global economy. Information also provides managers the ability to succeed within each trading region by providing strategic level managers a concrete foundation on which to base their decisions.

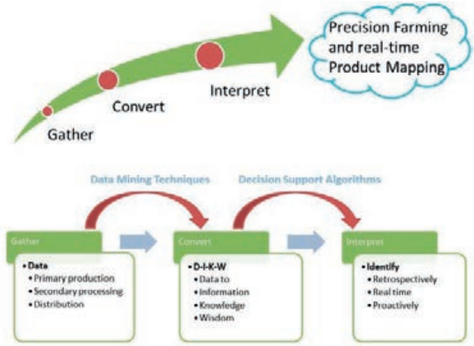


Figure 1 Data is the key to success – "Data Evolution"

In order to correctly manage these sources of data one must adopt a formal structured approach. There are a number of key steps involved in the gathering and utilisation of this data. All data must firstly be gathered at operational level and stored. Once gathered it must then be centralised in order to facilitate gathering, analysis, interpretation and redistribution via a number of channels to make strategic decisions which give companies the ability to create and sustain a competitive advantage in modern day agricultural practices. The centralisation process is important step in preventing the formation of information silos across the organisation [12]. This information can form the base of a number of collaborative levels within the organisation some of which include - collaboration assets (value chain interaction), engagement assets (motivation of employees), and finally time as an asset (how quick something is achieved) and also create external synergies across the complete supply chain. Correct ICT system has the ability to manage and distribute all these assets throughout the organization [9]. Most systems to date make use of manual, handwritten records however more modern systems are turning to the internet for wireless data transfer and display. The ability to network

these sensors systems underpins the development of information super highways across the agricultural sector. The infrastructure of these wireless environmental monitoring across production, processing and distribution has created this essential cyber physical link necessary for the gathering, handling transfer and interpretation of this large data sets. The ability to gather, handle, mine and interpret such large data sets in real time has been identified as one of the main key drivers of precision livestock farming.
To achieve this enhanced level of synergism, environmental sensing units will need to be networked (via radio satellite communication) to a cloud based management system and will provide an essential source of real time data gathered at operational level (primary production, secondary processing and distribution) then wirelessly transferred to a cloud-based decision supported infrastructure where this data undergoes a mining process.

This “data revolution” process involves converting this gathered data to a useful source of information forming the basis of effective management decisions, which leads to the ability to establish a fully networked value chain from farm to fork. This provides stakeholders an elevated level of transparency and access to real time actionable data delivering end-to-end production, supply chain integrity monitoring and product verification across supply networks. This level of integrated functionality will lead to a fully flexible more adaptable and responsive supply chain which will have the ability to respond in times of exception and provide advanced knowledge-based solutions towards improving primary production, secondary processing and distribution across the FMCG such as the agri-food industry. An organisation with such a system has the advantage of being able to link (compare and contrast) each different process within the organisation and provides the ability to make strategic decisions both on a local and international scale in real time, thus improving market adaptability [13]. It will also potentially aid in a number of business processes such as harmonisation of processes within the organization, synchronisation of information and product flow and finally facilitation of global expansion through standardised data transfer, productivity refinement, and enabled collaboration with supply chain trading partners.

## Material and Methods

***BOSCA:*** The sensor systems are currently being developed and trialed. The system consists of a number of environmental sensors (Table 1) incorporated into a single integrated networked platform. This sensor system is specifically designed for harsh processing environments such as broiler poultry production (Figure 2). The system has been deployed in a number of broiler house sites throughout Ireland. These systems are incrementally feeding data sets into a backend cloud based platform accessible to a limited number of users as can be seen in (Figure 4).
***CyberBar***: Similar to BOSCA, CyberBar will function from the same cloud-based

platform to avoid duplication. Each unit of product will have a unique identifier assigned at time of production to remain with the product throughout its lifetime. Remote environmental monitoring of product during transport will be delivered via commercially available RFID-based systems with enhanced GSM reader functionality (Figure 3).

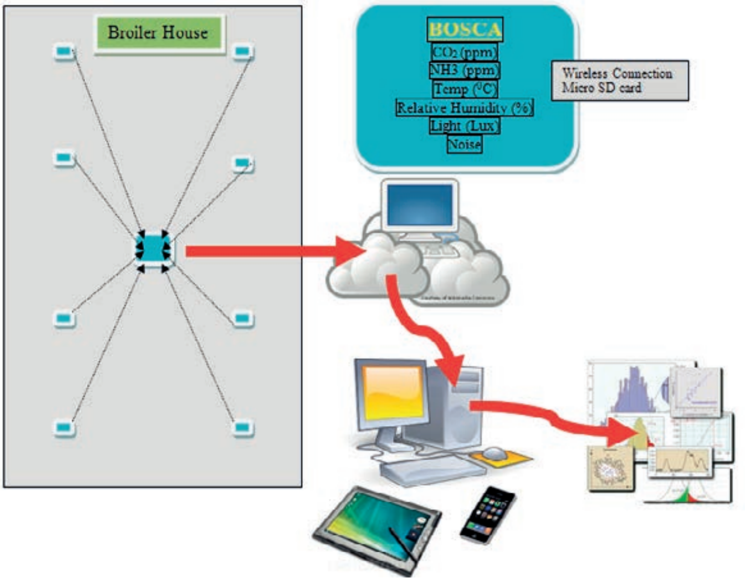


Figure 2 BOSCA - Smart real time networked monitoring system in the poultry industry

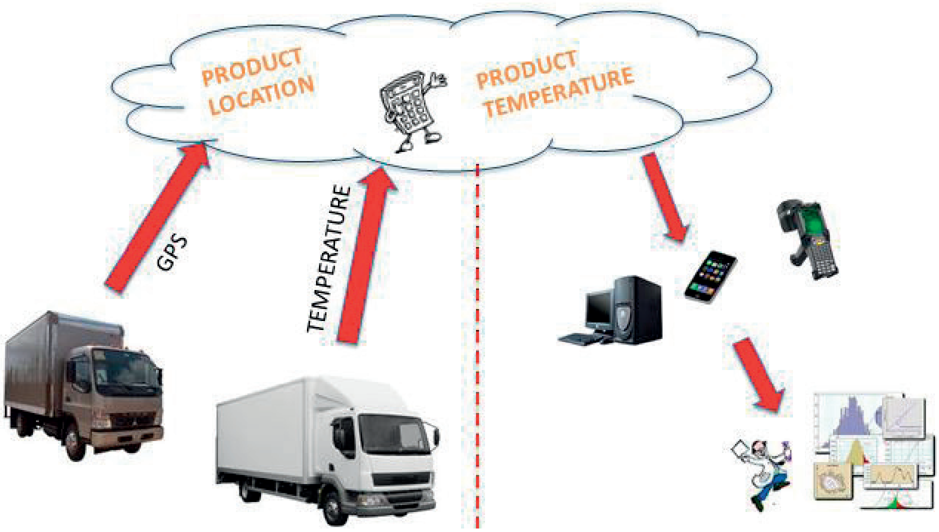


Figure 3 CyberBar - Smart real time track and trace telemetric platform

**Table 1 Environmental sensors that will be integrated into the smart monitoring system**

| Sensor | Part# | Supply chain | Interface | Power |
|---|---|---|---|---|
| Light intensity | Avago APDS-9007-020 | Digikey, USA | Analog | 1-20uA |
| Carbon dioxide | Epluse EE891 | Instrument Technology Ltd, Ireland | I2C | 2mA 30S |
| Temp/Humidity | Sensiron SHT21P | Element14, Ireland | I2C | .180mA |
| Ammonia | Micronas GAS8614B | Rutronik, UK | SPI/Digital | 10uA?! |
| Air speed | Wind Sensor | Modern Device, USA | Analog | 20mA |

## Results and Discussion

This data gathered from the above systems will be integrated into a user friendly platform as illustrated in Figure 4 which represents a screen shot of a real time data feed visible to users. This will present the processor with live (real-time) data relating to various production facility performances and therefore allows forward planning of slaughter regimes. When fully integrated at a system level, it will allow the prediction of the availability of poultry produce that is likely to enter the market in the coming days, weeks and months. This will help to optimise the production process so that the right chicken is produced at the right time. In addition, from a health and welfare perspective, a bird welfare-index could be defined by constant monitoring and interpretation of the assembled data.

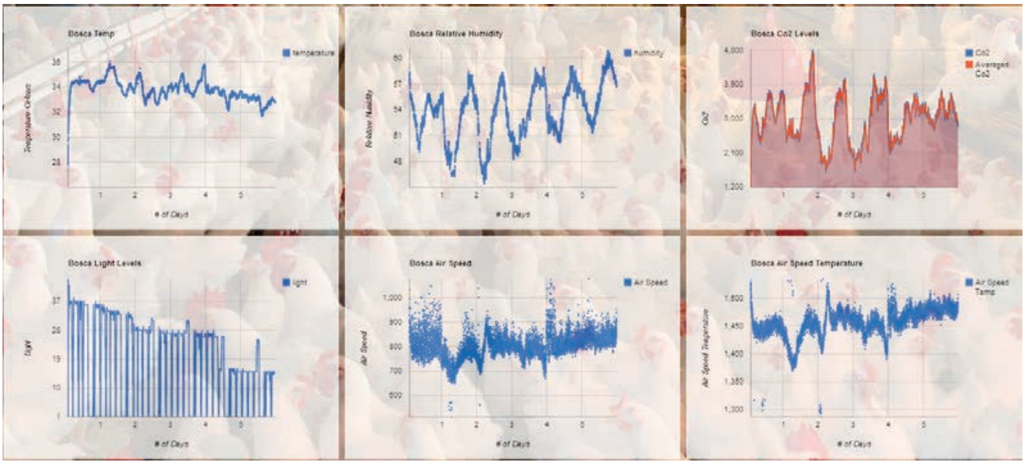


**Figure 4 Real-time data streaming of BOSCA monitoring**

## Conclusions

It has now been demonstrated that it is possible to stream large data sets from harsh production environments and expose these data sets to a mining process to extrapolate key performance indicators with a significant level of accuracy which can be used as proactive markers in production and processing. The industry changing potential of these smart safety and security systems cannot be underestimated in the area of Precision livestock farming. It is clear that the developments in smart cloud-based technology should be closely followed by the agri-food industry globally given its value adding potential. An effective ability to acquire (sensors), transmit (wireless networking), and interpret the data (data mining and decision support functionality) via both ***BOSCA*** and ***CyberBar*** will provide an information rich production and supply chain which delivering retrospective analysis, real-time functionality and visibility and proactive strategic planning capabilities so it is critical that this information be gathered and interpreted. The commercial application of this research has the potential to standardise precision livestock farming practices with roll out potential across the complete Agri-food sector.

## Acknowledgements

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**Analysis and countermeasure discussion of temperature sudden-drop in confined layer house under control of evaporative pad cooling system**

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## Abstract

This paper studies the temperature sudden-drop phenomenon at the beginning of evaporative pad cooling in confined poultry in summer, and countermeasures for this phenomenon in China. Field tests were undertaken to research the intensity and distribution of temperature sudden-drop in a layer house. The results show that the temperature sudden-drop phenomenon is significant. The maximum cooling effect in Beijing and Shijiazhuang was 8.6°C and 12.8°C, respectively within 20-25 minutes after starting the evaporative pad cooling system, and half the area of the house close to the pad was cooled by more than 5°C. In order to solve this problem, the pump intermittence regulation (PIR) method and multi-stage regulation (MSR) method of evaporative pad cooling are proposed. Results from a PIR field test show that the cooling effect can be regulated to below 5°C each time. The MSR method is still undergoing laboratory research. The CFD simulation analysis of MSR shows that the cooling effect is less than 3°C on each occasion when the wetted area of the pads is increased by stages. The evaporative pad cooling system produces a slow and graded cooling process.

**Keywords:** Confined poultry house, Evaporative pad cooling system, Temperature sudden-drop, countermeasures

## Introduction

An evaporative pad cooling system, combined with tunnel mechanical ventilation, has a significant effect on cooling, alleviating heat stress and improving production performance in poultry housing in the summer. A statistical analysis of China meteorological data for China shows that, with an evaporative pad cooling system, the temperature inside poultry houses could be maintained at less than 28°Con 65% of summer days in the Beijing, Jinan and Xi'an regions, and at less than 30°C on 70% of summer days in other regions of China (Wang *et al,* 2009). The field test trials in the Beijing area showed that the temperature inside a layer house could decrease by 5.3-6.1°C when the outside temperature wais over 33°C (Zhang & Yang, 2002). Researchers have also studied the cooling performance of evaporative pad cooling systems in many countries. The average cooling effect is 3.9°C inside a layer house (Bottcher *et al,* 1992). In North Carolina, USA, the temperature inside a 91.5 m long poultry house could be 5°C lower than the outside temperature, with 80% cooling efficiency (Timmons & Baughman, 1984). In the Mediterranean climate area of south Turkey, the evaporative pad cooling system works well. The cooling efficiency is about 70%, and the maximum cooling effect is 7.3°C (Dağtekin *et al,* 2009). Studies into the effects of different pad materials show that the cooling efficiency is 50-62% for a celluloseic paper pad (Al-Sulaiman, 2002),. 88.18% for a palm rachis pad (Abdul-Munaim, 2009) and 76-88% for a galvanised metal sheet pad (Alodan & Al-Faraj, 2005). Efficiencies for commercially available 45°-45° pads range from 73-90% under normal operating air velocities, and are higher than those of 30°-30°pads (Koca, R.W. *et al,* 2001). As the water temperature increases, the performance of evaporative cooling systems decreases (Simmons & Lott, 1996). In general, evaporative pad cooling systems have a significant cooling effect in summer, which guarantees production and economic benefit (Bayraktar, 2004). In China, the regulation method currently used in evaporative cooling systems is simple. Once the evaporative cooling system is operating, pads are wetted quickly and the maximum cooling effect occurs rapidly. This phenomenon of a large temperature decrease in a short time could be called temperature sudden-drop, which may cause cold-stress for layers, be injurious to poultry health and influence production. Previous experience indicates that infectious coryza and diarrhoea are likely to occur when the temperature sudden-drop range exceeds 5°C in a poultry house. This paper focuses on the problem of temperature sudden-drop and the countermeasures for this problem.

## 2 Field tests of temperature sudden-drop

### 2.1 Material and methods

The poultry houses used in the trials were located in Beijing and Shijiazhuang, north China, in a continental monsoon climate.
Test poultry house in the Beijing region: The poultry house dimensions were 100×12 m. Pads and six fans were positioned at the ends of the house. The total pad area was 36 $m^2$. Every fan had a maximum air capacity of 38,000$m^3h^{-1}$. Temperature measurement points were positioned at distances of 16 m, 40 m, 64 m and 88 m from the pads, near the pads and near the fans, and 0.5 m above the ground. T-CC thermocouples and a CADAC21 data collector (EKO Instruments, Japan) were used for temperature measurement. Data were recorded automatically every 10 min during July 2004.
Test poultry house in Shijiazhuang region:

The poultry house dimensions were 76×11 m. Pads and eight fans were positioned at the ends of the house. The total pad area was 34.2 $m^2$. Every fan had a maximum air capacity of 42,000$m^3h^{-1}$. Temperature measurement points were positioned at distances of 8 m, 16 m, 26 m and 36m from the pads, near the pads and near the fan at a height of 0.85 m above the ground. RS-13 series thermo-hygrometers (ESPECMIC Ltd. Japan) were used for temperature measurement. Temperature data were recorded automatically every 5 min during May and June 2012. The data for daily laying rate and health status were recorded manually.

2.2 Test results and discussion

In summer, the temperature in Beijing and Shijiazhuang regions is high and air relative humidity is low. The clear days were selected for analysis. The temperature variation in the poultry house on specific days is shown in Fig.1 and Fig.2.

The target temperature when using for the cooling system was 30°C in both test poultry houses. There is a difference between the actual temperature and target temperature, owing to errors in the control system and sensors. In the tests conducted in Beijing, the maximum cooling effect near the pads was 8.3°C within 20 minutes after starting the cooling system. One hour later, the maximum and minimum cooling effect for all temperature measurement positions was 8.9°C and 5.2°C, respectively. The average cooling effect for the whole house was more than 5°C.

The air relative humidity on 11 June2012 was very low, about10%, during the field test in Shijiazhuang. When the cooling system was operating, the cooling effect near the pads was 10.2°C in 5 minutes. 25 minutes later, the cooling effect near the pads, 8 m, 16 m, 26 m and 36m from the pads, and near the fans was 12.3°C, 10.1°C, 8.8°C, 8.1°C, 6.7°C and 3.9°C, respectively. This demonstrated the high cooling efficiency and a significant temperature sudden-drop phenomenon. Tab.1 presents the average cooling effect for different sections of a poultry house over one week after the evaporative cooling system began working. Each number is the average of the maximum cooling effect in 25 minutes.

The cooling effect decreases with increasing distance from the pads. The average cooling effect over the poultry house was 7.21°C over one week, and the maximum cooling effect of 8.8°C occurred on 9 June. In the 76 m long poultry house, the minimum cooling effect for the 36 m distance was 5.3°C, indicating that the cooling effect in about half the area of the poultry house was over 5°C.

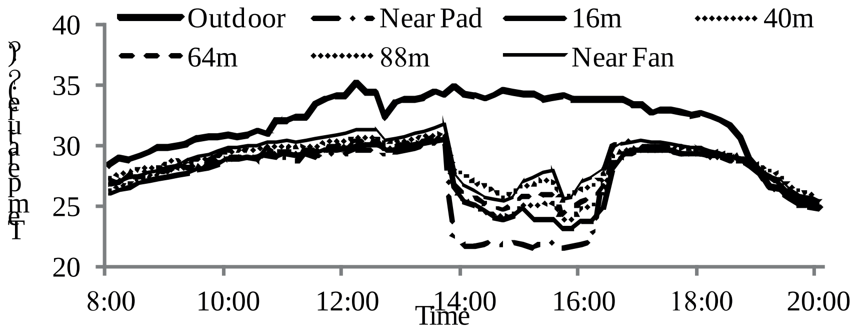


Fig.1 Temperature variation in poultry in Beijing (13 July, 2004)

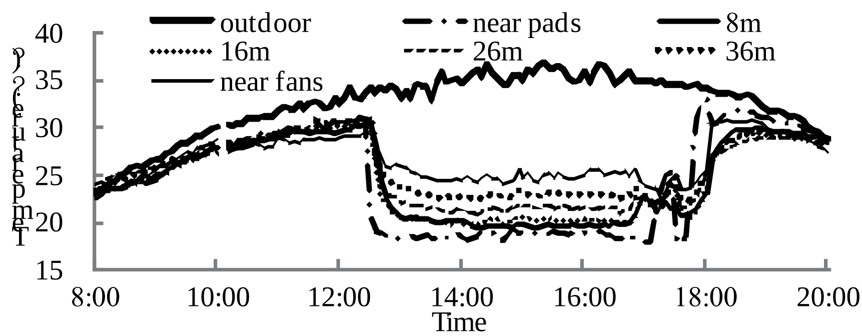


Fig.2 Temperature variation in poultry in Shijiazhuang (11 June, 2012)

In field tests, this cooling system completed the cooling process in 25 minutes, identifying the phenomenon as temperature sudden-drop reasonably well. The temperature sudden-drop phenomenon became more severe as the cooling effect increased. Previous experience has reported that the 5$^{o}$C cooling effect of temperature sudden-drop affects poultry performance and health. This means that at least 50% of the area of the test poultry houses might suffer reductions in performance.

The temperature sudden-drop phenomenon in poultry houses could be treated as a kind of cold stress. Research into cold-stress shows acute cold-stress (8$^{o}$C lower than normal temperature for 2 h, 12 h and 24 h) in 5-day old chicks reduces the level of cellular immunity (Yuan *et al,* 2002). There is little research into the effects of acute cold stress on layer production. Production performance and health records showed that daily laying rates started to decrease on the third day after starting the cooling system. Meanwhile diarrhoea among hens became serious one week later. This could indicate that temperature sudden-drop had affected layer health and production.

## 3 Countermeasures for the temperature sudden-drop phenomenon

The weather conditions in most of northern China are similar to those in Beijing and Shijiazhuang. Investigations show that most evaporative cooling systems are controlled by a simple on/off method, which means that the temperature sudden-drop phenomenon is likely to be common in these areas. Countermeasures for the problem of temperature sudden-drop are necessary.

Table 1 Average temperature drop range for different sections (□)

| Distance from pads | Date (Jun.2012) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 6.5 | 6.6 | 6.7 | 6.8 | 6.9 | 6.10 | 6.11 |
| Near pads | 10.1 | 12.8 | 7.6 | 11.4 | 12.4 | 10.7 | 12.3 |
| 8m | 7.6 | 9.7 | 7.6 | 8.4 | 9.7 | 9.4 | 10.1 |
| 16m | 6.4 | 8.4 | 6.2 | 6.7 | 7.8 | 7.5 | 8.8 |
| 26m | 6.2 | 7.7 | 5.9 | 6.8 | 7.9 | 7.0 | 8.1 |
| 36m | 5.5 | 7.1 | 5.3 | 5.8 | 6.5 | 5.8 | 6.7 |
| Near fans | 3.7 | 4.7 | 3.8 | 3.5 | 3.6 | 3.6 | 3.9 |

The cooling effect is closely related to the evaporation capacity of wetted pads. In order to solve the problem of temperature sudden-drop, the cooling effect on each occasion should be kept low by controlling the evaporation capacity of the wetted pad. Two countermeasures were proposed; one was pump intermittence regulation (PIR) in the water supply system, and the other one was multi-stage regulation (MSR) of the wetted pad area. MSR could grade the cooling effect by dividing pads into several sections and controlling the wetted area.

### 3.1 Pump intermittence regulation method for evaporative cooling systems

The on/off situation of the pump is controlled by the indoor temperature, according to the temperature requirement. The PIR cooling system has been used on a few poultry farms. Field trials studied the temperature distribution in a poultry house using PIR. The confined poultry house measured 98×11.5 m and was located in the Beijing region. Five temperature test points were positioned at equal distances apart in the house. T-CC thermocouples and a CADAC21 data collector (EKO Instruments, Japan) were used for temperature measurement. The data were recorded automatically every minute during the period 14-25 August 2009. The temperature variation inside and outside the poultry house is shown in Fig.3. The inside temperature was measured in the middle of the poultry house.

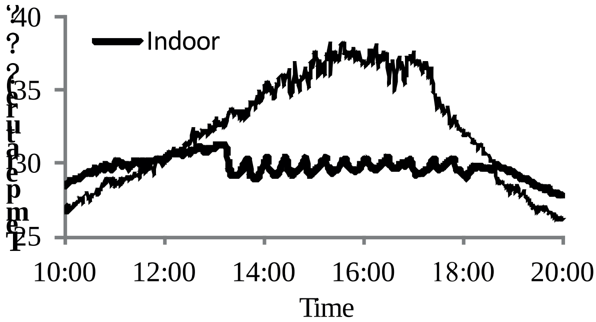


Fig.3 Inside and outside temperature in the middle of the house (20 August. 2009)

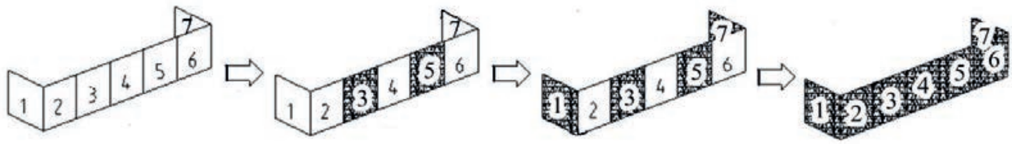


Fig.4 Design of multi-stage regulation cooling pad

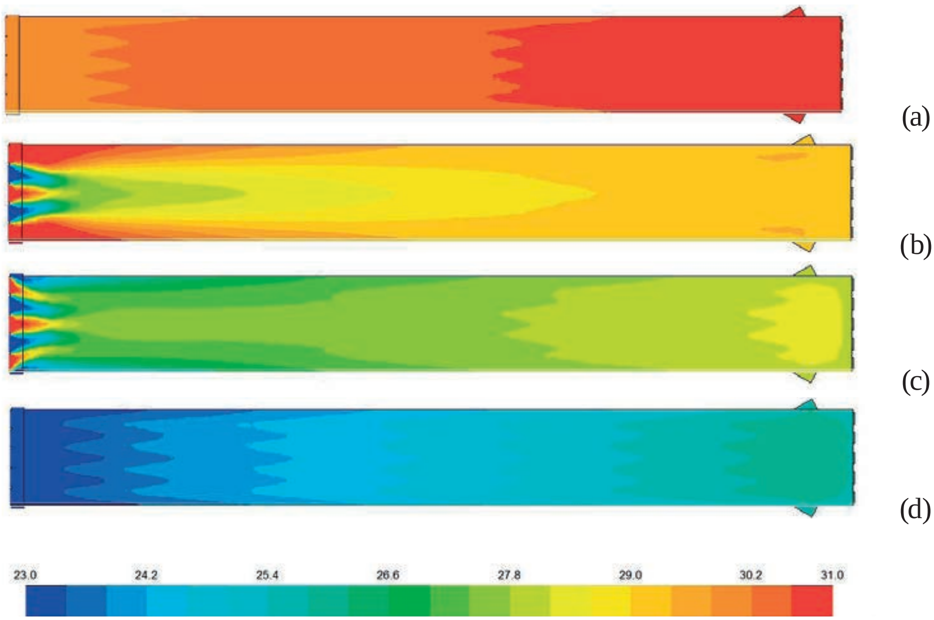


Fig. 5 Temperature distributions with multi-stage regulation

With PIR the cooling effect inside the poultry house was maintained at less than 3°C all the time. In the position close to the pads, the cooling effect was about 4°C. This indicates that the PIR method is an effective method of solving the problem.

### 3.2 Multi-stage regulation method for evaporative cooling systems

This regulation method could create wet and dry areas on pads alternately by controlling the water supply system. The pads cooled some air while some remained hot, and finally mixed evenly as it travelled over a longer distance. The MSR method is still undergoing laboratory research. The pads are divided lengthwise into several sections, with each section receiving a separate water supply. The wetted areas increase as the cooling requirement increases. Fig.4 shows the operating system for the multi-stage regulation method; the shaded areas represent wetted pads and the blank areas dry pads.
CFD software (computational fluid dynamics, Fluent Inc. NH, USA) was used to build a simulation model to analyse the temperature distribution in a poultry house of the same size using the MSR method. The theoretical temperature distribution at cage height is shown in (a)-(d) of Fig.5 for a simulated outside temperature of 31°C.
When the No.3 and No.5 pads were wetted, the cold and warm air flows were completely mixed at a location 20 m from the pads. The temperature was higher in areas near long walls than in the middle. The average cooling effect for the whole poultry house was about 3°C. When the No. 1, 3, 5 and 7 pads were wetted, the cold and warm air was completely mixed at a location 10 m from the pads. The average cooling effect for the whole poultry house rose by about 2°C. When the whole of the pads was wetted, the average cooling effect rose by another 3°C. The 8°C cooling effect was achieved in three steps, rather than a single temperature decrease.

## 4 Conclusions and Discussion

The field tests to study temperature sudden-drop were carried out in the Beijing and Shijiazhuang regions. In the 100 m long poultry house in Beijing, the maximum cooling effects in the poultry house were 8.3°C within 20 minutes after starting the evaporative cooling system. One hour later, the temperature across the house reached its lowest point, with maximum and minimum cooling effects of 8.9°C and 5.2°C, respectively. In the 76 m long poultry house in Shijiazhuang, statistical analysis showed that the cooling effects in the poultry house ranged from 3.4°C to 12.4°C, with half the area of the poultry house experiencing a cooling effect of more than 5°C (Tab.1). The cooling effect was obvious, and the temperature sudden-drop phenomenon was significant. In the field test in Shijiazhuang, the daily laying rate decreased from the third day, and about one week later widespread diarrhoea occurred among the hens. It indicated that the temperature sudden-drop phenomenon caused acute cold stress for layers.
PIR and MSR are two countermeasures that are proposed to solve the problem of temperature sudden-drop. Field tests of the PIR method showed that it could keep the cooling effect to less than 5°C all the time, but the temperature in the poultry house fluctuated constantly. Turning the pump on/off frequently would affect its performance and service life. The MSR method is still undergoing laboratory research. Results from

analyses using CFD simulation indicated that the cooling effect at each stage of cooling ranges from 2°C to 3°C when the wetted area of the pads is regulated, which enables hens to go through an adaptation process and avoid cold stress. But the air travelled a long distance from the pads before the cold and warm air mixed completely. This problem should be solved in future research through fine division of pads and devices designed for evaporative cooling systems.

It will be necessary to collect a large amount of field trial data on the effects of a sudden temperature drop of over 5°C in 20-25 minutes on layer health and performance. Further research to study the effects of different temperature sudden-drop levels on layer physiology and production will be carried out during the next stage of the work.

## Acknowledgements

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## Investigation of airflow characteristic around slatted floor in livestock building: a scale model study

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**Abstract:**

Airflow distribution around the slatted floor space, can greatly affect ammonia and odour distribution. Developing effective and practical approach to reduce the emissions depend on how much we know about the wind field around the slatted floor. Thus, the objective of this study is to investigate airflow characteristics in the headspace of slurry pit under the slatted floor and in the animal occupied zone (AOZ) above the floor. A 1:8 scale model of manure pit section with slatted floor was built in this study. Three different airflow velocities above the floor and two slat orientations were investigated. Computational fluid dynamics (CFD) simulations were applied and compared with experimental results. It was found that velocity under the slatted floor was very low despite the orientation of the slats and how large the wind speed above the floor is. Slat orientation did not significantly affect the air distribution in headspace of the slurry pit. The mean air velocity in the pit headspace increased as the wind speed increased. Standard k- ε model was found not suitable for predicting airflow patterns around a slatted floor.

**Keywords:** livestock building, slatted floor, airflow characteristics, CFD, orientation

### Introduction

Slatted floor system applied in piggery and cow buildings is popular in Denmark. In a livestock building with slatted floor system, pollutants like ammonia and odours mostly emitted from the zone near slatted floor, either floor surface or slurry pit under the floor (Saha *et al.*, 2010; Ye *et al.*, 2008; Zhang *et al.*, 2005). Airflow patterns and ventilation exchange rate around the area of slatted floor can significantly affect ammonia and other contaminants dispersion and deposition, which will further affect indoor air quality and pollutants emissions to the surrounding environment (Morsing *et al.*, 2008; Zhang & Strom, 1999). A better understanding of the airflow characteristics above and under the slatted floor for developing effective and practical methods to guide airflow in livestock building is highly desired.
Few studies on the airflow characteristics around the slatted floor have been reported. Ye *et al*. (2009) investigated the effects of ventilation rates, floor slat opening and

headspace height on airflow characteristics at the surface of manure in a storage pit. However, the airflow pattern was only described by smoke visualisation. The mean air velocity and Ti measured at three positions above the manure surface were used as the evaluation parameters. Knowledge of detailed airflow pattern and velocity profile along the pit headspace height and length is still lacking.

Due to the spatial resolution of the measurement instrument, it is still difficult to measure air velocity near the solid surface. To tackle this limitation, the possibility of using computational fluid dynamics (CFD) was applied in this study. The numerical results were compared with the experimental results, and to be supplements for experiments.

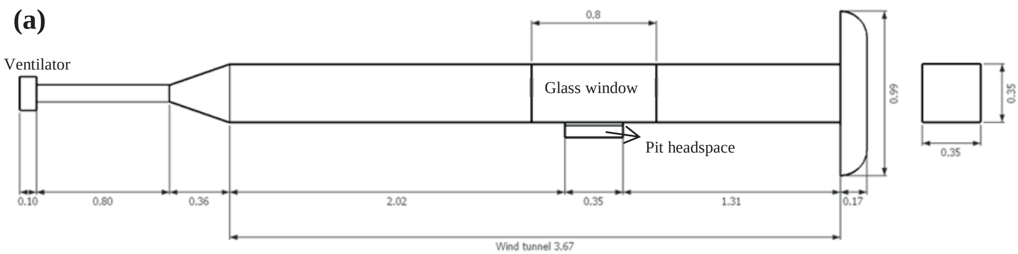
The objective of this study is to investigate how the airflow characteristics around the slatted floor affected by air velocity above the floor and the slatted floor orientation (one is orientated parallel to the wind direction, the other one is perpendicular). CFD was introduced in this study as a tool to predict airflow characteristics. The numerical results were compared with the experimental results, and to be supplements for experiments.

## Materials and methods

Experiments were carried out at the Air Physics Lab, Research Center Foulum, Department of Engineering, Aarhus University, Denmark.

<u>Wind tunnel</u>

The wind tunnel (Figure 1a) used in this study was 3.67 m long with cross area of 0.35 (W) m × 0.35 (H) m. There was a 0.8m long transparent glass for visual inspection and velocity measurements on one side of the tunnel. Air was extracted by a ventilator (Type CK200 B CBU, Lindab A/S, Denmark) at the end of the wind tunnel. The ventilator was connected with a transformer which could adjust the level of wind in the wind tunnel. Airflow into the wind tunnel was via a 0.17 m thick smooth surface contraction section fitted around the edges of wind tunnel inlet opening. Smoke was injected into the wind tunnel inlet opening as the seeding for Laser Doppler Anemometer (LDA) to measure velocities.



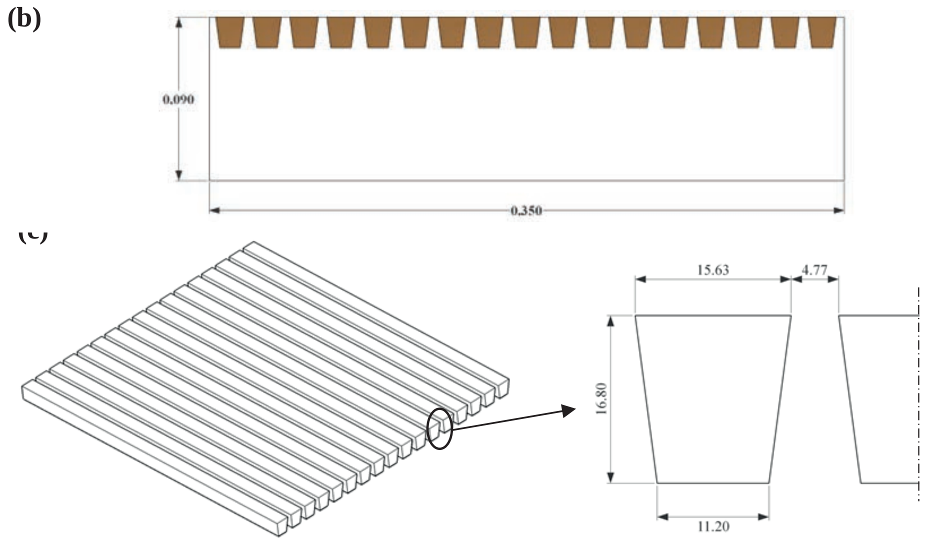



Figure 1: Schematic of (a) the wind tunnel (dimensions are in m); (b) the scaled pit model and slats (dimensions are in m); (c) the overall view of the slatted floor and dimensions of the slats (dimensions are in mm).

A one-eighth scale model of manure pit was constructed in the working section underneath the wind tunnel, and the front panel of the model was transparent glass. The size of the scale model was 0.35 (L) m × 0.35 (W) m × 0.09 (H) m (Figure 1b). Slatted floor consisted of a number of 17 slats was placed on the top of the scaled slurry pit. The top of the slatted floor and wind tunnel floor were at a same surface.

According to general practices and regulations of slatted floor buildings for livestock production in Denmark, the openings of slatted floor are varied from 10 to 40%, as related to different production systems (Jensen & Hansen, 2006).The slatted floor used in this study had an opening ratio of 23.38%. The dimensions of the slat were shown in figure 1c. Two types of slatted floor were included in the study. One kind of slatted floor was that the slats were orientated parallel to the wind direction in the wind tunnel (Floor P). The other slats orientation was perpendicular to the wind direction (Floor V).

Air velocity and turbulence measurement

Air velocities and turbulence intensities in this investigation were measured by a 2-dimensional Laser Doppler Anemometer (FlowExplorer System, DANTEC Dynamics A/S, Skovlunde, Denmark). Two pairs of laser beams radiated from the transmitting/receiving optics could measure the velocity horizontally and vertically. The measurement distance from the lens was 285 mm.

Based on Doppler Shift Effect, when light was reflected from a moving object like smoke particle, the frequency of the scattered light was shifted by an amount proportional to the speed of the object. The speed of a particle could be estimated by observing the frequency shift. As mentioned before, small neutrally buoyant particles made by the smoke generator were injected into the wind tunnel. The particles were illuminated by a known frequency of laser light. The scattered light was detected by a photomultiplier tube (PMT), an instrument that generated a current in proportion to absorbed photon energy, and then amplified that current.

The mean and root mean square (RSM) of the velocity at a position was then calculated within the recording time, which was 150 s for each spatial position in this investigation. The turbulence intensity could be calculated as the RSM divided by the average velocity. A two-dimensional traverse system was used for the measurements movements. It can move automatically in the vertical and horizontal directions. The route of the movement based on the required sampling positions was predefined. Then the traverse system carried the Laser optics to take measurements at the chosen positions. The measurement positions distribution in this study is shown in Figure 2. Air velocity and turbulence intensity were measured at seven vertical lines L1-L7 with seven vertical heights (0.063, 0.053, 0.048, 0.043, 0.038, 0.033, and 0.028m from pit bottom surface, signed as A, B, C, D, E, F, G) on each line (Figure 2). Two reference lines (R1 and R2) were set before and after the pit section in the wind tunnel (Figure 2), which were used to record the wind speed in the tunnel.

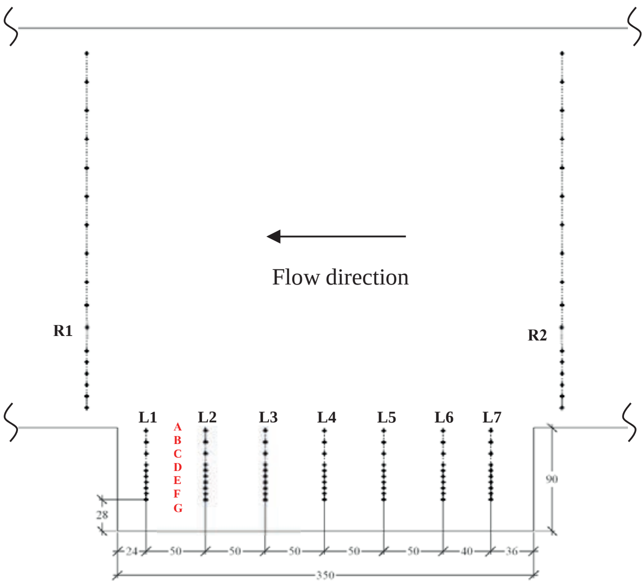



Figure 2: The velocity measurement locations. All dimensions are in mm.

Numerical modelling

We used the commercial CFD software FLUENT 12.1 (2009, ANSYS Inc., USA) to calculate the airflow.

The computational domain in this study was a simple cuboid of the wind tunnel with

the working section beneath the tunnel (Figure 3). The numerical building model was built as the same size of the wind tunnel. Defining boundary conditions that match the case being modelled closely enough is necessary for the use of CFD techniques. Three different types of boundary conditions were adopted in the present simulations: velocity inlet, pressure outlet, and walls. The wind tunnel surfaces are specified as wall boundary with no-slip condition. The simulations were conducted in isothermal case.
The standard k-ε model was used in street canyon field simulations, which had a similar shape with slurry pit in this study, and got acceptable results (Johnson & Hunter, 1998). The inlet air velocity was varied from 0.3 to 1.5 m/s and constant turbulence intensity of 20% was used in all simulation cases.

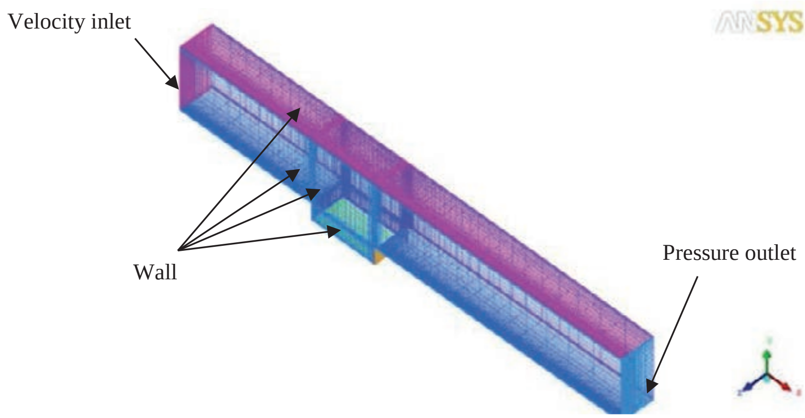



Figure 3: Example of the grid distribution in the rectangular grid of the wind tunnel.

2.3. Experimental set-up

The design of the experiment included two kinds of slatted floor, accompanying with three ventilation rates. As a result, there were 6 experimental runs in a total. The experimental treatments are shown in Table 1.

Table 1: Experimental treatments

| Slatted floor types | Wind speed (m $s^{-1}$) |
|---|---|
| slats orientated parallel to the wind direction | 0.5, 1.0, 1.5 |
| slats orientated perpendicular to the wind direction | 0.5, 1.0, 1.5 |

## Results and discussion

<u>Effect of wind speed and slatted floor orientation</u>

The variation of the measured mean vertical air velocities under the slatted floor paralleled to the wind direction (*Floor P*) followed the wind speed (Figure 4a). The mean air velocity decreased with the lower wind speed in the wind tunnel. The higher vertical velocity in the headspace of pit could increase the air exchange rate between the pit and room space (Zhang *et al*., 2008). However, this pattern for the case with slatted floor vertical to the wind direction (*Floor V*) was not clear.

Figure 4b gives the mean turbulence intensity (Ti). Higher Ti was observed when the wind speed decreased. Elzing and Monteny (1997) concluded that Ti had more influence on ammonia emission at lower air velocities than at higher air velocities.

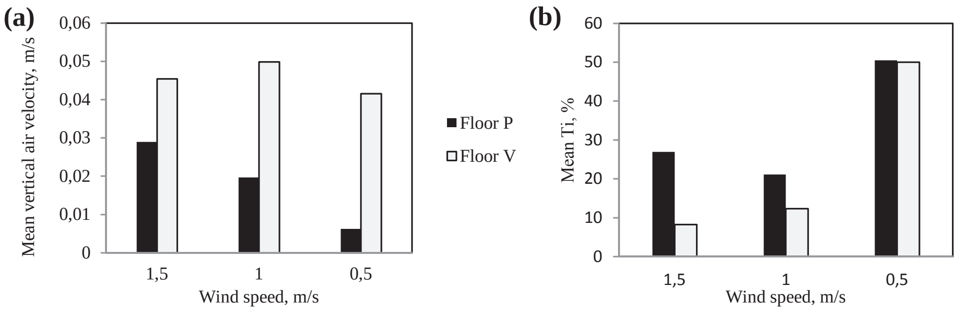
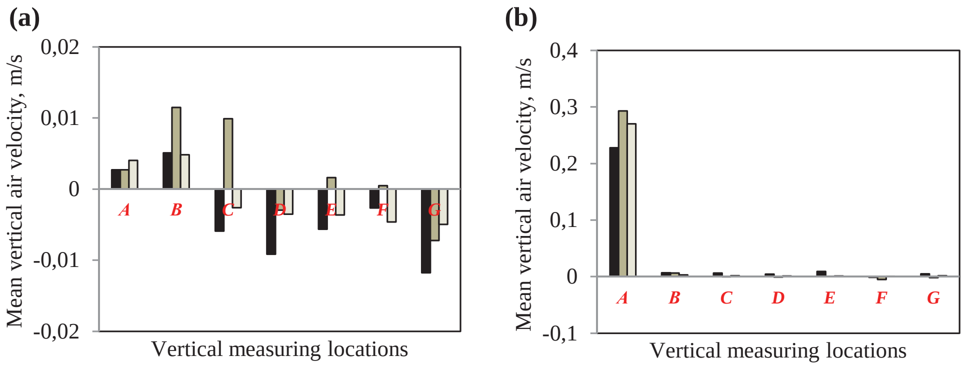



Figure 4: wind speed versus (a) mean air velocity and (b) mean turbulence intensity with different floors.

The mean vertical air velocities at different heights were shown in Figure 5a and Figure 5b. The velocity under slatted floor was quite low compared with the wind speed inside the tunnel. No much effect of wind speed was found on the velocities at different heights with both kinds of floors. For *Floor P*, the mean air at the area near the floor went up and went down near the pit bottom surface. However, in *Floor V* system, the air velocity at layer A was 35~100 times higher than the area farther away to the floor.

Figure 5c and Figure 5d shows the mean vertical air velocities at different vertical lines (L1~L7). There was no significant influence of wind speed on the air velocity at different vertical lines either. In *Floor P*, the highest mean vertical air velocity was found on L1 near the leeward of the pit wall. The air near the windward wall of the pit (L3~L7) went up, while that near leeward of the wall (L1 and L2) went down. In *Floor V*, the highest mean vertical air velocity was found on L2 which also near the leeward of the pit wall. Most of air went up in *Floor V* system.



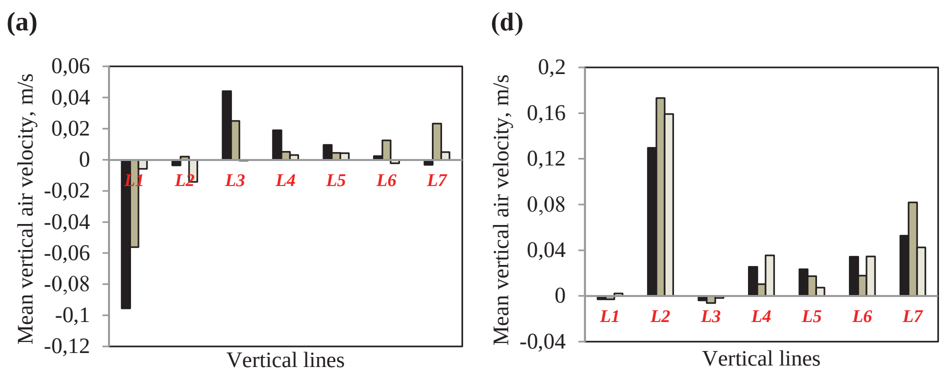



Figure 5: Mean vertical air velocity at different heights (A~G) with (a) Floor P and (b) Floor V; mean vertical air velocity at different vertical lines (L1~L7) along the pit with (c) Floor P and (d) Floor V. ■, ■, and □ represent U=1.5 m/s, 1.0 m/s and 0.5 m/s.

<u>Comparison between experimental and numerical results</u>

The comparisons between the experimental and the numerical results of velocity profiles are shown in Figure 6. There are large discrepancies in the pit area between simulated and measured velocity. The characteristics of measured velocity profiles can't be revealed by the numerical simulation with the standard k-ε model.

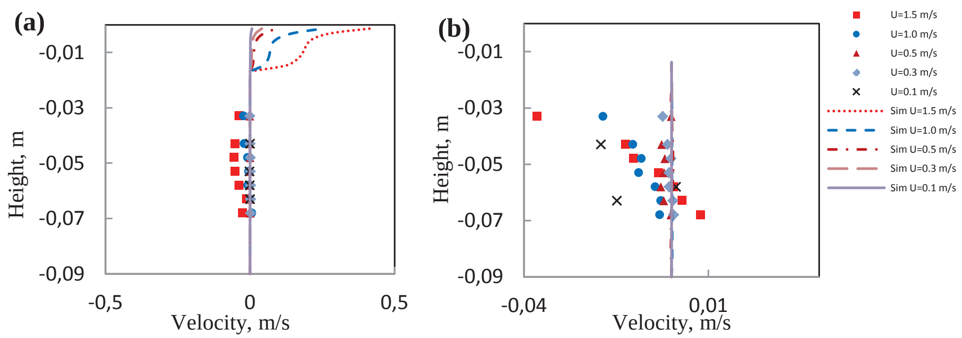
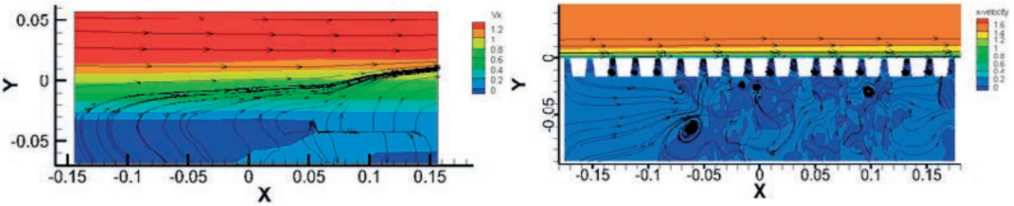



Figure 6: Comparison of velocity profiles between measurements (solid points) and simulations (solid lines) in the middle of slurry pit: (a) Floor P; (b) Floor V.

The velocity distribution and streamlines related to the mean flow field in the symmetry plane are represented in Figure 7. The pictures on the left side are generated from the results of measurements, and on the right side are from standard k- ε model simulation results. From these pictures, we can find out the wind speed under the slatted floor was very low (<0.4 m $s^{-1}$). The air inside the slurry pit with slats was chaotic. The simulated results are different with the measured results.

The difference between experimental and numerical results could possibly be the standard k-ε turbulence model does not account the detailed turbulent transport in a transient manner, which was believed to be the most important factor in calculate the air flow in a canyon shape (Johnson & Hunter, 1998). Unsteady turbulence models like Large Eddy Simulation are desired to be applied in further study.

**(a)**

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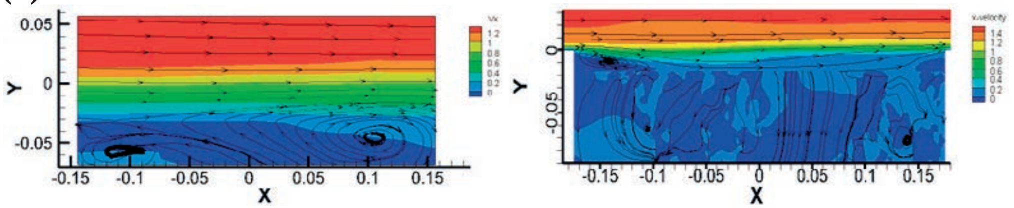


Figure 7: Example of airflow pattern and velocity field on the symmetry plane of the pit: comparisons between experimental and numerical results under (a) *Floor P* and (b) *Floor V.* Left: experimental results, right: standard k-ε model simulation results.

## Conclusions

In a livestock building, the velocity under the slatted floor should be very low despite the orientation of the slats and the velocity above the floor. The mean air velocity in the pit headspace increased as the wind speed increased. The wind speed and orientation of the slatted floor does not have a significant effect on the air distribution in headspace of the slurry pit. Standard k- ε model was found to be not suitable for predicting airflow patterns around a slatted floor.

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## Numerical and experimental assessment of the airflow field and ventilation rates in a naturally ventilated free cubical cattle house with large openings

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### Abstract

An efficient natural ventilation system in dairy cattle buildings is essential both for animal welfare and for environmental issues since the naturally ventilated livestock buildings are a major source of greenhouse gas emissions. Experimentally it is very difficult to analyse airflow in large ventilated buildings but it can be assessed using modelling techniques such computational fluid dynamics (CFD). The present study is the first step for developing a full 3D numerical model for predicting airflow, indoor climate and greenhouse gas emissions in a large naturally ventilated cattle building. A CFD model was constructed according to the real dimensions of the full-scale building wheras in the experimental part air velocities $CO_2$ concentrations inside the building were measured in various positions, as well as ambient climate conditions. The animal occupied zone (AOZ) was treated as porous media and the resistance coefficient of porous zone was derived by pressure drops across AOZ using a sub-CFD model. Airflow and temperature patterns were presented for a range of external wind velocities. In general the numerical results were in good agreement measured data. These first initial data indicating that CFD can be proven a useful tool for predicting airflow distribution and ventilation rates in large animal buildings and it gave promising results for its use for design optimisation purposes

**Keywords:** Ventilation rate; tracer gas; porous medium; sampling position

### Introduction

Intensive llivestock production is a major contributor to the world's environmental problems, contributing about 18% to global anthropogenic GHG emissions (Steinfeld *et al.*, 2006). The present economic situation in livestock production forces producers to focus on improving efficiency in order to increase their competitiveness. Among the important factors in achieving improved efficiency is the provision of an optimal building environment with low Greenhouse Gases (GHGs) emissions.

Large, naturally ventilated livestock buildings, such as cattle farms, are regarded as a major source of air pollutants (Pereira *et al*., 2010; Schrade *et al*., 2012). Considerable quantities of aerosols, ammonia, odors and other toxic substances are released during the framing activities that take place indoors, affecting animal and human health and welfare. Additionally, they may represent a risk for the outdoor environment as they are emitted outside the building during ventilation (Zhang er al. 2005). Reduction of emissions from dairy cow buildings will contribute to mitigate environmental pollution. However, it still lacks of reliable measurement and quantification methods of gas emissions from naturally ventilated livestock buildings.

Accurate quantification of gas emissions from livestock buildings to the atmosphere requires accurate determination of the ventilation rate and the representative gas concentration in the exhaust air. Unlike the mechanically ventilated livestock buildings, it is more difficult to determine the naturally ventilation rates (Demmers *et al*., 1998, Teye & Hautala, 2007).

On the other hand recent progress in flow modeling by means of computational fluid dynamics programs (CFD) allows to investigate and analyze airflow distribution and to predict ventilation rates in buildings including also farm buildings (Norton *et al*., 2010; Bartzanas *et al*. 2013). Actual weather conditions and structural specifications could be simulated and changed in the CFD model while maintaining stable and intentical boundary conditions. Computational fluid dynamics simulations can be a valuable tool for analyzing the internal airflow and understanding the effects of the building structural characteristics with respect to ventilation. However, very limited data are available in published literature for evaluate the performance of the numerical methods. This work will use a set field measurement data of air velocities and $CO_2$ concentrations in and outside of a large, naturally ventilated cattle building space, as well as $CO_2$ production model of animals as reference to compare with CFD modelling results.

## Materials and Methods

<u>Building</u>

Measurements were carried out in one free-stall cubical dairy cattle buildings, which was naturally ventilated, in the Mid-west of Jutland, Denmark. The building (Fig. 1a) was approximately 85 m long and 24 m wide and its rest geometrical details were shown in Fig 1b. Curtains for adjusting sidewall openings were mounted on the low edge of the opening and can be manually pulled up. The curtain height in the first two measurement periods was about 0.8 m and the curtains were fully open in the third period. One end of the building was entirely open with a dimension of 20.11×2.45 m, whereas the other end was closed except for a 5.7 x 2.75 m gate. The milking parlour was located in this end of the building. The feeding alley and resting area for cow to lie down had a raised platform. A narrow slatted floor in the centre of a lower walkway for cows was made of concrete. Underneath the slatted floors was manure channel equipped with scrapers. The manure in the gutters was scraped 12 times a day into manure storage tanks outside the buildings. There were another two buildings (Fig. 1a) near the measured building, which had dimensions of 58.2 m×24 m×7.6 m and 48.6 m×24 m×8.4 m, respectively. Inside the building there were 165 cows with an average weight of 625 kg and an average milk yield of 31 kg per day. There were also 14-23 calves with a weight of 450-500 kg on average in this section.

(a) (b)


Figure 1. Experimental building (a) and its geometrical features

<u>Measurements</u>

Air velocities and CO2 concentrations inside and outside the building were measured. Air velocities were measured by ultrasonic anemometers – WindMaster (Gill instruments Ltd, Hampshire, UK). All the anemometers were connected to a multi-port adapter, which supplies electricity power to anemometers and transfers the data to a computer. The three-dimensional air velocities were measured in a frequency of 20 Hz. An ultrasonic anemometer was placed 10 m above the ground to monitor the external wind velocities Air velocities inside the buildings were recorded at 6 positions (Fig. 2): two were near one sidewall openings; two were placed in the centre of the buildings near ridge openings; two were near another sidewall openings. The CO2 concentrations were measured using a Photo-acoustic Multi-gas Monitor, model 1312 and a multiplexer, model 1303 (Innova air Tech Instruments A/S, Denmark). The internal concentrations were sampled by three 20 m long tubes (Fig. 4.1b) with 20 uniformly distributed holes. The three tubes were near the three groups of velocity sensors, respectively. Gases at two outside positions about 2 m from a side wall were also sampled as background reference.

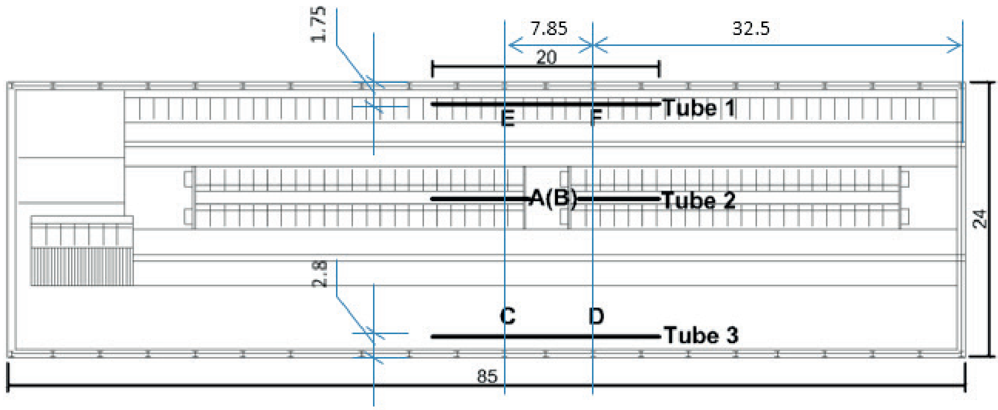


Figure 2. Schematic of the measured section (20 m) in the building and the sensor positions: A, B, C, D, E and F denote positions for velocity measurements; Point A is 5.7m from building's floor, B 4.3m, C and D 3.2m and E and F 2.2m.

Modelling

The CFD model is depicted in Fig. 3. The CFD model was constructed according to the real dimensions of the full-scale building. Two surrounding buildings were also established in the model. The thermal boundary conditions of the building and the heat released from animals were included in the CFD model via a user define function.

The animal occupied zone (AOZ) was treated as porous media and the resistance coefficient of porous zone was derived by pressure drops across AOZ using a sub-CFD model. The standard turbulence (Launder and Spalding, 1974) model was used for all the simulations. SIMPLE scheme was employed to couple pressure and velocity. Second order upwind method was used to discretize convection term. In the inlet of the computational domain a logarithmic wind profile was imposed.

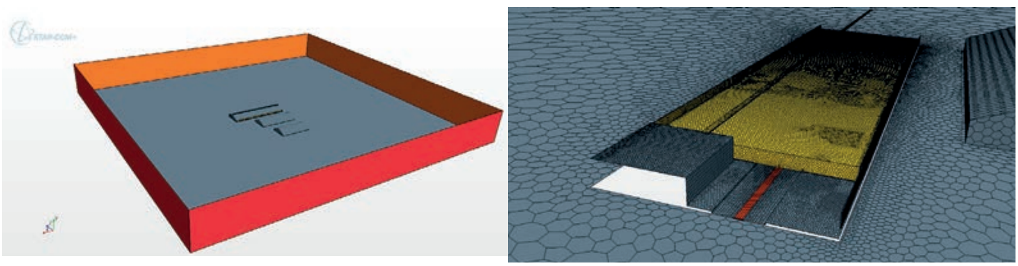

Figure 3. Computational domain (left part) and detailed mesh description (right part) of the CFD model

## Results and Discussion

The numerical calculated airflow field in the livestock building was presented in Fig. 4. The airflow was characterized by a strong air current from the windward opening. Air enters the building from the windward ventilation opening and exits through the leeward one. Three main recirculation loops with slower speed and flowing counter current with respect to the wind outside. Stagnation zones were also observed especially near the corners of the leeward side.

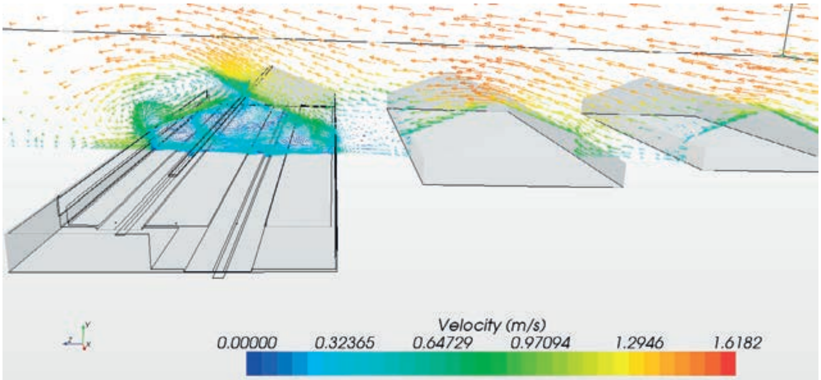


Fig.4. Velocity vectors in the computational domain

Table 1 shows the measured and simulated air velocities at different positions. Overall, good agreement was generally found between the simulated and measured air velocities. The simulated velocities in the middle section of the room were within the variation of the measured fluctuated data. For example, at the position near ridge opening, the simulated velocity was 0.051 m $s^{-1}$ the measured velocity ranged from 0.62 to 0.7 m $s^{-1}$. A relatively larger discrepancy existed at the position about 10 m away from the downwind side wall, where the simulated and measured velocity magnitude was 0.28 and 0.24 ± 0.08 m $s^{-1}$, respectively.

Table 1. Measured and simulated values of air velocity magnitude

| Measured point | Measured | | Simulated | |
|---|---|---|---|---|
| | Air velocity ($ms^{-1}$) | Temperature (K) | Air velocity ($ms^{-1}$) | Temperature (K) |
| A | 0.62 ± 0.8 | 296 | 0.51 | 293.6 |
| B | 0.31 ± 0.4 | 295 | 0.24 | 293.6 |
| C | 0.44 ± 0.7 | 295 | 0.52 | 293.1 |
| D | 0.17 ± 0.3 | 295 | 0.20 | 293.0 |
| E | 0.28 ± 0.8 | 296 | 0.24 | 294.0 |
| F | 0.17 ± 0.2 | 296 | 0.19 | 294.2 |

## Conclusions

Measurements of air velocities and $CO_2$ concentrations in a large, naturally ventilated cattle building, were compared to numerical (using a CFD model) obtained ones. The ultimate purpose of this ongoing study is to establish a numerical method for easy and accurate predicting ventilation rates in large naturally ventilated livestock buildings in order to more efficient control greenhouse gas emissions. The results showed that ventilation rates predicted using the CFD model were in good agreement measured data. Airflow and temperature patterns were presented for a range of external wind velocities. CFD proven a useful tool for predicting ventilation rates in large animal buildings and it gave promising results for its use for design optimisation purposes.

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**Mapping of the internal environment and contour conditions of housing for broilers using computational fluid dynamics techniques**

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**Abstract**

The housing environment of broilers has a direct influence on production, because an unhealthy indoor environment affects poultry welfare. The objective of this study was to map the internal environment of the broiler house and detect the dispersion of gaseous pollutants through simulation, with the aim of achieving welfare and comfort for the poultry. For this, we used CFD (Computational Fluid Dynamics) techniques with which it was possible to estimate various situations for the same problem by changing parameters, verifying the results for different boundary conditions and analysing the risks with confidence and speed. Data were collected in two sheds at a commercial broiler farm located in Campinas, for broilers at 28, 35 and 42 days old. In both sheds G1 and G2, the conditions near the hoods were of higher intensity than other locations in the shed, with no homogeneity in the region of the litter. The simulator proved to be a good tool for determining the behaviour of NH3 and of the air circulating inside the sheds.

**Keywords:** broilers, monitoring and control of environmental and computational fluid dynamics.

**Introduction**

The poultry industry is the third largest exporter in Brazilian agribusiness, putting Brazil in the lead in terms of export quality and thus helping to strengthen the trade balance (Miragliotta, 2002). The activity contributes to economic growth in three important areas: technology, production efficiency and diversification of consumption. Given the importance of breeding activity in the country, there is a need to develop adequate facilities for animals which provide a high level of welfare (Coelho & Borges,1999). The housing environment for broiler chickens has a direct influence on production because respiratory diseases suffered by these animals cause substantial losses for producers in this industry and compromise the welfare of the birds. The aim of this study was to map the internal environment of the house and detect the dispersion of gaseous pollutants through CFD, for the well-being and comfort of the birds.

## Materials and methods

First phase

A poultry farm in the Campinas region of Brazil was selected to survey experimental data for one batch of birds. For the simulation model, we assessed the following points: A survey of ambient air data in one batch of broilers made it possible to evaluate the housing environment in terms of air pollutants and thermal comfort. We evaluated two sheds with negative ventilation (exhaust), referred to as G1 and G2. Shed G1 measured 22.00 m x 90.00 m, with a ceiling height of 3.00 m. The HVAC equipment comprised 8 exhaust fans, misting lines arranged transversely with 15 nozzles/line, medium pressure. The air inlet to the shed was via a hollow brick wall to promote the passage of air as a cooling pad. Shed G2 has dimensions of 13.00 m x 125.00 m, with a ceiling height of 3.25 m. The HVAC equipment comprised 8 hoods (only 2 connected). The air intake was located on the back wall of the shed, through the access curtain. There were 10 misting lines in total, arranged transversely with 10 nozzles/line, medium pressure. To evaluate the concentration of NH3 inside the shed, air samples were collected on a weekly basis at the same moment at six equidistant points in the shed, using a portable digital gas monitor (BW Technologies ®). Samples were collected at four different times: 09:00, 11:00, 14:00 and 16:00. Ammonia measurement data collected at a height of 0.30 m in the litter were compared with measurements taken at 1.50 m and 1.80 m above the litter.

Second phase

Initially the parameters and boundary conditions of the simulation material were estimated, which in this case was the geometry of sheds G1 and G2. We also took into account the entry and exit of air from the sheds, and the concentrations of the gas mixture (NH3) and their physico-chemical properties. For this study, we chose to use PHOENICS computational fluid dynamics software. Table 1 describes the boundary conditions for the two sheds analysed.

Table 1: Boundary conditions for sheds G1 and G2

| Axis | Face of the shed | G1 | G2 |
|---|---|---|---|
| x | east | Air out– 1m/s (8 Hoods Centralised - all connected) | Air out– 1m/s (2– Hoods Centralised - only 2 connected) |
| | west | Inlet (porous wall – 50%) | Inlet (porous wall – 50%) |
| y | North | wall | wall |
| | south | Input contaminant (Ammonia – NH3 – 200 kg dia$^{-1}$) | Input contaminant (Ammonia – $NH_3$ – 210 kg dia$^{-1}$) |
| z | High | wall | wall |
| | Low | wall | wall |

## Results and Discussion

The average concentrations of NH3 in both sheds proved to be below the levels recommended in the literature (20-25 ppm) and there was no statistical difference between sheds. The values for the three different heights always decreased with time, as shown in Figure 1.

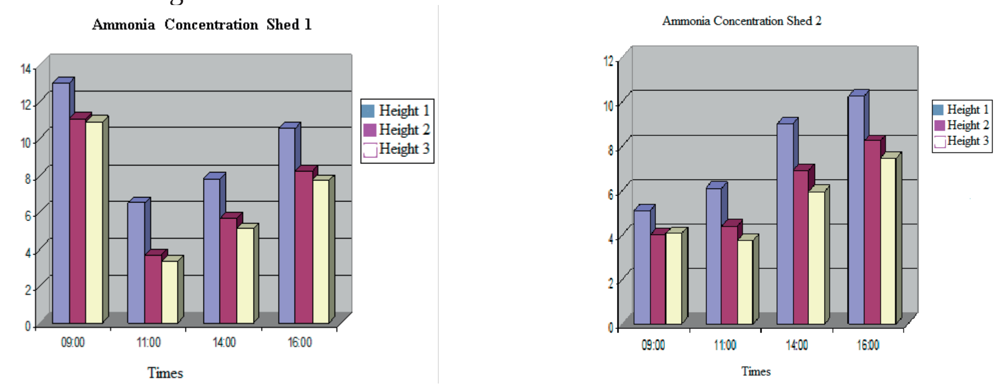


Figure 1: Concentrations of NH3 measured at three heights for four hours in sheds G1 (a) and G2 (b)

Ammonia emission rates rose with bird age, in agreement with Redwine *et al.* (2002), due to increased nitrogen excretion as the poultry grew, as shown in Figure 2.

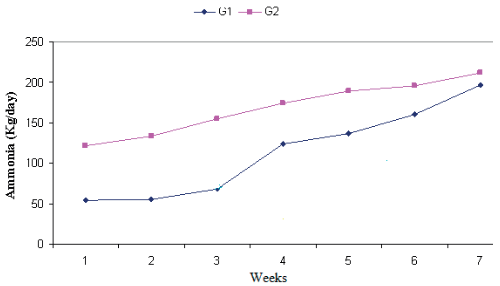


Figure 2: Emission of NH3 per day per shed.

Data for the two sheds are presented. The different shades of blue represent different ammonia gas intensities inside the sheds which were simulated. Figure 3 shows the simulation for sheds G1 and G2, for a height close to the floor when the birds were 28, 35 and 43 days old.

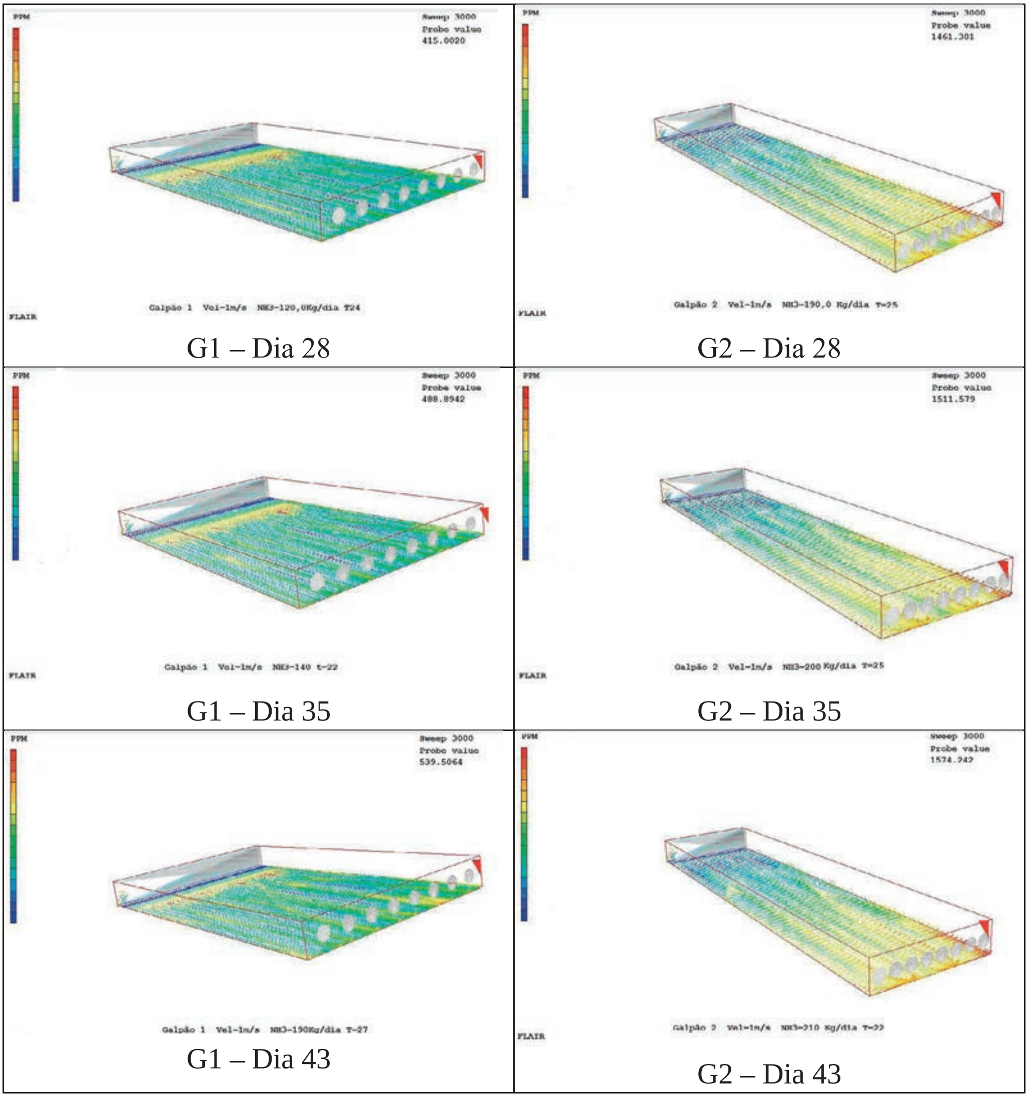


Figure 3: Shows the sequence in the behavior of ammonia in the Z axis close to the floor in two sheds in 3 stages in broiler growth.

It was observed that in both sheds G1 and G2, the conditions near the exhaust fans were more intense than at other locations in the shed, but homogeneity in the region of the litter was not demonstrated. It was observed during the study that both sheds which used recycled litter showed higher average emissions for poultry, which is in agreement with the literature and indicates that as the recycled litter produced higher amounts of ammonia nitrogen, the flow from this type of litter can be six times greater than the flow from new litter during the first weeks of use (Brewer & Costello 1999).

Comparing the distribution and concentration of NH3 in Shed 1 (Figure 3), it is observed that with each passing day, the gas concentration increases, and also the difficulty of creating sufficient air exchange inside the shed. Generally, close to the porous wall, the gas concentration is very low, as it progresses there is an area of high concentration (probably a range in which the exhaust cannot operate very efficiently or ambient air enters at insufficient pressure for dispersion). The longer this goes on, the greater the concentration of ammonia gas at the bottom of the shed (near the exhaust). Note also that the corners and walls of the shed have a higher average concentration of NH3; this can be explained by the restricted air flow, probably due to air flow being mostly in the line to the hoods.

In the Shed 2 (Figure 3), the concentration of ammonia gas reaches higher levels, with worse distribution inside the shed. This can be explained by the fact that, besides the fact that the shed was longer, only 2 of the 8 exhaust fans were operating during the period of the experiment. Higher concentrations are found near the exhaust and it is even more evident that there are high peak concentrations at the corners, where the air removal efficiency is lower.

The analyses were performed using simulation of the Z axis close to the floor due to the fact that higher concentrations of ammonia gas are found in the area up to 50 cm above the ground. Figure 4 presents an illustration of the distribution of gas concentrations in relation to the Y axis. Note that higher concentrations are found in the region of the litter and near the track in which the poultry circulate.

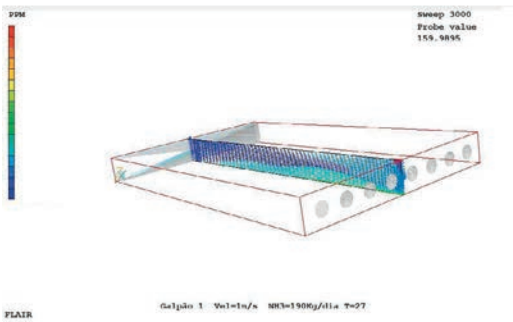


Figure 4. Example positioning the highest ammonia gas concentrations in relation to time.

We carried out the test to compare the means of these sheds and obtained a p-value of 0.21, showing that there was no statistical difference between their emission data.

## Conclusions

The simulator was adapted and adjusted for use in broiler sheds. It proved to be a good tool for determining the behaviour not only of NH3, but also of the air circulating inside the sheds. The tool supported decision-making and made it possible to evaluate the benefits for animals in terms of quality of life in relation to their wellbeing and overall health. Many functions are presented, but they still need to be explored. In this experiment the environment inside the poultry house was not considered unhealthy for birds housed in G1 and G2.

## Acknowledgements

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## Proposal for an integrated system for monitoring n flows from livestock husbandry in the autonomous Province of Bolzano – Northern Italy

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### Abstract

The Province of Bolzano (Italian alpine area) has a human and animal density which is comparable to other regions of Northern Italy. However, the special nature of its mountainous lands means that potentially critical situations must be monitored: (i) there is considerable anthropic and animal pressure on valleys, where the population is concentrated; (ii) little land is available for spreading animal slurry according to environmentally-sustainable strategies (i.e. limiting the N rate).

Therefore, an integrated system for monitoring the N rates spread in this region is proposed and applied to a set of pilot farms in South Tyrol. Unlike other similar systems, which have been proposed recently but are designed for monitoring intensive livestock husbandry only, this system also provides tools for managing alpine grazing through virtual fences (GNSS-equipped collars) and automatically compiling field-activity registers. The system considers each entity involved in the slurry chain from animal to field (collars; functional sites such as animal housing, tanks or digesters; tractors and slurry spreaders, etc.) and uses a multilevel-network approach, with a client-server logic for handling and combining all relevant information obtained. This flexible architecture also allows the system to handle farm contractors; it is suitable for third-party distribution and can generate many types of document to deal with environmental, legal and operational issues.

**Keywords**: Animal wastes; N-flows; automated monitoring; extensive livestock husbandry; information systems; Alpine technologies.

### Introduction

<u>The situation of nitrates in the autonomous Province of Bolzano</u>
A recent classification of soils based on the Nitrates Directive (91/676/EEC) showed the absence of “vulnerable” zones in the autonomous Province of Bolzano (Italy) (Bottarin & Tappeiner, 2010; Braioni *et al*., 2001; Gamper, 2008; Peratoner & Stimpfl, 2012; Peripoli, 2008; Salvati, Alessi, & Licopodio, 2005; Scarperi & Vidoni, 2008). Nevertheless, a provincial regulation (D.P.P. 6/21.01.2008) based on the Nitrates

Directive which acknowledges and takes into account the special nature of this essentially mountainous region imposes tighter than normal limits on spreadable-N: 213, 170, 127.5 $kg(N) \cdot ha^{-1}$ for agricultural land, <1250, >1250 and >1800 m above sea level, respectively. Agricultural activities fall into two distinct areas: (i) woody crops in valleys and foothills, (ii) animal husbandry (especially cattle) and fodder crops in mountainous areas above 900 m (Bottarin & Tappeiner, 2010).

Uncontrolled spreading of animal slurries on the land could throw the alpine ecosystems out of balance. The nutrients present in the slurry (especially N) could easily leach into the surface and the underground waters (Coldiretti, 2009; Soana *et al.*, 2011), causing serious changes in water quality and the entire ecological chain, with negative impacts on the tourist /recreational functions of the alpine environment and related economic and social consequences (Peratoner & Stimpfl, 2012). K and P rates should also be monitored.

Although official statistics indicate that the human and animal density is comparable to other regions of Northern Italy (Table 1), there are local potentially critical situations that have to be monitored. The first causes are: (i) the considerable anthropic and animal pressure on flat areas in valleys, where the population is concentrated, and (ii) the lack of land for slurry disposal according to environmentally-sustainable strategies (Peratoner *et al.*, 2012). Extensive and intensive livestock husbandry is a very widespread activity for cultural rather than economic reasons, and uses a relevant part of the land that is free of forests and slopes. Traditional agriculture typically used to integrate livestock and cultivation activities, using effluents as fertilisers. Modern agriculture is characterised instead by increased specialisation, clearly dividing manure management from cultivation activities (Provolo, 2012). Some very narrow valley areas (e.g., around Bruneck) where there is a lot of cattle housing and maize farms exhibit significant increases in the N level (Peratoner *et al.*, 2013).

Moreover, the Province's hydrology and the great availability of surface and underground water have contained possible pollution from N overloads until now, thanks to efficient dilution. However, due to the increase in annual mean temperature (Walker & Del Moral, 2003) it is estimated that 75% of glaciers have been retreating for the last 150 years and a future reduction in hydrological runoff is expected.
A study of aquifer vulnerability and a detailed soil map of the Province are needed, as is a monitoring of the Minimum Vital Flows of rivers and of animal feeding and housing methods.

Table 1: Situation of livestock husbandry in the north-east of Italy (ISTAT, 2010, 2012).

| **Quantity** | | **Territory (P=autonomous province, R=region)** | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Bolzano (P)* | *Trento (P)* | *Veneto (R)* | *Emilia Romagna (R)* | *Friuli Venezia Giulia (R)* | *Lombardia (R)* |
| **Surface (ha)** | Total | 740 000 | 620 700 | 1 839 100 | 2 245 600 | 785 500 | 2 386 100 |
| | UAA | **241 952** *(32.7%)* | **137 219** *(22.1%)* | **811 440** *(44.1%)* | **1 064 214** *(47.4%)* | **218 443** *(27.8%)* | **986 826** *(41.4%)* |
| **Estimated animal life weight per UAA unit ($kg \cdot ha^{-1}$)** | Total | 273.8 | 186.9 | 581.0 | 385.4 | 318.3 | 1 193.0 |
| | Of which: Cows | 222.8 *(81.4%)* | 134.7 *(72.0%)* | 378.4 *(65.1%)* | 212.6 *(55.2%)* | 165.7 *(52.1%)* | 611.0 *(51.2%)* |
| | Pigs | 1.5 *(0.5%)* | 3.0 *(1.6%)* | 74.3 *(12.8%)* | 88.5 *(23.0%)* | 74.8 *(23.5%)* | 364.1 *(30.5%)* |
| **Estimated N-load* ($t \cdot (ha \cdot year)^{-1}$)** | Total | **29.445** | **22.296** | **82.004** | **49.683** | **45.611** | **136.135** |
| | Of which: Cows | 27.495 *(93.4%)* | 16.616 *(74.5%)* | 46.689 *(56.9%)* | 26.233 *(52.8%)* | 20.449 *(44.8%)* | 75.391 *(55.4%)* |
| | Pigs | 0.158 *(0.5%)* | 2.958 *(13.3%)* | 22.768 *(27.8%)* | 10.617 *(21.4%)* | 12.729 *(27.9%)* | 10.747 *(7.9%)* |

* The total slurry production was estimated from the official tables that are used as a reference by the Italian legislation (attachments of D.Lgs.152/06 Part III) and are stored on corporate websites

Livestock effluents are an agronomical opportunity that has not yet been fully exploited, even though they are easily available and rich in nutrients (Bietresato & Sartori, 2013); however they are chemically-physically inhomogeneous, unevenly distributed on land, and economically worthless (Bietresato *et al*., 2012). Monitoring how and where slurries are spread could help the institutions to understand whether farmers need adequate information on the potential for using them properly as organic fertilisers.

Slurries also have an energy potential if they are used to produce biogas. Current production in South Tyrol is more than 16 million cubic meters but almost half of this is produced on only 30 farms, which feed digesters with the cattle effluents (Tis Innovation Park, 2011). This scenario can surely be improved if greater knowledge of the distribution of animal housing and digesters in the province is available.

Therefore, the need to monitor the N rate spread and, consequently, to design a system that is suitable for this purpose arises from several standpoints (environmental, legal, operational and management).

### *Aims of the research*

The aim of this work is to propose an integrated system for monitoring slurry production and distribution and for automatically compiling field-activity registers, in accordance with current regulations. Similar systems have recently been developed in other Italian regions, where specific research projects proposed solutions for intensive livestock husbandry (Mazzetto, Calcante, and Salomoni, 2009; Mazzetto, Calcante, Sacco, *et al*., 2009; Mazzetto *et al*., 2010; Sartori *et al*., 2010); this system is also suitable for extensive alpine livestock husbandry and provides tools for managing grazing systems through virtual fences (GNSS-equipped collars).

## Materials and methods

### *Definition of the monitoring system*

To define a monitoring system, it is necessary to highlight:

- *requirements* and *technology/components* that the system must satisfy and provide, limiting its complexity and enhancing its integration;
- *any aspects* related to the processing and security of the sensitive data collected.

A definition of these specifications has many practical implications and includes both managerial and technological innovations. A clear definition of the different types of animal wastes used in agriculture is needed first: unprocessed slurries (*direct use*) or slurries from anaerobic digesters (*indirect use*). According to the key steps in the whole flow (slurry chain from animal to field), the monitoring system must consider each entity involved (collars; functional sites such as animal houses, tanks or digesters; tractors and slurry spreaders, etc.), providing a general framework to act as part of an integrated information system which is capable of handling and combining all the relevant information obtained. The entities involved form part of the management control chain for effluents of animal origin and will be organised in a multilevel network operating with a client-server logic (Mazzetto *et al*., 2010).

### *System organisation*

The monitoring system is composed of three basic elements:

- *hardware devices*, for collecting and/or storing the data (sensors, data-loggers with geolocalization and communication capabilities, servers with storage units) and regulating valves and pumps on the slurry tankers (actuators) according to previously specified prescription maps;
- a set of *computing and inferencing procedures*, to obtain information in several tabular and graphical formats from the raw data achieved (Figure 1);
- *interfaces*, to enable users to access and use information in control activities related to management decision-making processes.

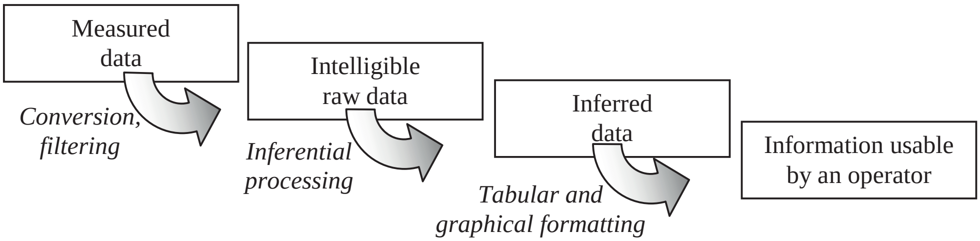


Figure 1: Three-stage computing and inference procedures used to obtain information from the raw data.

Three application scales were defined (Table 2, Figure 2), performing different tasks and managing different information (Pierce and Elliott, 2008; Mazzetto *et al.*, 2010):

- at *field level (Monitoring and Control System – MCS)*, on a single machine (e.g. slurry tanker, fertigation system), on a farm installation (e.g. slurry pit; Figure 3) or on a cow's collar (for extensive livestock husbandry, thus enabling virtual fence tasks; Figure 3)→ data loggers, GNSS devices, remote transmitters (Wang *et al.*, 2006), sensors (Mazzetto *et al.*, 2012; Bietresato and Sartori, 2013), CAN-BUS/ISO-BUS interfaces, actuators (on valves, pumps);
- at *farm level (Farm Information System – FIS)*, on every dairy farm and also on arable farms which make their land available for slurry spreading → servers, remote transmitters/receivers, TCP-IP interfaces, farm-management software (Mazzetto *et al.*, 2012);
- at *territory* level *(Territory Information System – TIS)*→ servers, remote transmitters/receivers, TCP-IP interfaces, territory-management software.

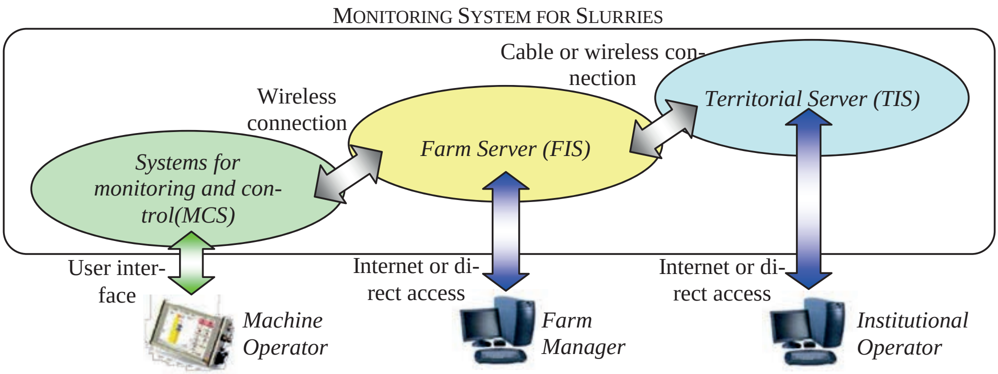


Figure 2: Interactions between operators and systems forming a traceability system.

Table 2: Monitoring and control systems for slurries

| System | Scale of operation | Requirements | Technology and components |
|---|---|---|---|
| *Monitoring and Control System - MCS* | *at field level*, placed on a single machine (e.g. slurry tanker, fertigation system) or on a farm installation (e.g. slurry pit) or on a cow's collar (only for extensive systems) | • Acquiring and sending data relating to slurry production by monitoring the storage facilities (*productive monitoring*)<br>• Acquiring and sending data relating to all the operations carried out by the spreading units (movements, spreading on the field; *operational monitoring*; Figure 3)<br>• Acquiring and sending geographical data relating to the position of cows in extensive systems (*pasture monitoring*; Figure 3)<br>• Actively controlling the quantities applied by regulating machine valves and pumps (*site-specific farming*) | • Data acquisition units (data loggers) with temporary storage memories (Figure 3)<br>• GNSS satellite devices<br>• Remote transmitters (GPRS, Bluetooth devices, RFID)<br>• Sensors (flow, level, total mass, nutrient content)<br>• CAN-BUS/ISO-BUS interfaces<br>• Actuators (on valves, pumps) |
| *Farm Information System – FIS* | *at farm level*, located on every dairy farm and also in all non-livestock farms that make their land available for spreading slurry | • Filing all the operations carried out by the spreading units<br>• Updating and filing the volume of effluents in the storage facilities (measured by devices on machines and infrastructures)<br>• Collecting and updating data relating to the principal farm resources (land, machinery, workforce, buildings, etc.)<br>• Monitoring events occurring in specific plots (fields, pastures) by creating virtual fences<br>• Generating documents for internal/ external audits (summary reports, registration extracts, thematic maps) | • (Farm)servers equipped with storage units<br>• Remote transmitters/receivers (GPRS) or TCP-IP interfaces for interconnecting FIS with MCSs and TIS<br>• Farm management software with:<br>o database of spreading units and slurry pits<br>o GIS interface |
| *Territory Information System – TIS* | *at territory level* | • Managing all the principal data relating to a specific portion of the territory<br>• Integrating all the archives concerning the spreading activities<br>• Consulting and modifying any spreading restrictions or limitations associated with specific vulnerable areas<br>• Updating the N levels of animal origin<br>• Generating documents for internal/ external audits (summary reports, registration extracts, thematic maps) | • (Territorial) servers equipped with storage units<br>• Remote transmitters/receivers (GPRS) or TCP-IP interface<br>• Territory management software (StoreEyes®, TractorEyes®, Farm Configurator®) with:<br>o database of farms, spreading units<br>o GIS interface<br>o inference engine |

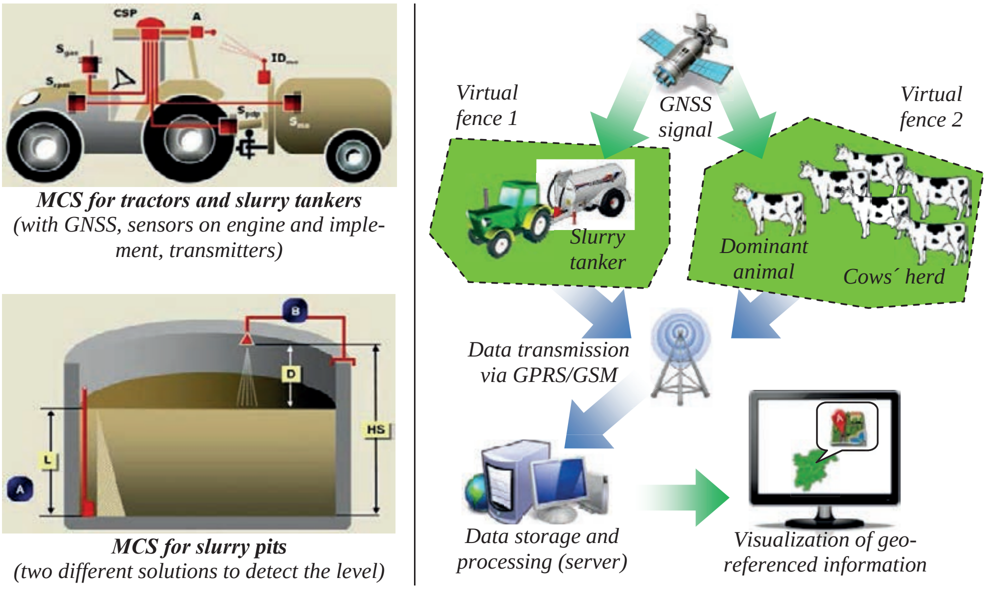


Figure 3: (*left*) example of two MCS devices (Mazzetto, Calcante, Sacco, *et al*., 2009); **(***right***)** operational and pasture monitoring using the proposed system.

## Discussion and conclusions

The above approach is expected to be applied on a set of pilot farms in South Tyrol. Every distribution or storage unit should be provided with an independent MCS device, while each dominant animal in grazing groups should be provided with a GNSS collar enabling virtual fence functions. Virtual fences will be used to enclose crop field but also pasture areas. This will make it possible to calculate the N rate arising from livestock husbandry, giving the farmer some guidance for periodically changing the grazing areas according to a turnover logic. FIS acts as a terminal that can be used to consult the system and manage the effluents according to TIS assessment methods.

The TIS processes the data from farms, while integrating them with digital cartography; users can also query it and download raw data via wireless or cable connections. The core of the TIS is an inferential engine which can recognise slurry production and machine operations (loading/unloading events in slurry stores, transfer and spreading activities) through a series of conditional instructions on the collected data (e.g. vehicle speed, slurry electrical conductivity). It is expected that the software interfaces provided by the TIS will be useful both for farmers and for local administrators for checking the status of the nitrogen spread in the territories for which they are responsible and certifying compliance of the spreading activities with the current environmental laws.

This architecture is very flexible: the system can also manage farm contractors and is suitable for third-party distribution; both FISs and TISs can generate many types of documents (summary reports, registration extracts, thematic maps).

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# Session 13

# Cattle - Precision Feeding

# Determination of minimum meal interval and analysis of feeding behavior in feedlot heifers

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## Abstract

Feeding behavior contains valuable information that can be useful for managing livestock, identifying sick animals, and determining genetic differences within a herd. The objectives of this work were to determine the minimum meal interval and to assess changes in feeding behavior of feedlot heifers when exposed to various temperatures with and without access to shade. The length of this minimum meal interval impacts the interpretation of meal data. The most appropriate minimum meal interval was determined by analyzing feeding behavior data to determine the number of meals, the average meal length, and total time spent eating at minimum meal intervals ranging from 1 to 60 min. These data were evaluated using rate of change based on interval differencing; a subsequent analysis identified the inflection point of the rate of change graph. A minimum meal interval of 10 minutes for finishing feedlot cattle was determined using this method. In the subsequent analysis, feeding behavior data from feedlot cattle with and without access to shade were evaluated. Feeding behavior data from 256 feedlot heifers (of 4 different breeds) were evaluated over 2 summer periods (128 heifers/year). Cattle were penned in one of 16 pens (8 shaded and 8 unshaded). Individual feeding behavior data was collected every 30 seconds throughout the 6 week summer period. It was determined that feeding behavior of cattle was impacted by THI, access to shade and breed.

**Keywords:** Feeding behavior, beef cattle, analysis methods, cattle breeds, heat stress, shade

## Introduction

Feeding behavior contains valuable information for livestock management. Systems are currently available to measure feed intake in association with feeding behavior for cattle (Bach *et al.* 2004; Basarab *et al.* 2003; Chapinal *et al.* 2007), swine (Andree and Huegle 2001; Chapinal *et al.* 2008; Hyun and Ellis 2002), small livestock (Gipson *et al.* 2006; Gipson *et al.* 2007; Goetsch *et al.* 2010), and poultry (Puma *et al.* 2001). Older studies focused on individual or small groups of animals; however, new technologies are providing measurements on animals in a larger group pen setting.

Feeding behavior in livestock species has been reported in many different studies

(Bach *et al.* 2004; Bigelow and Houpt 1988; Chase *et al.* 1976; Morgan *et al.* 2000; Nienaber *et al.* 1990, 1991). Brown-Brandl *et al.* (2011)FROM ServerSession observed that time spent eating was significantly influenced by rate of gain, health, and sex in finishing pigs. Each feeding behavior study calculated various feeding behavior parameters, which included feed intake, meal (bout) length and interval, number of meals (bout) per day, total time spent eating, and rate of eating. Parameters such as meal length, number of meals per day, and total time spent eating are influenced by a single assumption of minimum meal interval made at the beginning of the analyses. Most studies have made this assumption of minimum meal interval simple based on visual observation of the data. A mathematical method may be a better approach.

Feeding behavior has been shown to be influenced by temperature. Brown-Brandl *et al.* (2005a) observed cattle in warm temperatures had reduced feed intake compared to those in cooler temperatures. Taweel *et al.* (2006) observed a shift in the time the dairy cattle ate when the temperature exceeded 25°C. Shade has also been observed to impact feeding behavior (Brown-Brandl *et al.* 2005a) and other behaviors including water intake as well (Mitloehner *et al.* 2001). However, no study has compared individual animal feeding behavior of group penned feedlot animals in shade and non-shaded pens.

The objectives of this work were to determine minimum meal interval and evaluate feeding behavior of feedlot heifers with and without access to shade in various weather conditions.

## Material and Methods

### Equipment

A system to monitor feeding behavior in feedlot pen situations was described in Brown-Brandl and Eigenberg (2011)Electronic identification,Feeding behavior,Radio-frequency identification (RFID. A brief overview of the system is provided here. The core of the feeding behavior monitoring system includes a radio-frequency identification (RFID) system that was designed around a commercial reader (Texas Instruments, Series 2000 High Performance Remote Antenna-Reader Frequency Module [RA-RFM][RI-RFM-008B-00]). The radio-frequency signal was distributed to a series of antennas using a multiplexer (MPX).

### Cattle Site

A cattle research facility was constructed at the USMARC feedlot, consisting of 16 feedlot pens. Each pen was designed to hold 8 feedlot steers/heifers (7.3 m x 20.7 m). Eight pens (1001 – 1008) were partially housed under a shade structure having 50% of the pen surface in the shade, thus allowing the animals' access to a shaded environment. The remaining eight pens (1009 - 1016) had no shade access. Automatic waterers provide *ad-libitum* access to water in each pen. Feed bunks were centered on each of two pens and were designed for six individual eating spaces per pen. This site had a total of 96 eating spaces for 128 cattle

Animals: Cattle

A total of two experimental periods were used in this analysis. Each period had 128 feedlot heifers of four different breeds/cross-breeds and were selected based on their hide color and included: Angus (black), MARC III (dark red) [¼ Pinzgauer, ¼ Red Poll, ¼ Hereford, and ¼ Angus], MARC I (tan) [¼ Charolais, ¼ Braunvieh, ¼ Limousin, ⅛ Angus, and ⅛ Hereford], and Charolais (white). The heifers used in the study were born the spring prior to the start of the study.

Heifers were fed twice daily, at approximately 0800 h and after 1300 h such that feed was not limited, and were given free access to water throughout the study. During the experiment feed behavior records were checked daily to ensure all tags were working properly and each animal was healthy. All animals were checked at least once daily for health.

Data Analysis

The raw data files containing time, and RFID readings (Animal ID) were analyzed for feeding behavior (number of meals, average meal length, and total time spent eating) using the minimum meal interval times (the time between meals) of 1, 2, 3, 5, 10, 15, 22.5, 30, 60 minutes. The best minimum meal interval was determined by using the rate of change between the three meal parameters (number of meals, meal time, and total time spent eating) as minimum meal interval was increased. Rate of change was determined by interval differencing (first derivative). A second interval differencing was used to validate the period that was selected (second derivative). The best minimum meal interval was determined by the second derivative being equal to 0, which is when the rate of change of the minimum meal intervals becomes linear. It was assumed that when the change in meal parameters becomes linear, the driving force becomes only minimum meal interval time.

Once the correct minimum meal interval was determined, general linear procedure was used to analyze the effects of day, year, THI category, breed, and shade/no shade treatment on the feeding behavior parameters (number of meals, average meal length, total time spent eating). Least square means was used to discern significant differences at the $P \leq 0.05$ level.

## Results and Discussion

One hundred and twenty eight feedlot heifers (445.5±54.0 kg) were used in this study. Initial weight of the heifers was 407.8±43.9 kg and finished the trial at 476.6±47.4 kg. Cattle remained in the pens for 56 days during 2004 and 48 days during 2005.

The weather in the summer of 2004 was cooler on average than 2005. The average temperature in 2004 was 20.7°C (min 5.5°C - max 35.4°C) and was 24.1°C (min 8.7°C - max 37.7°C) in 2005.

Minimum meal interval analysis

Meal data was collected on a 30 second time basis throughout both studies in 2004 and 2005. Minimum meal intervals of 1 – 60 minutes were tested. Number of meals decreased from 38.1 meals/day to 6.10 meals/day as the minimum meal interval increased from 1 – 60 minutes. Average mealtime increased from 1.43 minutes/meal to 48.01 minutes/meal over the same minimum meal intervals. The total time spent eating in a single day increased from 54.4 minutes to 273.8 minutes. Figure 1 illustrates these changes with minimum meal interval.

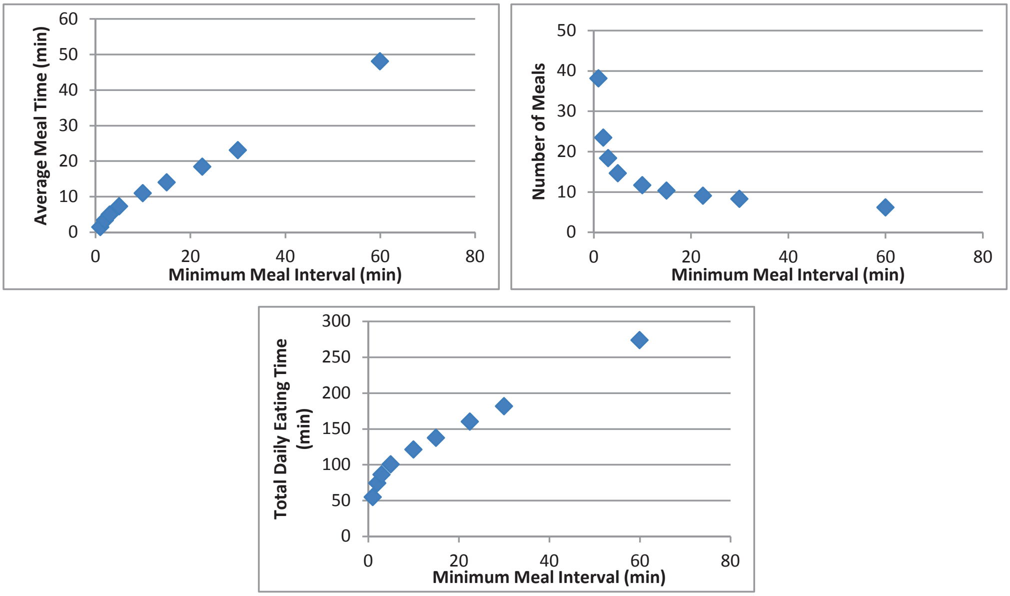


Figure 1: Feeding behavior patterns of feedlot heifers (average meal length, number of meals, and total daily eating time) as influenced by minimum meal interval

Examination of plotted data indicated that there is a change in data occurring at approximately the 10-minute minimum meal interval. This was confirmed by using interval differencing to determine the rate of change (1st derivative). Results can be found in Figure 2.

The first rate of change plots revealed that the data reaches a steady value at 12.5, or the point between 10- and 15-minute minimum meal intervals (Figure 2). To further confirm this parameter, a second rate of change was calculated (2nd derivative) (Figure 3). The second rate of change calculation identified a rate of change equal to zero (inflection point) at a time point for all meal parameters. The minimum meal interval at which the 2nd derivative is equal to 0 was at the time point of 15.625. However, the 2nd derivative is very close to zero between the time points of 10 and 22.5. For example the 2nd derivative of average mealtime was equal to -0.02 at 10; 0.00 at 15.625, and 0.01at 22.5; other parameters had a similar relationship. This suggests that any minimum meal interval between 10 – 30 minutes could be used. However; the larger the minimum meal interval the less dynamic the meal data becomes. So, the best choice is the smallest minimum meal interval that meets the criteria for an inflection point (at or near zero).

A minimum meal interval of 5 minutes was determined by visual observation (Gibb and McAllister 1999). Schwartzkopf-Genswein *et al.* (2001) reported that a minimum meal interval of 5 minutes was selected based on visual observation and other studies.

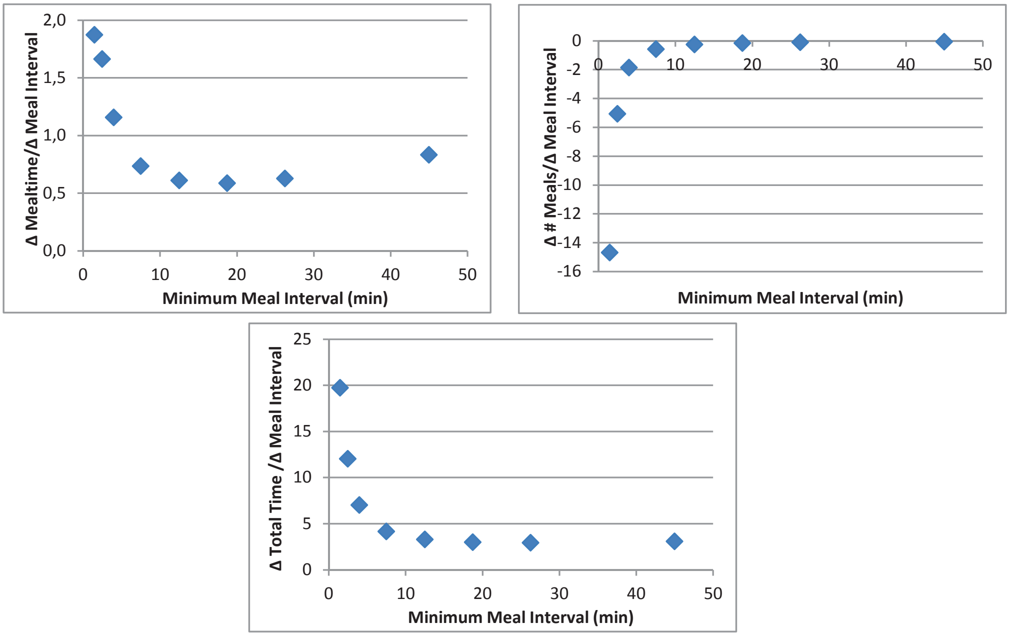


Figure 2: Rate of change in meal parameters (Δ) of feedlot heifers with change of minimum meal interval

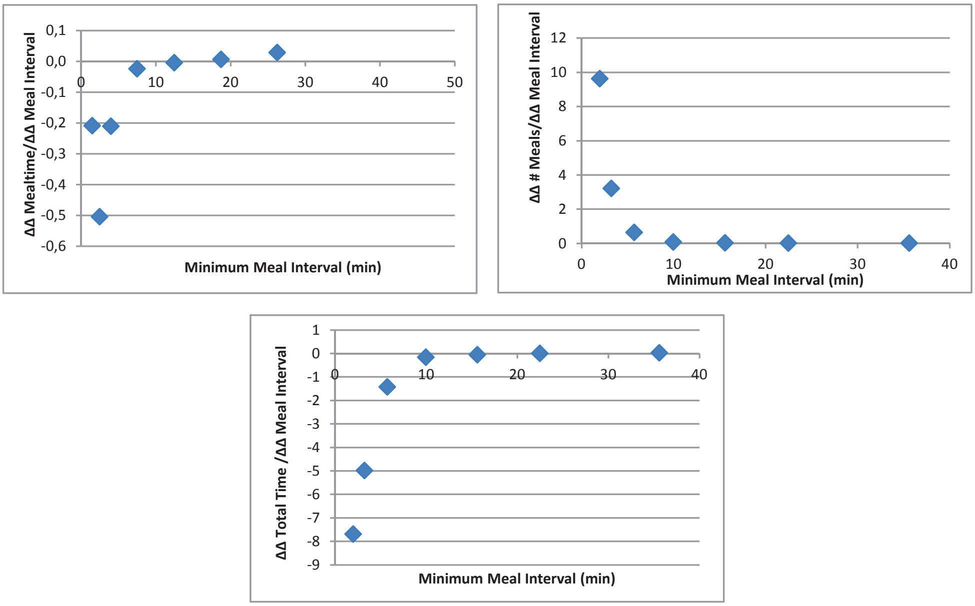


Figure 3: The second rate of change (ΔΔ) in meal parameters of feedlot heifers with respect to minimum meal interval in minutes

The minimum meal size that was chosen for the further analysis of this study was 10 minutes, as determined above. Data from 256 heifers was collected over two summers (128 heifers/summer). Effects of breed, weather, and access to shade on the meal parameters of feedlot heifers were of interest.

Day, year, breed, THI category, and shade treatment affected number of meals per day by category ($P<0.01$). Number of meals per day decreased as THI category increased 12.1±0.1, 11.4±0.1, 11.1±0.09, 10.1±0.4 for the normal, alert, danger, and emergency categories, respectively (Table 1). The effect of breed is difficult to explain, there does not appear to be an association based on frame size or color (Angus 11.1±0.16, MARC III 11.3±0.16, MARC I 10.4±0.16, Charolais 12.0±0.16). These data are lower than what has been reported in the literature. Bach *et al.* (2004) reported that dairy cows visited the bunk 46 times a day; however, it was noted that many visits were part of a single meal, and meal data was beyond the scope of the work presented. Brown-Brandl *et al.* (2005b) reported number of meals to range from 12 – 17 meals per day; steers under heat stress had higher number of meals than those exposed to thermal neutral conditions. Schwartzkopf-Genswein *et al.* (2001) reported beef cattle to have 16.8 meals/day on average; heifers were reported to have a larger number of meals than the steers (17.7 vs 15.4 meals/day). Schwartzkopf-Genswein *et al.* (2001) used a minimum meal interval of 5 minutes instead of 10 minutes. Data from the current study matches fairly well with Schwartzkopf-Genswein *et al.* (2001) when a 5 min minimum meal interval is used instead of the 10 minute interval, 14.6 meals/day (Figure 3).

Table 1: The effect of providing shade to feedlot heifers exposed to different temperature humidity index categories (THI) on number of meal per day

| | Shade | No Shade | Mean |
|---|---|---|---|
| Normal | 12.20.12±$^{a}$ | 12.10.12±$^{a}$ | 12.20.11$^{1}$± |
| Alert | 11.30.12±$^{bc}$ | 11.50.12±$^{b}$ | 11.40.11$^{2}$± |
| Danger | 11.50.10±$^{bd}$ | 10.80.10±$^{c}$ | 11.10.09$^{3}$± |
| Emergency | 10.00.44±$^{d}$ | 10.10.44±$^{d}$ | 10.00.37$^{4}$± |
| Mean | 11.30.13±$^{A}$ | 11.10.13±$^{A}$ | |

$^{abc}$ Indicates significant differences between treatments (shade, no shade) and THI categories.
$^{AB}$ Indicates significant differences between treatments (shade and no shade)
$^{1234}$ Indicates significant differences between THI categories.

It was determined that average mealtime was impacted by day, year, shade treatment, breed, THI category, and the interaction of shade treatment and THI category (P<0.05). The effects of shade treatment and breed, and breed and THI category tended to be impacted (P<0.1). Cattle with access to shade spent 11.4±0.20 minutes eating compared to 9.3±0.20 minutes eating for the cattle without access to shade (Table 2). As THI category increased average mealtime decreased numerically; significant differences were found between alert and danger categories, and normal and danger categories. The effect of breed on mealtime is difficult to explain: Angus 10.0±0.24, MARC III 10.6±0.24, MARC I 11.6±0.24, and Charolais 9.1±0.24.

Table 2: The effect of providing shade to feedlot heifers exposed to different temperature humidity index categories (THI) on average meal length (min)

| | Shade | No Shade | Mean |
|---|---|---|---|
| Normal | 11.60.18±$^{a}$ | 9.60.18±$^{c}$ | 10.60.16$^{1}$± |
| Alert | 11.80.18±$^{a}$ | 9.80.18±$^{c}$ | 10.80.16$^{1}$± |
| Danger | 10.90.15±$^{b}$ | 9.40.15±$^{c}$ | 10.20.13$^{2}$± |
| Emergency | 11.20.66±$^{a}$ | 8.50.66±$^{c}$ | 9.80.54$^{12}$± |
| Mean | 11.40.20±$^{A}$ | 9.30.20±$^{B}$ | |

$^{abc}$ Indicates significant differences between treatments (shade, no shade) and THI categories.
$^{AB}$ Indicates significant differences between treatments (shade and no shade)
$^{1234}$ Indicates significant differences between THI categories.

Total time spent eating was affected by day, year, shade treatment, breed, THI category, and the three-way interaction of shade treatment, breed, and THI category ($P<0.05$). Heifers, that had access to shade, spent 123±1.8 minutes eating a day compared to 101.5±1.8 minutes a day for heifers without access to shade. These averages compare reasonably well with Schwartzkopf-Genswein *et al.* (2001), who reported an average time eating of 112.1 min/day and 124.9 min/day for heifers. The total time eating decreased as THI increased: Normal 125.9±1.5, Alert 119.5±1.5, Danger 109.8±1.2, and 94.7±5.1 min/day. The MARC III cattle spent the most time eating 116.1±2.3 min/day and were similar to the MARC I cattle 115.8±2.3 min/day. Charolais (109.2±2.3 min/day) and Angus (108.7±2.3 min/day) spent less time eating than the two composite breeds. The relative change in time spent eating when the different breeds were provided with shade, in the THI danger category, were MARC III 26 min (more in the shade), Marc I and Charolais 22 mins, and Angus 14.5 mins.

## Conclusions

The value of minimum meal interval impacts the interpretation of feeding activity data. The best minimum meal interval was determined by analyzing feeding behavior data to determine the number of meals, average meal length, and total time spent eating at minimum meal intervals ranging from 1 to 60 min. These meal activity data were evaluated using rate of change based on interval differencing. A subsequent analysis identified the inflection point of the rate of change graph. This last step identified a minimum meal interval of 10 minutes for feedlot cattle.

In a subsequent analysis (using the established minimum meal interval), feeding behavior data from feedlot heifers with and without access to shade were evaluated. Feeding behavior data from 256 feedlot heifers (of 4 different breeds) were evaluated over 2 summer periods (128 heifers/summer). It was determined that cattle decrease time spent eating, average meal size, and number of meals as the THI increased. Cattle provided with shade spend more time eating, with longer meal sizes over all THI categories.

## Disclaimer

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## Effect of precision feeding according to energy balance on performance of early lactation dairy cows

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### Abstract

The objectives of this study were to evaluate individual precision feeding (IPF) and nutrient utilization according to individual energy balance at early lactation compared to the control which was the traditional total mixed ration (TMR) feeding strategy. Fifty-eight Holsteins cows, blocked by parity and production during the pre-treatment period and then randomly assigned at 21 d postpartum to a control TMR diet [n = 29; 16.2% crude protein (CP), 1.64 Mcal of net energy for lactation ($NE_L$), 22% starch, and 19% forage neutral detergent fiber (NDF)] or a diet with caloric density manipulated weekly (precision diet, n = 29, 16.2% CP, 1.59 to 1.68 $NE_L$, 18 to 26% starch, and 16 to 22% forage NDF) to promote a calculated positive energy balance of 5 Mcal/day. Diets were fed as total mixed rations and precision cows had their diets adjusted individually once a week, by grain supplementation from 0 to 25% of daily DM offered, according to energy balance of the preceding week. Daily energy balance was calculated out of measured DM intake and data provided by commercial sensors (milk meters, on-line milk composition analyzers and walk through scales for body weight measurement), The study lasted from wk 3 to 19 postpartum. Compared with controls, precision cows had similar DM intake (24.3 kg/d), but $NE_L$ intake tended to be greater primarily between wk 4 and 8 postpartum. Yields of milk (45.2 vs. 41.9 kg/d), milk components, 3.5% fat-corrected milk (44.0 vs. 40.8 kg/d), and energy-corrected milk (43.4 vs. 40.2) were all greater for precision than control cows, resulting in greater energy-corrected milk production per kg of diet DM consumed (1.79 vs. 1.72). Precision cows produced more milk calories per kg of metabolic weight (0.227 vs. 0.213 Mcal of $NE_L$/kg), although the amount of consumed calories partitioned into milk (82.3%) and measures of energy status did not differ between treatments throughout the study.

**Keywords**: dairy cow, precision feeding, energy balance, nutrient utilization

### Introduction

The goal of any feeding program is to provide the correct and balanced amount of nutrients to a cow at the proper time to achieve optimum production, reproductive efficiency and profitability. Applying these guidelines to every single cow in the herd would create the optimal results providing the correct amount and balance of nutrients to cows at the proper time are known. Nevertheless, technological and practical limitations as well as expansion of herd size have diverted management from the individual to the group feeding approach. The emerging feeding method of choice for both small and large dairy herds is a TMR (NAHMS, 2002). The guidelines described above apply also for TMR formulated to address a theoretical representative cow that may be the average or in the upper percentile in the herd or the group. Under these circumstances, we potentially underfeed or overfeed a large proportion of the herd especially when the entire lactating herd receives a single ration throughout lactation. The assumption that higher or lower-producing cows will balance their energy output by more or less DM intake might not always happen, therefore, creating a wide range of BCS at dry-off and at calving, particularly when lactation is extended by delayed pregnancy.

Alternatives to a single TMR were evaluated by establishing feeding groups according to stage of lactation and lactation potential (Spahr *et al.*, 1993), and adjust the ration accordingly. This is particularly important in early lactation when nutrient secretion in milk is not compensated for by a rapid increase in DM intake, resulting in a period of negative nutrient balance and extensive body tissue mobilization (Coffey *et al.*, 2002). Attempts to adjust concentrate supplementation according to milk production has had mixed success because milk yield itself does not provide sufficient information for a more precise feeding program (Maltz *et al.*, 1992). The availability of daily BW measurements improved the accuracy of concentrate supplementation (Maltz *et al.*, 1992; Maltz *et al.*, 1997; Maltz, 1997), and attempts to apply individual supplementation with computer-controlled self-feeders according to the potential production of the cow resulted in economic gains (André *et al.*, 2010). Technological developments such as an on-line milk composition analyzer (Afilab, S.A.E. Afikim, Israel) that measures milk fat, protein and lactose on-line at each milking with concurrent measurements of BW might generate information to be used to refine the feeding program of dairy cows (Maltz *et al.*, 2009). It was anticipated that commercially available sensors will allow implementation of precise feeding regimens to dairy herds that can feed early lactating cows individually either by computer controlled concentrates self feeders, in the milking parlor or in robot milking systems. The hypothesis was that feeding cows according to individual energy balance improves production and nutrient utilization compared with a single diet to all cows. The objectives were to evaluate performance of early lactation dairy cows fed a TMR adjusted for energy balance using daily BW and yields of milk components for ration decision.

## Materials and methods

Study design, animals, housing, and feeding

The experimental design was a complete randomized with blocks. After the 7-d pre-treatment period, cows from weekly cohorts were blocked by parity (lactation 2 and lactation > 2) and the ratio of milk energy secretion per kg of metabolic BW (**$BW^{0.75}$**) and, within each block, randomly assigned to one of the two treatments, a control diet or a diet that was manipulated according to the calculate energy balance of cows (precision treatment). Data collected during the pre-treatment period (week 3) were used for covariate adjustment during statistical analyses (Cov). Fifty-eight multiparous early-lactation Holstein cows from the University of Florida Dairy Unit were enrolled in the study. Cows at 14 DIM were moved to the experimental pens for a 7 d pre-treatment period and to acclimate to Calan gates. During the pre-treatment period, cows were fed the control TMR (Table 1). On d 21 postpartum, treatments were initiated and the study period lasted 16 wk, (wk 4 to 19) postpartum. Cows were housed in the same free-stall barn with sand bedded stalls, and each cow was randomly assigned to an individual feeding gate (individual feed intake, Calan Broadbent feeding system, American Calan Inc., Northwood, NH). Fans and nozzles along the free-stalls were activated once ambient temperature reached 20 $^{o}$C.

Cows were fed twice daily, immediately after the morning milking at 08:30 h and again at 12:30 h. The amounts of feed offered to individual cows were adjusted daily to result in at least 5% refusals, which were weighed once daily, before the morning feeding. The DM intakes of individual cows were calculated based on DM of feeds measured at 105 $^{o}$C.

Treatments

Diets mixed and fed twice daily as base mixture (Table 1) were designed to meet the nutrient needs of a 650 kg cow consuming 23 kg of diet DM and producing 40.0 kg of milk, 3.5% fat and 3.0% true protein. Grain supplement was formulated to contain the same concentration of protein, minerals, vitamins and additives as the base mixture (Table 1).

Table 1: Ingredient and nutrient composition of the diets (% DM)

| | Treatment[1] | | | |
|---|---|---|---|---|
| Ingredients | Control | | Precision | |
| Corn silage | 32.5 | | 37.0 - 27.7 | |
| Alfalfa hay | 15.3 | | 17.4 - 13.0 | |
| Concentrate[2] | 40.2 | | 45.6 - 34.3 | |
| Grain supplement[3] | 12.0 | | 0 – 25.0 | |
| | TMR[1] | | | |
| | Control | Precision mean | Precision range | |
| Grain supplement | 12% | 16.6% | 0% | 25% |
| $NE_L$,[4] Mcal/kg | 1.636 | 1.652 | 1.590 | 1.683 |
| OM, % | 93.8 | 93.8 | 93.5 | 94.0 |
| CP, % | 16.2 | 16.2 | 16.1 | 16.2 |
| NFC, % | 39.4 | 40.2 | 37.5 | 41.5 |
| Starch, % | 22.0 | 23.4 | 18.2 | 26.1 |
| NDF, % | 34.2 | 33.6 | 36.0 | 32.4 |
| Forage NDF, % | 19.1 | 18.0 | 21.7 | 16.2 |
| ADF, % | 22.1 | 21.6 | 23.4 | 20.7 |
| Ether extract, % | 4.0 | 4.0 | 4.0 | 4.0 |

[1]Control = 12% of the diet DM as grain supplement. Precision mean = average amount of grain supplement (16.6% of DM) offered to precision cows. Precision range = range of grain supplement (0 to 25% of DM) offered to precision cows.
[2]The concentrate contained (DM basis) 14.3% cottonseed, 17.1% ground corn, 19.1% citrus pulp, 21.0% soybean hulls, 9.5% cooker-processed soybean meal (AminoPlus; Ag Processing Inc., Omaha, NE), and 7.6% of a vitamin-mineral-protein premix.
[3]The grain supplement contained (DM) 63.5% ground corn, 18.0% soybean hulls, 7.5% soybean meal, 7.5% cooker-processed soybean meal, 3.5% a vitamin-mineral-protein premix. Vitamin-mineral-protein premix added to the concentrate and grain supplement.
[4]Net energy for lactation according to Weiss (1998).

Control cows received the base mixture and an additional 12% of the total daily DM offered as grain supplement (Table 1), which was split into the two daily feedings. Precision cows received from 0 to 25% of the total daily DM offered as grain supplement which was thoroughly mixed with the base mixture for each individual cow. The precision treatment received a TMR to support each individual cow's milk production and to achieve a positive energy balance of up to 5 Mcal/d, but with a

maximum $NE_L$ concentration of 1.68 Mcal/kg of DM calculated at 3 x maintenance requirements (Weiss, 1998). The minimum amount of grain supplement was 0 (only the base mixture with 54% forage fed) and the maximum was 25% of the daily DM offered (TMR with 40% forage). The amount of grain supplement to be incorporated into the TMR of each precision cow was determined once weekly, based on the preceding week calculation of energy balance to achieve a +5 Mcal/d. When a reduction or increase of grain supplement was between the extremes, this change was implemented in two steps. It was anticipated that the average precision cow would consume a TMR with similar nutrient composition as control cows. The resulting calculated $NE_L$ content of the diet ranged from 1.58 to 1.68 Mcal/d calculated at 3 times the caloric maintenance intake (Weiss, 1998).
Analyses of Dietary Ingredients was performed on monthly composite samples according to standard procedures. The energy density of the diet was estimated using analyzed feed values and calculated at 3 x maintenance intake (Table 1; Weiss, 1998).

Measurements of Milk and Milk Components
Cows were milked twice daily at 07:30 and 19:30 h and individual yield of milk and concentrations of fat, true protein and lactose (AfiFlo milk meters, AfiLab on-line real-time milk analyzer, S.A.E. Afikim, Israel) were recorded. The AfiLab system was calibrated once monthly with data on milk composition from 450 cows analyzed by the Southeast DHIA laboratory. The 3.5% FCM yield was calculated as: [(0.4324 x milk yield) + (16.218 x milk fat yield)] (NRC, 2001). The ECM yield was calculated as: [(0.3246 x milk yield) + (12.86 x fat yield) + (7.04 x protein yield)] (NRC, 2001). Weekly means of daily values were used for statistical analyses.

Body Weight, Body Condition Score and Measurement of Energy Balance
Cows were weighed on a walk-though scale (AfiWeigh, S.A.E. Afikim, Israel) located on the exit lane of the milking parlor. Body condition was scored once weekly using a 1 to 5 scale (Ferguson *et al.*, 1994) with increments of 0.25 units by the same trained evaluator. Energy balance was calculated using daily caloric intake calculated based on DM intake and the energy content of the dietat 3 x maintenance (Weiss *et al.*, 1998), minus the summation of the daily calories required for maintenance (0.08 x $BW^{0.75}$) and the calories secreted as milk according to yields of fat, protein, and lactose (milk yield x [(0.0929 x fat %) + (0.0563 x protein %) + (0.0395 x lactose %)]). The average energy balance during the week was used to adjust the diet of precision cows. Daily values were averaged into weekly means for statistical analyses.

Statistical Analyses
Data were analyzed using the GLIMMIX procedure of SAS version 9.2 (SAS/STAT, SAS Institute Inc., Cary, NC, USA) fitting either Gaussian (continuous data) or Logistic (binary data) distributions. Distributions of the residuals of continuous data were tested for normality and data were transformed when appropriate using a link function in

SAS and ilink function to back-transform the LSM and SEM. The Kenward-Roger method was used to calculate the denominator df to approximate the F tests in the mixed models. Outcomes with repeated measurements within the same cow were analyzed with models that included the fixed effects of block, pretreatment covariate value, treatment (control vs. precision), parity (2 vs. > 2), time (hour, day, or week), the interactions between treatment and parity, treatment and time, parity and time, and treatment and parity and time. Cow nested within treatment by parity was the random error for test of treatment effects. The covariance structure with the lowest Bayesian information criterion from the fit statistics parameters was chosen for each analysis performed. Model fitting was evaluated using the fit statistics.
Treatment differences with $P \leq 0.05$ were considered significant, whereas tendencies to differences were accepted if $0.05 < P \leq 0.10$.

**Results**

Lactation Performance

The proportion of concentrates in the ration consumed by precision cows was greater (P < 0.01) than that of control cows from wk 3 to 12 postpartum (Figure 1A). Caloric density of the diet was greater for precision than control, and a 0.7 kg/d numerical increase in DM intake (Table 2.), resulted in caloric intake greater (P < 0.05) between wk 4 and 10 postpartum (Figure 1B).

Table 2: Effect of precision feeding on performance (control n=29; precision n=29)

| | Treatment[1] | | | P[2] | | |
|---|---|---|---|---|---|---|
| | Control | Precision | SEM | TRT | Wk | TRT*Wk |
| Diet $NE_L$, Mcal/kg | 1.635 | 1.652 | 0.004 | <0.01 | <0.01 | <0.01 |
| DM intake, kg/d | 23.9 | 24.6 | 0.4 | 0.23 | <0.01 | 0.55 |
| Caloric intake, Mcal/d | 39.1 | 40.6 | 0.7 | 0.10 | <0.01 | 0.27 |
| Milk, kg/d | 41.9 | 45.2 | 0.7 | <0.01 | <0.01 | 0.87 |
| 3.5% FCM, kg/d | 40.8 | 44.0 | 0.5 | <0.01 | <0.01 | 0.90 |
| ECM, kg/d | 40.2 | 43.4 | 0.5 | <0.01 | <0.01 | 0.90 |
| Milk fat % | 3.35 | 3.35 | 0.04 | 0.97 | <0.01 | 0.96 |
| Milk fat Kg/d | 1.40 | 1.51 | 0.02 | <0.01 | <0.01 | 0.95 |
| Milk protein % | 2.93 | 2.93 | 0.02 | 0.97 | <0.01 | 0.62 |
| Milk protein Kg/d | 1.23 | 1.33 | 0.02 | <0.01 | <0.01 | 0.95 |
| Lactose % | 4.75 | 4.76 | 0.01 | 0.80 | <0.01 | 0.78 |
| Lactose Kg/d | 1.99 | 2.15 | 0.04 | <0.01 | <0.01 | 0.85 |

[1]Control = cows received 12% of DM as grain supplement. Precision = cows received

on average 16.6% of the diet DM as grain supplement (ranged from 0 to 25% of DM).
[2] TRT = effect of treatment; Wk = effect of week postpartum; TRT*Wk = interaction between TRT and Wk.

Grain supplement allocation was maximal at wk 5 postpartum and gradually decreased until equalizing that of controls at wk 13 postpartum. The difference in concentrate intake between treatments was maximal at wk 7 (Fig. 1B). For the entire study, concentrate intake averaged 0.86 kg/d more for precision than control cows. In similar fashion, the proportion of precision cows receiving a TMR containing more concentrates than the control TMR was over 90% at wk 5 and gradually declined until wk 16 postpartum, when the proportions of precision cows receiving the grain supplement above and below the control TMR became similar. This greater proportion of concentrates in the first 13 wk postpartum increased ($P < 0.01$) the calculated $NE_L$ (Table 2). The DM intake of cows did not differ between treatments (Table 2) and it increased gradually to peak at wk 14 postpartum, when cows in both treatments were consuming an average of 25.7 kg/d.

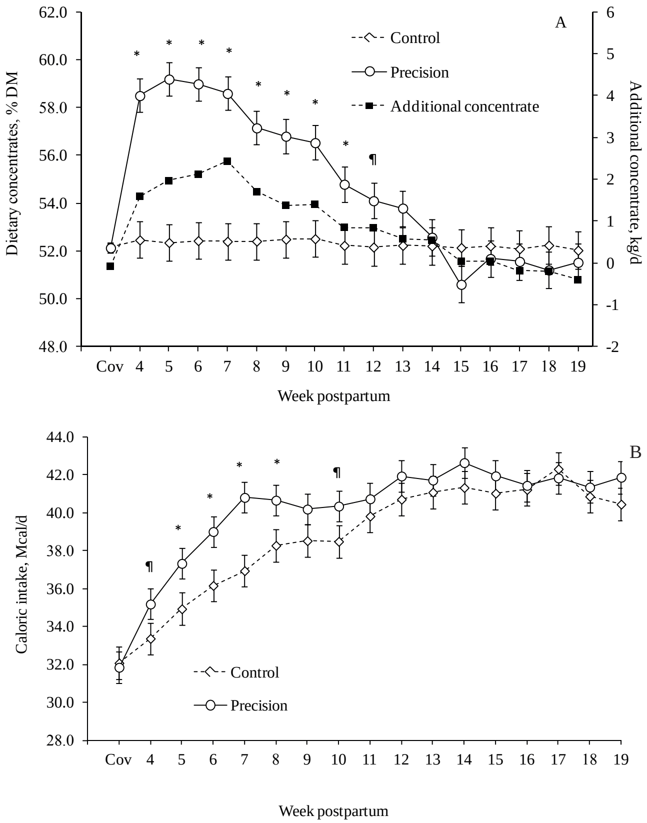



Figure 1: Percentage of the diet DM as concentrates including the additional concentrate (kg/d) consumed by precision cows (A) and caloric intake (B) in cows receiving control

or precision treatments. Cov = Week 3, covariate. *within a week, treatments differed (P < 0.05); ¶within a week, treatments tended to differ (P < 0.10). Precision cows consumed (panel A) a diet with a greater (P < 0.01) percentage of concentrates than controls (55.0 ± 0.01 vs. 52.3 ± 0.01%).

The milk production increased (P < 0.01) 3.3 kg/d for precision compared with control cows (Table 2) and this response was observed starting at wk 4 postpartum (Figure 2A). Similarly, precision cows produced 3.2 and 2.8 kg/d more 3.5% FCM and ECM, respectively, than control cows (Table 2). The concentrations of fat, true protein and lactose in milk of cows were not affected by treatment, although they all changed (P < 0.01) with week postpartum. Nevertheless, because of the increased production with precision feeding, cows in the precision treatment produced more (P < 0.01) fat, true protein, and lactose.

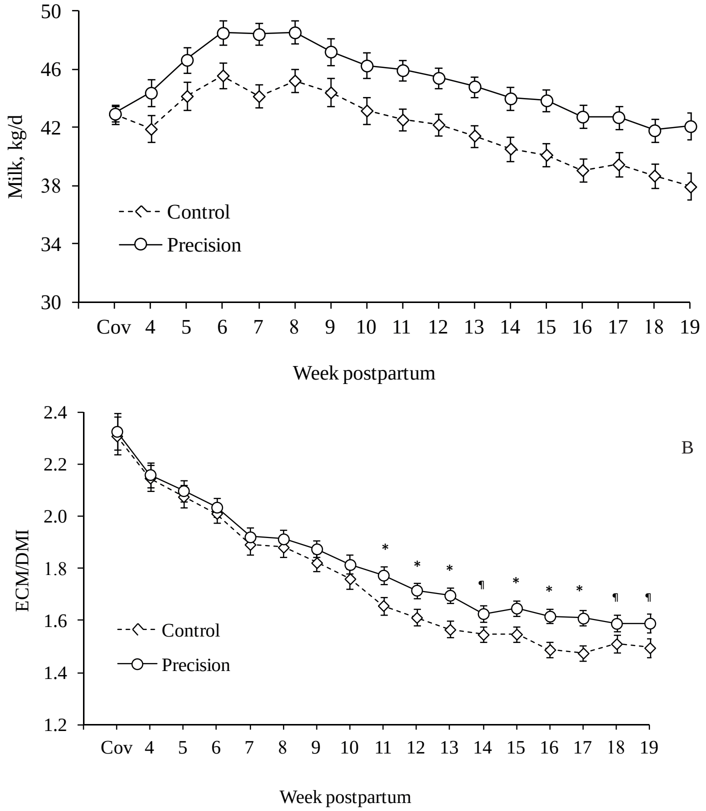



Figure 2: Milk yield (A) and efficiency of converting DM intake into energy-corrected milk (B) in cows receiving control or precision treatments. Cov = Week 3, covariate. *within a week, treatments differed (P < 0.05); ¶treatments tended to differ (P < 0.10). For A, P < 0.01 for every weekly difference.

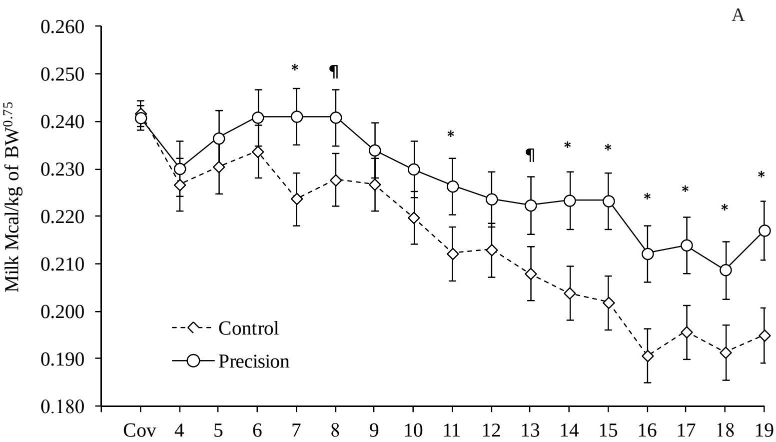
Production Efficiency and Energy Balance

The conversion of DM intake into ECM was 4.1% greater (P = 0.02) for precision than control cows (Table 3). Most of this difference was observed after wk 10 postpartum, when precision cows had a 7.1% greater feed efficiency (Figure 2B). The caloric content of milk did not differ between treatments; however, daily $NE_L$ secreted as milk was greater (P < 0.01) for precision than control cows (30.0 ± 0.4 vs. 27.9 ± 0.4 Mcal/d). Proportion of consumed calories partitioned into milk synthesis was similar in both treatments, but cows in precision feeding produced more (P = 0.05) Mcal as milk per kg of $BW^{0.75}$ than control cows (Table 3, Figure 3A).

Table 3. Effect of precision feeding on efficiency of nutrient utilization and energy status

| | Treatment[1] | | | P[2] | | |
|---|---|---|---|---|---|---|
| | Control (n = 29) | Precision (n = 29) | SEM | TRT | Wk | TRT*Wk |
| ECM/DM intake | 1.72 | 1.79 | 0.02 | 0.02 | <0.01 | 0.84 |
| Milk Mcal, % of caloric intake | 82.5 | 82.1 | 1.4 | 0.95 | <0.01 | 0.59 |
| Milk Mcal/kg of $BW^{0.75}$ | 0.213 | 0.227 | 0.05 | 0.05 | <0.01 | 0.35 |
| Energy balance, Mcal/d | 1.17 | 0.46 | 0.61 | 0.40 | <0.01 | 0.20 |
| Wk to positive energy balance | 10.1 | 9.8 | 0.9 | 0.74 | --- | --- |
| Body weight, kg | 640.0 | 635.3 | 4.8 | 0.48 | <0.01 | 0.96 |
| Body condition, 1 to 5 | 2.65 | 2.64 | 0.07 | 0.86 | <0.01 | 0.45 |

[1]Control = cows received 12% of the diet DM as grain supplement. Precision = cows received on average 16.6% of DMI as grain supplement (from 0 to 25% of DM).
[2]TRT = effect of treatment; Wk = effect of week pp; TRT*Wk = interaction between TRT and Wk.



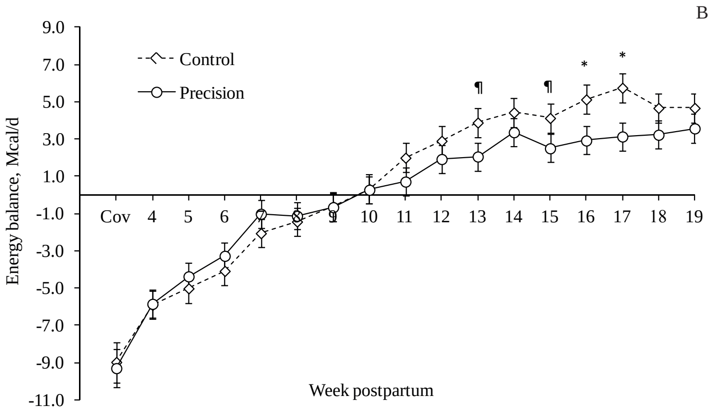



Figure 3: Milk energy secretion per kg of metabolic weight (A) and energy balance (B) in cows receiving control or precision treatments. Cov = Week 3, covariate. *within a week, treatments differed ($P < 0.05$); ¶within a week, treatments tended to differ ($P < 0.10$).

Control and precision cows reached positive energy balance at similar interval postpartum (Figure 3B). In agreement with energy balance, the mean and changes in BW and BCS did not differ between treatments (Table 3). Cows in both treatments lost on average 22 kg of BW between wk 3 and 7 postpartum, and began to regain weight at wk 12 postpartum, whereas BCS remained relatively stable after wk 10 postpartum.

## Discussion

The results from this experiment endorsed the hypothesis that feeding cows according to individual needs, based on energy balance, improves lactation performance and conversion of diet DM into ECM, thus challenging the consensus that, for high-producing cows, the delivery of a group diets as TMR is advantageous.
The control diet used represents a typical lactating diet that was formulated to support production of 41.5 kg/d of milk when cows consume 23 kg of DM/d (NRC, 2001). This was the intermediate value compared with precision cows fed the minimum or maximum amount of grain supplement. In fact, the average intake of the control cows was 23.9 kg/d and they produced 41.9 kg of milk/d during the 16-wk experiment, thus, similar to predicted by the NRC (2001). Therefore, the NRC (2001) predicted accurately the needs of the average cow and improvements in performance would require additional DM intake.

The improvements in lactation performance were observed throughout the 16-wk of the experiment, although efficiency of conversion of diet DM into ECM was improved mostly after wk 10 postpartum (Figure 2B) when only approximately 40 to 50% of the precision cows were consuming a diet with a greater proportion of concentrates than controls, and concentrate during that time was similar between control and precision cows (Figure 1A). Therefore, the improved caloric intake in the first weeks postpartum and the individual allocation of nutrients based on energy balance improved lactation performance that extended beyond the period in which the average cow in the precision treatment was consuming a more energy dense diet than control cows. Throughout the study, precision cows consumed an average of 1.5 Mcal of $NE_L$ more than control cows. This amount of calories is enough for an additional 2.3 kg of milk, which contained 0.66 Mcal/kg. Because the difference in milk yield between treatments was 3.3 kg/d, the additional 1.0 kg cannot be explained by the average caloric intake of cows. By feeding cows according to energy balance, it is possible that the individual allocation of nutrients favored cows that were able to respond to additional concentrates, thereby producing more milk.

Other methods to selectively allocate additional nutrients to lactating dairy cows are the use of automatic self-feeders or supplement cows during milking. Studies with high-producing cows in Israel have demonstrated that offering a portion of the concentrate in automatic feeders can either maintain or even increase yields of milk and milk components (Halachmi *et al*., 2009). When conventional starchy pellets were replaced with pellets high in digestible NDF by substituting soybean hulls for ground corn and wheat bran, increments in yields of milk, milk fat and protein were observed in cows producing approximately 40 kg/day (Halachmi *et al*., 2009). A similar response was not observed in a second experiment with cows producing approximately 35 kg/day (Halachmi *et al*., 2006). Although the study lasted for the first 19 wk postpartum, there was no indication that the response to precision feeding declined over time. Because precision cows had their diets adjusted to achieve 5 Mcal of $NE_L$ positive energy balance, it is likely that, as the lactation progressed, control cows would be in a better energy balance and gain more BW than precision cows. At wk 19 postpartum, control cows were consuming 0.5 kg more concentrate than precision cows, despite having lower milk production. This clearly indicates that by feeding cows a single diet, partition of nutrients might favor body reserves in place of production. High-producing cows that are fed diets with limited nutrient density might not achieve full production potential if they do not increase DM intake to compensate for by the high nutrient secretion in milk. Conversely, less productive gaining BW might require less nutrient dense diets. Therefore, either individual supplementation or multiple diets are needed to accommodate the differences in nutrient requirements of cows with varying production potential.

The challenge to implement multiple feeding groups is how to determine what cows will respond to a more nutrient dense ration. Although diets were fed as TMR in the current study, it is possible to individually supplement cows either through automatic feeders or by the use of supplementation during milking. The inability to measure individual feed intake in cows should not prevent the attempt to apply this strategy. André *et al*. (2011) developed mathematical models to estimate milk production responses to concentrate intake and suggested that algorithms be incorporated to determine the daily individual optimal allowance of concentrates to optimize production. The ability to weigh cows daily after milking provides insights on how nutrients are partitioned to decide on the need to reduce or increase dietary nutrient density. Also, development of methods to rank cows such as milk energy secretion per kg of $BW^{0.75}$ with the use of real-time on-line milk composition might offer an alternative to select cows that might respond to additional supplementation (Maltz *et al*. 2009). Spahr *et al*. (1993) suggested classifying cows based on their lactation potential using 3.5% FCM relative to BW in the first weeks postpartum. Developing methods to identify cows that might respond to additional supplementation beyond what the TMR offers might allow for nutritional strategies for precise feeding to be incorporated in a production setting when daily DM intake of individual cows is not available. There is evidence that implementation of differential feeding of cows by automated feeding improves profitability by adjusting the nutrient supply to the needs of the cow (André *et al*., 2010, Maltz *et al*., 2009). In large herds, in which the ability to supplement cows individually might not be feasible, alternative strategies such as multiple groups of cows with specifically formulated diets might be necessary to minimize under and overfeeding during the lactation.

## Conclusions

Individual allocation of additional concentrates by altering the amount of grain supplement fed to cows improved lactation performance and efficiency of DM conversion into ECM compared with feeding a single TMR to all cows. The response to precision feeding persisted even when the caloric intake was similar between treatments. It seems that the timing of supplement and/or diminution of concentrates to cows that are identified through their energy balance as capable to respond to either, can become a practical way to efficient production and save on concentrates. Future research should focus on methods to incorporate these concepts in large dairy herds to determine if individual allocation of supplements, based on BW and online assessment of yields of milk components, improves performance when measurements of individual cow DM intake is not feasible.

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## Sensor controlled total-mixed-ration for nutrient optimized feeding of dairy cattle

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### Abstract

Feed mixer wagons are used to feed grass and maize silage together with other components in one ration. It can be used in combination with a transponder system for concentrated feed as well as for feeding of a total mixed ration. The implementation of a measurement system based on NIR-spectrometric sensors to measure DM-content and other nutrients should result in a more precise nutrient adjustment of the ration.
To calibrate the measurement system spectra of many different silage samples are taken offline and analysed by wet chemistry. The goal is a good calibration model which can be used in the online measurement system. The NIR sensor and the spectrometer have to be integrated to the mass flow of the feed mixer wagon. The calibration model is the start point for the online measurement at the feed mixer wagon. The model and the integration of the complete measurement system have to be improved by testing feed crops of different silos.

**Keywords:** Total-mixed-ration, Near infrared spectroscopy, Feed mixer wagon, Feed ration improvement

### Introduction

The exact regulation of dry matter, energy and ingredients in green fodder has a large advantage in the ration optimization of economical animal nutrition. The production of in-house fodder is connected with varying contents of dry matter, energy and ingredients in the individual green fodder of each farmer. Control of the feed values concerning the investigations of samples does not fully capture the often high variation in the feed stock. A permanent determination of these parameters can be ensured by the integration of near-infrared spectroscopy (NIRS) in the feed delivery and storage technology.
The near infrared spectroscopy (NIRS) is used in many agricultural ranges. It is a fast and not destructive method to determine substrate-specific characteristics (Stockl *et al.*, 2011). The documentation of contents in case grass, silage and hay in round bundles was

likewise accomplished on basis of NIRS successfully (Walther *et al*., 2011).
Main object of the project “SenToMiRa” is a nutrient optimized total mixed ration for feeding dairy cattle. By installation of a near infrared sensor (MUT-Group) on the material flow at a self-propelled feed mixer wagon (STRAUTMANN). It will be tested to fill and analyze the individual ration components according to the specific needs of the respective performance group. Particularly the in-house basal feed can be analyzed real time regarding the content of dry weight, nutrients and energy content. The adaptation of the ration has to be done by balancing the components depending on the actually measured values of the different parameters. The parameters of the desired ration should be nearly consistent at every feeding time. So with the developed technology it should be ensured that at each time and each feeding place, a qualitatively homogeneous TMR is mixed. This TMR is adapted to the performance level and specific ration requirement of the respective group of dairy cattle.

## Material and methods

For a precise measurement of fodder it is important to have a good calibration. To get a good calibration model 400 - 500 samples are needed. The samples are measured with the near infrared sensor and calibrated by the wet chemistry analyzes. For the calibration of the NIRS we measured the samples with an offline method by using a developed turntable. Figure 1 presents the turntable for simulation.

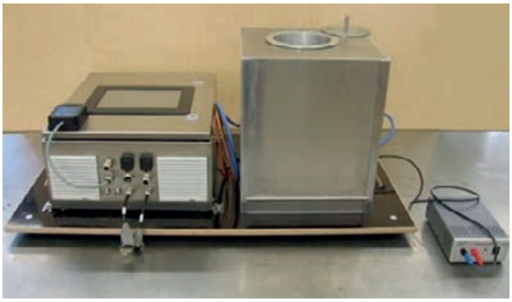

Figure 1: Turn table with NIRS

Figure 2: Self-propelled feed mixer wagon (Strautmann, 2013)

Figure 2 shows the self-propelled feed mixer wagon where the near infrared sensor was installed. With a modification the NIR sensor hang under the fodder samples. Through this process we simulated the silage-taking from the silo surface into the fodder mixer. Reference measurements of dry weight, nutrients and energy content with wet chemistry analysis in the laboratory complete the components for the calibration. The wet chemistry analyses are performed by a certificated laboratory (LKS Landwirtschaftliche Kommunikations- und Servicegesellschaft mbH). By the measurements we took of each silo surface different samples.

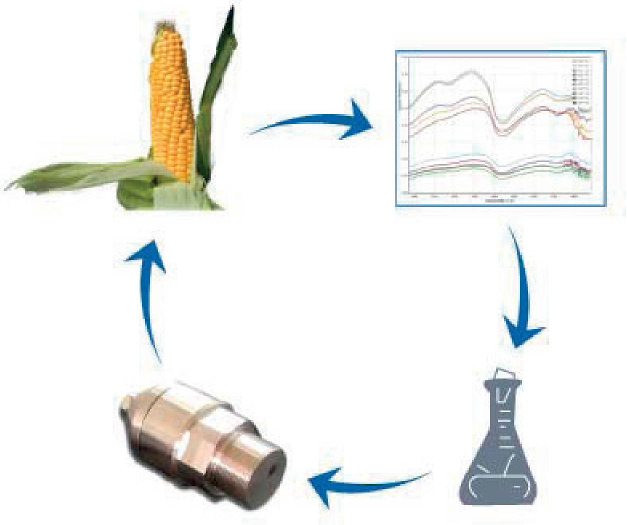

Figure 3: schematic diagram of the calibration (m-u-t, 2012)

Figure 3 shows the schematic diagram of the calibration. These analysis results are used for the basic calibration. In the next step we installed the near infrared spectroscopy system in the material flow on a self-propelled feed mixer wagon.
Figure 4 shows the NIR sensor in the cutter of the self-propelled feed mixer wagon.

Figure 4: near infrared sensor head

Since 2012 we test the machine at the experimental and educational center agriculture house Riswick in Kleve. Everyday round about 500 cattle were fed. Also we take samples from the silages for the NIR measurements to get more reference date to improve the calibrations of grass silage und maize silage.

## Results and discussion

By analyzing the off line measurements we noted that in the surface of the silo it was a high variability. The contents of dry matter changed significantly between maize silage and grass silage (Figure 5 and 6). The results show the dry matter contents of 35 samples taken at 10 maize silos. The dry matter changed from 270 to 400 g DM kg$^{-1}$ FM. The dry matter of grass silage changed from 270 to 570 g DM kg$^{-1}$ FM, by 15 silos with 45 samples. In the Figures one point presenting one sample.

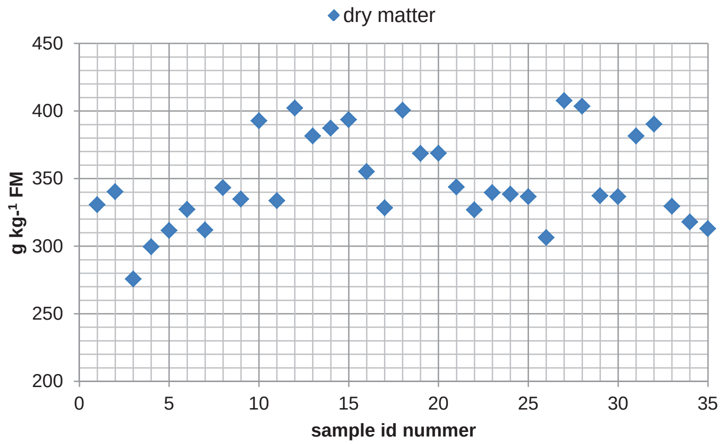


Figure 5: DM content in different grass silage silos

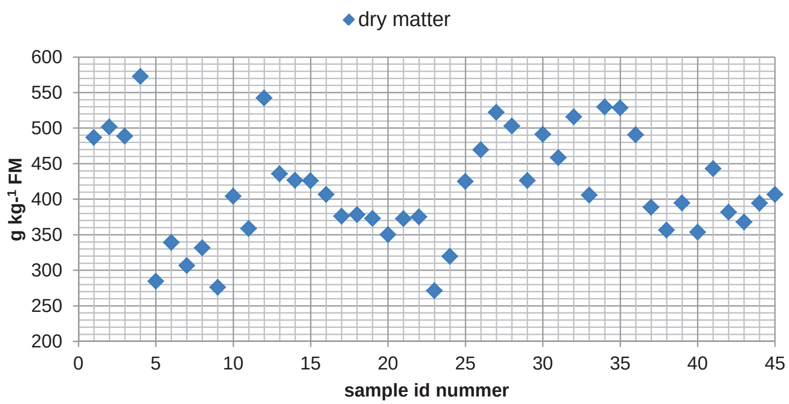


Figure 6: DM content in different maize silage silos

Figure 7 and 8 show the comparison of the values measured by near infrared spectroscopy estimator function with the values from the wet-chemical analysis of reference. The solid line represents the regression. Figure 7 show the model calibration of DM content in grass silages. The first calibration of grass silage with dry matter shows very good results. The root mean squared error of prediction (RMSEP) is located at 3,194. The range/standard error of performance (SEP) has a value of 10,738. The displayed calibration model consists of 98 samples. The samples are evenly distributed over a range of DM 22 – 53 %.

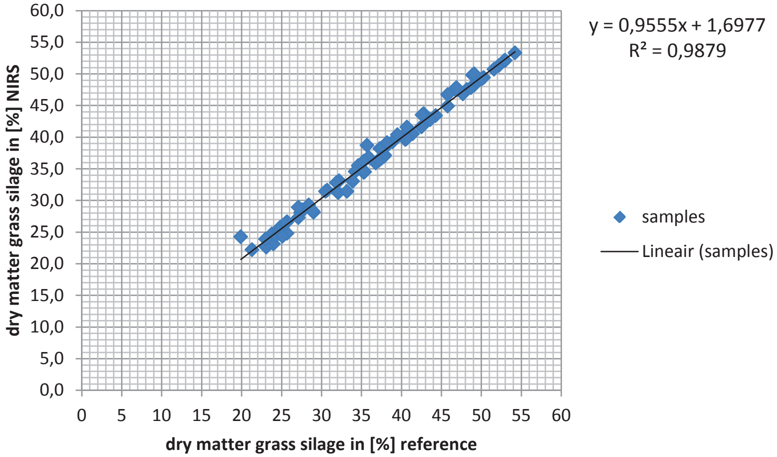


Figure 7: model calibration dry matter for grass silage

Fig. 6 shows the model for the DM content of maize silage. The RMSEP is located at 1,711. The range/SEP has a value of 16,486. The model contains currently 314 samples.

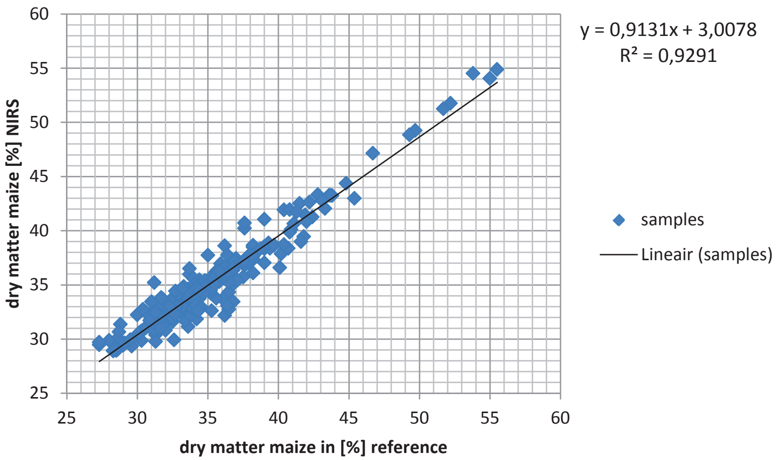


Figure 8: model calibration dry matter for maize silage

The results in Figure 5 and 6 support our presumption that there is wide variation in dry matter and ingredients in the silo and especially to the silo surface area. These large variations in individual silos demonstrate that a continuous measurement give significantly more detail information about the differences in the silo during the feed intake than is possible through the examination of samples. The results show however that an extension of the calibration models to minimize the treasure error measurement needs further effort.

These large variations in individual silos show that continuous measurement during food intake may reflect the differences in the silo considerably more detail than is possible through the examination per hand of samples. However, the results also show that an extension of the calibration model to minimize the estimation error in the measurement still requires additional effort. These fluctuations within a fodder silos can be documented through a permanent online NIRS monitoring of the basic forage qualities during the feed mixture. With the help of the computer system the ration can be optimized immediately before dosing off.

## Conclusions

The next steps are to improve the calibration models and adjusting the dry matter prediction to the administration computer. The idea according to what ingredients is optimized, is a major point of discussion. After this step the ration computer optimized the TMR of the values of dry matter and ingredients.

The permanent and detailed qualitative analyses allow during the feed out, conclusions on preservation, and storage problems and thus support the optimization of the basal feed preparing. By the enumerating of the different contents of dry matter in the same silo and in different silos it is important to know the true contents of dry matter, energy and ingredients. Only by this quality parameters of the desired ration should be nearly consistent at every feeding time.

## Acknowledgements

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## Detection of diseases in dairy cows based on water and feed intake measurements

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### Abstract

Automated detection of diseases like mastitis and lameness in dairy cows based on automated measurements of milk yield, activity and concentrate intake is possible nowadays. Automated measurement of water intake might also be useful for this purpose but this is not customary. A data set of 40 cows with measurements of water intake, concentrate intake and roughage intake and milk yield during 102 days was available to test this hypothesis.
For each cow on each day, variable measurements were compared with the expected value (the running average over the four preceding days). A univariate alert was given when the difference was outside the 80% confidence interval. A combined alert was given when two or more variables were alerted on the same day.
Eight disease cases (three mastitis, three lameness and two other disease) occurred in the experimental period. For most cases there were one or more univariate alerts in the six-days period from five days before up to and including the day of disease diagnose. The block sensitivity (percentage of detected cases) was 100% for detection based on water intake and lower when based on another variable or on combined alerts. The specificity (percentage of non-alerted healthy cow-days) was around 86% for detection based on water intake and at the same level or lower when based on other variables or combined alerts. Disease detection based on water intake has good prospects.

**Keywords:** Dairy cows, water intake, feed intake, monitoring

### Introduction

Economic losses associated with diseases like mastitis and lameness and a decrease of reproductive performance negatively influence the profitability of the dairy farm. So it is helpful to detect diseased dairy cows in an earlier state, which makes the treatment shorter and more effective. In addition of restrict economic losses, an earlier treatment is also positive for the cow's welfare. The number of cows per available amount of labour on dairy farms increases. This trend results in less time available per animal. In order to ensure that this development is not at the expense of animal health, welfare and sustainability, the Smart Dairy Farm project (www.smartdairyfarming.nl) attempts to develop real time decision supporting systems that recognizes diseased cows and reports them to the farmer. This project is a collaboration between research institutes, technological companies, veterinarians, practical farmers and the founders of the project, FrieslandCampina, Agrifirm and CRV. The goal of the project is to increase the number of lactations per cow in 2015 with two and increase the lifetime milk production per cow with 20,000 kg. This finally should result in an increase in animal health and sustainability of dairy farms. To realise this goal the research is focussed on three main topics, namely animal health, nutrition and fertility.

This paper is restricted to the topic animal health. The objective of this research was to investigate the perspectives of the application of automated measurements of water intake for detection of diseases in dairy cows by developing and testing a detection model based on elementary data processing.

Water intake is important for dairy cows. A sufficient supply of clean water is essential to prevent negative effects on animal health, performance and welfare (Meyer *et al*., 2004). The main water intake (83%) is drinking. The other part comes from water included in feedstuffs and by water originated from metabolic oxidation of body tissues (Meyer *et al*., 2004). Total water intake is often calculated by the sum of drinking water intake and ingestion of water contained in feed (neglecting the metabolic water). A dairy cow consumes on average 84 litres per day (Cardot *et al*., 2008). Some studies concluded that water intake was a difficult variable to detect diseases, because water intake was influenced by many factors. This resulted in wide variation of intake levels under apparently similar conditions (Winchester and Morris, 1956). In contrast a study over 70 dairy cows housed in a tie stall showed that water intake had the potency to detect diseases or oestrus, because of the strong correlation with dry matter intake (Lukas *et al*., 2008).

## Material and methods

### Experimental data

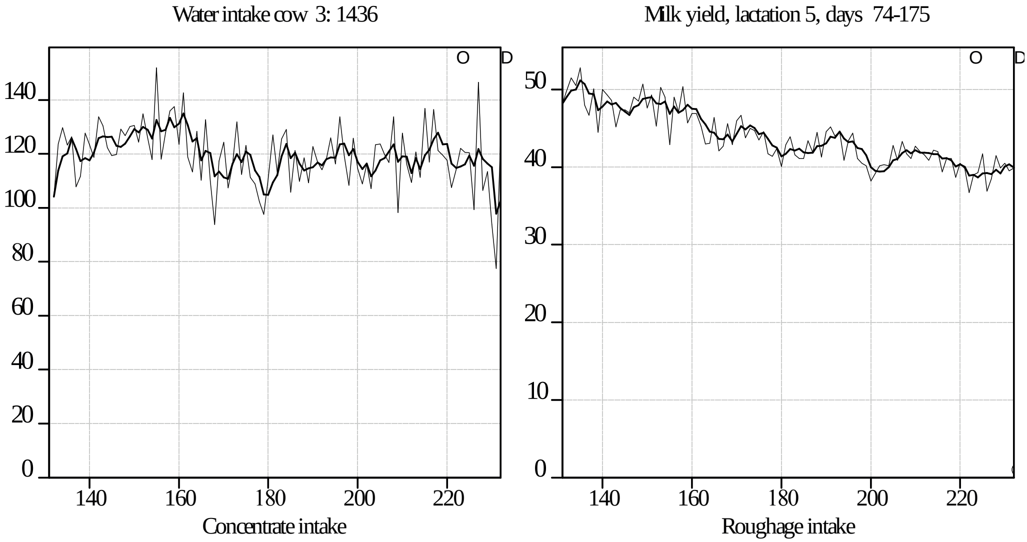
Data were available from an experiment with 40 Holstein/Friesian cows (12 first parity cows, 8 second parity cows and 20 older cows) during 102 days at the Dairy research farm "De Waiboerhoeve", of Wageningen UR Livestock Research in Lelystad, the Netherlands. The cows were housed without grazing in a free-stall barn with individual cubicles and a concrete slatted floor. The cows were fed ad libitum roughage and additional concentrate. To measure feed intake of the individual cows 32 electronic feed weighing troughs with transponder controlled access gates were used and two transponder controlled concentrate dispensers were used to determine concentrate intake. Water intake was measured by water troughs equipped with flow sensors and transponder controlled access gates. The cows were milked in a ten stands open tandem milking parlour with electronic cow identification and milk flow recording and cluster removal.

Sensor data were available for the detection model:

- daily water intake (kg);
- daily roughage intake, fresh and dry matter (kg);
- daily concentrate intake (kg);
- milk yield per milking (kg).

These variables were correlated but principal component analysis showed that all variables did have an added value.
Observations from the farm works related to health and fertility recorded in the management system were available as reference data.

<u>Data analysis</u>
Sensor data should be converted into alerts to make it applicable as management information. This was achieved by pre-processing the data and analyse this data by a detection model.
In the first step, data was visualised and corrected for errors caused by missing measurements and incorrect measurements. An example is given in Figure 1. Some of the first measurements of water and concentrate intake were obvious too low or too high. This was corrected by replacing the first values with missing values if the value was higher or lower than two times the standard deviation over the full experimental period. This method was also used for some specific dates and measurements when there had been technical problems with the sensor equipment.



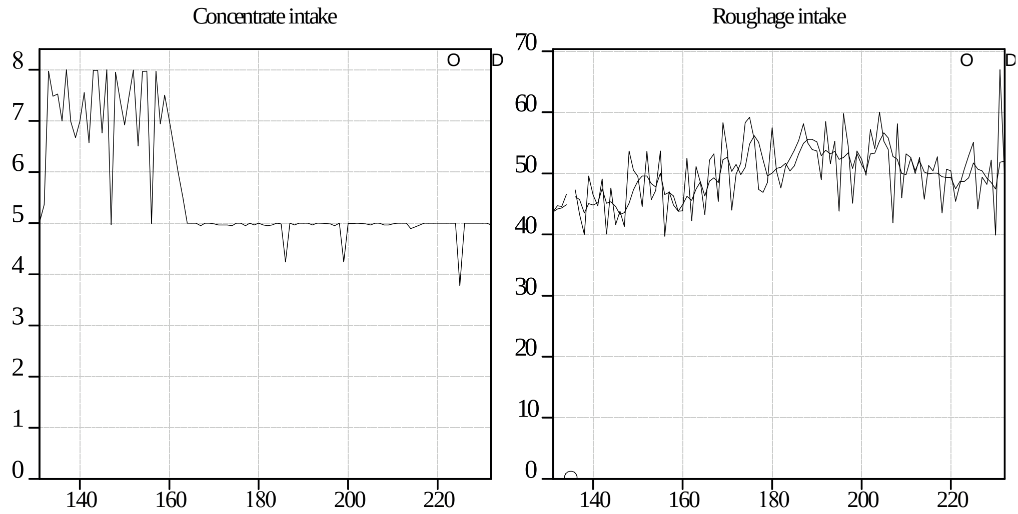



Figure 1: Example of the data visualisation for the third cow (1436) for water intake per day (top left), milk yield per day (top right), concentrate intake per day (bottom left) and roughage intake (bottom right); this cow was in oestrus at day 222 and a disease was recorded on day 232

The detection model gave cow-specific alerts for the univariate variables if the deviation between running average and actual value of the variable was larger than the standard deviation (calculated over the previous seven days) times a factor. A combined alert was given if the number of alerts for a cow in a certain period exceeded a set threshold. The running average of variable x was calculated according to:

$$\text{Running average}=(x_{(i-n)}+..+x_i)/n \qquad (1)$$

with:

$x_{(i-n)}$, $x_i$ = value of variable x at time (i-n), i;
i = delay time (days);
n = time span of calculation (days); n is equal to 4 in the initial model.

The deviations for water and roughage intake and milk yield were based on the difference between actual value and running average. The deviation of concentrate intakes was based on leftovers, the difference between actual intake and maximum available concentrate. An alert was given for a variable when the deviation was outside a pre-set confidence interval.

Data fusion was applied to integrate data from different variables to make more confident disease detection decisions than is possible with univariate variables (Sohn *et al.*, 2004). The used method for data fusion was a combined alert based on the sum

of univariate variables. A combined alert was given for a specific day if the total alerts exceeded the set threshold over a defined period. This number could be higher than four, because multiple alerts of the same variable on different days in the accumulation period were counted separately.
The performance of the model was determined with block sensitivity and specificity. A disease case was true positive (TP) if there were alerts within a block of six days before and up to and including the day of recorded disease, it was false negative (FN) if there where none alerts in this period. The sensitivity was defined as the percentage of detected cases TP/(TP+FN). Days with an alert outside these blocks (and more than two days after a disease case) were considered false positive (FP), otherwise such a day was true negative (TN). The specificity was the percentage of healthy cows that were classified correctly: TN/(TN+FP).

## Results and discussion

During the experimental period eight disease cases were recorded: three mastitis cases, three severe lameness cases and two other diseases (damaged udder and respiratory disease) in seven cows (one cow suffered from both lameness and mastitis).
The performance of the model, expressed in sensitivity and specificity, to detect these diseases with the initial settings is summarized in Table 1. Detection based on water intake resulted in the highest sensitivity, all cases were detected. Sensitivity was lower when detection was based on other variables or on combined alerts. Also specificity was highest for detection based on water intake, the specificity was at the same level or lower when detection was based on other variables or combined alerts.

Table 1: Sensitivity (sens.) and specificity (spec.) for the univariate alerts and combined alerts with the initial settings of the model

| | Water intake | | Milk yield | | Concentrate intake | | Roughage intake | | Combined alert | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) |
| Initial model | 100 | 86 | 62 | 86 | 62 | 76 | 75 | 86 | 62 | 85 |

The effects of the settings of the model on the performance have been examined by varying these settings. First the performance with varying confidence intervals was studied; results are included in Table 2. A broader confidence interval resulted in a higher sensitivity and lower specificity; a smaller confidence had a reverse effect.

Table 2: Sensitivity (sens.) and specificity (spec.) with varying confidence intervals (initial setting in bold) for the univariate alerts and combined alerts

| Confidence interval (%) | Water intake | | Milk yield | | Concentrate intake | | Roughage intake | | Combined alert | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) |
| 60 | 100 | 77 | 88 | 77 | 62 | 68 | 88 | 78 | 75 | 73 |
| 70 | 100 | 82 | 75 | 82 | 62 | 72 | 88 | 82 | 75 | 80 |
| **80** | 100 | 86 | 62 | 86 | 62 | 76 | 75 | 86 | 62 | 85 |
| 90 | 88 | 91 | 50 | 91 | 62 | 80 | 62 | 91 | 50 | 92 |
| 95 | 88 | 94 | 38 | 94 | 62 | 84 | 62 | 93 | 50 | 95 |
| 99 | 62 | 97 | 25 | 97 | 62 | 89 | 25 | 96 | 25 | 98 |

The influence of time span of the standard deviations was determined by varying the time span between 3 and 13 (Table 3). A time span of n days corresponded with a period from n days before till one day before the current day. The detection performance was not strongly influenced by this setting.

Table 3: Sensitivity (sens.) and specificity (spec.) with varying time span for the standard deviations (initial setting in bold) for the univariate alerts and combined alerts

| Time span std. dev. (day) | Period (day) | Water intake | | Milk yield | | Concentrate intake | | Roughage intake | | Combined alert | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) |
| 3 | -3/-1 | 100 | 83 | 62 | 83 | 75 | 71 | 75 | 83 | 50 | 80 |
| 5 | -5/-1 | 88 | 84 | 62 | 84 | 75 | 74 | 75 | 85 | 50 | 83 |
| **7** | -7/-1 | 100 | 86 | 62 | 86 | 62 | 76 | 75 | 86 | 62 | 85 |
| 9 | -9/-1 | 88 | 86 | 50 | 86 | 62 | 77 | 75 | 87 | 50 | 87 |
| 11 | -11/-1 | 88 | 87 | 50 | 87 | 62 | 78 | 62 | 88 | 50 | 88 |
| 13 | -13/-1 | 88 | 87 | 50 | 87 | 62 | 79 | 75 | 88 | 62 | 88 |

The influences of the time span for the running average on the performance were determined by varying the time span from 1 to 5 days (Table 4). The running average was used to establish a standard value where the current value is to be compared with. Also this setting did only have minor effects on the detection results.

Table 4: Sensitivity (sens.) and specificity (spec.) with varying time span for the running average (initial setting in bold) for the univariate alerts and combined alerts

| Time span (day) | Period (day) | Water intake | | Milk yield | | Concentrate intake | | Roughage intake | | Combined alert | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sens. | Spec. | Sens. | Spec. | Sens. | Spec. | Sens. | Spec. | Sens. | Spec. |
| 1 | -1/-1 | 88 | 85 | 75 | 85 | 62 | 76 | 88 | 85 | 75 | 85 |
| 2 | -2/-1 | 88 | 86 | 75 | 86 | 62 | 76 | 75 | 86 | 62 | 85 |
| 3 | -3/-1 | 88 | 86 | 62 | 86 | 62 | 76 | 75 | 86 | 62 | 85 |
| **4** | -4/-1 | 100 | 86 | 62 | 86 | 62 | 76 | 75 | 86 | 62 | 85 |
| 5 | -5/-1 | 88 | 86 | 75 | 86 | 62 | 76 | 75 | 87 | 62 | 86 |

The influence of delay time of running average on the performance of the system was determined by varying the delay time from zero until four days, while the time span was fixed on four days (Table 5). The setting influences also the standard where a new value was compared with. Also this setting had only minor effects.

Table 5: Sensitivity (sens.) and specificity (spec.) with varying delay time for the running average (initial setting in bold) for the univariate alerts and combined alerts

| Delay time (day) | Period (day) | Water intake | | Milk yield | | Concentrate intake | | Roughage intake | | Combined alert | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sens. | Spec. | Sens. | Spec. | Sens. | Spec. | Sens. | Spec. | Sens. | Spec. |
| 0 | -3/0 | 75 | 91 | 50 | 91 | 62 | 76 | 62 | 91 | 62 | 91 |
| **1** | -4/-1 | 100 | 86 | 62 | 86 | 62 | 76 | 75 | 86 | 62 | 85 |
| 2 | -5/-2 | 75 | 86 | 50 | 86 | 62 | 76 | 75 | 87 | 62 | 85 |
| 3 | -6/-3 | 75 | 86 | 62 | 86 | 62 | 76 | 62 | 87 | 50 | 85 |
| 4 | -7/-4 | 75 | 86 | 62 | 86 | 62 | 76 | 75 | 87 | 62 | 84 |

The influence of time period and threshold of accumulated alerts on the performance of the combined alert was also studied. The time period was varied between 0 and 2 days and threshold was varied from 1 to 4 cumulative alerts. The results are included in Table 6. Both settings had a great impact on the results. A lower threshold gave a higher sensitivity and lower specificity; a higher threshold had reverse effects. A broader period also gave a higher sensitivity and lower specificity.

Table 6: Sensitivity (sens.) and specificity (spec.) of combined alerts with varying thresholds and periods (initial setting in bold).

| | **Period: n** | | Period: n-1...n | | Period: n-2...n | |
|---|---|---|---|---|---|---|
| Threshold | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) | Sens. (%) | Spec. (%) |
| 1 | 100 | 50 | 100 | 28 | 100 | 17 |
| **2** | 62 | 85 | 88 | 60 | 100 | 41 |
| 3 | 25 | 96 | 62 | 83 | 88 | 66 |
| 4 | 0 | 100 | 38 | 95 | 50 | 83 |
| 5 | - | - | 25 | 99 | 38 | 93 |
| 6 | - | - | - | - | 25 | 98 |

The timeliness of alerts for all eight disease cases was examined. In Table 7 for each case the number of days between first alert and observation is given. Automated detection, especially when based on water intake, resulted in early warnings for diseases.

Table 7: Days of earlier detection by model with initial settings per univariate variables and combined alerts (a minus sign is given when no alert was given)

| Cow nr | Type of disease | Number of days between first alert and observation | | | | |
|---|---|---|---|---|---|---|
| | | Water intake | Milk yield | Concentrate intake | Roughage intake | Combined alert |
| 2382 | Mastitis | 1 | 4 | - | 2 | - |
| 3492 | Mastitis | 4 | - | 5 | - | - |
| 3667 | Mastitis | 2 | 4 | - | - | - |
| 3667 | Lameness | 2 | 1 | 1 | 5 | 1 |
| 3674 | Lameness | 1 | 1 | 5 | 2 | 1 |
| 9490 | Lameness | 1 | - | 2 | 1 | 1 |
| 1436 | Other disease | 2 | - | - | 2 | 2 |
| 3468 | Other disease | 5 | 5 | 3 | 5 | 5 |

It was decided to use quite simple data processing techniques for the detection model. The sensitivity can be at a reasonable level, the specificity might be too low for practical application of the detection model. Results might be improved by applying more advanced data processing techniques, but that was outside the scope of this research.
It is a known fact that the settings influence the performance of the model: lower thresholds give an increased sensitivity and a decreased specificity; higher thresholds have the reverse effect. It is also a choice of the end-user which settings are preferred.
Only eight disease cases were recorded in the experiment. Therefore the results should be taken with reservation and further testing on larger data sets is advised.

## Conclusions

Water intake can be very useful for automated detection of diseases. Water intake measurements are easier to realize than roughage intake measurements and are therefor a realistic option for practical application. For a data with 40 cows during 102 days detection based on water intake gave better results than detection based on milk yield, concentrate intake and roughage intake. All eight disease cases were detected, the specificity was 86%.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# Session 14

# Pigs - Health/Welfare

## Quantifying acute infection in pigs using model-based biomarkers

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### Abstract

This study aimed at exploring the usefulness of data-based modelling methods to quantify the dynamics of interleukin-6 (IL-6) in pigs before and after infection by *Actinobacillus pleuropneumoniae* as a further step in developing an early warning monitor for sepsis and inflammation processes.
Time series of IL-6 responses (n=5 pigs) were analysed before and after infection by *Actinobacillus pleuropneumoniae* (endobronchial inoculation with 1 x $10^7$ CFU). Eight blood samples were collected starting from the moment of catheterization at a sample frequency of 1 sample/2hours (before infection). In addition, a second series of blood samples was taken with the same sampling frequency starting from eight hours before the moment of infection until maximally 24 hours after infection for the surviving pigs. For every blood sample the IL-6 value was determined resulting in one IL-6 time series for every pig. In addition, all pigs were clinically scored by a veterinarian. The experiments were approved by the ethical commission of Ghent University. Changes of IL-6 time series characteristics were quantified by fluctuations (variance, $\sigma^2$) and dynamics (parameters of first order autoregressive models).
The estimated autoregressive model parameters were for all pigs close to zero in the pre-infection state. After infection, the model parameters of the pigs were significantly different from the pre-infection state ($p < 0.0001$) and all parameter estimates where significantly different from zero (i.e. for all autocorrelation values ($a_1$): $a_1 - 2.SE(a_1) > 0$). These results indicate that the infection causes a downwards shift of the autocorrelation value (figure 1). The non-survivors showed also a significant shift in signal fluctuations ($p = 0.005$), whereas no increase in variance was found for the surviving pig.
The results indicate the advantages and need for individualized infection monitoring based on time series of IL-6 responses. These results might be a further step towards the development of an objective individualized method for monitoring of sepsis and inflammation processes and early prediction of disease outcome in pigs.

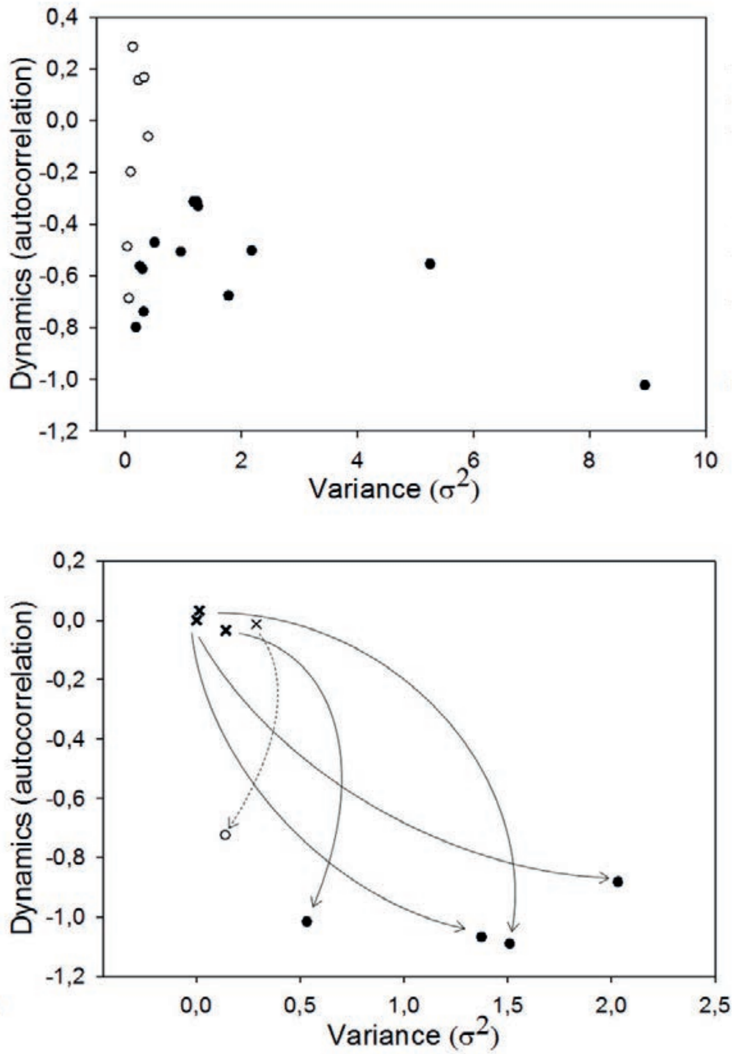


Figure 1. Shifts in fluctuations (variance) and dynamics (autocorrelation) of IL-6 in individual pigs.

**Keywords:** Infection monitoring, dynamics, autoregressive models, pigs

## The Pig Cough Monitor: from research topic to commercial product

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### Abstract

Respiratory diseases are an important cause of mortality and decreased productivity in pigs. Manually checking pig cough occurrence is labour-intense, subjective and difficult to manage, especially in larger farms. An automatic pig cough monitor, that registers pig coughs 24/7, is therefore a valuable tool for the farm manager: it allows him to have an objective measure of pig cough occurrence throughout his entire farm. The pig cough monitor contributes to improved animal health and welfare, and aims at reducing the global use of antibiotics, by detecting respiratory problems in an early stage, as soon as first coughing symptoms are present. This paper has three contributions: First, it details the research trajectory that resulted in the SoundTalks pig cough monitor. In this research the properties of spontaneous coughing (due to an infection) and induced coughing (due to an air pollutant) are examined. Second, it discusses the pig cough monitor design and operating principle. Third, it presents our further validation strategy to assess product value for the farmer. For this end, forty fattening pig compartment are currently being equipped with pig cough monitor systems.

**Keywords:** pig respiratory disease, early warning system, sound analysis, antibiotics use, monitoring applications

### Introduction

Intensive livestock farming is evolving to larger farms. Managing these farms efficiently is a big challenge. Using technology to automatically monitor the animals will save farmer’s time and thus lowers the farmer’s workload. Furthermore, by using these systems a more objective measurement of the animal’s condition can be made. For instance automatically monitoring the animal’s health will improve the chances of detecting diseases in an early stage.
An example automatic monitoring system is an early warning system for diseases. Detecting diseases at an early stage is beneficial to the farmer. With such a system the farmer can react to diseases in an early, less severe, stage. Thus decreasing the negative impact the disease has on the growth of his animals. In general the pig farmer spends less time controlling his pigs for possible diseases and his animals grow better because

they are less affected by diseases. Better growth means intensive livestock farming is more profitable. Therefore the sustainability of pig farming is improved as this is now not profitable in Flanders (Platteau *et al*., 2012).
Detecting diseases at an early stage means that the global amount of antibiotics used to cure the pigs will decrease. This use of antibiotics in intensive livestock farming is creating antibiotics resistance (Khachatourians, 1998), so by decreasing the number of used antibiotics the development of resistant bacteria decreases. This also has consequences for humans as it has already been shown that the proportion of livestock associated resistant bacteria found among humans is correlated with the pig density in that region (Van Cleef *et al*., 2011).
This paper considers an early warning system for respiratory diseases based on the detection of pig coughs sounds. The assumption is that an increase in coughs indicates the beginning of a respiratory disease. In Van Hirtum *et al*. (1999) it was first researched how pig coughs can be detected with sound analysis. This paper considers specifically the design step from research to the product 'Pig Cough Monitor' (PCM) and the use in EU-PLF project. It first briefly shows the research done before the PCM was developed. Afterwards it shows how the research was translated into commercial hardware and software and how the farmer can see the number of coughs detected. Currently the PCM is being installed in different barns across Europe for the EU-PLF project.

## Material and methods

### Timeline

Research on cough detection started with artificially inducing coughs in controlled environments. The coughs were induced with citric acid vapour following the method of Moreaux *et al*. (1999). For instance in Moshou *et al*. (2001), one pig was housed in a metallic box in each experiment. During each experiment the citric acid vapours were dispersed in the metallic box and the resulting coughs were recorded with a microphone in the box. Herein it was proven that coughing sounds can be distinguished from metal clanging sounds. In the following experiments of Van Hirtum (2002), pathologic coughs were induced and recorded by inoculation of *Pasteurella multocida* (Kobisch and Friis, 1996). In Guarino *et al*. (2008) an automatic cough detection method in a pig barn was researched. Here the microphone was manually being put close to the head. Exadaktylos *et al*. (2008) investigated a real-time method detecting cough sounds. In all these research studies, the sound files were labelled by an experienced labeller (Aerts *et al*., 2005) before they could be used to develop the detection method.

### Animals and housing

In the EU-PLF project, pigs in 40 compartments of 10 farms will be monitored during 60 fattening periods (combined). These farms are located in the Netherlands, Hungary, Spain, France, Italy and Northern Ireland (United Kingdom), in order to cover a wide range of different housing configurations, climatologic conditions, pig breeds and management styles. Figure 1 shows a pig cough monitor system and how it is mounted in the farm. The pigs are grouped into pens of 10-15 pigs inside a compartment comprising 4-12 pens.

### Data collection

The sound acquisition system consists of a condenser microphone (type Behringer C4) and a sound card (type ESI Maya 44). The microphones are phantom-powered and are connected using balanced audio, in order to allow the use of long cables with very limited susceptibility to noise. The sound data is recorded with a precision of 16 bits and a sampling frequency of 22050 Hz. The sound card is mounted in an embedded board (x64 architecture), running a GNU/Linux operating system. The embedded board is fanless and installed in a sealed enclosure to protect the system from the harsh environment. Furthermore, diagnostics software regularly checks the system operation, including monitoring the sound recording quality, the system temperature and the system processing load. The system condition can be checked remotely via a wired or wireless internet connection. Several factors put high stress on the equipment and demand for a robust design as well as automatic diagnostic utilities built into the equipment, including unstable power supplies, high temperatures and humidity, acid compounds in the air, internet connection problems, accelerated corrosion due to ammonia concentrations, rats biting cables, …
The microphone is typically mounted in the centre of the pig barn and records the sound continuously. Figure 1 depicts the microphone and the protective case for the hardware.

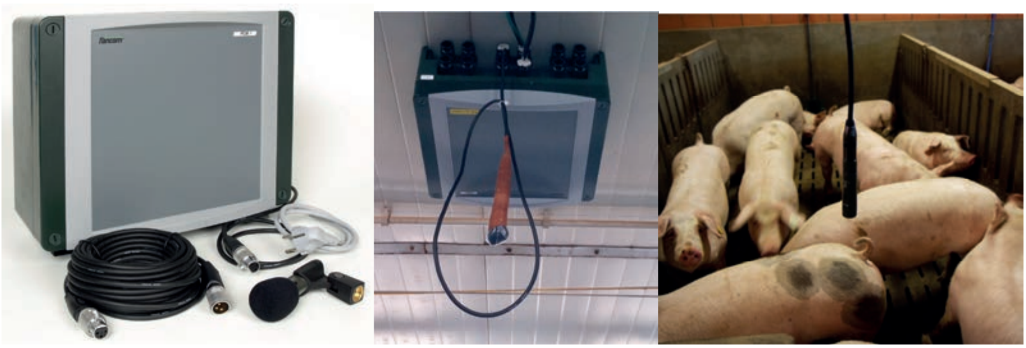

Figure 1: Pig cough monitor in its protective enclosure, with microphone and microphone cable (left). Mounted pig cough monitor with protective cover on microphone (middle). Typical pig pen (right).

### Data processing

A key element in the pig cough monitor is the cough detection algorithm that filters the cough information out of the sound measurements. Early versions of the algorithm can be found in Van Hirtum and Berckmans (2001), Guarino, *et al.* (2008) and Exadaktylos, *et al.* (2008). The working principle consist of (1) defining a set of acoustic features in the time and frequency domains that have typical values for coughs and atypical values for non-cough sounds, (2) designing a classifier which divide the sound events into different classes based on the defined features. As an example, Figure 2 displays the spectrograms of a cough sound, a sneeze sound and a metallic barn sounds measured by the pig cough monitor. From these figures it is clear that the different sound types have distinct time-frequency characteristics. For example: the sneeze sound has much more high frequency content compared to the cough. The metallic sound has a more banded structure.

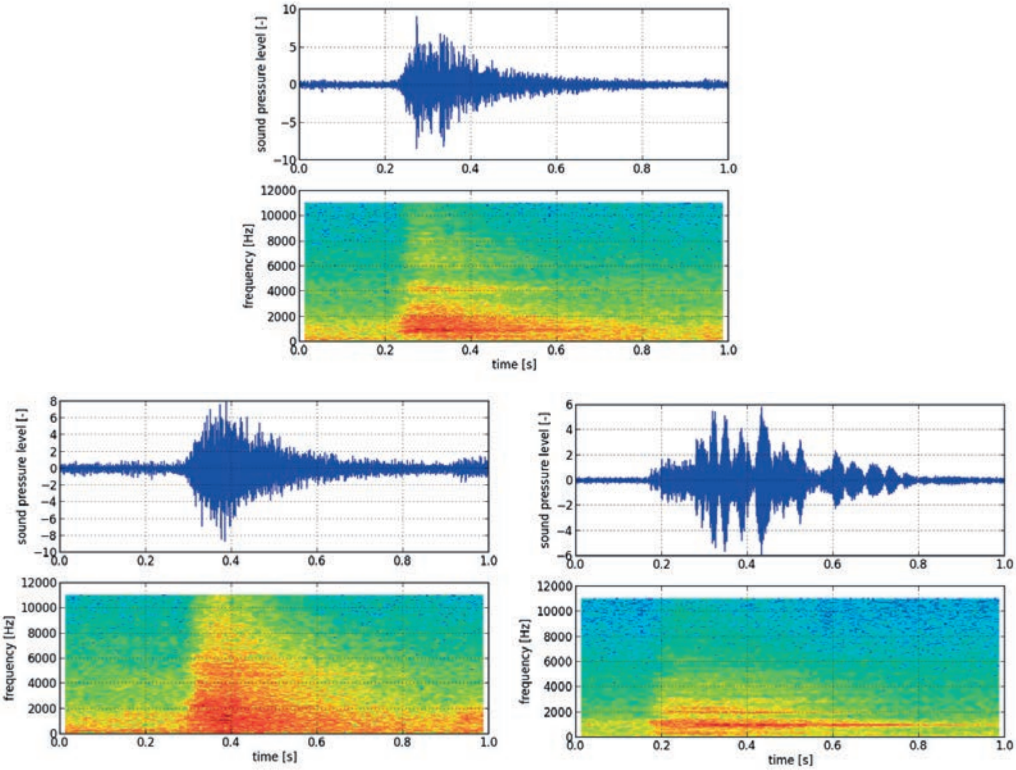


Figure 2: Typical time-frequency spectrograms of a cough (top), sneeze (bottom left) and metallic (bottom right) barn sound.

Interface for the farmer

The pig cough monitor supports internet connectivity, either via a wired Ethernet connection, or via a wireless WLAN or WAN connection. The internet connection is used for three functions. First, it is used for diagnostics, as described in section Data Collection. Second it is used for data archiving, if desired by the user. Third, it is used to stream cough results from the system to a SoundTalks webserver. The farmer has access to his cough data via a secured website. Figure 3 depicts typical screenshots from the interface. The cough index expresses the cough level in the compartment. It corresponds to the total counted coughs, scaled with the number of pigs inside the compartment.

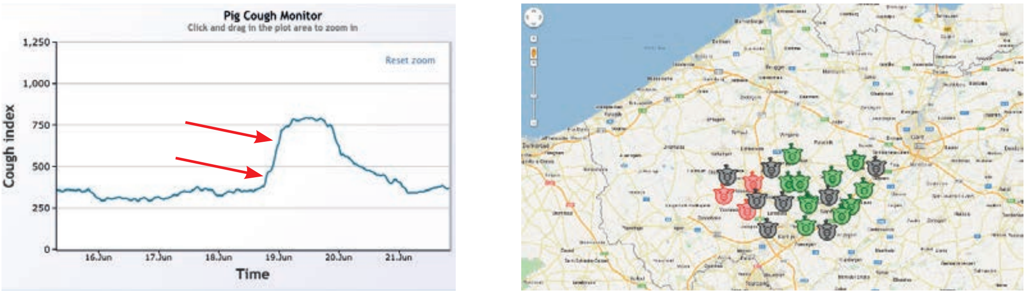


Figure 3: Parts of the interface for the farmer. Cough index evolution over time (left). Overview of pig compartments on a map (right). Colour code: green = low cough index, grey = neutral cough index, red = elevated cough index.

## Results and Discussion

Timeline

The results from previous research studies showed that pig coughs can be detected in experimental set-ups. These sensitivity and specificity results are shown in Table 1. In this table it is worth noting that Van Hirtum and Berckmans (2003) used much more data compared to the other research studies. All these results were made under laboratory conditions or under much more ideal conditions than it is the case for the PCM.

Table 1 Results from previous research studies. ‘CA induced’ stands for citric acid induced coughs.

| | **Moshou, et al. (2001)** | **Van Hirtum and Berckmans (2003)** | **Guarino, et al. (2008)** | **Exadaktylos,** ***et al.*** **(2008)** |
|---|---|---|---|---|
| nr coughs | 212 (CA induced) | 2034 (CA induced) | 159 (not induced) | 231 + 291 (CA induced) + (sick) |
| nr other | 50 (metal clanging) | 3285 | 433 (environmental) | 149 |
| sensitivity | 94% | 92% | 85.5% | 82% |
| specificity | 94% | / | 86.6% | / |

Pig Cough Monitor

After the first year of working with the PCM it was found that there are more cough versions than only wet coughs (infectious) and dry coughs (non-infectious) as shown in Ferrari *et al.* (2008). What the exact couch versions are is still an open research question. However first indications show that there is indeed a difference between dry and wet coughs but also coughs containing more vocal characteristics and coughs belonging to cough attack series are encountered.

After detecting the coughs, the number of coughs over time can be monitored by the cough index as shown in Figure 3. It can be seen that on June 18-19 the number of coughs shows a steep rise relative to the normal behaviour. This indicates a possible disease and will send an alarm to the farmer. It is still an open question what the optimal threshold values for warning the farmer should be. For instance when is the economically optimal time to start administering the antibiotics. If the threshold is set too low the farmer will be warned needlessly while on the other hand if the threshold is set too high the farmer will only be warned in later stages of the disease. Examples of possible thresholds are indicated by orange arrows in Figure 3. This question will be further researched in the EU-PLF project. The PCM is currently operational in forty compartments in Europe. The practical aspects of this system are robust against the harsh environment. Except for power or internet connection failure most problems from the environment as mentioned in material and methods are taken care of. The EU-PLF project will test the system extensively for four years. An economic analysis of the PCM will be done in EU-PLF project. Main question is what the exact economic benefit for the farmer is. This will prove the farmers that adoption of this system is beneficial for them.

Other questions that will be investigated are the possibility to include the detection of other sounds in the PCM, such as screams, sneezes and barks. Furthermore, it will be investigated whether acoustic warning systems have potential in other species, specifically in calves and poultry.

## Conclusion

The pig cough monitor was successfully developed from experimental set-ups in research to a full product in pig barns. The PCM is now used in forty different compartments and will be tested in the EU-PLF project. This project will investigate the economic benefit of the PCM and what the optimal cough index value is to warn the farmer of starting disease. Further research will also consider detection of other sounds such as screams or sneezes and the possibility to monitor other species with this system.

## Acknowledgements

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# Temperature-dependent water intake behavior of weaned piglets

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## Abstract

The study aimed to develope a drinking system in combination with a climate control system that can take into account the water intake behaviour of rearing piglets depending on the stable temperature. The experiments took place from the 5th to 9th week of life. During the experiments, the piglets could choose out of three separate drinking troughs with different water temperatures (cold, stable temperature, warm). The climate computer was able to record stable and water temperature as well as water consumption quantity. There was a distinct preference of cold drinking, at all stable temperatures. Significant reactions in the drinking behaviour of the animals could be observed at a stable temperature change of > 5° C.

**Keywords:** Climate control system, piggery, ambient temperature, water temperature, water consumption, animal welfare, well-being

## Introduction

The adaptability of pigs on stable climatic changes varies strongly. In the so-called thermal neutral zone (TNZ) the necessary physiological functions are maintained with the lowest energy expenditure (Mount, 1968). Outside this zone the animal must adapt to the environmental temperature physiologically and with the help of the behaviour (Bianca 1976). One of the most important climate factors is the temperature. The performance and the well-being and consequently also the economic efficiency of livestock production is affected by temperature (Banhazi *et al*., 2007). There are different studies which have examined the effects of high and low ambient temperatures on pigs. Besides feed consumption for example, the lying behavior, the pollution of the floor with excrements and urine as well as the respiration rate, are significant variables when assessing animal well-being (Huynh *et al*. 2007; Banhazi *et al*. 2007; Behninger *et al*. 1997). The physiological mechanisms of heat loss cover the radiation, conduction, convection and evaporation (respiration and transpiration) (Jungbluth *et al*., 2005). The assessment and control of the stable climate in pig houses is usually carried out on basis of predefined temperature values. However, the animal itself is, the best indicator for an adequate stable climate and therefore for the well-being (Shao, 2008). Huynh *et* *al*. (2005) and Steiger (1978) describe pigs adapting their lying behaviour for example per ‘social huddling’ or lateral lying position depending on the ambient temperature in order to support their thermoregulation.

The objective of this study was, to investigate the animals’ reaction on the environmental temperature by interpreting their drinking behaviour. There are several studies on the total water consumption of pigs. With rising stable temperatures the animals do drink more water per kg of live weight (Brooks *et al*., 1993), since more water is passed on to the surroundings about respiration (Georgiev, 1972). Vajrabukka (1981) and Steinhardt *et al*. (1970) figured out, that pigs prefer cooler water temperatures (11 degrees Celsius; 1 degree Celsius) at environmental temperatures between 30 degrees Celsius and 35 degrees Celsius. In order to determine the interaction environmental temperature and drinking behaviours, three drinking troughs with different water temperatures were offered to the pigs. In future the water absorption behaviour of the weaned piglets shall be processed by a climate computer. This climate computer shall make modifications according to the thermal needs of the animals at the attitude of the set-point temperature.

## Material and Methods

The animal groups were offered a watering system which includes three troughs with different water temperature. Differing from the ambient temperature water trough (trough 2), there is one trough with 10 degrees Celsius warmer water (trough 3) and a trough with 10 degrees Celsius cooler water (trough 1). The water temperatures were regulated by using the respective stable temperature as a reference. Water temperatures were automatically adjusted by a control unit using temperature sensors. This control equipment detects the stable and water temperature as well as the water consumption quantity with digital flow meters. The digital flow meters have a flow range of 0,5-30,0 l $min^{1-}$ at 480 impulses $l^{-1}$ and a precision of +/- 2 % (figure 1).

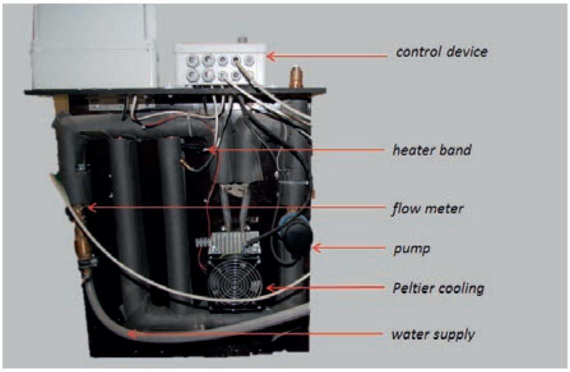


Fig. 1: Parts of the drinking system to record water consumption quantity of weaned piglets in rear view

The connection between the water absorption behaviour of the animals, the stable temperature and the climate computer is schematically represented in figure 2.

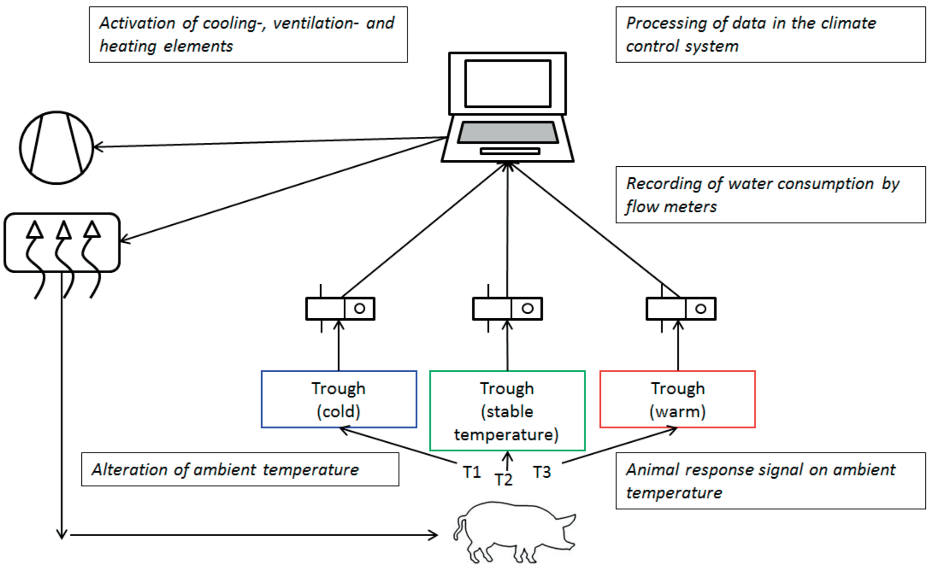


Fig. 2: Figure of the animal response on ambient temperature and the reaction of the climate control system

The tests were carried out on the research station Frankenforst of the University of Bonn with piglets. The pen for groups of 21 piglets (German landrace, Pietrain x Duroc) was equipped with a watering system with three different water temperatures. The feeding troughs were located oppositely and the food was offered ad libitum. The trial period referred to the fifth until ninth life week. Stable and water temperature as well as the water consumption were recorded.

## Results

Efficiency of the drinking system

The developed watering system is able to include all demanded parameters. The water consumption was recorded by digital flow meters for every trough. The stable temperature was detected by temperature sensors. The water temperatures of trough 1 and trough 3 could be adjusted with 10 degrees Celsius difference referring to the stable temperature trough. However, deviations of the water-set-point temperature were recorded at the individual troughs. Including all tests, the temperature of the cold trough differed by 21.5 % on average from the set-point temperature. The trough with stable temperature differed by 5% and trough with warm water by 2.9 % on average. The strong deviation of the cold water is caused in problems of water cooling at high environmental temperatures. At warm ambient temperatures cooling of water is more difficult than heating. This could be caused by the limited cooling capacity of the Peltier element.

Water absorption behaviour of the weaned piglets

The average water consumption of the weaned piglets was, in all tests which could be carried out without technical failures, of 2592 l on average. The water consumption was 4.4 l per piglet and day and 123.4 l within the whole rearing period. In the summer months, the animals consumed more water than in the winter months. The highest consumption in summer was 3881 l for a rearing period and in winter 1552 l. During the test series the stable temperatures were changed. The temperature difference ΔT during the raising periods was varied between 5 and 10 K. Including all trials the temperature difference ΔT was between 18 and 33 K. Every test group shows a clear preference for a water temperature. In figure 3 the relative water consumption is shown in dependency of the stable temperature classes and old age of the animals of all trials.

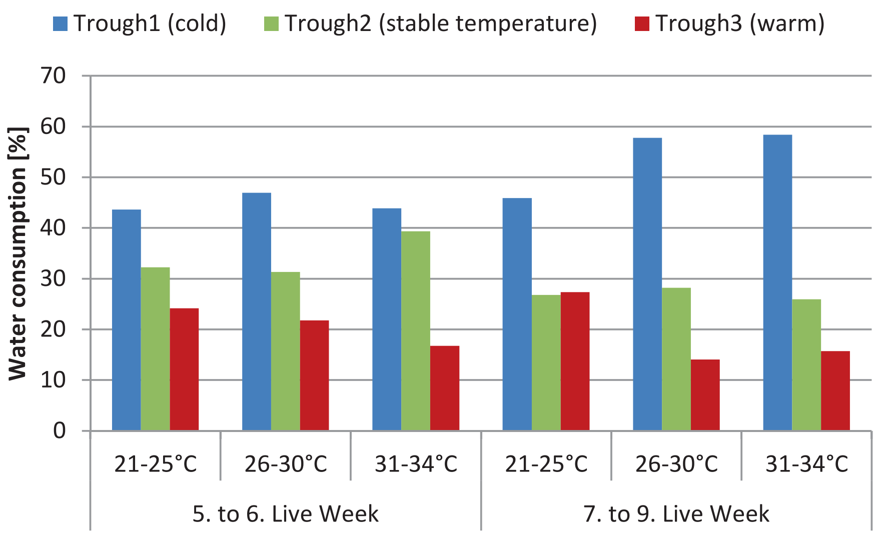


Fig. 3: Representation of the relative water consumption over all trials summarized in dependence of stable temperature classes and the age of piglets

The results show, that the animal groups prefer the cold water (Ø 49,4 %) at all stable temperatures. Trough 2 (Ø 30,6 %) is at the second rank. The trough with warm water (Ø 19,9 %) is most seldom used by the animals.

Considering the relationship of the three drinking troughs within the trials, changes in the drinking behaviour were established using analyses of variance (Anova) in connection with the stable temperature. In the trials, in which the temperature difference

ΔT is less than 5 degrees Celsius, there is no significant ($p=0.05$) change in the drinking behaviour of the piglets. Only at stable temperature differences of >5 degrees Celsius the measured differenced are significant. Different trials with the stable temperature ranges and the significance standards appeared are represented in table 1.

Tab. 1: Stable temperature range of different trials and the effect on water consumption of piglets at each trough

| Test number | Temperature range [°C] | Group number | Significance Trough 1 | Trough 2 | Trough 3 |
|---|---|---|---|---|---|
| 7 | 18-29 | 1 | 0,009* | 0,012* | 0,001* |
| | | 2 | n.s. | n.s. | n.s. |
| 12 | 22-33 | 1 | 0,082 | 0,168 | 0,212 |
| | | 2 | 0,038* | 0,002* | 0,007* |
| 13 | 23-33 | 1 | 0,018* | 0,015* | 0,001* |
| | | 2 | 0,017* | 0,012* | 0,013* |
| 9 | 25-29 | 1 | 0,104 | 0,668 | 0,001* |
| | | 2 | 0,105 | 0,461 | 0,384 |
| 10 | 25-30 | 1 | 0,596 | 0,034* | 0,442 |
| | | 2 | 0,383 | 0,575 | 0,564 |

Analyses of variance (Anova); *p=0,05
n.s.= no specification; Data fail

Water consumption was significantly increasing at high stable temperatures (>27 degrees Celsius) at the cold trough and takes off at the warm trough. Conversely, the consumption at the warm and stable temperate trough increased significantly at lower stable temperatures (<24 degrees Celsius). It is noted, that the consumption of the cold water, as described above, is the highest on average. Due to the low consumption of the stable and warm temperate trough, the changes in these troughs are relatively small.

## Conclusions

The developed system meets all requirements. The data on the stable and water temperatures and water consumption are recorded and processed. In all groups of animals a preference for cold drinking was determined, regardless the stable temperature. Significant changes in the drinking behaviour of animals only occur from changes in stable temperature of >5 degrees Celsius. In addition, the individual reactions of the animal groups on the stable temperature have to be considered. The water consumption at each trough is set in relation to each other. This causes the climate computer stand out from conventional air computers. They can only determine the total water consumption of a group of animals. The animals respond to high ambient temperatures with an increased consumption of cold water. With this signal, the climate computer can be a control recommendation to the farmer. He can manually change the set-point temperature.

**Acknowledgement**

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## Monitoring of group housed sows based on indicators for feeding, drinking and locomotion behaviour

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### Abstract

The overall aim of a collaborative research project is to develop a model for monitoring changes in health and behaviour of group housed pregnant sows and make the findings available for practical use by a management software. Here especially first results related to the locomotion behaviour are presented. Between February 2012 and May 2013 n= 8271 locomotion scores of a herd of 75 to 80 pregnant group housed sows have been collected. Additionally direct observations were carried out, observing at 18 days during two forenoon hours the walking behaviour of six randomly selected sows. First data analysis indicates relations between locomotion scores, observed walked distances and calculated walking distances derived from several places inside the stable with electronic animal identification.

**Keywords:** locomotion behaviour, sow, group housing, health monitoring

### Introduction

In the past there have been many studies concerning the influence of health problems on the change of behaviour in livestock. It could be shown that feeding behaviour (Cornou *et al*., 2008; Brown-Brandl *et al*., 2011), drinking behaviour (Madsen and Kristensen, 2005) and locomotion behaviour (Häggman, 2012) are useful indicators to monitor impairment of health in livestock. Furthermore the present trend of rising herd numbers in piglet production, shows justified request for reliable parameters indicating an impairment of sow`s health condition. Therefore the aim of a collaborative research project between University of Hohenheim, Claas Agrosystems KGaA mbH & Co KG and gridsolut GmbH & Co KG is to develop a model for monitoring changes in health and behaviour of group housed pregnant sows. Basic indicators are feed intake, water intake and locomotion behaviour. The overall aim is to implement this monitoring model into a management system to be used by farmers.

### Materials and methods

The data collection takes place at a sow gestation barn at the Agricultural Experiment

Station of the University of Hohenheim. Sows are being held in a dynamic large group of about 75 to 80 animals. Because of a one week rhythm of piglet production, every week six to eight serviced sows are integrated into the group and the similar amount of sows, which are close to parturition leaves the group. The approximately 220 m² barn is fitted with a slatted floor over most of the activity area and with a solid concrete floor with minimal litter in the lying area (Figure 1). Additionally sows have unrestricted access to an approximately 124 m² outdoor area with deep litter. Feeding takes place at two Electronic Feeding Stations (EFS) and sows can drink water ad libitum at eight drinking troughs with pin valves, which are located at the pen barriers. In order to register the water flow during each drinking event, each water pipe is equipped with a water flow meter. All sows are fitted with a passive ISO earmark transponder (low frequency) by which radio frequency identification at the EFS, at all drinking troughs, at the boar recognition and at the doors between stall and outdoor area is possible.

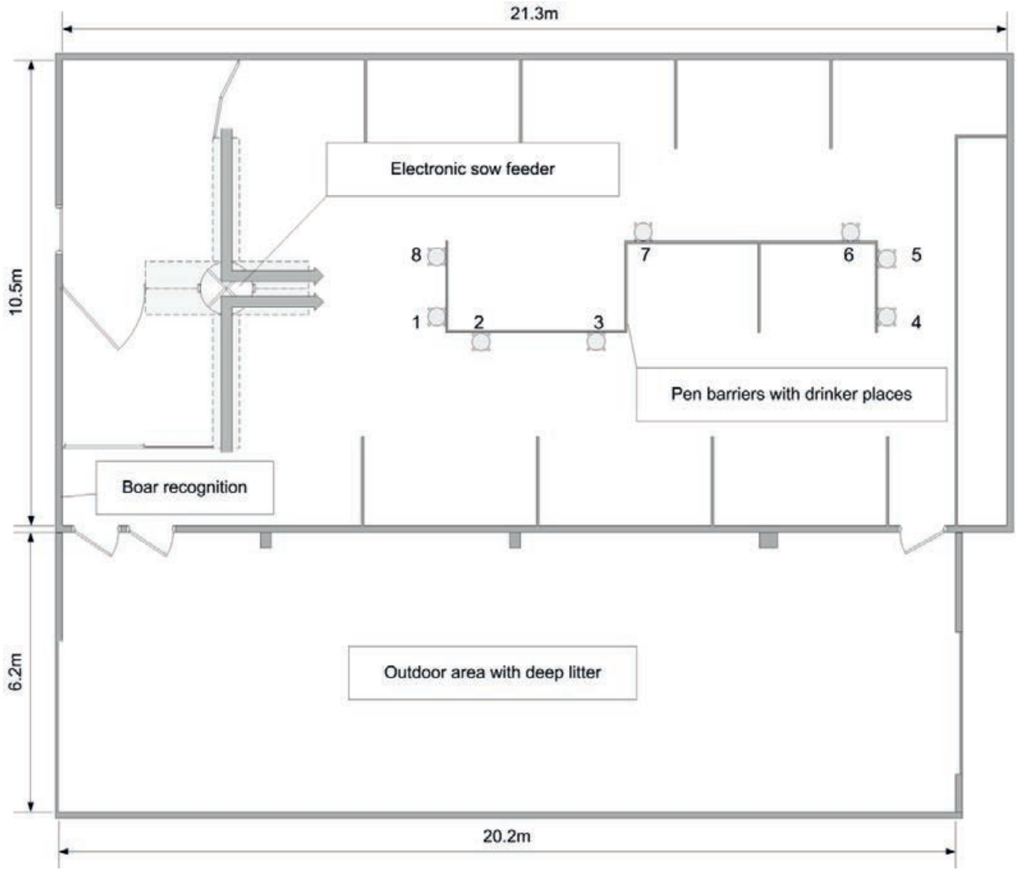


Figure 1: Ground plan of the group housing stable for 80 pregnant sows at the Agricultural Experiment Station

Locomotion Scoring (LS)
To gain information on the locomotion behaviour the walking ability of each sow is scored twice a week with a four-category "Locomotion Scoring" system (LS 0= normal walking, LS 1= slight lameness, LS 2= clear lameness, LS 3= lameness on two feet, sow can hardly walk) (Feet First™ Zinpro Corporation).

Walking distance
Since sows are already automatically registered several times a day at various places of the barn, these information are used to calculated a minimum walking distance of each sow. In the frame of a special period with direct observations also actual walking distances have been collected for individual sows. Direct observations were conducted three times per week during six weeks. As observation window served the two forenoon hours from 09:30 to 11:30 h. Every week six new sows were randomly selected and observed. The locomotion scoring was done for all six sows on every day of direct observation. Every 60 seconds the position of each sow was plotted in a ground plan of the group housing stable. Afterwards the walking distance was calculated out of the distances between the plots.

## Results and Discussion

Between 28/02/2012 and 15/05/2013 n= 8271 Locomotion Scores (LS) were collected, of which the vast majority with about 85.5% were LS 0, followed by 10.0% scored as LS 1, 3.7% scored as LS 2 and 0.7% as LS 3. In a sum almost 15% of sows which were scored for walking ability showed at least some impairment in locomotion behaviour.

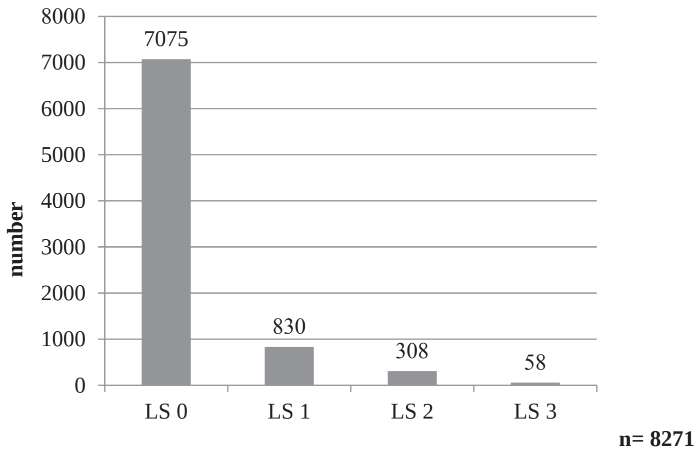


Fig.1: Distribution of Locomotion Scores (LS) n= 8271 scored between 28/02/2012 until 15/05/2013 (LS 0= normal walking, LS 1= slight lameness, LS 2= clear lameness, LS 3= lameness on two feet, sow can hardly walk). Dynamic group of gestation sows; herd size 75 to 80 sows.

The comparison of the walking distances determined during the direct observations within two hours (9:30 to 11:30 h) hints at an interrelation between the observed distances and corresponding locomotion score (Figure 2). When sows showed no impairment of locomotion behaviour (LS 0), the mean value for the observed distance walked was 85 m. Within the same time sows with a LS 1 walked 73 m, sows with LS 2 walked on the average only 28 m and one sow which was scored with an LS 3 walked only 16 m. The comparison of the mean values of the calculated minimum distances from electronic identification points within two hours (9:30 to 11:30 h) with the locomotion scores does not display such clear relations. On the average sows with LS 0 (16 m) were found to have lower calculated minimum distances than sows which were scored with LS 1 (24 m) and LS 2 (30 m), but also than LS 3 (0 m). Whereas the mean values of the calculated minimum distances in 24 hours and the locomotion score comply good with each other.

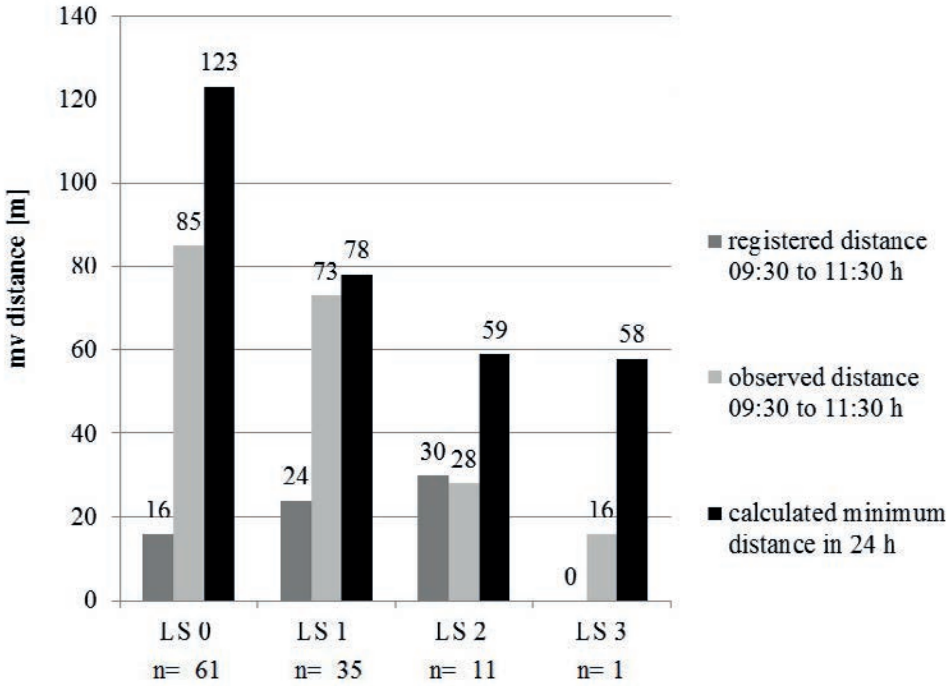


Fig. 2: Medium values (mv) for observed distances (direct observation) [m] and calculated minimum distances from electronic identification points during two forenoon hours and during 24 h, classified for the corresponding Locomotion Scores of six sows of the respective observation day (LS 0= normal walking, LS 1= slight lameness, LS 2= clear lameness, LS 3= lameness on two feet, sow can hardly walk) n= 108 observations

Sows scored with LS 0 were calculated to walk at least 123 m far within one day and sows with LS 1 78 m (Figure 2). Sows with LS 2 had a calculated minimum walking distance within 24 hours of 59 m, but one sow scored with LS 3 also walked at least 58 m within one day. Unfortunately during the direct observations only one sow was scored with LS 3, thus a comparison with sows with better locomotion abilities is biased.

The individual comparison of actual walked distances of six sows which were observed directly and scored for the LS on three following days (9:30 to 11:30 h) show again a relation (Figure 3). On day 1 sow no. 986 was scored with an LS 2 and walked within two hours only 25 m far. The following days 2 and 3 with no impairment of locomotion behaviour (LS 0), the same sow walked longer distances with 207 m respectively 173 m. Sow no. 858 showed the same tendency of longer walking distances with an improving locomotion ability (day 1: LS 2, 48 m; day 2: LS 1, 64 m; day 3: LS 0, 169 m). The remaining sows no. 765 (day 1: LS 1; day 2: LS 0; day 3: LS 0) and sow no. 152 (day 1: LS 2; day 2: LS 1; day 3: LS 1) did not walk at all during the observation window. Of course the actual activity pattern hence locomotion behaviour is also influenced by many other parameters as e.g. day-time, time of feeding, rank position, group activity and individual rhythms.

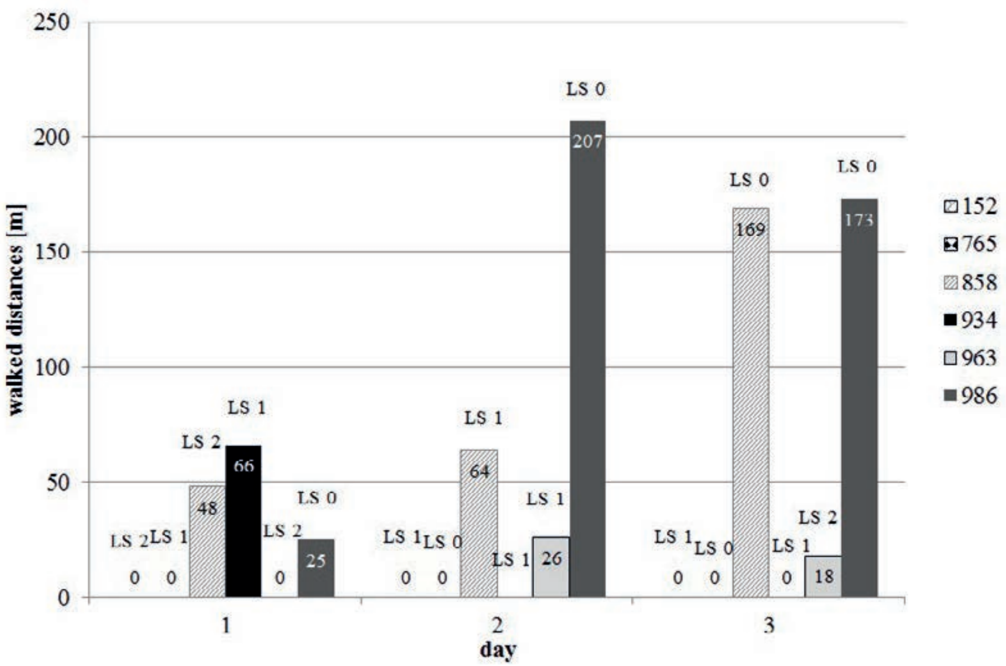


Fig. 3: Walked distances (direct observation) from 9:30 to 11:30 h of six individual sows on three following days and corresponding Locomotion Scores (LS 0= normal walking, LS 1= slight lameness, LS 2= clear lameness, LS 3= lameness on two feet, sow can hardly walk)

## Conclusions

Analyzing the observed locomotion behaviour of gestation sows in group housing, give a first idea about the influence of lameness on walking distances. It could be shown that there are measurable changes in walking distances, when sows show lameness, but there are differences from one individual to the other. More statistical analysis is needed to get deeper insight into the inter- and intra-animal variability of behavioural patterns. The indicators feeding and drinking behaviour will be examined in more detail. The influencing factors e.g. time of day, rank position and group activity have to be taken into account. Then a first monitoring model will be established and implemented in the farm management software and tested both on the experimental farm and on a commercial farm.

## Acknowledgements

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# Session 15

# Aquaculture

**Feed Management in aquaculture - operational precision livestock farming**

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**Abstract**

Aquaculture production of salmon in sea cages is a growing industry based on intensive production in floating net pens at sea. Cost of feed makes up approximately half of the total production costs. In addition to economic incentives, waste of feed affects the environment and aquatic flora and fauna in close proximity to the farms. Farmers therefore have a vested interest in using their feed as efficiently as possible and this can be achieved through effective operational feed management. This paper will describe some of the current feed management challenges facing intensive aquaculture and will also outline some possible solutions and steps that the farmers can take to eliminate or circumvent these difficulties.

**Keywords:** Feed management, intensive aquaculture,

**Introduction**

Aquaculture is defined as "the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants" (FAO, 1988). It covers aquatic farming in marine, brackish and freshwaters, is the fastest growing global food production sector with an annual growth rate of 6.6%, a production volume of 52.5 million tonnes (excluding aquatic plants) and a worldwide value of US$98.4 billion (FAO, 2010). In this paper we will specifically discuss the aquaculture of food fish, which in 2008 accounted for nearly half (45.7%) of all fish consumed by humans (FAO, 2010)

Fish farming can vary in its intensity and can be classified in terms of feed requirements, from i) extensive, where no nutritional inputs are intentionally added to the rearing system, to ii) intensive, where production of the reared species is dependent upon feed being supplied to the production system (e.g. Edwards *et al.*, 1993). As with terrestrial agriculture production, aquaculture is becoming increasingly intensive and this is driven by the need to increase productivity per unit area, economies of scale and also competition for available production resources (Foley *et al.*, 2005; Tacon and Halwart, 2007). Fish farming utilises numerous types of production systems that can include tanks, raceways and floating net pens. As aquaculture becomes more intensive these systems are getting larger and larger and both the size of the production system and also the nature of the aquatic environment makes it difficult to monitor the behaviour and performance of fish below the water surface. This is especially important in large scale intensive aquaculture of species such as Atlantic salmon (*Salmo salar* L.), which is the apex European farmed fish in terms of both market value and production tonnage (over 1 million tonnes per year FAO, 2010). Large scale Norwegian Atlantic salmon production currently utilises large tanks to produce juvenile fish (> 80,000 fish per tank) and large scale net pens (157 m  circumference, 20-40 m deep, up to 200,000 fish per net pen) to produce adult fish.

One of the challenges fish farmers constantly face when implementing their production strategies is to maximise productivity and minimise waste. This challenge must be met in an environmental, economical and ethically sustainable manner according the three tenets of sustainability and this sustainable approach is crucial when it comes to feeding the fish. Feeding decisions in operational aquaculture cover i) how to present feed to the fish (feed management) e.g. the number of meals, meal duration, ration size and its spatial and temporal distribution (Talbot *et al.*, 1999; Noble *et al.*, 2008) and also ii) the choice of diet or feed ingredients (nutrition). The economic and environmental effectiveness of feed management strategies is commonly measured using the Feed Conversion Ratio (FCR). FCR is the ratio of feed supplied to the weight of fish produced, and the lower the value, the more efficient the process. In intensive aquaculture fish are usually fed a formulated pelleted diet and the costs of this feed can be very high, accounting for as much as 60% of the total economic running costs of a marine fish farm (Le François *et al.*, 2010). Sourcing sustainable ingredients for this feed is also a challenge in itself, especially when feeding carnivorous fish that require high quality feed.

Farmers therefore have a vested interest in using their feed as efficiently as possible and this can be achieved through effective operational feed management. However, the feed management challenges in intensive aquaculture can be somewhat different to those faced in terrestrial agriculture, as fish usually have a limited time to access feed before it becomes unavailable and exits the production system. In the case of marine net pen aquaculture, this can be due to the pellets sinking through the bottom of the net pen or being washed out of the sides of the pen by water currents. In tank based aquaculture it can be due to pellets being washed down the tank drain or breaking down in water and deteriorating on the tank bottom. In addition, the drive for larger production systems has come at a cost of reduced control; the farmers lack robust data on how their feed management decisions affect the performance of the fish as they may only carry out growth audits and sample their fish on a ca. monthly basis. Robust feed management must therefore be coupled with improved biomass monitoring and control.

The consequences of poor feed management are severe and far reaching, and problems can start with what appears to be the simple task of calculating daily feed requirements. Unfortunately for the farmer, appetite and feed consumption rates and requirements for numerous aquacultural species can vary within and between days (Noble *et al.*, 2007). Appetite changes can be related to numerous factors including changes in stomach fullness and time since the last meal (Ruohonen *et al.*, 1997), competition (Kadri *et al.*, 1997), light intensity and day length (Madrid *et al.*, 2001), season (Sæther *et al.*, 1996), water temperature (Brett, 1979) and oxygen level (Thetmeyer *et al.*, 1999) amongst many other factors. This makes it difficult for a farmer to accurately match feed delivery to appetite and any errors the farmer makes can lead to either under- or over-feeding. Underfeeding can increase FCR (Bureau *et al.*, 2006), reduce growth performance (Gaylord *et al.*, 2001), reduce fish condition (Bureau *et al.*, 2006), increase inter-individual growth variation (Johansen & Jobling 1998), be detrimental to welfare (Cañon Jones *et al.*, 2010) and ultimately increase mortality (Shan *et al.*, 2008). Overfeeding increases FCR (Talbot *et al.*, 1999), the amount of wasted feed (Le Francois *et al.*, 2010) and also the production of large quantities of nutrient-rich faeces (Jobling, 1994). This can also lead to environmental problems if the production system discharges their waste in open waters (Cho & Bureau 1998; Le Francois *et al.* 2010).

These problems can be eliminated at source if farmers use feeding technologies that i) deliver a responsive ration that efficiently matches feed delivery to appetite and ii) minimise waste via the use of waste detection technologies. The technologies that are currently available must be tailored to both the species and production system. For example, net pen aquaculture systems can use either underwater camera's (Ang & Petrell, 1997) or infra-red pellet sensors deployed near the base of the cage (Blyth *et al.*, 1993 see Figure 1) as interactive feedback systems to monitor feed wastage. The farmer or a computer algorithm can then adjust feed delivery in relation to the amount of wastage detected and provide the fish with a responsive ration that can match their daily needs. Tank based feeding systems can use self-feeders, where fish bite or pull a trigger to receive food (Flood *et al.*, 2010) to provide the fish with a responsive daily ration. However, their on-farm deployment is poor and may be related to the length of time it can take before the fish start using the system. For example, rainbow trout can take up to 4 weeks (Alanärä, 1994) to start using self-feeders, making them an unattractive operational tool for farmers.

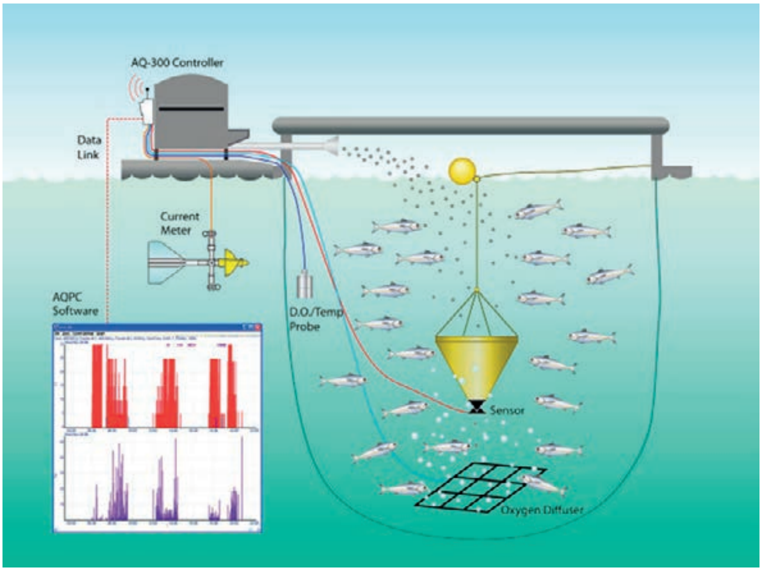


Figure 1: A schematic diagram of an appetite based interactive feeding system for net pen aquaculture (reproduced with permission by AQ1 Systems, Australia)

This paper will describe some of the current feed management challenges facing intensive aquaculture and will also outline some possible solutions and steps that the farmers can take to eliminate or circumvent these difficulties.

**Results and Discussion**

Feeding strategies should not be based on the modelled correlations between fish size, temperature and growth, as this does not take any account of day to day variability in appetite (Figure 2). The average feed intake per day shown here was 0.72 percent of body weight per day, but with more than 4-fold difference between minimum and maximum levels. The average is based on actual appetite, but it also reflects how any feeding regime based on modelled growth, like a feeding table, would relate to the actual food demand. In addition the feed intake also varies within days, and can, for example, peak at dusk and dawn (Figure 3). Restricted rations, would reduce the variability but not allow the fish to utilise their full growth capacity. It is clear though that fixed rations, unless they are based on substantial overfeeding, will limit the growth of the fish. Hence, the best way to satiate the fish is to feed responsive rations. Feeding responsive rations means that the fish should be fed according to their individual needs and that feed intake should be limited only by their appetite. Ideally this also means all fish should have access to feed in sufficient amounts timed to match the return of appetite on individual fish level, e.g. all fish should have access to feed when they are hungry.

This is the core of precision livestock farming, with the main promise of PLF developments being that automation and increased information technology would make animal production more efficient as a result of increased control.

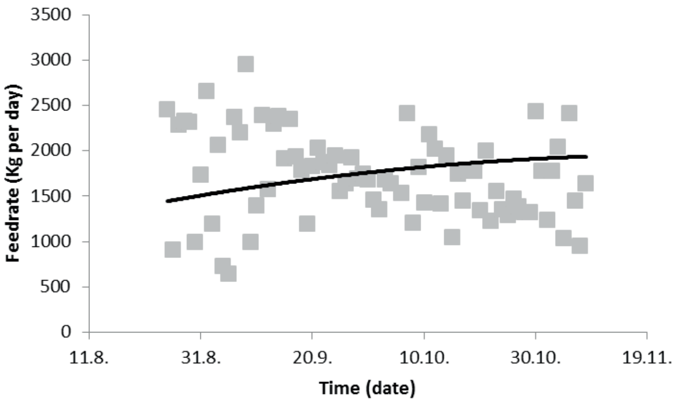


Figure 2: Example of day to day variability in feed intake in a grow-out cage with salmon growing from 4.2 to 6 Kg. The fish were fed to apparent satiation as assessed by an operator using underwater cameras. Feed intake is given as kg feed per day. The line indicate average feeding rate at 0.72% of bodyweight per day (recalculated from Sæther and Aas, unpublished).

In large scale operations with two hundred thousand fish per cage, day-to-day variability in appetite can lead to differences in feeding of several tonnes of feed per cage. Even minor differences in set-points for when the fish are perceived as being satiated can add up to several tonnes of difference in feed expenditure at a farm per day, with the associated costs of over or underfeeding that follows. Using feedback systems that allow the farmer to feed responsive rations can meet much of the requirements of PLF-feeding. However, the technology need also to adapt to changes in environmental conditions, like water currents, as this may alter the sinking speed, direction of drift or rate of wasted feed that actually are recorded. In practice most Norwegian salmon farms use a human operator controlling the feeding, integrating the information from environmental sensors, underwater cameras and behaviour of the fish. The best operators can utilise the growth potential of the fish close to maximum, and are close to getting one kilo growth out of each kg feed. Automated systems are developing towards increasing integration between environment (weather, water temperature, oxygen etc.) and the feeding, but full integration can currently only be achieved by human operators.

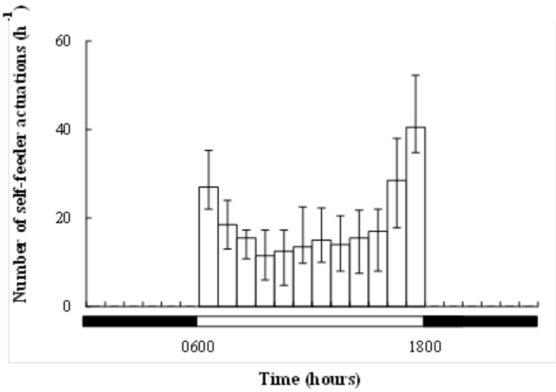


Figure 3: An example of the crepuscular diurnal feeding rhythms of that can be exhibited by tank-held rainbow trout fed with self-feeding systems. Data represents the median ± interquartile range.  The horizontal black and white bars below the graph show the dark and light phases of the LD cycle (the diurnal phase was between 0600 and 1800 hours each day) (Noble, unpublished data)

A submerged camera located under the feeding area facing towards the surface gives the operator a view of the midst of the feeding arena. The visible volume is usually limited to only a limited percentage of the total cage volume. The fish is usually trickle fed a few times before the meal starts to prime the interest amongst the fish. When the feeding starts, feeding rate is usually set close to maximum capacity of the systems. This is important to reduce social interactions by making the feed available to as many fish as possible during meals; hence, the meals are intensive. When the operator starts to register pellets in the lower part of the defined feeding arena, this indicates that the fish are no longer hungry enough to keep up with the feeding rate, and the rate is reduced. At a certain minimum feeding level, the meal is ended if pellets still keep on passing through to the lower end of the arena. Competent operators are able to satiate nearly all fish in the cage every day, without wasting too much feed or limiting growth potential. Assessing the appetite of fish in large groups is difficult, and care should be taken to ensure that satiation is accurately perceived by the person or system controlling the feeding. There are individual differences in growth and appetite as well as differences in a fish's ability to gain feed when it is available. As with many terrestrial animals, fish have social hierarchies where dominant or despotic fish secure access to feed whereas subordinate individuals will get less than their equal share of the meal (Grant, 1997). In practice a restricted ration will only be restricted to some, as dominant fish tend to feed to satiety at the expense of subordinates. An important side of feed management is therefore to reduce the possibility of dominant fish or better competitors controlling the feeding arena by making it less predictable in space or time.

Good feeding practice also involves monitoring the fate of the feed that is delivered and assumed to be ingested. A direct way of doing this is to measure the weight gain of the fish over time. Previously this involved handling the fish, potentially losing growth and imposing stress to the fish, but modern technology allows biomass monitoring of the fish while they are undisturbed in the cages (e.g. VAKI or Storvik). Trusting only the apparent feed intake may have large consequences, as shown in Figure 4. This example show two full scale farming groups fed to apparent satiation. The operators were not happy with the amounts of feed they could get fish in two of the cages to eat (grey scattered lines), and were considering possible interventions. With this information available, any operator would be concerned about underperformance of the fish. The cages were equipped with biomass estimators, allowing monitoring of individual weight changes in the cages. This information revealed that there was no difference in growth between cages, despite a difference in apparent appetite that aggregated to approximately 23% between cages black solid vs grey scattered line. Hence, the fish that were perceived as being underperforming were actually doing very well, and still are top ranked in this company in terms of feed utilisation. This type of biomass estimation equipment is now being implemented in an increasing number of farms.

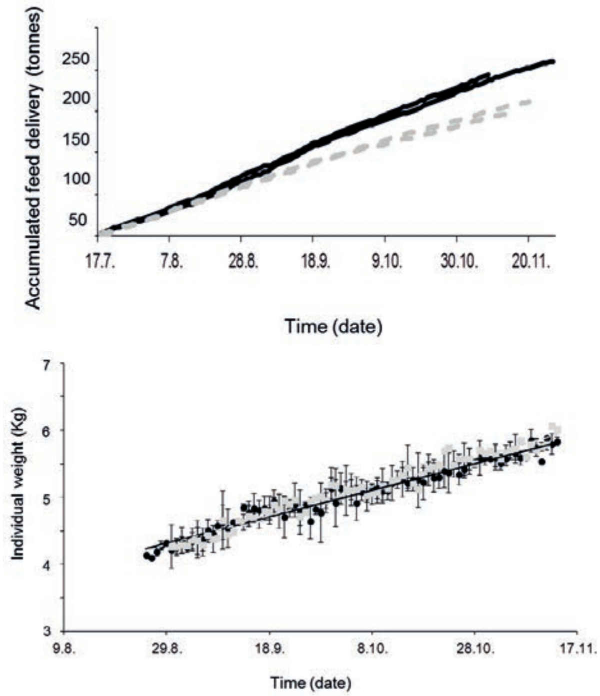


Figure 4: Example of development of accumulated feeding and weight increment in four cages fed responsive rations using underwater cameras. The trial was conducted at a commercial fish farm and operating conditions (based on Sæther and Aas, unpublished data).

Within few years it is likely that we will see more sophisticated surveillance systems in fish farms with more advanced control of feed waste, perhaps involving automated systems that also monitor and analyse fish behaviour to decide i) return of appetite (time for a new meal) and ii) satiation to improve accuracy of feed management. There is also a line of development that focuses on individual fish, and uses tag-technology to not only monitor feeding activity, but also to utilise the fish's behavioural and physiological response to the environment as a biological sensor of environmental stressors.

## Conclusions

Current best practise feed management in salmon aquaculture involves the use of responsive rations, feeding the fish according to appetite on a daily basis. Feeding systems that integrate assessment of appetite and responsive feeding are now widely used. These are increasingly combined with assessment of growth, which allows a final control of the efficiency of feeding. Future systems are likely to involve assessment of appetite that will improve feed delivery timed to return of appetite.

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## Sensors for Predicting Caviar Maturity in Farmed Sturgeon

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### Abstract

Declining wild sturgeon populations around the world have led to a significant increase in the production of farm-raised caviar, but sturgeon farmers face difficult challenges to produce eggs of sufficient size and firmness to yield high-quality caviar. We report the development and preliminary testing of a microfluidic sensor for on-farm measurement of plasma calcium as an indicator of vitellogenin. The sensor gives readings in 4 minutes consistent with laboratory measurements of total calcium. Plasma calcium can be used in the fall to separate nonvitellogenic sturgeon from vitellogenic sturgeon. Initial results from white sturgeon brood-stock fish suggest the possibility to predict egg size in the spring from plasma calcium measurement in the winter and therefore, the optimum time for caviar harvest. Preliminary tests on whole blood gave results similar to tests on plasma, suggesting that separation of plasma by centrifugation is not necessary.

**Keywords**: Caviar, Sturgeon, Aquaculture, Vitellogenin, Plasma, Calcium

### Introduction

Depletion of wild sturgeon populations around the world has led to a significant increase in the production of farm-raised caviar. In California, caviar is sustainably grown from the native white sturgeon (*Acipenser transmontanus*), with an annual of production of 15,000 kg, at a farm-gate value of over $8 million dollars and a retail value of $37.5 million dollars. With increasing competition on the global market and uncertainties in labor availability, sturgeon farmers around the world face difficult challenges to produce eggs of sufficient size and firmness to yield high-quality caviar at reasonable production costs.

On sturgeon farms, the fish are raised for 2-4 years after hatching and then sorted by sex (Doroshov *et al*., 1997). Sturgeon lack external sex dimorphism, so sorting is done by examination of the gonads through an abdominal incision (Van Eenennaam *et al*., 2004). Females are separated for caviar production and most of the males are sent to market, except those retained for brood-stock. In captivity, females reach sexual maturity around 7 years, depending on species, and the oocytes (eggs) are examined by surgical biopsy in the late fall for color and size. Maturing fish have eggs larger than 2 mm and have begun to develop darker color due to deposition of melanin pigment in the egg cortex.

Ovarian maturity of white sturgeon has been classified in 6 stages, A-F, based on the microscopic and macroscopic appearance of the oocytes (Linares-Casenave *et al.*, 2003). The 3 most advanced stages, D-F, are characterized by increasing color development and size, and the eggs are generally referred to in the industry as "black" eggs. Fish with black eggs must be held in cooler water (10-14º C) to allow the eggs to continue growth and maturation during the winter and spring. In California, these fish are transported to a cold-water facility. If these fish are held in warmer water (16-20 ºC), egg growth and maturation will be terminated and the advanced eggs will be resorbed during a process called "follicular atresia" (Linares-Casenave *et al.*, 2002).

The exact time of harvest to produce optimum quantity and quality of caviar cannot be predicted based on egg size or color at the time of biopsy in the fall because of individual variations in the rate of egg growth and development. Oocyte development in fish can generally be separated into a period of growth (meiosis arrested), followed by a period of final maturation (preparation to resumption of meiosis), during which time the oocyte nucleus moves from the center to the periphery of the egg (Lubzens *et al.*, 2010). There is some overlap between the periods of final growth and early maturation. If the eggs are harvested before the end of the growth phase so they have not reached their nominal final size (3.2-4.0 mm for white sturgeon) (Chapman & Van Eenennaam, 2007), the caviar yield is lower and the quality can be inferior. If the eggs are harvested in the later stage of maturation or during the onset of follicular atresia, the caviar is soft and may be unmarketable, resulting in the loss of both fish and product. The challenge for caviar farmers is to predict in the fall when to harvest the eggs in the spring for optimum quality and yield.

Egg development in sturgeon is under complex neuroendocrine control, involving the brain-pituitary-gonad reproductive axis (Doroshov *et al.*, 1997; Webb & Doroshov, 2011). Rapid measurement of biochemical indicators such as steroid and protein hormones is not currently possible on the farm with simple real-time sensors. During an ovarian cycle, eggs sequester the yolk precursor vitellogenin (VTG), a glycolipo-phosphoprotein secreted into the bloodstream by the liver under stimulation by 17β-estradiol produced by the ovaries. Changes in the concentration of circulating vitellogenin reflect growth of the eggs and the transition to final maturation (Doroshov *et al.*, 1997). The vitellogenic period of egg growth covers a period of about a 1.5 years in white sturgeon. Over the last half year of this period, the eggs rapidly increase in diameter from 1 to

>3 mm and change in color from white to yellow, gray, and finally dark brown/black due to the synthesis of melanin granules. Yolk platelets and oil globules gradually fill the entire cytoplasm, with finer platelets closer to the nucleus (Chapman & Van Eenennaam, 2007). The end of the growth phase is marked by a sharp decline in circulating vitellogenin, after which time egg diameter changes very little and major cyto-architectural changes occur as the nucleus (i.e., germinal vesicle) migrates toward the animal pole and the larger yolk platelets and oil globules accumulate toward the vegetal pole. The position of the nucleus with respect to the animal pole is scaled by the egg diameter to yield a maturity parameter referred to as the "polarization index" (PI), which decreases to <0.1 during maturation (Chapman & Van Eenennaam, 2007).

The total calcium concentration in the plasma of sturgeon has been shown to be highly correlated with plasma vitellogenin concentration, ranging from 8-10 mg/dl for males and non-vitellogenic females to 20 mg/dl and higher for vitellogenic females (Linares-Casenave *et al.*, 2003). Calcium in blood plasma generally exists as free ions (i.e., "free calcium") or bound to various serum proteins such as albumin (i.e., "bound calcium"). "Total calcium" refers to the sum of the free and bound calcium fractions. The concentration of free calcium is tightly regulated at homeostatic levels, but the concentration of bound calcium varies with the concentration of the binding proteins. Vitellogenin binds large amounts of ionized calcium to its polar phosphate groups, as well as other divalent cations such as magnesium (Allen *et al.*, 2009).

Total calcium can be measured in the laboratory by several methods, including atomic absorption spectrophotometry and inductively coupled plasma mass spectrometry. Chemical assays are also used, in which calcium ions react with various chromogenic agents and the resulting complex changes optical absorbance at a specified wavelength. One of the more common assays uses o-cresophthalein and absorbance is measured at 575 nm. Automated machines use this assay for clinical analysis of serum, plasma, and urine samples. The degree to which these chemical assays also detect bound calcium is unclear, even though the manufacturers often suggest that they measure total calcium.

Oocyte examination to detect vitellogenesis and later stages of egg development is an invasive procedure, stressful for the fish and creating the risk of infection and disease transmission. Generally this examination is done by surgical removal of a sample of eggs. Hurvitz *et al.* (2007) reported the use of endoscopy on cultured Russian sturgeon to determine sex and ovarian stage by examination of intact gonads. Although this technique was probably less stressful for the fish compared to egg extraction, an incision into the body cavity was still necessary.

The long-term vision of this research is to improve the efficiency of caviar production from farm-raised sturgeon by development of sensors to guide management decisions and improve welfare of the fish. The specific objective in this phase of the work was to develop a sensor to measure blood components for detection of vitellogenesis and prediction of optimum harvest time.

## Materials and methods

### Sensor design

Based on preliminary testing at UC Davis, we chose a simple diagnostic assay for measurement of free calcium in fluid samples (DICA-500, BioAssay Systems, Hayward, California USA). The assay uses phenolsulphonephthalein as the indicator reagent and absorbance of the resulting reagent-calcium complex is measured at 612 nm. Although this assay was developed to measure free calcium, a strong chelating agent also allows calcium bound to plasma proteins such as vitellogenin to be measured.

To facilitate on-farm operation, a miniature sensor platform using micro-pumps and micro-valves was designed to run the assay in a polystyrene cuvette, with a complete measurement cycle of less than 4 minutes (3 min testing and 1 min cleaning). Light absorbance is measured using a 610 nm light-emitting diode and a large area photodiode coupled to photovoltaic amplifier. All operations are controlled with an embedded controller and LCD, and the optical density results are immediately presented to the operator (Figure 1). The fluidic control and measurement cycle is summarized in Table 1. Calibration was done using standards made with calcium chloride dihydrate in distilled water over the approximate range of physiological concentration of total calcium in blood plasma.

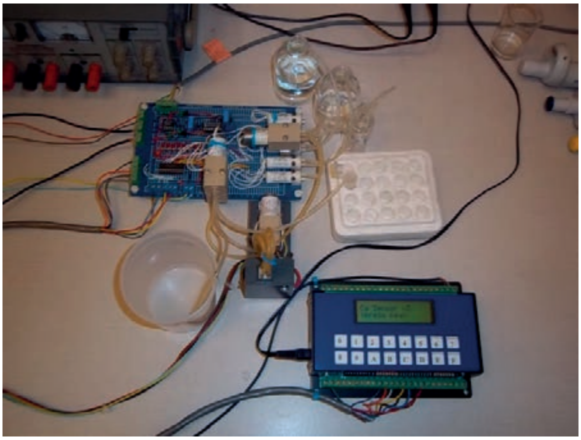

Figure 1. Calcium sensor and microfluidics.

Table 1. Sensor control and measurement cycle.

Prime sample line
- pump 12 strokes ( ~510 µl) of sample diluted 1:10 with distilled water
- drain and rinse cuvette
- clear manifold

Add reagent
- pump 17 strokes (~850 µl) of reagent
- mix 10 s, delay 20 s
- read initial light intensity, $v_0$

Add sample
- pump 3 strokes of sample (~150 µl) diluted 1:10 with distilled water

Reaction development (60 s)
- mix 10 s, delay 20 s
- read light intensity
- repeat
- $OD = \log(v_0/v_{60})$

Rinse
- drain cuvette and mix pump
- pump ~1.25 ml distilled water
- mix and drain
- clear manifold

<u>Blood plasma and egg samples</u>

Blood samples were taken from the caudal vein of male and female 4-yr white sturgeon in November 2011. Similarly, blood samples were collected from female white sturgeon brood-stock at Sterling Caviar in 2012 and 2103. Eggs were collected from the brood-stock fish by surgical biopsy. Samples were taken at the first screening in late January/early February, and subsequent screenings later in the spring. Blood was collected in 10 ml vacutainers with sodium heparin. The plasma was separated by centrifugation (4 min at 1500 RPM in 15 ml tubes) and frozen at -20 ºC for later testing. Eggs were stored in 10% formalin prior to measurement of the polarization index (Chapman and Van Eenennaam, 2007). For comparison with the sensor readings, plasma samples were measured for total calcium in the UC Davis Analytical Laboratory by inductively coupled plasma atomic emission spectrometer (ICP-AES), after treatment with hot nitric acid to digest proteins.

## Results and Discussion

Sensor calibration was done using standards made with calcium chloride in distilled water over the approximate range of physiological concentrations of total calcium in blood plasma (Figure 2). Optical density (OD) was linearly related to $Ca^{2+}$ concentration up to about 20 mg/dl, with a sensitivity of 29 mOD per mg/dl. Above 20 mg/dl, OD began to saturate, as indicated by the assay manufacturer.

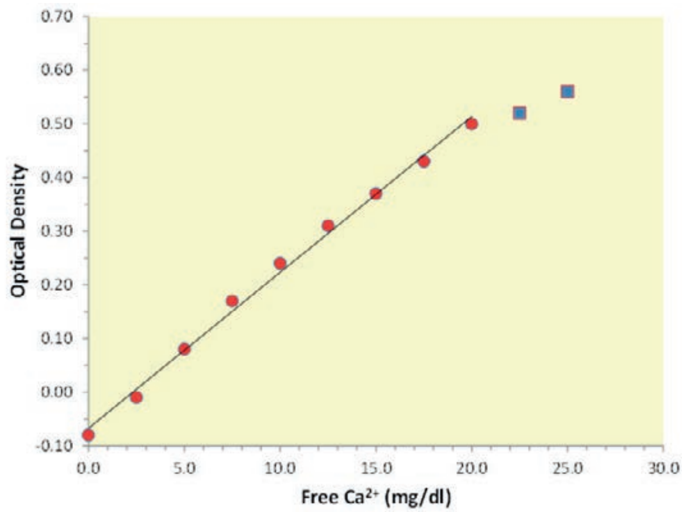


Figure 2. Sensor calibration with free calcium standards over the physiological range of total calcium, $[Ca^{2+}] = 34.4OD + 2.3$.

Comparisons were made between plasma calcium readings with the sensor and by ICP-AES (Table 2). The automated sensor gave plasma calcium readings consistent with ICP-AES readings, so we think it is suitable for rapid field measurement of total calcium. Clear and consistent differences were found in sensor readings of plasma calcium among vitellogenic females, immature females, and immature males. Therefore, plasma calcium measured by the sensor can be used to separate nonvitellogenic sturgeon (<10 mg/dl) from vitellogenic sturgeon (>15 mg/dl), corresponding to a threshold of about 0.25 OD (based on data from Linares-Casenave *et al.*, 2003). In later tests, the sensor readings were left in units of optical density.

In January 2012, eggs from the brood-stock fish were about at the end of the growth phase and had reached their nominal final size (~3.5 mm). Two months later, egg size had not changed (3.55 mm vs. 3.54 mm), but the polarization index had decreased (0.149 vs. 0.109) due to migration of the germinal vesicle during maturation. Plasma calcium in January 2012 plotted against egg diameter in April (Figure 3) suggests the possibility to predict egg growth based on sensor readings and therefore, the optimum time for caviar harvest. It should be noted however, that these data were collected from brood-stock females that had undergone multiple ovarian cycles. The results could be different for first ovarian cycle females used in caviar production. Determination of the relationships between plasma calcium and egg growth rate in production fish is part of our future research.

Table 2. Plasma calcium measured with the sensor and ICP-AES, egg size, and polarization index for vitellogenic and nonvitellogenic sturgeon (SD in parentheses).

| Sample | Plasma Calcium, mg/dl | | Diameter, mm | | Polarization Index | |
|---|---|---|---|---|---|---|
| | sensor | ICP-AES | | | | |
| Brood-stock | 15.2 (1.9) | 14.3 (2.9) | 3.55 (0.16) | 3.54 (0.14) | 0.149 (0.040) | 0.109 (0.034) |
| (female, N=24) | 27-Jan-12 | 27-Jan-12 | 27-Jan-12 | 30-Apr-12 | 27-Jan-12 | 30-Apr-12 |
| Immature | 8.7 (1.0) | 7.8 (0.1) | - | - | - | - |
| (female, N=2) | 26-Oct-11 | 26-Oct-11 | | | | |
| Immature | 7.8 (1.3) | 7.1 (2.8) | - | - | - | - |
| (male, N=2) | 26-Oct-11 | 26-Oct-11 | | | | |

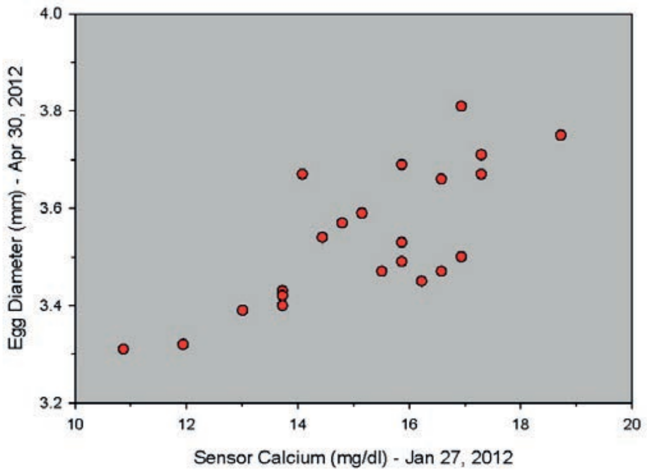


Figure 3. Plasma calcium in January 2012 vs. average egg size in April 2012.

Brood-stock data collected at the first screening in 2013 (February 1) were separated into groups of five fish based on polarization index (Table 3) The group with the lowest polarization index (mean=0.092) had an average sensor reading of 0.32 OD. Two months later, the polarization index of this group had decreased to 0.070, but the sensor reading (0.30 OD) was about the same, indicating little change in plasma vitellogenin. The group with the highest polarization index (mean=0.234) had an average sensor reading of 0.39 OD. Two months later, the polarization index of this group had decreased to 0.203, and the sensor reading had decreased to 0.32 OD, indicating that plasma vitellogenin had started to decline, similar to previous reports (Doroshov *et al*. 1997). The average OD for male plasma in 2013 (0.20) was consistent with 2012 data.

Table 3. Plasma optical density for groups of brood-stock fish sorted by lowest and highest polarization index.

| Fish # | | 1-Feb-13 | | | 1-Apr-13 | |
|---|---|---|---|---|---|---|
| | | diam. (mm) | PI | OD | PI | OD |
| 132 | | 3.45 | 0.079 | 0.23 | 0.078 | 0.23 |
| 130 | | 3.53 | 0.083 | 0.36 | 0.064 | 0.30 |
| 10 | | 3.74 | 0.097 | 0.32 | 0.030 | 0.29 |
| 68 | | 3.60 | 0.098 | 0.35 | 0.060 | 0.36 |
| 119 | | 3.47 | 0.104 | 0.34 | 0.116 | 0.32 |
| | mean | 3.56 | 0.092 | 0.32 | 0.070 | 0.30 |
| | SD | 0.12 | 0.011 | 0.05 | 0.031 | 0.05 |
| 7 | | 3.47 | 0.206 | 0.39 | 0.195 | 0.37 |
| 92 | | 3.35 | 0.208 | 0.41 | 0.203 | 0.31 |
| 109 | | 3.15 | 0.221 | 0.37 | 0.186 | 0.43 |
| 31 | | 3.74 | 0.235 | 0.47 | 0.171 | 0.29 |
| 47 | | 3.42 | 0.302 | 0.33 | 0.258 | 0.20 |
| | mean | 3.43 | 0.234 | 0.39 | 0.203 | 0.32 |
| | SD | 0.21 | 0.040 | 0.05 | 0.033 | 0.09 |
| 69 male | | - | - | 0.18 | - | - |
| 33 male | | - | - | 0.22 | - | - |
| | mean | | | 0.20 | | |

Separation of plasma from whole blood was done by centrifugation. For on-farm testing, it would be desirable to minimize processing steps such as centrifugation before measurement with the sensor. A preliminary comparison was made between the average sensor reading for whole blood and for plasma separated from that blood (Table 4). The average difference in between whole blood and plasma readings was 0.03, indicating that plasma separation might not be necessary. More data are needed to verify this result over a wider range of vitellogenin.

## Conclusions

An automated sensor was developed using microfluidic components and an embedded controller to measure calcium by chemical assay. The sensor gives plasma calcium readings in 4 minutes that are consistent with inductively coupled plasma atomic emission spectrometer readings on plasma after protein digestion, so it is suitable for rapid field measurement of total calcium. Plasma calcium readings in the fall can be used to separate nonvitellogenic white sturgeon from vitellogenic white sturgeon. Initial tests on brood-stock fish suggest the possibility to predict egg size in the spring from plasma calcium measurement in the winter and therefore, the optimum time for caviar harvest. However, this observation needs to be evaluated on first ovarian cycle females used for caviar production. Preliminary tests with the sensor on whole blood gave results similar to tests on plasma, suggesting that centrifugation is not necessary.

Table 4. Comparison between sensor optical density from whole blood and plasma.

| | OD 1-May-13 | | |
|---|---|---|---|
| | blood | plasma | difference |
| mean, N=9 | 0.30 | 0.27 | 0.03 |
| SD | 0.03 | 0.06 | 0.04 |

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## Automatic underwater weight estimation of omega perch by computer vision

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### Abstract

The aim of this study was to test and evaluate a computer vision technique that estimates the weight of Omega Perch swimming freely in a tank of a recirculation aquaculture system.
A set of 105 images of fish were captured out of the water in order to build up a relationship between the fish shape and its weight. Regression analysis revealed that the coefficient of determination ($R^2$) between area and weight is 0.98. Based on this model the mean predicted error weight is 9±7% when compared with the value measured by a weighing scale. This model was then used to estimate the biomass of 15 fish that were moving freely through an underwater corridor where a camera was installed. The results revealed a 10±5% estimation error when compared with the value measured by a weighing scale.
Therefore the proposed method might be useful for continuously and automatically estimating the biomass of freely swimming fish without causing stress or damage to them.

**Keywords:** aquaculture, image processing, weight estimation

### Introduction

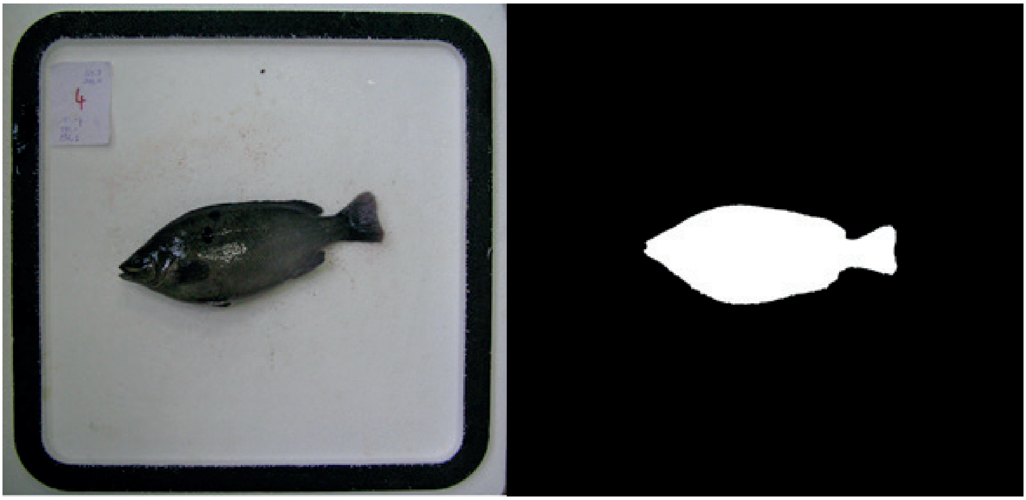
Monitoring fish weight is essential for effective management of aquaculture farms. Information about fish weight enables the farmer to calculate the daily feed ratio and the fish stocking density. In addition, harvesting and grading of fish is highly dependent on the fish weight and the weight distribution among the fish population.
The most common method of estimating the weight of a fish population is to net and harvest sample fish from the tank and weigh them. However, this method is labour intensive and stressful or may even damage the fish (Pickering & Christie, 1981; Maule *et al.*, 1989). Furthermore, according to Klontz (1994) it is 15-25% inaccurate. The stress also results in a significantly lower feed intake during the days following harvesting, and therefore in a reduced growth rate.

The relationship between fish shape and weight has been extensively investigated in previous studies (Spencer, 1898, Huxley, 1924, Le Cren, 1951). The weight is usually estimated by measuring the fish length or area.
The increased use of image processing in aquaculture (Zion, 2012) opened up the possibility of estimating the weight of fish automatically and without needing to remove the fish from the water.
The objective of the present study is therefore to use a camera that estimates fish weight under -water continuously and fully automatically.

## Material and methods

Experimental setup
The experiment was carried out in the Aqua4C aquaculture laboratory at KU Leuven and conducted on jade perch or Omega Perch®, *Scortum barcoo,* farmed by Aqua4C. The Omega Perch is a robust fish that is naturally rich in omega-3 fatty acids and can weigh up to 2 kilograms and reach a length of 40 centimetres.
Fifteen Omega Perches were used for the experiment. The fish were kept in a tank measuring 1.1 m in height, 1.5 m in diameter and with a volume of 1.8 $m^3$. The tank had a glass window (size 0.45 m x 0.45 m). A corridor (length: 0.5 m, width: 0.2 m, depth: 0.2 m) was built from plexiglass and stainless steel and placed in front of the window in order to have a fixed white background and a constant distance between the camera and the fish. Two lights (230 W each) were placed above the tank in order to improve the illumination in the water. The lights were turned on automatically and only during the video recordings in order not to disturb the fish biorhythm.
A Prosilica GC1350 camera with a Pentamax lens (4.8 mm) was placed perpendicular to the tank window. The camera was connected to a computer with Intel Pentium D CPU 3.40 GHz processor and 2 GB of RAM.
The video recording system was developed in C++. The software recorded videos at 20 fps from 8h00 until 20h00 from 25 April until 17 June 2013.

Model development (weight estimation out of water)
In order to develop the relationship between area and fish weight, 105 pictures of fish were used for calibration. The fish were harvested out of the tank, sedated with 70 ppm tricaine methane sulfonate (MS-222) in the water, and placed on a polystyrene board (Figure 1a). A picture was taken with an Olympus C770UZ camera with Olympus AF Zoom lens (6.3-63mm). Each fish was weighed using a Kern 572 weighing scale with a precision of 0.1 gram. Six times during the experiment (approximately every 10 days), the 15 fishes were harvested out the tank and weighted individually in order to compare the value predicted by the model. The fish were individually identified by the unique dark skin spots that are typical for Omega perch.



(a) (b)

Figure 1. Fish placed on the polystyrene board (a). Binary image of the fish after segmentation (b).

The images were processed in Matlab 2012b. After segmentation (Figure 1b), the fish was rotated so that the axis of the fish was horizontal and three parameters were extracted: 1) the maximum length, 2) the maximum height, 3) the area.
These parameters were normalised by using the dimensions of the black square on the polystyrene board (Figure 1a).
Regression analysis was used to estimate the relationship between the variables and to develop the weight prediction model.

Algorithm for weight estimation in water
The recorded videos were processed in Matlab 2012b overnight by the computer that was used for video acquisition. In order to build the background model, a video without fish was recorded before starting the experiment.
Background subtraction was applied to each frame of the video (Figure 2). If the segmented object matched certain length-width relationship criteria, the object was considered to be a fish and the area, length and height were calculated in pixels.

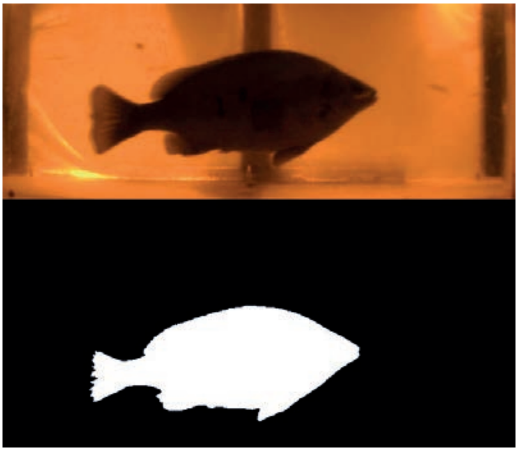


Figure 2. Frame extracted from the video recording with a fish (top) and the result of segmentation (bottom).

These parameters were then normalised by using the size of the channel. In a final step, the weight was calculated using the model obtained by regression analysis. The average weight measured each day was used to estimate the biomass in the tank.

**Results and discussion**

<u>Model for weight estimation (out of water)</u>

The regression analysis revealed that the area was the variable with the highest determination coefficient ($R^2 = 0.9832$) in relation to weight. Therefore, the following model was developed (Figure 3):

Weight = 0.0002 * Area + 0.0181

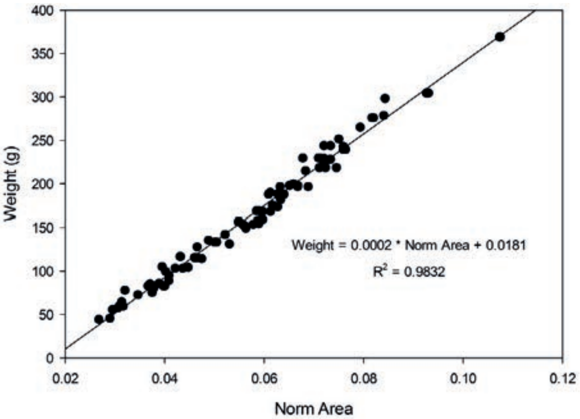


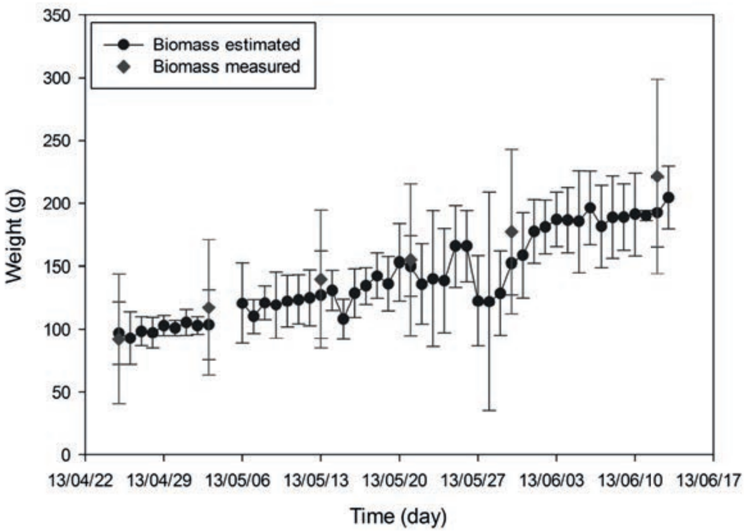

Figure 3. Regression analysis showing the relationship between the weight and area of the fish measured out of the water.

Table 1 shows the error of the model's weight prediction. The mean error was 6.2±4.8 g and the error in relation to the weight was 9±7%.

Table 1. Error of weight prediction out of water as an absolute and a percentage value.

| Error | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|
| **Absolute** | 6.2 g | 4.8 g | 0 g | 23 g |
| **Percentage** | 9 % | 7 % | 0 % | 22 % |

Biomass weight estimation (in water)




As mentioned, the model was used to estimate the average weight of the fish on a daily basis (Figure 4).

Figure 4. Estimated and measured biomass.

On May 4 and 5 2013, the computer broke down and no measurements could be collected. When compared with the manual measured fish weight, the mean error was 14.9±9.2 g and the error in relation to weight was 10±5%.

Table 2. Error of weight prediction in water as an absolute and a percentage value.

| Error | 20130425 | 20130503 | 20130513 | 20130521 | 20130530 | 20130612 | Mean |
|---|---|---|---|---|---|---|---|
| **Absolute** | 4.9g | 13.6g | 12.4g | 4.8g | 24.9g | 28.9g | 14.99.18±g |
| **Percentage** | 5% | 13% | 10% | 3% | 16% | 15% | 105%± |

## Conclusion

The use of an automated algorithm to estimate the biomass of fish in a tank might be useful in order to avoid removing fish from the water and thus causing stress, injuries and weight loss. In this study, the weight estimation model was derived from pictures of fish out of the water. Regression analysis between the fish area and its weight resulted in a $R^2$ of 0.98 and a mean error in weight estimation of 9±7% compared to the values measured by a weighing scale. This model was used to estimate the biomass of 15 fish in the water in a fully automated way. When compared with the biomass measured by weighing scale, the results show a mean error rate of 10±5% of the fish weight. Hence this tool might be useful for continuous estimation of the biomass in a tank without needing to remove the fish from their natural environment.

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**How can computer vision technologies promote precision aquaculture ?**

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**Keywords:** Computer vision, Aquaculture, Size, Biomass, Gender, Species, Welfare, Behaviour

**Extended Abstract**

The use of technologies in agriculture can be divided into two partially overlapping categories: pre- and post-harvest. While postharvest operations pose complex inspection challenges, such as high speed or detection of hidden internal quality attributes, in most cases, the environment and conditions under which the technology operates are controllable (e.g. lighting, product position with respect to the sensor, mechanical stability). This is not the case in agricultural field operations in general and specifically in aquaculture. Application of computer vision technologies in aquaculture is much more complicated in this respect. The inspected subjects are sensitive, prone to stress and free to move in an environment in which lighting, visibility and stability are not controllable in most cases. The equipment must operate underwater or in a wet environment and is expected to be inexpensive.
The presentation describes the state of the art and the evolution of computer vision technology in aquaculture. It will focus on aquaculture operations and inspection needs in all stages of production, from hatcheries to harvest. It is organized by inspection tasks which are common to almost all production systems: counting, size measurement and mass estimation, gender detection and quality inspection, species and stock identification, and the monitoring of welfare and behavior.

Counting

One of the basic and most important requirements for all aquaculture operations is a means for counting stocks. Counting eggs, larvae, fry and fish at various growth stages (from the nursery to marketing) can be of crucial importance, helping growers to accurately stock their containers, ponds or cages, manage precise feeding strategies and design a marketing schedule. There is a descent variety of commercial equipment for counting fish eggs, fish fry or large fish. Some examples: Vaki's "Bioscanner" (Vaki Aquaculture Systems Ltd., Iceland) is based on optical detection of fish (3 g–12 kg) as they slide along a chute; the AquaScan "Fishcounters" (AquaScan AS, Norway) is used for counting fish (0.2 g–18 kg) while being transferred through a pipe or over a flat, wide channel, and SRI's "Fish Counter" (Smith-Root Inc., WA, USA) is based on electrical conductivity and used for assessment of upstream and downstream fish movement in rivers; Vaki also has “Nano” and “Macro” counters for fish fry of 0.05–20 g or larger than 0.2 g, respectively, based on computer vision systems, with a reported accuracy of 98%; Impex’s TPS counters (Impex Agency Hoerning ApS, Denmark) are designed for a few ranges of fish sizes (between 0.2 and 50 g), also with a reported accuracy of 98%; The AGM Rognsorterer (Maskon AS, Norway) sorts salmon and trout eggs according to size and quality by imaging the eggs from two sides and processing the images.

Size measurement and mass estimation

Relationships between fish shape features and mass have been investigated for many years as measures of structural indices, for growth-rate assessment. The most common mathematical model characterizing the relationship between fish length (L) and mass (W) is the power model $W = aL^b$, where a and b are empirically characterized species- and strain-dependent parameter (Fulton, 1904). Monitoring mass of fish is important for growth control and accurate feeding. With the advances in optical imaging and image-processing technologies, attempts have been made to develop sophisticated sensors and methods to characterize various fish dimensions, and then infer the mass. Most of the published works dealt with fish out of water [(Poxton & Goldsworthy, 1987), (Strachan, 1993), (Zion *et al.*, 1999), (Odone *et al.*, 2001), (Balaban *et al.*, 2010a; Balaban *et al.*, 2010b; Gumus and Balaban, 2010)] . Others forced fish into an oriented position or kept them at a known distance from the imaging system [(Hufschmied *et al.*, 2011), (Zion *et al.*, 2012)]. In other cases, stereovision must be used, as it enables sensing the depth dimension but adds some complexity [(Ruff *et al.*, 1995), (Beddow *et al.*, 1996), (Tillett *et al.*, 2000), (Lines *et al.*, 2001), (Martinez-de Dios *et al.*, 2003), (Costa *et al.*, 2006), (Costa *et al.*, 2009), (Torisawa *et al.*, 2011). Some commercial applications for biomass estimation offer a technological alternative to physical sampling and weighing of fish in cages.

Gender identification and quality assessment

Identification of fish gender by rapid optical technology could be of high economic value. In some species, the morphological shape of the urogenital opening and pectoral fins can be used to distinguish the genders (Di Marco *et al.*, 2011). Tilapia growers are interested in males since their growth rate is higher than that of females. In ornamental fish farms, gender determination is important in breeding programs and marketing [(Gomelski *et al.*, 1995; Wohlfarth and Rothbard, 1991), (Wallat *et al.*, 2002), (Zion *et al.*, 2008), (Karplus *et al.*, 2005; Karplus *et al.*, 2003)]. Edible fish quality in terms of appearance (shape and color) is almost exclusively tested postharvest, before or after processing. This could be due to the lack of sensing technologies for in-situ (underwater) applications and/or lack of intervention methods (e.g. means for removal of fish of inferior quality from a large population) during the growout period.

Monitoring welfare

When fish are stressed, they undergo various metabolic changes, all of which are expressed externally by variations in their behavior. Similarly, a change in fish feeding behavior, swimming behavior or skin color is a sign of unfavorable conditions, stress, distress or pathogenic conditions (Conte, 2004). Monitoring systems of changes in such traits can alarm growers of potentially disastrous problems in their systems. Even though this R&D area has a great commercial potential it has attracted limited activity so far. Perhaps due to the extremely challenging underwater conditions under which such monitoring systems are required to operate in cages, ponds or reservoirs. In edible or ornamental fish farms which use a recirculated aquacultural system (RAS), water depth is relatively shallow, feeding location can be adjusted if needed and lighting can be controlled. In such systems, monitoring fish size and health while they are being transferred between pools and monitoring feeding behavior seem to be worth looking at for developers of computer vision systems. Since feed represents a major portion of the cost of aquaculture production and since feeding behavior is an indicator of welfare, it is well worth following up on initiatives (or initiating new ideas) for monitoring excess feed in sea cages (and other systems) as an indirect way of monitoring health and welfare and of pursuing direct monitoring of fish behavior. There has been quite a lot of preliminary work in these directions [(Savage *et al*., 1994), (Foster *et al*., 1995), (Parsonage & Petrell, 2003), (Israeli & Kimmel, 1996), (Israeli-Weinstein and Kimmel, 1998), (Xu *et al*., 2006), (Stien *et al*., 2007), (Duarte *et al*., 2009), (Rodriguez *et al*., 2011), (Pinkiewicz *et al*., 2011)]. The needs of the aquaculture industry and the commercial potential are significant, and a tight collaboration between engineers, fish physiologists and ethologists could contribute to the search for viable solutions for the benefit of aquaculture.

**The presentation is based on*: *Zion B. (2012). *"The use of computer vision technologies in aquaculture - A review*". Computers and Electronics in Agriculture, 88: 125-132.**

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# Session 16

# Cattle - Bites/Rumination

# Registration of cow bites based on three-axis accelerometer data

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## Abstract

The objective of the presented experiments was to develop a method to estimate bite count on pasture by measuring the activity of cows' heads using easily accessible accelerometers and to test the accuracy of the accelerometers. A state of the art 3D accelerometer, developed for measuring grazing time, was used. Manually measured bite events were used to develop the model, using threshold values for the peak values. In addition, estimated grazing time was used to model the threshold for the minimum amount of bite-like events to be defined as bites. The accelerometers proved to give a usable estimate of bite count per minute with a variation of ±10, where normal bite frequency lies between 30 and 70 bites per minute.

**Keywords:** Dairy cow, Grazing, Bite frequency, Accelerometer, Pattern recognition

## Introduction

It is a challenge for farmers to quantify feed intake of grazing cows from pasture. If these amounts were known, needs for supplement feeding in the barn could be managed more accurately. Known feed intake from grazing would contribute to optimizing feed composition, stabilized milk yield, cost saving, and it would secure grass intake from pasturing (Oudshoorn *et al.*, 2012). State of the art acceleration sensor technology is used widely to measure activity and motion. Acceleration can be measured in two or three dimensions, with different sensitivity and accuracy. This depends on the resolution in relation to gravity (g) and the frequency of registering (Hz). Activity and motion parameters can be used to find cows at heat, steps taken, or resting time, which then can be used in management decisions. One of the latest applications of accelerometer registrations was, to measure grazing time as a possible indicator of feed intake (Moreau *et al.*, 2009; Umemura *et al.*, 2009; Barth & Gyöngy, 2011).

However, it showed that grazing time alone was not sufficient in estimating feed intake. In the field, grass intake changes over time, and is defined by the number of bites and the grass amount per bite; number of bites is a product of grazing time and bite frequency during grazing (Chacon et el., 1976; Gibb *et al.*, 1997). Several factors can influence both bite frequency and grass amount per bite, such as fasting time before grazing, time of the day grazing takes place, and grass height in the pasture (Pulido & Leaver 2001; Barrett *et al*. 2003; Chilibroste *et al.*, 2007). Thus estimating the grass intake consists of two problems: estimating the number of bites, and the amount of grass in each bite.

Assuming the bite size is dependent on the grass height, focus is on bite frequency whilst grazing on a documented sward. Bite recorders tested up to now are complex and designed for research only. (Ungar and Rutter, 2006). The method described in this article focusses on estimating the bites during grazing time, by analysing neck collar acceleration data to identify each unique bite. The benefit is to have continuously updated bite counts, reflecting changes during the day, but also registering changes in the cow's preference over time. The objective of the presented experiments was to develop a method to estimate bite count and to test the accuracy of measuring bite count with accelerometers.

## Material and methods

IceTag sensors® specified to a resolution of 0.1 g with a measurement range of ± 3 g which is approximately ±30 m $s^{-2}$, and a sample rate at 16Hz, were used to register cows' head movements when out on the pasture. An experiment was conducted in southern Denmark using seven different Holstein-Friesian cows. The acceleration sensors were attached on a collar, loosely tightened too allow some movement of the collar, but tight enough to make some useful assumptions about the sensors position relative to the cow. Captured data were downloaded, after dismantling the tags. Manual observations of grazing behaviour and bite counts were performed, as previously described by Kristensen *et al.* (2007). The manual bite markings were obtained using custom software to log timestamps for each key press. The timestamps were tagged with system time of the logging computer and stored with one second resolution, thus allowing up to one second delay in synchronization based on time resolution alone. This also means that visualization of manual markings are overlapping when the biting frequency is above 1 hz. Synchronization was achieved by storing the starting time of the IceTag® sensor, and resetting the system time of the computer used for the manual timestamps to the time of the computer used for download of the IceTag® data.

For comparison of accelerometer bite count registration with another automatic registration device, the IGER behavioural recorders were used (Ungar & Rutter, 2006). The two devices were simultaneously attached to the head of the cow and recordings were thereafter analysed. In addition, manual bite count was performed in this experiment.

<u>Pre analysis</u>

Bite movements are known to be within the range of 30-70 movements per minute (0.5 – 1.2 Hz) therefore all data were filtered before doing any data analysis, using a low pass filter, to exclude all frequencies above 2 Hz, keeping a good safe margin to relevant frequencies. A 50th order filter with a flat frequency response in the pass band was implemented using MATLAB, thus removing any pendulum effect from a loose collar, or any other higher frequency content.

Shape matching

The idea was to search the datasets for a known bite template. For this purpose, a motion template was created to resemble the expected acceleration seen between two bites in a continuous sequence, where the cows' motions could be considered repetitive and thus similar in appearance, ensuring the template represents a typical bite and not a stray movement.

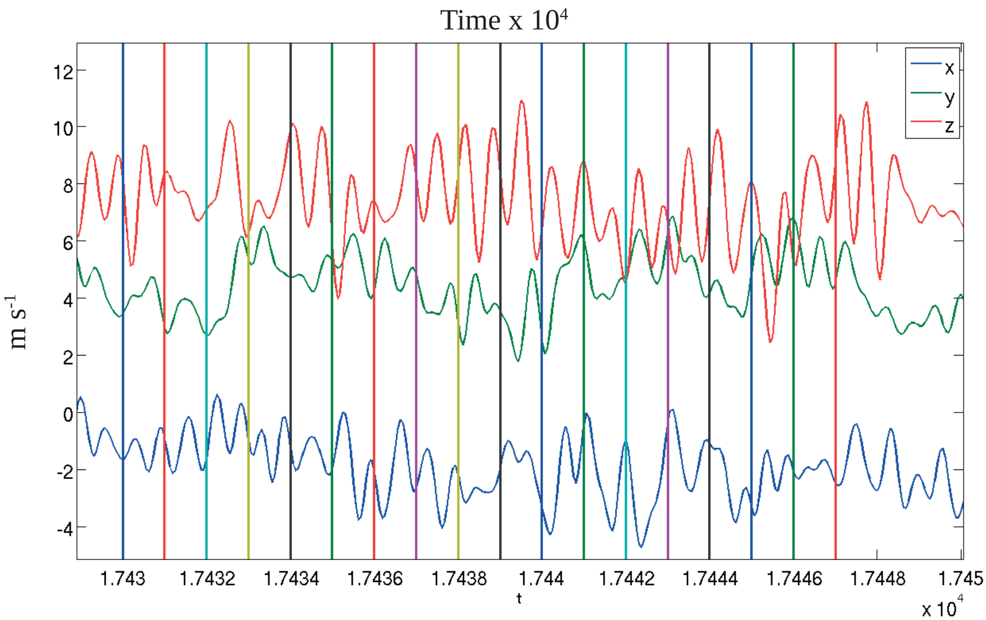


Figure 1: Section of sensor data for dataset number 2, manual bite markings shown as vertical lines

## Results

From accelerometer to bite count

Observing a section of raw sensor data (Figure 1), with manual bite markings superimposed as vertical lines it was apparent that the z-axis had periodic content consistent with the manual markings. The time synchronization between sensor data and manual markings might be skewed, however the data collected showed consistency with approximately one local peak in acceleration between each marking. Considering the changes in acceleration is mainly due to change in angle, a cosine function would theoretically be the right choice, however the general peak shape is more important than an exact match, therefore a simple $t^2$ was used. To detect bites the template was correlated to the z-axis using the built-in MATLAB function "corrcoef" that calculates correlation coefficients. In essence the method is searching for correlation between the recorded signal, and a known bite. Thus we named the method "BCM", short for Bite Correlation Method.

The BCM had only one adjustable parameter; the bite correlation threshold. This determines how well a bite must resemble the used template signal, to be counted. A correlation threshold of one means perfect match, which realistically will never happen, thus the threshold needs to be lowered for real observations to be accepted. Conversely, if the threshold is set too low, any local peak in acceleration will be accepted as a bite. There are general guidelines of how to select the threshold, however what is considered “high” correlation is very dependent on the application. Data from experiment one was used to find the optimal value of the threshold value. To find the optimal threshold, the threshold value was decreased starting at 0.99, until the point of 100% correspondence with manual bite counts was passed. Figure 2 shows 13 sets of data correspondence with manual bite counts. Depending on which graph is used, the optimal correlation threshold with respect to the manual bite counts is between 0.55 and 0.85.
Average performance of the 13 sets of data was used, filtering out the outliers, to find an average correlation threshold of 0.65.

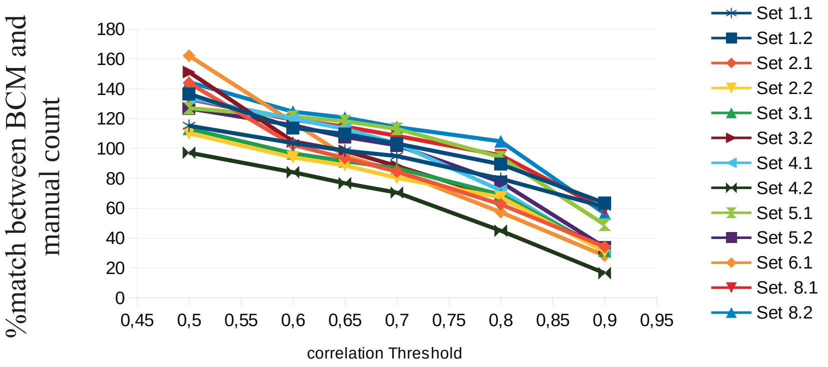


Figure 2: 13 datasets for comparison of manual bite counts with the bite correlation method (BCM).

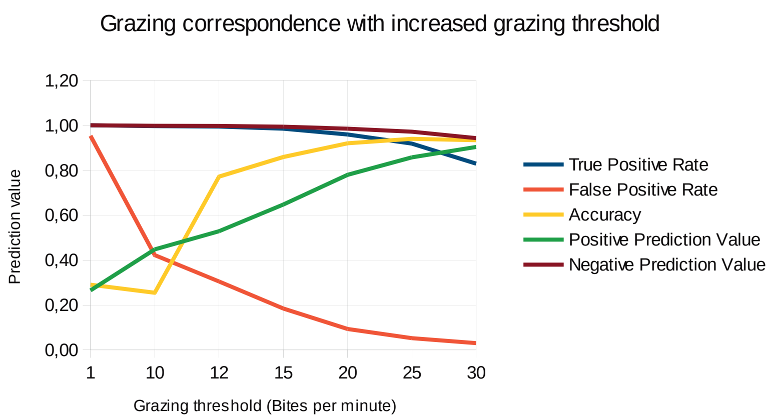


Figure 3: Grazing correspondence with IceTag grazing annotation with bite frequency as threshold.

Some movements of the head will not be expressing grazing, but searching for grass. By correlating the estimated (BCM) bite frequency with the IceTag® annotation of the same sequence we could estimate a threshold for the amount of bites per minute showing grazing behaviour of approximately 20 (0.3 Hz).

Verifying results from BCM with IGER

For the second analysis, the manual bite counts were registered the same way as in experiment 1, however with millisecond resolution. The time for the first and last time stamp of the manual count intervals was used as reference for the proposed method, and the IGER units. Results for comparing IGER and BCM with manual counts are presented in Table 1.

Table 1. Manual observations and computations of bite count using accelerometers and the IGER bite/chew counter

| | bite count | | | | bites per min | | |
|---|---|---|---|---|---|---|---|
| obs.nr. | manual | BCM | IGER | time (s) | manual | BCM | IGER |
| 1 | 83 | 113 | 74 | 152.69 | 32.62 | 44.40 | 29.08 |
| 2 | 104 | 103 | 91 | 144.69 | 43.13 | 42.71 | 37.74 |
| 3 | 87 | 112 | 76 | 138.88 | 37.59 | 48.39 | 32.83 |
| 4 | 44 | 39 | 125 | 112.5 | 23.47 | 20.80 | 66.67 |
| 5 | 91 | 53 | 156 | 130.5 | 41.84 | 24.37 | 71.72 |
| 6 | 133 | 115 | 72 | 135.5 | 58.89 | 50.92 | 31.88 |
| 7 | 111 | 101 | 73 | 136.63 | 48.74 | 44.35 | 32.06 |
| 8 | 18 | 47 | 83 | 76.19 | 14.18 | 37.01 | 65.36 |
| 9 | 107 | 84 | 168 | 133.06 | 48.25 | 37.88 | 75.76 |
| 10 | 105 | 69 | 161 | 133.58 | 47.16 | 30.99 | 72.32 |
| 11 | 61 | 73 | 191 | 144.19 | 25.38 | 30.38 | 79.48 |
| 12 | 84 | 94 | 102 | 143 | 35.24 | 39.44 | 42.80 |
| 13 | 81 | 117 | 92 | 139.94 | 34.73 | 50.16 | 39.45 |
| 14 | 44 | 49 | 94 | 77.81 | 33.93 | 37.78 | 72.48 |
| 15 | 62 | 43 | 115 | 120 | 31.00 | 21.50 | 57.50 |
| 16 | 45 | 45 | 128 | 135.06 | 19.99 | 19.99 | 56.86 |
| 17 | 125 | 103 | mv | 124.81 | 60.09 | 49.52 | mv |
| 18 | 130 | 104 | mv | 134.31 | 58.07 | 46.46 | mv |
| 19 | 72 | 71 | mv | 137.31 | 31.46 | 31.02 | mv |
| 20 | 77 | 77 | mv | 147.44 | 31.33 | 31.33 | mv |

mv = missing value

## Discussion

BCM computes bite frequencies with a mean square error (MSE) of 10 bites per minute compared to the manual counts, where IGER has a MSE of 30 bites per minute. The reasons for IGER not being more accurate might be the lack of selectivity between chewing and biting. The IGER bite count was significantly higher than the estimations of BCM ; 54 bites $min^{-1}$ versus 36 bites $min^{-1}$ (*P=0.001*) with $\alpha$= 0.05

The BCM computed bite frequencies were not statistically different from the manual bite counts (*P=0.81*) where the IGER was significantly different from the manual bite count (*P=0.003*) with $\alpha$= 0.05.

The MSE of 10 bites per minute within the normal range of bite frequency between 30 and 80 seems acceptable, especially considering that by using automatic registration, data is collected for the whole grazing session. In this article only one axis was used in the analysis, with promising results, however, it is desirable for future experiments to examine ways of incorporating information from all three axes to further improve robustness/detail of extracted information and possibly minimize dependence on exact mounting position.

## Conclusion

Accelerometers attached to the neck collar of cows can be used to estimate total bite count per cow per day with a moving average error of 10 bites per minute. Considering this was achieved using simple 3D sensors that are easy to attach, with relatively long battery life, accelerometers provide a feasible method for long term monitoring of cattle bite count. In addition, grazing time per cow per day can be computed using total bite count and a threshold value of 20 bites identified movements per minute as minimum.

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## Application of a rumination sensor to detect the temperature influence on the rumination activity of dairy cows

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### Abstract

Rumination is a typical characteristic of cattle and an essential requirement to ensure the physiological process in the forestomach system.
The aim of the study was to evaluate the rumination activity of a group of cows and of some individual cows using the system RuminAct™ (Milkline, Italy) at the Frankenforst research station of Bonn University. Furthermore climate effects on the rumination activity of dairy cows were investigated.
The research on the temperature influence on the rumination activity indicated that in a warm period some cows reacted with a significantly reduced daily rumination time. For other cows, however, no relationship between the daily rumination time and higher temperatures was found.

**Keywords:** dairy cow, sensor technique, rumination, climate effect, heat stress

### Introduction

Increasing milk production, and the associated rise in heat production of the animal, leads, especially in high-producing dairy cows during summer months to a reduced ability of heat emission. This heat load induces a decreased well-being of the cows and is expressed in a reduced feed intake, abated milk production, poor fertility and a weakened health status (Heidenreich *et al*., 2004). Furthermore the rumination activity of the cow may be influenced by a changed lying and standing behaviour. All these effects may have an economical effect for the farmer. Up to now the extent of the reaction and the influence of individuality are not clarified.

The quantification of rumination activity generally takes place by measuring the daily rumination time. Over the last 60 years different technical instruments have been developed to measure the rumination activity of sheep, goats and cows (cf. Balch, 1958; Nagel *et al*., 1975 and Kaske *et al*., 2002).
The aim of the study was to evaluate the rumination activity of dairy cows with the aid of the RuminAct™ system by Milkline (Podenzano, Italy). As well as the general rumination behaviour the influence of the environmental temperature on the rumination activity of dairy cows was measured.

## Material and Methods

The research took place in the cow barn of the Frankenforst research station of Bonn University. The herd consisted of 60 German Holstein cows, which were housed in a two-row open free stall barn with 30 computer-controlled feeding troughs, 4 water troughs and 2 concentrate feeders (Insentec B.V., Marknesse, the Netherlands). The average milk yield for the year 2011/2012 was 10,285 kg milk, with 4.1% fat and 3.4% protein.

The recording of the rumination activity was performed using the RuminAct™ system (Milkline, Podenzano, Italy). The rumination sensor (HR-Tag) included a microphone which detected the rumination sounds of the cow. Schirmann *et al*. (2009) validated the sensor by comparing the measured values of the sensor with the counted values of two observers. In trial 1 the correlation between the two observers and the system was $r = 0.96$ ($n = 15$, $P < 0.001$) and in trial 2 the correlation was $r = 0.92$ ($n = 36$, $P < 0,001$).

The identification unit used to read out the data was placed between the milking parlour and the barn. Each cow passed the unit twice daily after milking. Data storage was done in 2-hour intervals for 22 hours. Due to the need for a twice daily readout dry-off cows could not be included.

For this study the data of air temperature and the air humidity was measured every 10 minutes at a height of 2 m by a Campbell climate station. Furthermore the daily maximum and minimum temperature were stored.

To evaluate the influence of the air temperature on the daily rumination time, the maximum daily temperature from 10.02.2012 to 19.08.2012 and the average daily rumination time were used. For a comparison of the rumination time of 2 hours with the environmental temperature three temperature periods were chosen to evaluate the reaction in a thermoneutral period (cf. Heidenreich *et al*., 2004; Hoy *et al*., 2006) and in two warm periods (Tab.1).

Table 1: Temperature periods ‘thermoneutral’, ‘warm I’ and ‘warm II’, maximum daily temperature and maximum daily air humidity

| Period thermoneutral | | | Period warm I | | | Period warm II | | |
|---|---|---|---|---|---|---|---|---|
| Date | Maximum temperature | Maximum air humidity | Date | Maximum temperature | Maximum air humidity | Date | Maximum temperature | Maximum air humidity |
| 20.04.2012 | 14.1 °C | 63.3% | 25.07.2012 | 27.8 °C | 55.0% | 14.08.2012 | 26.2 °C | 62.6% |
| 21.04.2012 | 10.9 °C | 69.1% | 26.07.2012 | 29.2 °C | 59.4% | 15.08.2012 | 29.8 °C | 57.3% |
| 22.04.2012 | 11.8 °C | 69.8% | 27.07.2012 | 29.2 °C | 62.5% | 16.08.2012 | 25.6 °C | 64.6% |
| 23.04.2012 | 12.7 °C | 65.6% | 28.07.2012 | 32.6 °C | 68.4% | 17.08.2012 | 28.2 °C | 56.0% |
| 24.04.2012 | 11.8 °C | 73.0% | | | | 18.08.2012 | 32.4 °C | 49.0% |
| 25.04.2012 | 13.1 °C | 71.8% | | | | 19.08.2012 | 36.3 °C | 47.7% |
| 26.04.2012 | 14.4 °C | 64.4% | | | | 20.08.2012 | 27.9 °C | 64.7% |
| | | | | | | 21.08.2012 | 28.7 °C | 70.6% |

## Results and Discussion

On herd average there was no clear tendency concerning the reaction towards higher temperatures. For this reason an individual animal monitoring was performed.

Figure 1 presents the relationship between the maximum daily temperature and the daily rumination time of cow no. 44. With increasing temperature the daily rumination time is decreasing, but with a high variation in the measurement readings.

The inter-individual variance between the animals is high. This is shown in figure 2, in which the relationship between daily rumination time and daily maximum temperature is shown for cow no. 51. For this cow there is only a poor correlation between the two visible parameters.

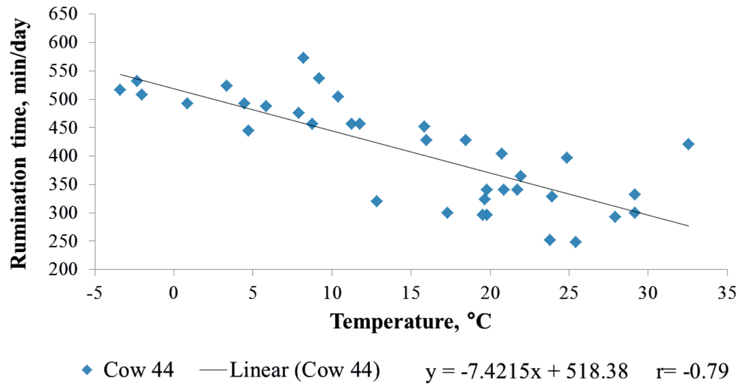


Figure 1: Cow no. 44 – Relationship between the daily rumination time and the maximum daily temperature

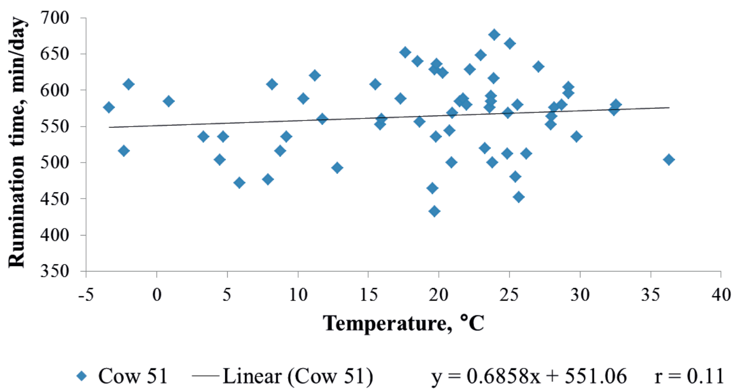


Figure 2: Cow no. 51 – Relationship between the daily rumination time and the maximum daily temperature

In addition to the relationship between the daily rumination time and the daily maximum temperature, the influence of different temperature periods on the rumination time in minutes per 2 hours was measured. It was evaluated whether the different temperature periods would shift the rumination activity during the course of the day.
Figure 3 shows the curve progressions of the rumination time of cow no. 44 in different temperature periods. A comparison of the rumination time during the thermoneutral period with the rumination time during the period ‘warm I’ reveals that on days with higher temperatures (max. 32.6°C) the rumination time was lower than on colder days (max. 14.4°C). A decrease in the rumination time is particularly visible in the warm noon time. In the time period ‘warm II’ just a slight reduction in the rumination time can be registered and the curve progression is more similar to the curve progression in the thermoneutral period.

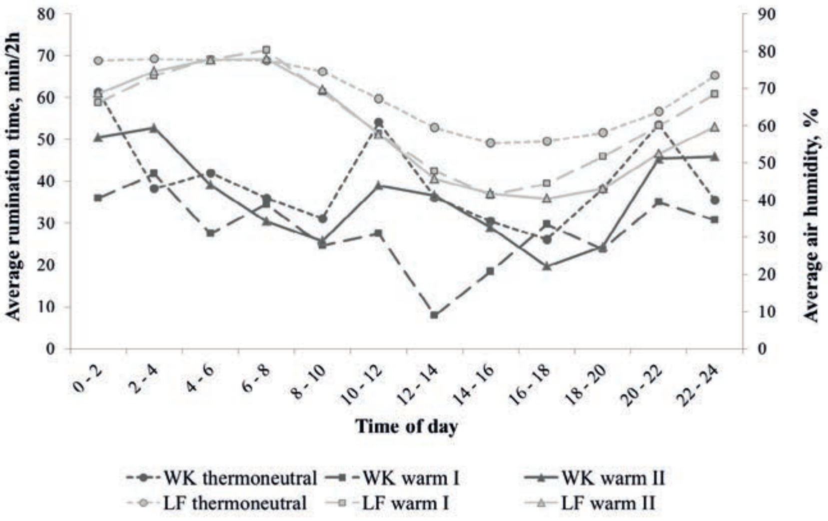


Figure 3: Cow no. 44 – Relationship between the average rumination time (WK), the temperature ranges and the humidity (LF) in the ‘thermoneutral’, ‘warm I’ and ‘warm II’ periods.

Heidenreich *et al.* (2004) identified that not only high temperatures indicate a heat load in the animal. The air humidity is another critical parameter that influences the temperature perception. Since the course of the average air humidity was similar in periods ‘warm I’ and ‘warm II’, the air humidity cannot be used to identify the differences of the average rumination time in these periods.
It was assumed that, in particular, cows with similar rumination times per day in the thermoneutral and warm periods show a kind of compensation effect in the night hours. Therefore, the different temperature periods were also considered for cow no. 51 but did not show a significant correlation between the daily rumination time and the maximum daily temperature.

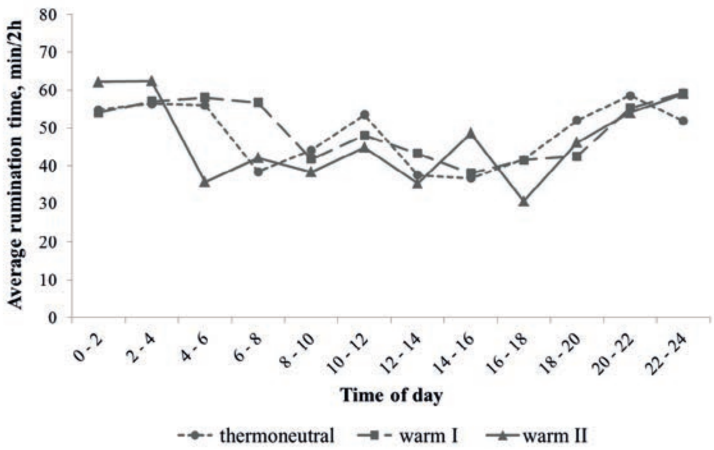


Figure 4: Cow no. 51 – Relationship between the average rumination time and the temperature ranges ‘thermoneutral’, ‘warm I’ and ‘warm II’

Figure 4 shows the relationship between the average rumination time and the different time periods for cow no. 51. Also in this approach no significant correlation between the rumination activity and the air temperature could be identified. The hypothesis of the compensation effects in the night hours could not be verified.

## Conclusions

In this study there were no definite results concerning the correlation between the environmental temperature and the rumination activity of cows. In summary, there were high individual differences between the cows that might be interpreted when including more influencing parameters such as milk yield, feed consumption and animal health status. The apparently stable cows especially will be the focus of the next studies concerning their reaction to environmental temperature.

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## Characteristics of rumination behaviour around calving

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### Abstract

The detection of rumination behaviour serves multiple purposes in feeding and herd management of dairy cows and can be recorded with non-invasive methods. The process of calving is a major event for cows and knowledge of alterations in behavioural patterns of animals in the time around calving is of great importance for a detailed understanding. The objective of this study was to describe the changes of rumination patterns in dairy cows in the 24-h period before and the 24-h period after parturition in comparison to a reference period. Altogether 17 cows were fitted with ART-MSR rumination sensors, able to monitor rumination time (rt), number of rumination boli and number of rumination jaw movements (rjm). Most obvious differences concerning decreased rumination time were found in the 6 h before and in the 6 h after parturition. Rumination time returned to base level in the second part of the 24-h period following parturition. The number of rjm and boli per day was reduced on the 24-h period postpartum. Rumination rate, which is number of rjm per rumination minute (rm), and the number of boli per rm did not change around calving. Cows stopped ruminating 122.9 +/- 58.2 min before calving and restarted ruminating 355.1 +/- 193.9 min afterwards. The results underlined that rumination behaviour was altered in the hours around parturition.

**Keywords:** rumination behaviour, calving, sensor, boli, jaw movements

### Introduction

A detailed knowledge about alteration of animals behaviour or physiology around calving helps to identify time periods with a special need for observation. An improved understanding and monitoring of these periods can enhance welfare and economy of cows (Goff & Horst, 1997). In literature, a decrease in dry matter intake (DMI) is reported for dairy cows in the week before parturition (Bertics *et al*., 1992). Furthermore, the days around calving are characterised by decreased feeding time and increased number of standing bouts and standing time (Huzzey *et al*., 2005). A detailed description of

typical behaviour patterns of cows in the first stage of labour is given by Wehrend *et al.* (2006). Generally, calving events are considered as worthwhile incidences for an automated monitoring to reduce disturbed parturitions and resulting health disorders (Mottram, 1997; Soriani *et al.*, 2012). Automatic monitoring of cows increased in research and farm practice during recent years both during lactation (e.g. Brandt *et al.*, 2010, Melfsen *et al.*, 2012) and in the calving period (e.g. Cangar *et al.*, 2008). Up-to-date, only sparse data describe the effects of calving on rumination activity. Bar and Solomon (2010) reported a decrease in daily rumination time by around 255 min during the day of calving. Similar results were derived by Soriani *et al.* (2012) who found a clear reduction of daily rumination time in the days close to calving. In addition, rumination time is described as a possible indicator for detection of calving events (Soriani *et al.*, 2012). Nevertheless, no further aspects of rumination behaviour around calving in a higher temporal resolution than one day have been specified yet.
The objective of this study was to evaluate several automatically recordable aspects in rumination behaviour of dairy cows in the 24 h before and after parturition and to identify characteristic variations.

## Material and methods

The research study was conducted at the federal state research farm LVZ Futterkamp (chamber of agriculture Schleswig-Holstein, Germany). The farm milked around 190 German Holstein cows with an average herd yield of 10.700 kg milk/305 d (3.9% milk fat and 3.2% milk protein) during the trial period. Data recording was scheduled between March and May 2012.

### Animals, housing and feeding

The rumination behaviour of 17 cows around parturition was monitored. The cows were housed in a freestall barn during the dry period until approximately two weeks before expected calving. At this point of time, cows were relocated to maternity pens which in this case were straw-bedded pens with a size of 20 $m^2$. Cows were separated when physiological signs indicated imminent parturition at the latest. During their stay in the maternity pen cows were fed total mixed ration (TMR) ad libitum. Fresh ration was delivered once a day at approximately 0600 h, pushed up throughout the day and refilled if necessary to ensure ad libitum supply.

### Calving event

Birth was monitored and documented by the farm staff. A calving event was regarded as finished when both back legs were outside the cow ("time of calving"). Calving events were classified as easy (0, no help), medium (1, slight help) and difficult (2, mechanical help). Calves were left with the cow for some hours after parturition but were separated before the first milking time postpartum at the latest. Cows stayed in the straw boxes to recover for a few days and were moved to the lactating herd when having no apparent health problems.

Rumination Recording

The collection of rumination data was done with four ART-MSR rumination sensors (Agroscope Reckenholz-Tänikon, Switzerland). Cows were equipped with a rumination sensor as soon as their physiological constitution indicated upcoming parturition in the next few days. Sensors were taken off when cows left the maternity pen. The rumination sensors consisted of a noseband sensor and a Modular Signal Recorder (MSR) 145 logger (Nydegger *et al.*, 2010). The logger registered and stored pressure shifts caused by jaw movements of the animal with a frequency of 10 Hz. The evaluation of raw data was performed with R-based software. Resulting rumination and feeding characteristics of the data classification were: rumination time (rt), number of rumination boli (rb), rumination jaw movements (rjm), feeding time and number of feeding jaw movements. The two last named feeding characteristics were not taken into consideration for analysis in this investigation.

The duration of the last three rumination periods before and first three periods after the calving events were evaluated manually based on the raw data set. Furthermore, the lengths of breaks between third and second last (antepenultimate break), second last and last rumination period (penultimate break), and last rumination period and calving (ultimate break), and those between calving and first subsequent rumination period (first break), between first and second rumination period (second break) and between second and third rumination period (third break) after calving, were analysed manually. Manual labelling of raw data was done consistently by one analyser.

Statistical Analysis

The recorded rumination characteristics (rt, rb, rjm) were analysed basically in time blocks of 2-h periods. The 2-h period in which calving took place was defined as hour zero and excluded from 24-h periods. The twelve 2-h periods before calving were defined as 24-h period antepartum, the twelve 2-h periods after calving as the 24-h period postpartum. Rumination records preceding the 24-h period antepartum formed an average 24-h reference period. The final analysis of rumination characteristics comprised data of the 2-h periods, as well as data that were summed up and evaluated in 6-h and 24-h periods. The used nomenclature defines on the one hand the starting hour in the 24-h period (i. e. hour 06 is defined either as 42 h before the calving event in the reference period, as 18 h before the calving event antepartum, or 06 h postpartum) and on the other hand the duration of the considered time period, e. g. $12^{6h}$, in this case meaning the time between hour 12 and 18 of the concerning day. The program used for statistical analysis was PASW 18.0 (IBM).

## Results

Reference period

Mean daily rumination time of the cows was in average 397 min with a standard deviation of 86 min (Table 1). In average, 481 +/- 124 rumination boli and 28,874 +/- 7,915 rumination jaw movements per cow per 24 h were masticated. The rumination time varied during the day whereby most cows ruminated less during morning and above average during night time. A diurnal minimum and maximum was calculated based on the lowest and highest values for rumination time per 2 hours per cow, respectively. It averaged 12.0 +/- 8.9 in diurnal minimum and 55.7 +/- 15.9 min in diurnal maximum (Table 1).

Table 1: Mean values and standard deviation (SD) of rumination characteristics per cow during reference period, 24 h antepartum and 24 h postpartum

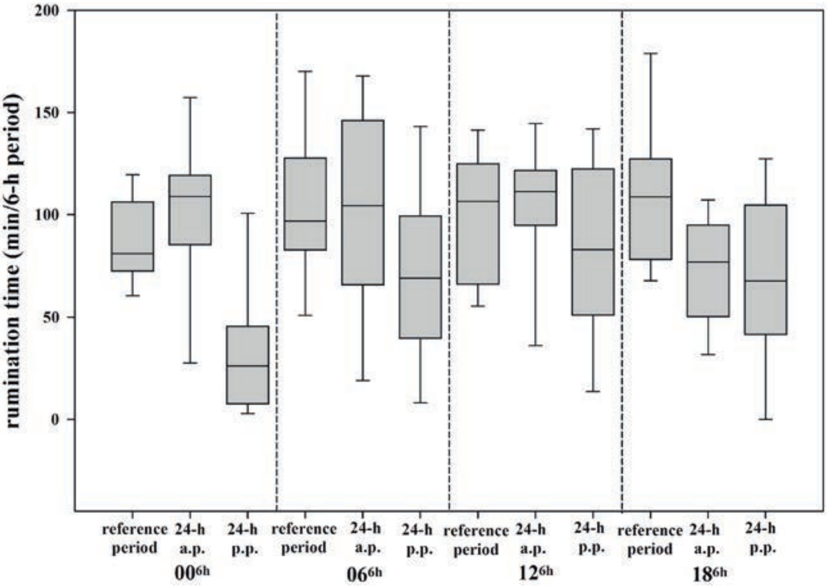
| Rumination characteristics | Rumination time (min) | | | Number of boli per rm[1] | Number of rjm[2] per rm |
|---|---|---|---|---|---|
| Selected time period | mean<br>24 h | minimum<br>2 h | maximum<br>2 h | mean<br>24 h | mean<br>24 h |
| 24 h reference period | 397[a]<br>+/- 86 | 12.0[a]<br>+/- 8.9 | 55.7[a]<br>+/- 15.9 | 1.28[a]<br>+/- 0.16 | 71.04[a]<br>+/- 4.80 |
| 24 h antepartum | 374[a]<br>+/- 110 | 5.3[a]<br>+/- 5.7 | 58.0[a]<br>+/- 17.2 | 1.44[a]<br>+/- 0.80 | 71.79[a]<br>+/- 5.95 |
| 24 h postpartum | 278[b]<br>+/- 64 | 0.6[b]<br>+/- 1.0 | 52.7[a]<br>+/- 23.9 | 1.48[a]<br>+/- 0.45 | 72.49[a]<br>+/- 4.93 |

[a,b] different indices indicate significant differences for cows with consistent data during all three 24-h periods within one column (Friedman-test, $p < 0.05$)
[1] rm = rumination minute; [2] rjm = rumination jaw movement

Period 24 hours antepartum

The reference period and the 24-h period antepartum did not differ with regard to daily rumination time, number of boli per day or number of rjm per day. The same issue accounted for number of boli per rm and number of rjm per rm (Table 1). Subsequent comparison of the four 6-h periods before calving, however, revealed a decrease in rumination time from period $12^{6h}$ to period $18^{6h}$, i. e. in the 6-h period directly before calving (Wilcoxon-test, p = 0.004; Figure 1). In addition, the rumination time in period $18^{6h}$ antepartum was lower than on the corresponding 6-h period in the reference period (Wilcoxon-test, p = 0.006; Figure 1).

Figure 1. Rumination time per 6-h period ($00^{6h}$; $06^{6h}$; $12^{6h}$; $18^{6h}$) during reference period, and periods antepartum (24-h a.p.) and postpartum(24-h p.p.)




Number of boli per rm was not changed on any of the 6-h periods when comparing reference period and 24-h period antepartum.

A closer look on the last three rumination events (Table 2) showed in tendency a decrease of the length of the ultimate rumination period before calving and an increase of the ultimate break. The break between the last rumination period and calving tended to be longer than the two preceding breaks ($p = 0.059$, Table 2). In average 122.9 min passed between the end of the last rumination period and the calving event (Table 2). The last rumination period before calving was in average approximately 10 min shorter than the others, although the difference was statistically not significant. In nine cows the penultimate rumination period was longer than the ultimate rumination period, in eight cows the ultimate rumination period was longer than the preceding period.

Table 2. Average duration and SD of last three rumination periods and the last three breaks in ruminating before parturition

| | Antepenultimate event | Penultimate event | Ultimate event |
|---|---|---|---|
| Length rumination period (min) | $33.5^{a}$ +/- 19.1 | $32.9^{a}$ +/- 16.8 | $22.3^{a}$ +/- 12.5 |
| Length break (min) | $84.9^{a}$ +/- 54.8 | $81.3^{a}$ +/- 43.0 | $122.9^{a}$ +/- 58.2 |

$^{a,b}$ different indices indicate significant differences within one row (Friedman-test, $p < 0.05$)

Period 24 hours postpartum

Daily rumination time was clearly reduced in the 24 h after calving (Friedman-test, $p = 0.034$; Table 1) compared to the reference period. Likewise, a significant reduction was found for number of boli per day (378 +/- 130 boli per day; Friedman-test, $p = 0.008$) and number of rjm per day (20,958 +/- 5,945 rjm per day; Friedman-test, $p = 0.014$) but not in case of rjm per rm or boli per rm (Table 1). Rumination time increased clearly from period $00^{6h}$ to period $06^{6h}$ (Wilcoxon-test, $p = 0.009$; Figure 1). Nevertheless, rumination time in period $00^{6h}$ (Wilcoxon-test, $p = 0.008$) and in period $06^{6h}$ (Wilcoxon-test, $p = 0.021$) postpartum were both still lower than during the reference period. An increase in number of boli per rm was found from period $12^{6h}$ to period $18^{6h}$ (Wilcoxon-test, $p = 0.012$) although the number of boli per rm calculated in 6-h periods for the 24-h period postpartum did not differ from those of the reference period.

The first rumination period after parturition was shorter than the third rumination period postpartum (Friedman-test, $p = 0.012$). On average it took 355.1 min until cows restarted ruminating after having given birth to the calf (Table 3). Length of break per cow between calving and first rumination period after calving ranged from 42 min to 726 min. As a consequence the first break postpartum was longer than all other considered breaks (Table 3).

Table 3. Average duration and SD of first three rumination periods and breaks in ruminating after parturition

| | First event | Second event | Third event |
|---|---|---|---|
| Length rumination period (min) | $24.6^{a}$ +/- 26.8 | $27.8^{a,b}$ +/- 19.3 | $30.8^{b}$ +/- 12.6 |
| Length break (min) | $355.1^{a}$ +/- 193.9 | $90.4^{b}$ +/- 143.6 | $60.3^{b}$ +/- 34.3 |

$^{a,b}$ different indices indicate significant differences within one line (Friedman-test, $p < 0.05$)

## Discussion

Period 24 hours antepartum

Dairy cows obviously change their behaviour in the days resp. hours before and after calving. Bertics *et al.* (1992) found a decrease in feed intake of nearly 30% in the last week before parturition. Rumination time declined in the last days antepartum (Bar and Solomon, 2010; Soriani, *et al.*, 2012) and the extent of decrease in rumination time on the day of calving is supposed to be more than half when compared to the dry period (Soriani *et al.*, 2012). Miedema *et al.* (2011) compared changes in the behaviour of cows in the 24 h before calving with behaviour in late pregnancy. The last 24 h before calving were characterised by increases in lying frequency, walking frequency and tail raising frequency (Miedema *et al*., 2011). The significant shifts in those behaviours were found in the last six hours before calving and in addition a decrease in eating time was described by Miedema *et al*. (2011) in the same time period. These alterations in behaviour characteristics during the six hours before calving are in temporal accordance with the decline in rumination activity during the last 6-h period antepartum in the presented study. The decrease in rumination time was primarily based on a change in rumination behaviour in the last four to six hours antepartum. In general rumination time and lying time are correlated positively (Schirmann *et al*., 2012). Despite an increased lying time in the two hours before calving (Jensen, 2012), the reduced rumination activity in this time period and in the 2-h calving period found in the current study is not surprising because of cows’ calving preparations. An increased number of lying bouts with decreased lying durations might show discomfort and could be interpreted as restlessness. An increasing level of restlessness, interpreted as stress, could provide a possible explanation for reduced rumination activity because stress can have a negative impact on rumination activity (Herskin *et al*., 2004).

Period 24 hours postpartum

Rumination time, number of rjm and number of boli were reduced in the 24-h period after calving when compared to the reference period. Rumination time of cows was basically decreased in the first twelve hours after parturition and increased in the second part of the 24-h period postpartum. Jensen (2012) analysed the behaviour of dairy cows around parturition. When calves were left with the cows the highest level of interaction between cow and calf was found in the first hour after calving. Within the first 6-h period postpartum the amount of interactions decreased with increasing time-lag to calving. The opposite was found for lying and feeding time of cows which were lowest in the first hour after calving, and then increased clearly in the hours two to six after calving (Jensen, 2012). In the present study cows and calves were separated before the first milking time of cows postpartum at the latest. Cows started their first rumination period on average 355.1 +/- 193.9 min after calving. The presence of the calf and thereby interaction between cow and calf might have had a considerable impact on the restart of rumination. The shift in behaviour of cows in the hours after calving offers an approach for explaining the reduced rumination activity in that time period. The combination of results from Jensen (2012), observing a reduced lying time and restlessness in the first six hours after calving, and Schirmann *et al*. (2012), who found positive correlations between rumination and lying time, could give another reason for the decrease found in rumination time after calving.

## Conclusions

In this study, rumination characteristics (rt, rjm, number of boli, number of boli per rm, rjm per rm) around parturition on the one hand and length of rumination periods and breaks around calving on the other hand were evaluated. Results showed that cows stopped ruminating in average two hours before and restarted ruminating approximately six hours after calving. Rumination activity was reduced significantly in the hours around parturition but was not in all cows quitted completely. Other rumination characteristics, namely boli per rm and rjm per rm hardly changed in the time period around calving.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## A novel method of calculating a SARA index by wireless rumen pH telemetry

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### Abstract

The wireless rumen pH telemetry bolus has been used in research in fistulated animals since 2005 where the requirement is high accuracy and raw data output. Commercial farmers require information to make management decisions, usually about dietary constituents. This paper describes the construction and use of a Sub-Acute Rumen Acidosis (SARA) index combining the mean daily value, the evenness of the daily profile, the lowest pH values in the period and the depth of drop in pH after a meal. Boluses were placed in two cows in a commercial farm in May 2012 each in a group of 60 cows and data downloaded by wireless every 28 days at afternoon milking for five months. The cows were fed a Total Mixed Ration (TMR) for average group yields of 11000 litres per 305 days. Reticulum pH rarely fell below 5.8 and the usual daily range was 0.5 pH units usually above 6.45, well clear of the SARA range. The bolus data were used to rule out acidosis 35 days post partum in contra-indication to dung analysis. At 110 days the SARA index registered high risk and subsequent analysis showed SARA was present in the group and feed was adjusted accordingly. A trial using 60 boluses on ten farms is in progress in 2013 to evaluate the decisions and resultant outcomes that different farmers make with bolus information.

### Introduction

Reports of rumen wireless telemetry pH measurement boluses used in research have been available since Mottram *et al.* 2008. However, there have been no reports of the use farmers and their advisers make of rumen pH and temperature data. Existing methods for detecting SARA in commercial cows are based on either rumenocentesis or through use of a sampling tube (Tajik & Nazifi, 2011). Both methods are invasive and can only gain one data point from an unknown location within the rumen whereas the rumen pH is highly variable in time with up to 2.5 pH range through the day and varying spatially up to 0.5 pH units from top to bottom within the rumen (Gasteiner et al 2008) . The wireless telemetry bolus is intended to replace these crude techniques with a continuous recording of data from a fixed location within the rumen-reticulum thereby overcoming the variability in data. The pilot study described here had the intention of both checking the operability of the bolus in farm conditions and the use the farmer and his nutritionist made of the data.

## Materials and methods

The boluses used were the eBolus from eCow Ltd. The eBolus is 115mm long by 26.5 mm diameter weighing 200g. The sensor end is made of stainless steel which inverts the bolus into a normally sensor down position in cows with a normal shaped reticulum. The electronics is encapsulated with a cold poured resin coat that has proved resilient against rumen liquor in trials and obviates the need for vulnerable seals. The sensor is a combined electrode pH probe routinely used in applications in industry. The temperature probe is embedded in the stainless steel end cap, which has machined holes to allow rumen liquor to flow past the sensor tangentially without permitting direct impact of stones or grit on the glass sensing bulb.

Figure 1: An eBolus ready for deployment

The weight of the bolus allows it to remain in the reticulum for the life of the cow. The bolus contains no toxic materials at doses harmful to the cow. The bolus measured pH and temperature every 60 s and took an average value every 15 minutes and stored up to 2700 lines of data in a .csv format date, time, pH, temp, battery V, which at 96 lines of data per day stored over 28 days of data. If data was not collected the file on the bolus was overwritten from the beginning.

The bolus is administered by mouth with a standard bolling gun, the only restriction on operation is that a period of 2 hours should be allowed for it to migrate to the reticulum. The bolus has a temperature switch which causes it only to activate when the temperature is above 31C, this enables a long shelf life of 2-3 years. As with all pH sensors the device needs to be calibrated before use and the calibration is accurate for four weeks in normal storage. Once in the cow drift is less than ±0.1 pH unit per 30 days. The radio frequency used is in the free to use ISM band, in this study we wanted to compare the utility of two available frequencies 433 MHz and 868 MHz and identify any operational issues with the different frequencies.

In this study two boluses were inserted into two fresh calved commercial cows on 28th May 2012. The herd of 170 cows averages 34 litres per day through the year on a wholly housed system with total mixed ration (TMR) system based on maize and grass silage with additional straights feeds. Data was downloaded onto a tablet computer every 28 days at afternoon milking until January 2013.

## Results and Discussion

The data exhibited the classic saw tooth profile of the diurnal feeding and ruminating cycle and the raw data for one cow are presented in Figure 2.

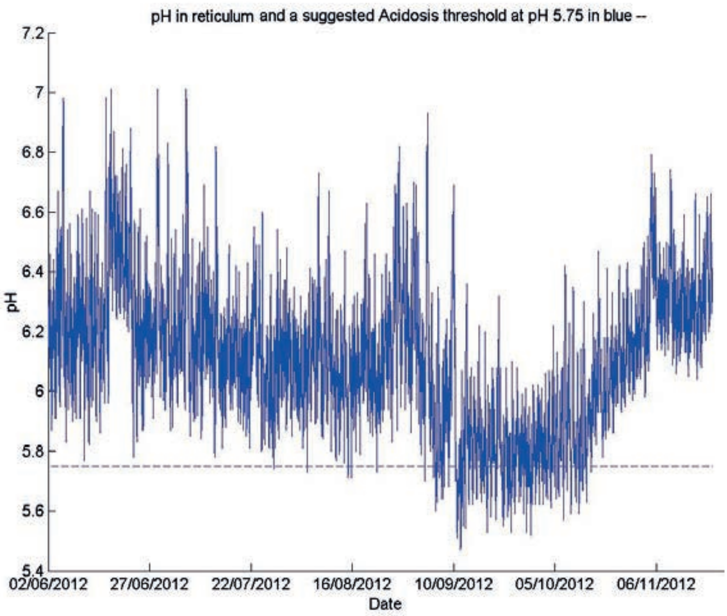


Figure 2: A continuous profile of rumen pH for 150 days in a cow in 2012

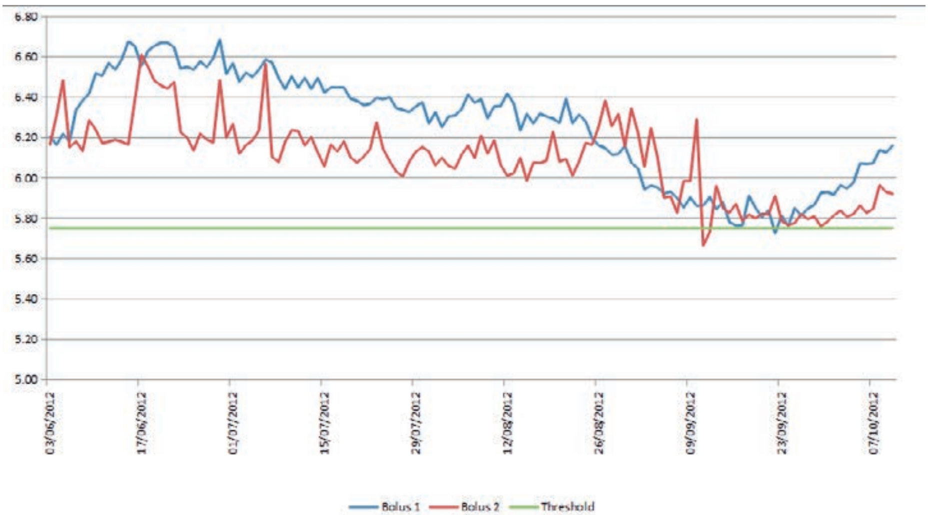


Figure 3: The mean daily profile recorded from boluses in two commercial cows for four months in 2012

The mean daily plot for both cows are displayed on the same time line in Figure 4. The two cows were in different groups until September. The cow with bolus 2 suffered from some mastitis infections in June and this may have caused the sudden spikes in rumen pH when she may have been eating less. In June the herd manager believed his cows were suffering from SARA and reduced the concentrate feed – hence the rise in pH in this period. After the data for June was presented the diagnosis of SARA was questioned and the silage was found to have a mycotoxin contamination and feeding was changed, leading to a stabilisation of milk proteins and increased yield. As the summer progressed the mean pH slowly reduced until the cows became at risk of SARA indicated by the threshold of 5.8 pH units. The feed was adjusted and the rumen pH recovered.

The data was processed to create an acidosis index by combining four main parameters.

- The mean daily profile
- The flatness of the daily feeding profile
- The time below pH 5.8
- The depth of drop after a feed

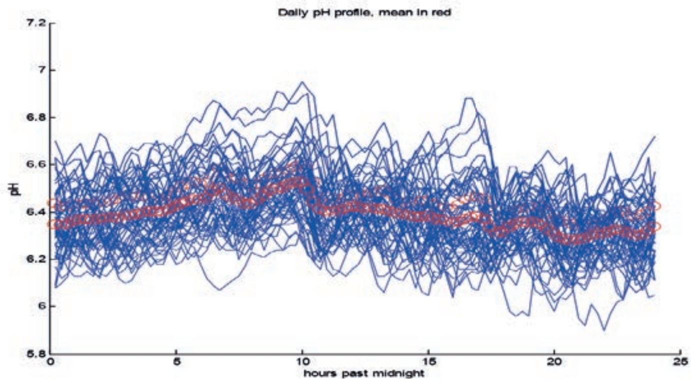


Figure 4: The mean daily feeding profile was built up by overlaying the data for each day. The flatter the curve the better. This one normally ranges by only 0.2 pH units.

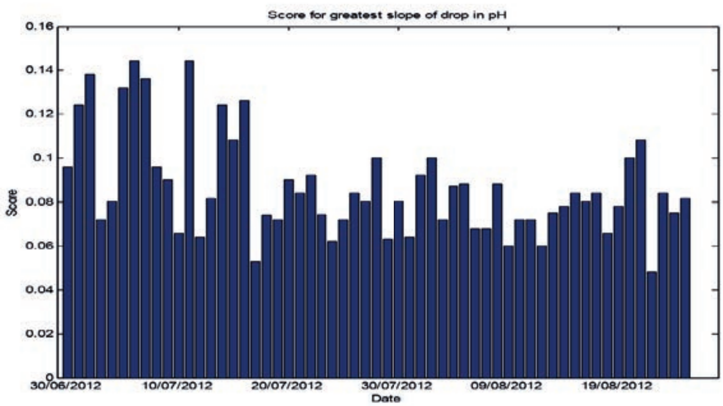


Figure 5: An element of the index based on the depth of drop after a feed

The temperature sensor gave a useful indicator of drinking activity. The summer was not hot at the farm and variations of drinking behaviour are due to factors such as access to water.  The average number of drinks was 6 per day.

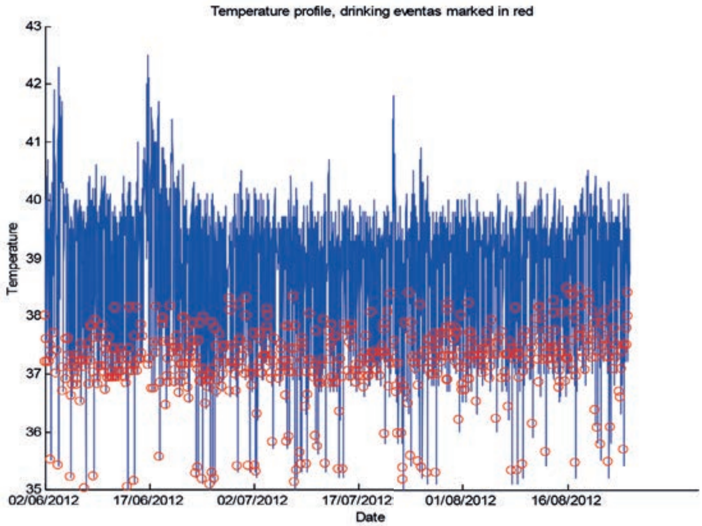


Figure 6: Drops in temperature indicate drinking, temperatures above 40C indicate infections

The data are aggregated together to produce an index on a per cow basis.

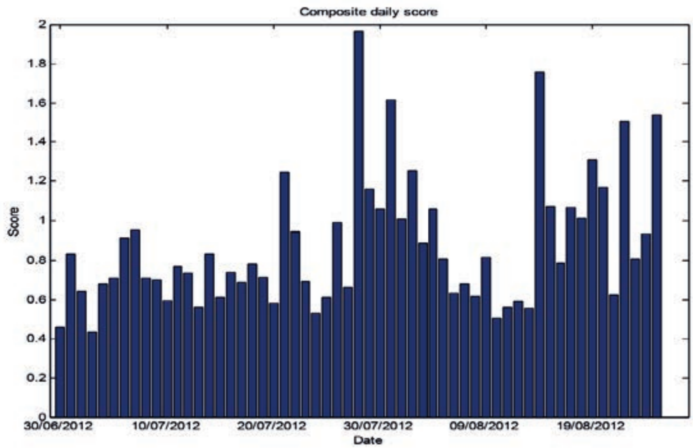


Figure 7: Agregated index indicating the increasing risk of SARA during summer 2012

Data continued to be downloaded from the boluses within the cows until  January 2013 some 7 months after insertion.  However, inspection of the data received after November 2012 indicated that the sensor was no longer functioning across the expected range and we concluded that the electrodes had become contaminated after over150

days in operation. Due to the pilot study nature of this trial data was collected at 28 day intervals, however, for better response to nutritional change daily or weekly checks would be preferable.
The signal from the bolus transmitting at 433 MHz could be read at 5 m from the cow and it became normal to download from this cow in the milking parlour pit. The signal from the 902 MHz bolus could only be read from 1-2 m and it was necessary to hold the cow in a stall for consistent downloads.

## Conclusions

These results indicate that a rumen pH measurement bolus can be used in a rational manner to maintain rumen pH above a level where SARA is indicated in high yielding dairy cows. The boluses gave accurate data for over 150 days. The 433 MHz frequency gave better transmission from the cow than 902 MHz, unfortunately this frequency is only legal in some parts of the world. In 2013 a larger trial will be conducted with 60 boluses on 10 farms with a variety of diets with weekly data downloads. We propose that the combination of measures of rumen pH are a better indicator of risk of SARA than crude thresholds particularly when captured invasively.

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# Session 17

# Pigs - Sensors

## Individualized on-line monitoring tool to analyse the complex physiological signal of heart beat fluctuations in pigs

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### Abstract

Quantifying and understanding the complex fluctuations of physiological signals is the focus of many research. The complexity of physiological signals reflect the ability of organisms to adapt and function within an ever changing environment. The most studied physiological signal to reflect the autonomic imbalance in cases of disease, chronic stress and impaired welfare, in both human and animals is Heart Rate Variability (HRV). Given the limitations of current HRV analyses, like spectral or total entropy analyses, it is suggested to improve our understanding by decomposing the heart rate fluctuations with a dynamic model, based on a Bayesian approach for time series analysis.
The model consists of three components describing the interbeat-intervals dynamics: (1) level and trend, (2) autoregressive process of order 2 and (3) observation error (white noise). The analysis also detects abrupt changes and slightly growing deteriorations. A dataset with continuous ECG recordings from 2 pigs was analysed. The model decomposed total Heart Rate dynamics successfully in the time domain. So, it was possible to detect abrupt changes and slightly growing deteriorations in RR-interval in terms of the moments of occurrence, the magnitude, the duration and recovery.

**Key words:** Dynamic modelling, Bayesian forecasting, inter-beat interval, heart rate variability, autonomic nervous system

### Introduction

Early detection of alteration in health status is of great importance in farm animals, as early intervention after e.g. infection can minimize symptoms, may shorten the recovery period and diminishes production losses due to disease. Most early warning systems in animals focus on the early detection of disease symptoms or infectious agents. When a certain population of pathogens is present, it is uncertain whether, when and to what extent animals will get ill or how capable the animals are to cope with the present pathogenic load without showing symptoms. This is caused by differences in

the capability to maintain a certain health state under varying conditions.
The complexity of cardiovascular dynamics has been studied as an indicator for autonomic balance or health state. To describe the variations in both instantaneous heart rate and fluctuations in RR-intervals over time, the term that has become conventionally accepted is "Heart Rate Variability" (HRV) (Malik 1996). In both humans and animals, high complexity of HRV is associated with good health and high adaptive capacity. Low complexity of HRV has become a popular marker for autonomic imbalance in cases of disease, chronic stress and impaired welfare (Malik 1996; Goldberger, Challapalli *et al.* 2001; von Borell, Langbein *et al.* 2007) and has gained widespread acceptance as a clinical and investigational tool (Billman 2011).
HRV is usually measured under one of the two common settings: short term measurements under controlled laboratory conditions, or long term measurements derived from 24 hour ECG-recordings made while performing daily activities. The current methods used to describe HRV deliver conventional time domain measures, spectral measures, geometric measures, and a variety of nonlinear variables. Each single variable derived from the different methods reflects a different aspect of HRV. They all show significant associations with physiological outcome or state, but it is still unclear which is the best variable to describe and assess HRV (Kleiger, Stein *et al.* 2005). Therefore, the clinical utility and predictive value of the existing HRV measurements is under discussion, which focusses on (1) the relationship between the autonomic nervous system (parasympathic and sympathic effects) and the descriptive variables of HRV and (2) the substantial variance in HRV within and between normal individuals (Goldberger, Challapalli *et al.* 2001; Peng, Costa *et al.* 2009). It can be concluded that we still lack an effective reconstruction method for the phenomenon of interbeat fluctuations in heart rate, that is characterized by a non-stationary process and a degree of stochasticity (Ghasemi, Sahimi *et al.* 2006).
The goal of this paper is to show the first experiences with an adaptive dynamic model that is able to analyse the non-stationary and non-linear heart rate fluctuations in the time-domain in terms of fast and slow variation. We used the model to analyse time series of ECG recordings (RR-intervals) of 2 pigs to show that it reveals the non-stationary complexity of the cardiac function both in terms of fast and slow variation simultaneously, as well as the detection of the moment of occurrence and extent of changes in its dynamics. Results are presented and it is discussed whether this model can be used in longitudinal on farm settings as an online monitoring tool to detect process disturbances in early stage.

## Materials & Methods

<u>Experimental protocol</u>
Four crossbred pigs (Yorkshire x Landrace) were kept together in a pen with rubber flooring (150 cm wide and 120 cm deep) from 11 days until 86 days of age. Milk replacer

(Sprayfo Pork, Husdyr Systemer as, Mosby, Norge) was provided *ad libitum* with an automatic wetfeeder (Mambo, Husdyr Systemer as, Mosby, Norge). Milk replacer was slowly reduced until the Mambo was removed at 46 days of age. Solid piglet feed (pellets) were available *ad libitum* from the start of the experiment. Water was provided *ad libitum* during the experimental period. The pigs were exposed to a 12h light (6am until 6 pm) - 12 h dark (6pm until 6 am) photoperiod. Temperature was kept at 28$^{o}$ C from start until 35 days, at 25$^{o}$ C until 64 days age and at 24$^{o}$ C until the end of the experiment. Average relative humidity of the air was 55% during the experiment. The pigs had 2 weeks for acclimatization to the housing facility and weaning regime. At the age of 26 days, two of the four pigs were surgically equipped (intra-abdominal) with implantable telemetry transmitters (Data Science International, DSI, St Paul, MN) to record continuously temperature, activity and cardiac activity (ECG) until the end of the experiment. When the pigs were 35 days old, the two pigs without implants were removed from the pen to enlarge individual space. The growth curve of the two pigs with implants was similar to the curves of the animals that did not have surgical treatment. One pig at the time was monitored during 24 hours (weekdays) and 72 hours (weekends). Every day the pens were cleaned and the animals were inspected clinically. During the experimental period no signs of illness appeared..

Data acquisition telemetry system & video recording

The telemetry system (Data Science International, DSI, St Paul, MN, USA) consisted of implantable transmitters with two bio-potential leads (positive and negative) for measuring ECG signal, a temperature sensor to measure body temperature and one blood pressure fluid filled catheter (model TL11M2-D70-PCT; 49 grams, 33cc), a data exchange matrix and receivers (DSI PhysioTel® Receivers - RMC-1 Model for Large Animals). Only the ECG recordings were analysed in this paper. Signal strength between transmitter and receiver was recorded and expressed in a physical meaningless number ranging from 0 to 51 units. No data were recorded when signal strength dropped below 17 units. During the experimental period video recordings were made with a Sanyo (type RC506CH) camera and Samsung SHR-2040 digital recording system of the complete pen during the light period (6am until 6pm). Telemetry data of the implants were collected with DSI Dataquest A.R.T.™ version 4.31. The ECG signal was measured and stored at 1 kHz.

Data pre-processing

The length (time in msec) of the RR-interval was derived from the raw ECG data with the Ponemah Physiology Platform version 5.0 software (Data Science International, DSI, St Paul, MN, USA). Due to weak radio or transfer signal or high noise some R-peaks were incorrectly detected, resulting in extreme RR-intervals ($RR \leq 200$ msec or $RR \geq 700$ msec). These RR-intervals (denoted as extreme RR-intervals), together with sections where no PQRS complex could be detected (denoted as missing RR-intervals), were omitted from the data series. Subsequently, equidistant time series were formed by averaging the RR-intervals per second (further indicated as averaged or observed RR-intervals). Missing values in the time series were replaced by interpolated data and weighted zero in the analysis.

Data selection

From the experiments we randomly selected and analysed one hour of one pig (pig #231 from 15:00 until 16:00 on the 23d of January 2012). For detailed explanation of the Bayesian model for analysis of HRV, two periods of 5 minutes were selected within this hour. The two periods of 5 minutes were selected, one with high and one with low activity of the pig based on the video recordings.

Modelling and analysis

Variation in interbeat intervals was decomposed in three parts:

$$\begin{Bmatrix}\text{interbeat}\\ \text{interval}\end{Bmatrix}=\begin{Bmatrix}\text{level\&}\\ \text{trend}\end{Bmatrix}+\begin{Bmatrix}\text{autoregression}\\ \text{component}\end{Bmatrix}+\begin{Bmatrix}\text{white}\\ \text{noise}\end{Bmatrix}$$

Level and trend represent slow dynamic variation, the autoregression component and the white noise represent fast dynamic variation. The white noise represents the independent random residual error. Figure 1 shows a simulated series of 5 min (=300 sec) illustrating the 3 components of the model.

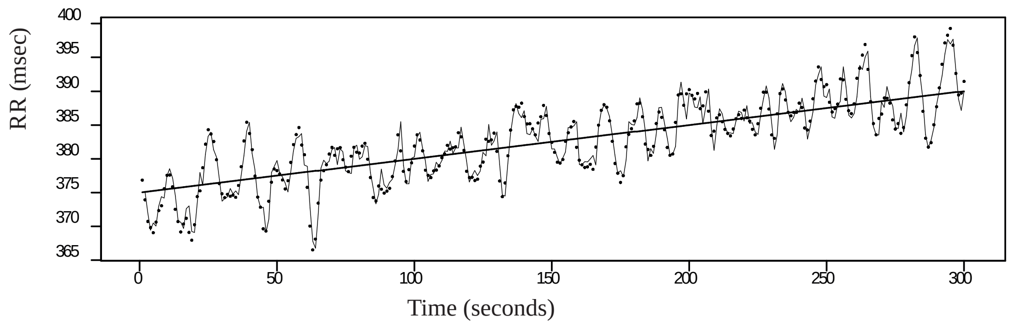


Figure 1: Simulated time series of RR intervals of 5 minutes (300 sec.) showing the 3 components: level and trend (thick straight line); auto-regression component (thin fluctuating line) and white noise scattered around the thin line (points).

A dynamic model was formulated for analysis of the time series of averaged RR-intervals per second $Y_t$ . The dynamic model consisted of an observation and a system equation. The observation equation described the relation between the observation and the parameters:

$$Y_t = \mu_t + Z_t + \nu_t \quad (1)$$

with the parameters: $\mu_t$ (level), $Z_t$ (autoregression, AR2) and $\nu_t \sim N(0, k_t V_t)$ (observation error or white noise, with unknown variance $V_t$ and weight $k_t$ equal to the number of beats per second). The system equations and describe the evolution of the parameters over time:

$$\begin{aligned} \mu_t &= \mu_{t-1} + \beta_{t-1} + \omega_{1,t} \\ \beta_t &= \beta_{t-1} + \omega_{2,t} \end{aligned} \quad (2)$$

$$\begin{aligned} Z_t &= \phi_{1,t-1} Z_{t-1} + \phi_{2,t-1} Z_{t-2} + \omega_{3,t} \\ \phi_{1,t} &= \phi_{1,t-1} + \omega_{4,t} \\ \phi_{2,t} &= \phi_{2,t-1} + \omega_{5,t} \end{aligned} \quad (3)$$

with level $\mu_t$, trend or incremental change $\beta_t$, two autoregression coefficients $\phi_{1,t}$ and $\phi_{2,t}$ with system errors $\omega_{1\ldots5,t}$ normally distributed with zero mean and variance matrix $\mathbf{W}_t$. The dynamic parameters are locally constant and follow a random walk. Two kinds of parameter estimates were achieved: online estimates, which were based on observations from the past only, and retrospective estimates, which were based on all observations from the whole time series. All parameters were recursively estimated following the Bayesian approach to the analysis of time series according to (West and Harrison 1997) including a monitoring procedure followed by automatic intervention to detect process disturbances.

The results describing variation in the time domain were linked to results in the frequency domain. Level and trend corresponded to ultralow frequency variation, the pseudo (or stochastic) cyclic behaviour, described by the autoregression AR(2) component corresponded with low frequency variation and the white noise (or random error) corresponded to the high frequency variation. From the parameter estimates at any point in time the correlogram, spectrum and variances were calculated (Diggle 1990).

## Results and Discussion

Within the complete analysed hour, 147 RR-intervals were indicated as extreme values and left out of this analysis. Out of the 3600 averaged RR-intervals, 3480 intervals were classified by the monitoring routine as normal, 51 as warnings and 69 as outliers. According to the video recordings, between 15:00 and 15:30, the pigs were mostly resting/sleeping. After this period they awoke, stood up and started eating and drinking, at 15:44 the pigs lied down again.

The results of the analysis are shown in figures 2 to 5. Figures 2a and b show the observed (averaged per second) and forecasted RR intervals for the two periods of 5 minutes within the hour. Figure 2a shows the period of 5 minutes in which the pig was mostly resting and figure 2b shows a more active period where the pig was eating, drinking and playing with its pen mate. Even during these short periods a substantial variation in RR-intervals was detected.

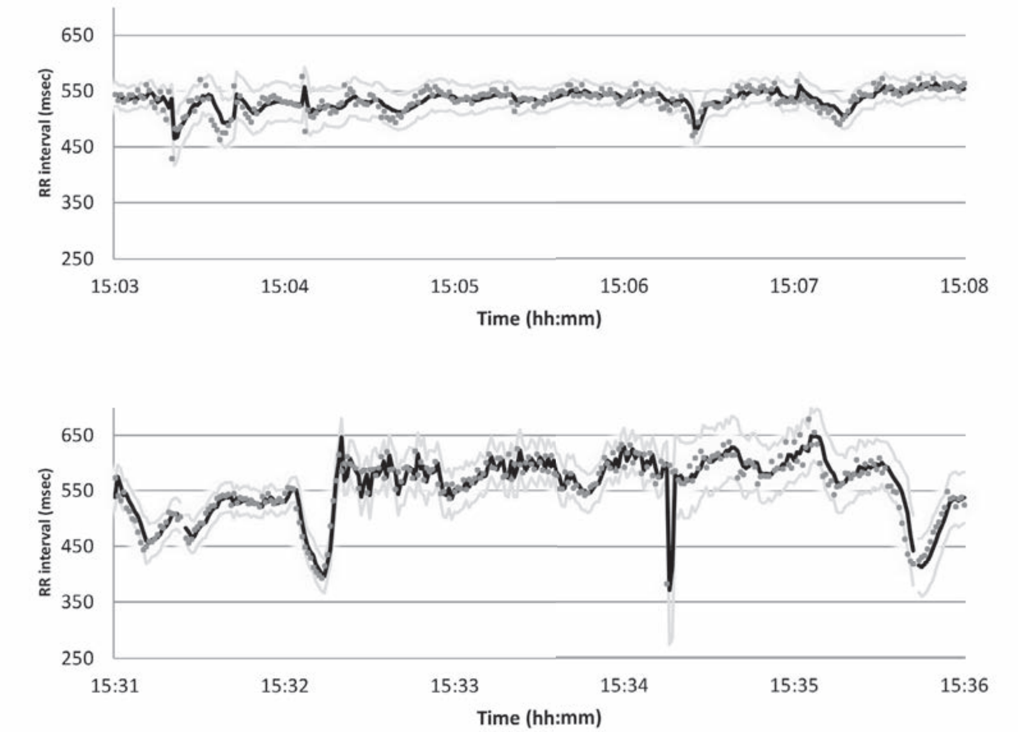


Figure 2a&b Observed and forecasted RR-interval; 2a: Selection of 5 min. period (resting): above and 2b (active): below; observed values (grey points), forecasts (black line), upper and lower level of 90% confidence interval (light grey lines).

Figure 3a and b show the estimated parameters for level ($\mu_t$) and trend ($\beta_t$) for the selected hour, representing the slow changing dynamics. Level was accurately estimated at any point in time. More active periods were described by a shorter RR-interval and changes in level were easily picked up, even sudden changes. Figure 4b shows the trend $\beta_t$. In the first period of the hour, the trend was not significantly different from zero (the confidence intervals were not above or below zero). It resulted in a more or less constant level, which is shown in figure 3a. Only at t=15:36 a significant negative trend was seen, followed by a significant positive trend, which resulted in an temporary reduction of RR-interval. This is the period the pig was active and was detected by a change in level and trend by the model. Thus, the moment of occurrence of changes in trend of RR-intervals were properly detected by the analysis and could directly be related to the behaviour of the animals. Rapid changes (e.g. at t=15:10 and t=15:12) did not result in a change in level or trend. However, the variance of the process increased, which resulted in a larger confidence interval.

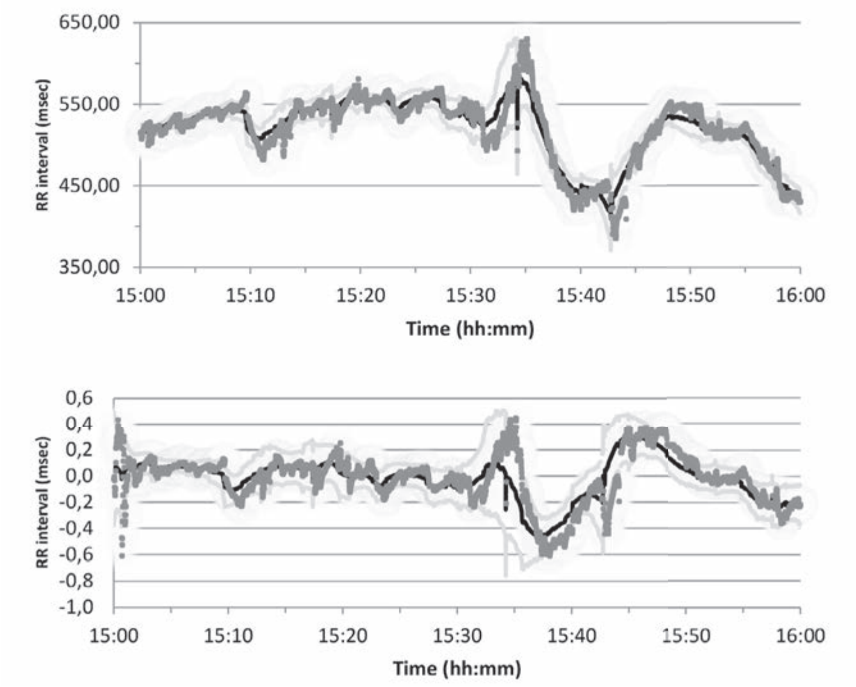


Figure 3a: Estimated level $\mu_t$ (above) and 3b: Trend $\beta_t$ or incremental growth (below); online estimates (grey points); retrospective estimates (black line) incl. 90% confidence interval (light grey lines)

In fig 4a and 4b the parameter estimates that describe the fast dynamics changes are shown. These are the autoregression component $Z_t$ the forecast variance $Q_t$ and observation variance $S_t$ . The variances fluctuated, even during both 5 minute periods. The variances increased, especially after abrupt changes. The two AR-parameters $\phi_{1,t}$ and $\phi_{2,t}$ described the properties of the AR(2)-process, i.e. the shape and rate of decay of random deviations from the base level. In figure 5 $\phi_{1,t}$ and $\phi_{2,t}$ are plotted for both selected periods of 5 minutes.
The AR-process is stable when the AR-parameters lie within the triangle (figure 5). If they lie outside the triangle, the process is unstable and the heart rate will exponentially grow or decline which is physiologically not possible in living organisms. When the AR-parameters lie within the triangle and below the parabola the decay of the deviations follows a decaying cycle, otherwise they follow a decaying curve.

The stochastic cycle during the resting and active period showed different characteristics. It appeared that when the pig was resting, the AR-parameters lied clustered together and more to the left in the upper part above the parabola. In this area, the fluctuations around the base level are characterized by a relatively fast exponential decay (dark grey cluster in figure 5). When the pig was more active, the estimated AR-parameters lied in a strip near to the right side of the triangle (light grey strip in figure 5) where the decay of fluctuations appear to be slower (light grey line in figure 5).

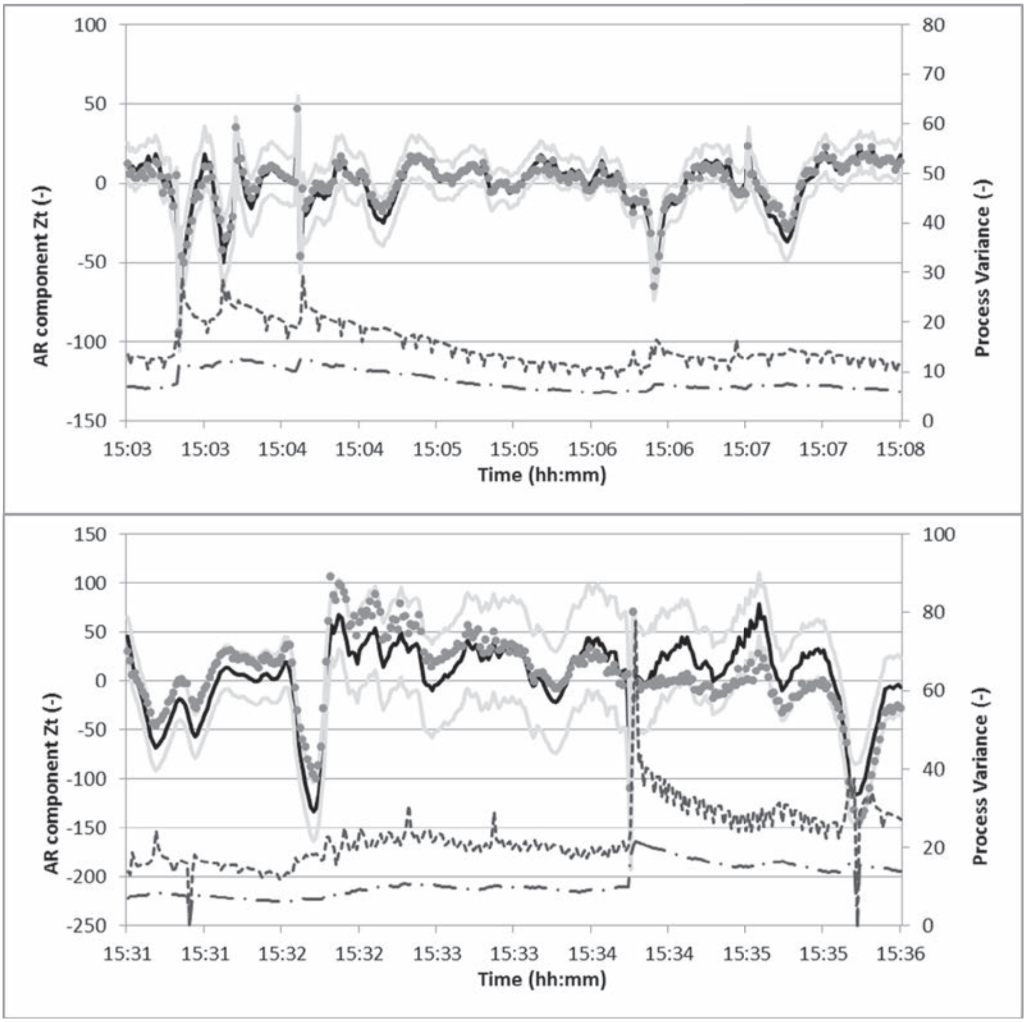


Figure 4a & b: Autoregression component $Z_t$ and variances within the two selected periods of 5 minutes; 4a sleep (above) 4b active (below): Online estimates (grey points); retrospective estimates (black line) incl. 90% confidence interval (light grey lines).

Forecast variance $Q_t$ (------) and observation variance $S_t$ (white noise, - . -)

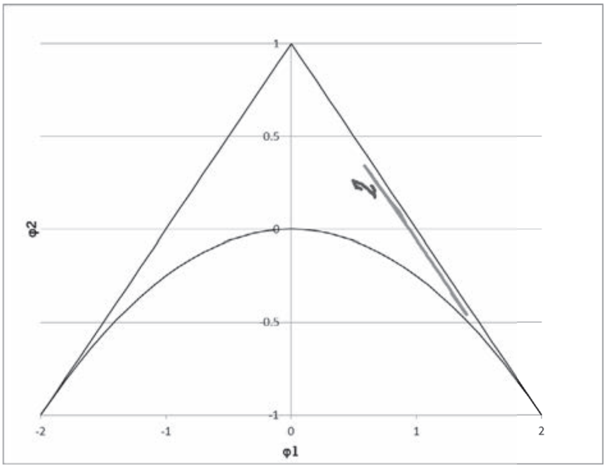


Figure 5 Retrospective estimated AR parameters $\phi_{1,t}$ and $\phi_{2,t}$ showing the two selected 5 minute periods while sleeping (dark grey line 15:03-15:08) and active (light grey line 15:31-15:36).

The first two components level ( $\mu_t$ ) and trend ( $\beta_t$ ) adjust the base level of heart rate to the required set point according the behaviour and physiological demands at that moment. Significant trends appeared whenever an increase or decrease in base level is required to meet the physiological needs. Changes in RR-interval at arousal were described by a decreasing trend, followed by a slow increasing trend to adjust to the desired level again. Sudden fast changes in level (mainly drops in RR-intervals) were not detected by trend since the process variance increased simultaneously. This indicates that the level and trend components of the model reflect the slow dynamic changes in RR-interval.
Within 5 minute periods substantial variation in interbeat interval can be seen. This actual, more subtle, variation in RR-intervals cannot be described accurately by models based on the assumption of a stationary process, like the Fast Fourier Transformation (FFT). They were, however, captured by the decomposing model, which moment by moment follows every fluctuation and any changes in dynamics. These fast dynamic fluctuations around the slowly changing base level is described by the autoregression and error components, corresponding to low and high frequency variation. The AR2-process ensured that the modelled RR-interval oscillated around the base level that was set by level and trend. This process with more or less decaying deviations can be seen as continuously fine-tuning towards the desired heart rate.

As expected, the random error component $\nu_t$ could not be captured within any pattern or related to any cause. This is the white noise component, which is shown as random scattering around the AR oscillations as shown in figure 1. As shown in figure 4 the variance of this white noise component was not constant within the 5 minute periods.

So, the white noise variance is dynamically changing even within short periods.
The parameters were estimated online at each moment of the time series and together characterized the total dynamic variation in RR-interval and the dependency between successive observations in the actual situation. The accuracy of the online estimates was improved afterwards by the backward smoothing procedure, resulting in the retrospective estimates.

## Conclusion

Our model is based on a beat to beat calculation, which is necessary for timely detection of the dynamical changes in HRV that apparently occur continuously over time. Techniques that cannot calculate on a beat to beat basis, such as other time or frequency domain techniques, overlook the dynamic changes when a mean value over a longer time period is calculated, and therefore provide less (detailed) information.
We concluded that the adaptive dynamic model is able to analyse the non-stationary and non-linear heart rate fluctuations in the time-domain in terms of fast and slow variation. The model detects sudden changes as well as slightly growing deteriorations.
These characterisations of dynamics will differ depending on the physiological state of the animal and may be individually different. Further research will focus on the relation between estimated parameter values and the physiological state of animals. After the physiological interpretation of the parameters with respect to the autonomic nervous system the model will be further developed as an online monitoring tool that can be used to detect early alterations in physiological state of animals in husbandry systems.

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**Simultaneous monitoring of feeding behaviour by means of high frequent RFID in group housed fattening pigs**

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**Abstract**

The study examined asimultaneous individual animal identification of fattening pigs based on radio frequency identification (RFID) using passive high frequency (HF) transponders under practical conditions on farm. The individual feeding behaviour of the pig was recorded continuously online in the form of an attendance check at the trough via HF RFID. The feeding behaviour of six focal pigs was analysed in detail to determine the accuracy of the innovative HF-RFID feeder. For validation video data of 9 fattening days were taken into consideration.
With the aid of the innovative high-frequency HF RFID system individual feeding frequency of fattening pig can be monitored simultaneously, and online. However, the HF RFID technology does not register the pigs standing at the trough continuously. Gaps of few seconds occur between single registrations. In order to analyse the total feeding time, the gaps have to be taken into consideration.
In the future, decision-making models for precision livestock farming can be developed from such data so that errors within the production chain can be discovered early on and that improvements can be made, thereby minimizing financial losses

**Keywords:** Fattening pigs, feeding behaviour, high frequency, radio frequency identification

**Introduction**

Modern pig husbandry is characterized by an increasing herd size per production unit. As a result, new management solutions will be necessary in pig housing, in particular for monitoring the welfare and performance of individual animals within the herds. The aim of this study is the development of a sensor system, which can be used for an early warning in case of potential health problems and drops in performance or welfare.
Health and welfare problems are mostly recognised by changes in individual behaviour. Feeding behaviour and activity are often considered to be indicative of general health (Baumgartner and Ketz-Riley, 1999). Behaviour is an important means of influencing energy input; sick individuals usually decrease feeding activities while increasing time

at rest, likely as a means of conserving energy for the febrile response and for mounting an immune response (Hart, 1988). Researchers have traditionally viewed behavioural changes as simple signs of the wasting effects of disease, but more recently thinking has shifted to seeing these as motivated sickness behaviours that represent a coordinated and adaptive response to illness (Weary *et al*., 2008).

Warning signs, such as alterations in feeding behaviour, might enable an early detection of diseases or environmental related problems. Feeding behaviour can be used as a valuable indicator of the pig's health. Since the routinely gathering behavioural information from animals to evaluate their performance and welfare is very time-consuming for farmers, the new high frequent (HF) RFID system demonstrably aid this task, especially with large herds.

Normally low frequency (LF) transponders are used for individual animal identification. However the main disadvantage of LF transponders is that they can only be read individually in the radio reception field (Kern, 2006). The main advantage of HF RFID technology is that the behavioural and performance related data of group-housed animals can be recorded in real time simultanously, for every individual animal, continuously, and online. Therefore, the use of HF RFID technology at the feeder was undertaken in this study. The new animal identification system was tested in fattening pigs.

## Animals, material and methods

<u>Experimental setup</u>

The study has been carried out in a compartment with 8 pens on a farm located 22 km away from Vechta, Germany. Four HF RFID feeders are installed into a mechanically ventilated pig house. The HF-RFID system, which is used in this experiment is based on the system which is described in Hessel and Van den Weghe (2012) and Reiners *et al*. (2009). However, in contrast to the previous studies in this study the antennas are not integrated into the trough but positioned on top of the trough (Figure 1). Custom made antennas (13.56 MHz, DTE Automation GmbH, Enger, Germany) are attached to the feeders (Lean Machine, Big Dutchman, Vechta, Germany). The antennas have a diameter of 385 mm, the supporting martial is made of 30 mm rigid plastic in which an edge is milled for the antenna. The antenna, which is made of copper, works with a transmission power of 1.8 W and an operation frequency of 13.56 Mhz. The antennas are positioned centre top in a height of 460 mm above the troughs (diameter 400 mm). During a fattening period the height of the antenna is not changed. The four antennas are connected via Multiplexer (HF Multiplexer ID ISC.Ant MUX, FEIG ELECTRONIC GmbH, Weilburg, Germany) to a Long Range Reader HF Long Range (Reader ID ISC. LRM 2500 B, FEIG ELECTRONIC GmbH, Weilburg, Germany).

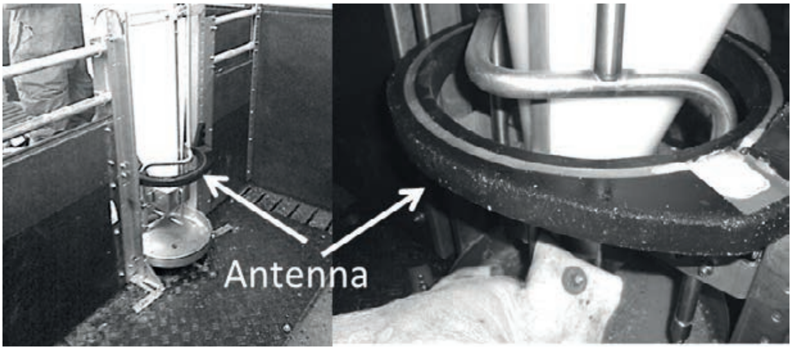



Figure 1: Feeder equipped with HF antenna

Every pig was tagged with a passive HF transponder with an operating frequency of 13.56 MHz (IN Tag 300 I-Code SLI tags, ISO 15693, HID Global Corporation, California, USA). The round transponders were clipped onto the ear tags of the pig (Allflex, Hamburg, Germany). Further details about the technology used can be found in Reiners *et al.* (2009), a common publication of the Division Process Engineering of the University of Goettingen and the Institute for Agricultural Engineering and Animal Husbandry of Bavarian State Research Centre for Agriculture.

<u>Data collection</u>

The pens (3.6 m x3.6 m) are equipped with fully slatted floor. Each feeder is positioned within a partition between two pens resulting in eight pens that were equipped with the RFID feeders. Sixteen pigs ((Large White x, German Landrace) x Pietrain) were housed in each pen, resulting in 128 pigs in total. Pigs were brought into the stable with a weight of approx. 30 kg and were reared until they reached a weight of 110 kg. Six randomly chosen pigs from 2 different pens were marked individually on their back and their behaviour was recorded on videos for validation purposes. A pig was classified as feeding if it is standing with its head down at the trough. Starting and ending time of each feeding event was registered.

RFID data were registered automatically by the HF-RFID system. For each fattening day a data file was available in which RFID data of registered focal pigs were stored to the second.

<u>Data analysis</u>

The feeding behaviour of the focal pigs was analysed in detail to determine the accuracy of the innovative HF-RFID feeder under practical conditions. For validation video data of 9 fattening days (day 2, 21, 30, 37, 43, 50, 60, 73 and 78) during 8 am to 4 pm of six focal pigs were taken into account. In total, 480 feedings were detected using video analyses.

Both Petrie and Gonyou (1988) and de Haer and Merks (1992) found that fattening pigs had short breaks within a given meal. However, if the meal is not continued within

5-6 minutes then according to these authors it can be assumed that the meal has been finished. In the present investigation, a meal was defined as the sum of feedings with intervals lower than 6 minutes, resulting in 303 meals.

## Results and discussion

Referring to the videos, single feeding events last on average 4.27 minutes; the median of single feedings is 2.00 minutes. In total, 22 (4.6 %) of 480 feedings are not detected by the HF RFID system. The missed feedings last on average 23 seconds (s) according to the video recordings. Normally, these missed feeding occur within a meal. Pigs are feeding for a short time, then after a short break they continue feeding. Or, before finishing a meal, they take in a last very short meal before leaving the trough. Due to this short feeding duration it can happen that the HF RFID system did not register single feedings.
Referring to the videos, meals of the pigs last on average 7 minutes. Comparing the HF RFID data with the data of the video analysis, a pretty good correlation was found. As an example one meal of a pig on fattening day 21 is shown in Figure 2

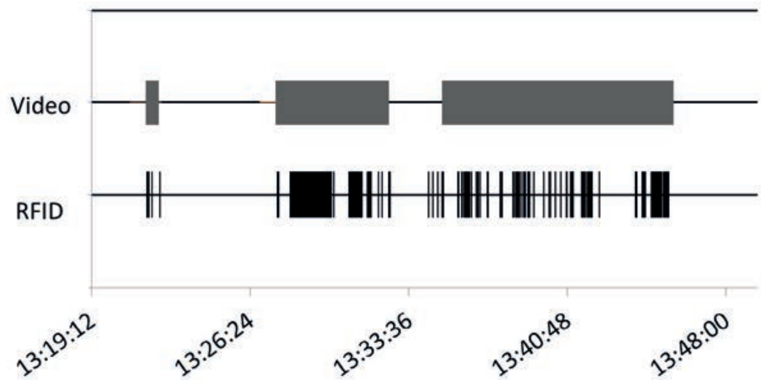



Figure 2: Registered meal of one pig on fattening day 21 using video recording as well as HF RFID system

All meals which are established by the video analysis are also registered by the HF RFID technology. It can concluded, that feeding frequency of individual pigs can be recorded by the HF RFID system in this experimental setup. However, looking in to the data in more detail, it was found out that the HF RFID system does not register the pigs standing at the trough continuously. Gaps of few seconds occur between single registrations. The Figure 3 shows the distribution of the gaps. On average these gaps last 6,15 s, 95 % of the gaps are lower than 25 s, and 99 % are lower than 59 s

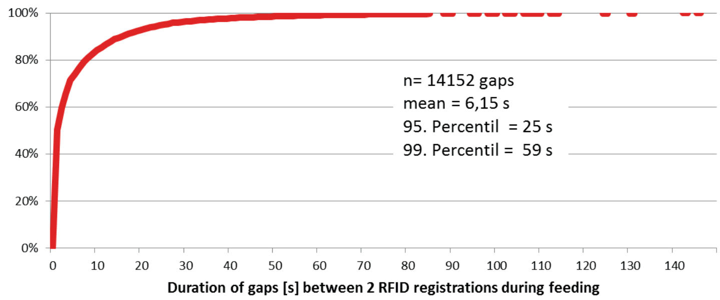



Figure 3: Gaps [s] between 2 RFID registrations during feeding

The day of fattening has an influence on the duration of these gaps (Table 1). At the beginning of the fattening period the median of these gaps is 3 s, at the end of the period the median amounts only 1 s. The 95 percentile decreases from 36 s to 13 s during the fattening period. The mean decreases from 9 s to 3 s, and the standard deviation decreases from 16 s to 5 s. The reason for shorter gaps between single HF RFID registrations might be due to the pigs themselves as well as to the HF RFID system. Younger pigs are much more active than older ones, also during feeding they move more which could lead to the higher gaps. Furthermore with younger pigs the distance between transponder, which is attached to the ear, and antenna is greater compared to older pigs. This higher distance between ear and antenna is due to the small body size of the young pigs. Both, the greater distance between transponder and antenna as well as the higher activity of younger pigs during feeding might lead to higher gaps. The transponder cannot be read, because it exits the range of the antenna. However, using an antenna with a greater range would result in registration of pigs, with are near the trough, but not actually feeding.

Table 1: Duration of gaps [s] between RFID registrations during feeding

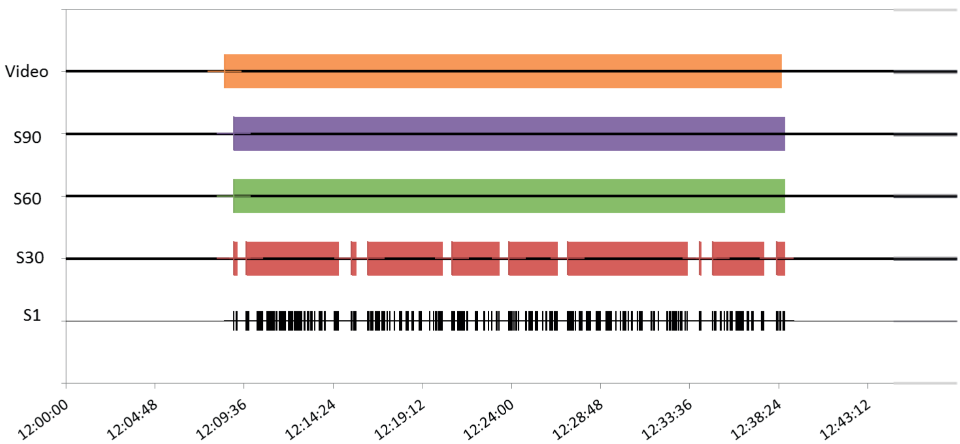
| Day of fattening | N | Median | Mean | Standard deviation | 95.- Percentil | 99. Percentil |
|---|---|---|---|---|---|---|
| 2 | 2962 | 3,00 | 8,86 | 16,08 | 36,00 | 80,00 |
| 21 | 733 | 3,00 | 11,12 | 20,73 | 47,00 | 109,00 |
| 30 | 1188 | 2,00 | 7,43 | 13,10 | 32,00 | 59,00 |
| 37 | 852 | 2,00 | 7,56 | 13,62 | 29,00 | 61,00 |
| 43 | 1826 | 1,00 | 5,87 | 13,17 | 24,00 | 56,00 |
| 50 | 1812 | 1,00 | 5,04 | 8,77 | 20,00 | 44,00 |
| 60 | 1516 | 1,00 | 4,41 | 7,93 | 19,00 | 39,00 |
| 73 | 1526 | 1,00 | 3,51 | 6,83 | 14,00 | 33,00 |
| 78 | 1736 | 1,00 | 3,14 | 5,33 | 13,00 | 25,00 |

N= number of gaps

These gaps lead to clearly lower values of feeding time registered by RFID compared to the video analysis. Taking these gaps into consideration following scenarios are analysed:

- S1: RFID registered feeding is taken into account to the second.
- S30: if the time gap between to RFID registrations was lower than 30 s the pig was classified as feeding
- S60: if the time gap between to RFID registrations was lower than 60 s the pig was classified as feeding
- S90: if the time gap between to RFID registrations was lower than 90 s the pig was classified as feeding

As an example, one feeding of one focal pig on fattening day 60 is shown in Figure 4. With the aid of the video recording, it was found that the feeding in this example lasts 30 minutes. Summarizing all seconds (S1), in which the RFID system registered the pig during this feeding the duration amounts only 5.2 minutes. Applying S30 this feeding lasts 24.4 minutes, using S60 and S90 it lasts 29.7 minutes, which corresponds quite good to the video analysis.




According to Table 1, it can assumed, that for calculation of feeding time the time gaps of the different scenarios decrease with an increase of pigs' age during a fattening period. The next step will be a development of an algorithm for estimation of feeding times on basis of the RFID data, using different time gaps between single HF RFID registrations depending on the age of the pigs.

## Conclusions

In conclusion, with the aid of the innovative high-frequency HF RFID system individual feeding frequency of fattening pig can be monitored simultaneously, and online.

However, the HF RFID technology does not register the pigs standing at the trough continuously. Gaps of few seconds occur between single registrations. In order to analyse the total feeding time, the gaps have to be taken into consideration. Regarding feeding behaviour of pigs, the HF RFID technology has a huge potential, it can be used for early warning system for detection of health, production and welfare problems.


## Acknowledgments

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## Predicting farrowing based on accelerometer data

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### Abstract

Piglet production is currently going through rapid structural changes, with increasing herd size and more labor-intensive management. Simultaneously, animal welfare is an issue receiving more and more general interest, and concerns have been raised on how animal welfare can be guaranteed with the reduction of human monitoring of the animals.
The aim of this study is to develop a system to predict farrowing based on accelerometers attached to a neck collar of the sow. Wireless 3D accelerometers were attached to neck collar of 12 sows housed in the farrowing crate at least 48 hours before farrowing.
Activity of the animal was extracted from the data in 10min epochs and a dynamic linear model was used to extract trend, slope and seasonal components from the data. The decomposed data was used to detect activity increase before farrowing using a cusum chart and subsequent decrease from decomposed slope.
We were able to predict increased activity before farrowing in 92% of the sows in average of 12.8  1.4 hours before farrowing and the start of the farrowing in average 0.16 0.05 hours before farrowing.

**Keywords:** Farrowing, accelerometer, dynamic linear model, CUSUM chart

### Introduction

Piglet production is currently going through rapid structural changes, with increasing herd size and more labour-intensive management. Simultaneously, animal welfare is an issue receiving more and more general interest, and concerns have been raised on how animal welfare can be guaranteed with the reduction of human monitoring of the animals. In order to develop methods to increase farm efficiency without decreasing animal welfare, there is a great demand for technology for monitoring animal health and behaviour, especially during critical periods such as farrowing in the sow.
In the last few decades, research in the field of animal reproduction has mainly focused on ovulation and pregnancy rate, in order to optimize sow fertility (Cutler *et al*., 2006). However, on average one piglet per litter is lost during parturition, and an additional piglet deaths can occur within a few days after birth (Valros, 2003).
Parturition should thus be closely supervised in order to minimize losses due to problems with sows or piglets. However, supervision of all the farrowing events by the

personnel in a herd is not feasible due to high labour costs and uncomfortable working hours. In large litters some of the piglets are also more likely to be weaker and need assistance soon after birth in order to survive (Smith, 1997).

The behavioural changes before the start of farrowing have been widely studied. The nest building sequence begins with an increased activity level of the sow 1-2 days before parturition. From approximately 12 hours prior to parturition, the sow engages in more and more actual nest building activity, such as rooting, pawing and arranging available materials (Haskell & Hutson, 1994). In most cases, the activity level of the sow is again reduced one-two hours prior to farrowing (Petersen *et al.*, 1990).

Cornou *et al.* (2011) used accelerometers to measure the activity of sows before farrowing and developed a model (Cornou & Christensen, 2012) to detect the onset of farrowing based on increased activity 15h before farrowing. We have used force sensors and photocells to measure activity before farrowing (Oliviero *et al.*, 2008).

The aim of this study is to develop a system to predict farrowing based on accelerometers attached to a neck collar of the sow.

## Materials and methods

<u>Measurements</u>

Wireless 3D accelerometers were attached to neck collar of 12 sows housed in the farrowing crate (210 × 80 cm) at least 48 hours before parturition. Acceleration data was logged using dedicated logging software. Accelerometers were custom made for the project and used 868 MHz radio frequency and a power saving radio protocol which included a motion trigger that caused the sensor only transmit data at 20Hz when there were changes in the acceleration as compared to previously transmitted data. Farrowing times of the sows were registered from video.

<u>Processing raw data</u>

The acceleration data was interpolated to 20Hz sampling rate using piecewise cubic interpolation to fill in missing data during inactive periods of the sow. Sum acceleration was calculated as from the three axes as:

$$acc_t = \sqrt{x_t^2 + y_t^2 + z_t^2}$$

Total activity  of each sow was calculated in 10 minute epochs as:

$$At = ln(\sum_{t=1}^{N} | acc_t - acc_{t-1} |)$$

The log transform was used because the data was found to be log normally distributed. Further in order to standardize the activity measure across animals the amplitude the data was normalized using the normal activity of the animal:

$$An = \frac{At}{A_{normal}}$$

, where $A_{normal}$ is the average activity of the animal during first 24 hours of the measurement.

There was an obvious diurnal rhythm in the activity characterized as high activity periods during feeding times and low activity during resting. A dynamic liner model was used to decompose normalized data (*An)* into mean, trend and Fourier form seasonal component with a period of 24 hours (Giovanni *et al.* 2009). The decomposition of the data is shown in Figure 1.

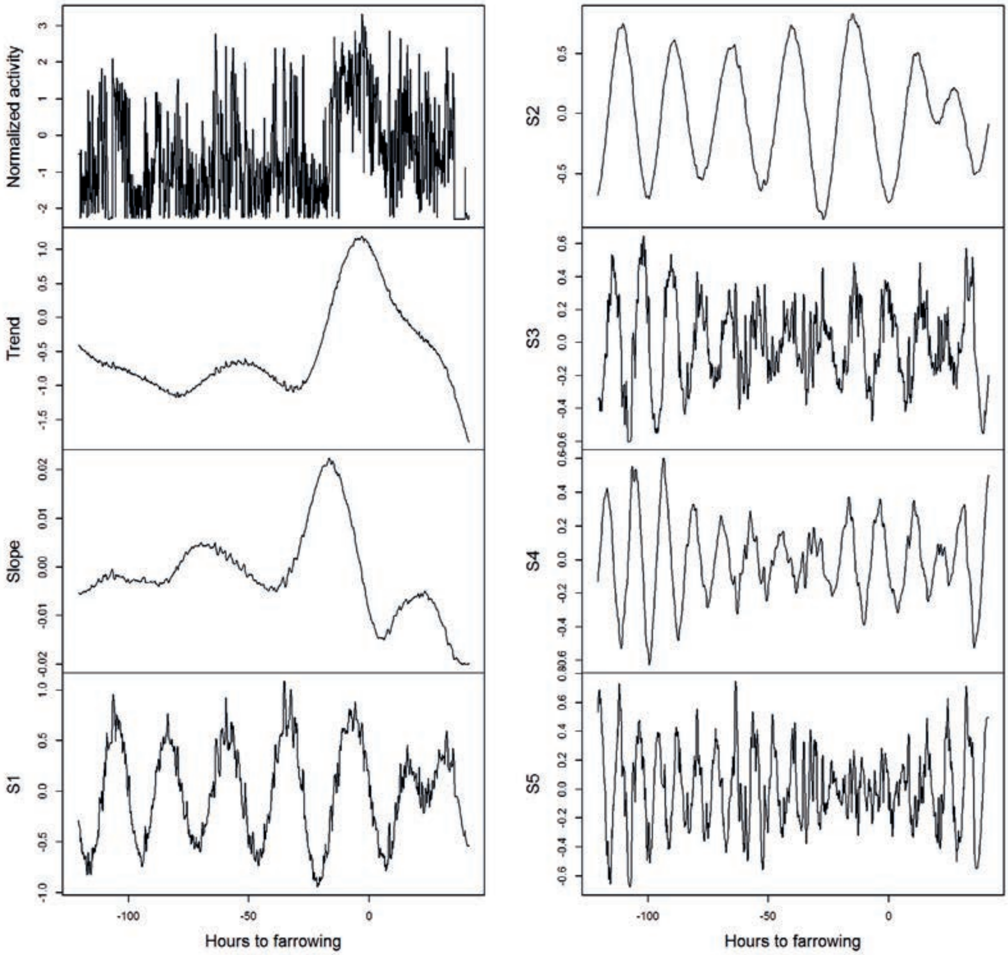


Figure 1. Decomposition of normalized activity using a dynamic linear model into: Trend, Slope and seasonal components (S1 to S5).

R 2.14.2 R (Development Core Team, 2012) with dlm-package was used in the analysis.

Predicting farrowing

A one-sided CUSUM chart was used to detect increased activity from the trend component of decomposed data before farrowing starts. In a one-sided CUSUM chart the cumulative sum between the data (in this case trend) and the target value  is calculated as:

$$C_t = \sum_{t=1}^{N} T_t - S - k$$

with the limitation $C_t$=max[0,$C_t$] and where k is a user defined constant.
An alarm is given if $C_t$ is greater than given alarm limit *h*. We set design parameters to *S=0, k=0.1, h=1* based on experimentation.
The activity of the sow decreases again before the farrowing starts. An alarm was raised when the slope component turned negative after the CUSUM chart had alarmed about increased activity.

## Results and discussion

All sows showed a clear increase in activity during the last 24 hours of farrowing. The mean normalized activity *An/h* is shown in Figure 2. It shows that the peak activity is reached just before parturition and that when parturition time the activity decreases rapidly.

The CUSUM chart was able to detect increased activity in 92% of sows during 24 hours before farrowing (mean  SE) 12.8  1.4. An example of CUSUM chart is shown in Figure 3. An alarm is given when $C_t$ goes over the horizontal alarm line.

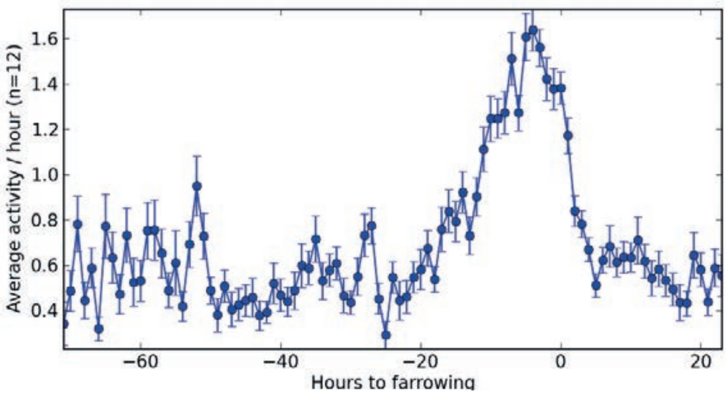


Figure 2. Average normalized activity  SE of sow/hour from 72 hours before to 12h after farrowing. 0 is the farrowing time

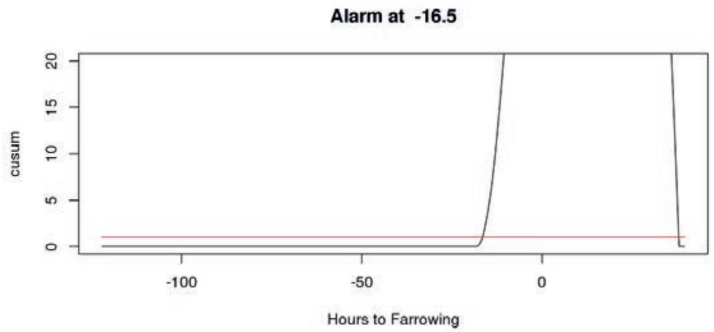


Figure 3. CUSUM chart used to detect increased activity from trend component.

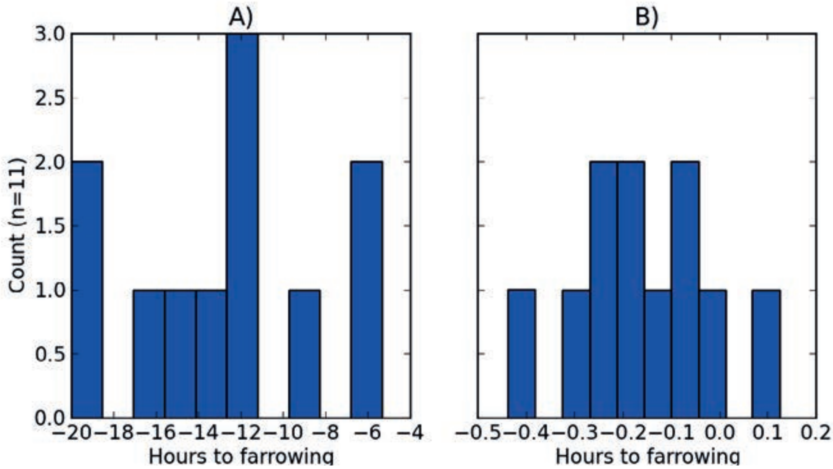


Figure 4. The distribution of alarms from A) Increased activity B) = Start of farrowing

<u>Discussion</u>

We used methodology that is close to Cornou & Christensen (2012), they also Dynamic General Linearized Model for diurnal activity and another method using CUSUM charts for alarms. Cornou & Christensen (2012) were able to detect farrowing 15h before the onset which is close to our 13h. We introduced a second alarm based on decreasing activity after initial increase that was able to detect onset of farrowing in less than 30min accuracy.

Future work will include modeling the sow behavior instead of raw activity and applying the method to sows farrowing in pens.

**Conclusions**

We were able to predict increased activity before farrowing and the start of farrowing with good accuracy. The method shows promise for on farm use. Future work is needed to test the model with a larger number of sows.

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# A health monitoring system for growing-finishing pigs based on the individual feeding pattern using Radio Frequency Identification and Synergistic Control

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## Abstract

Alterations in an individual pig's feeding pattern can be warning signs for diseases, environmental issues or other problems, so automated monitoring of feeding patterns can aid farmers in their daily tasks. Using decision support tools to detect any relevant changes in the automatically gathered patterns allows for detection of problems in an early stage preventing economic losses for the farmer and increasing pig's welfare. A High Frequent Radio Frequency Identification (HF RFID) system was used to collect feeding pattern data of growing-finishing pigs. Different variables for quantifying feeding patterns are extracted from these data. These variables are monitored for each individual pig using a Synergistic Control approach. Using the concept of Synergistic Control it is possible to define animal-based threshold values to identify normal and abnormal variation in each pig's feeding pattern, hence implementing an early warning system for individual pigs. Two spontaneously occurring problems with individual pigs (lameness and general illness) were detected by the early warning system, even several days before the clinical signs were present or the pig was recognized as ill by its caretakers.

**Keywords**: growing-finishing pigs, feeding pattern, radio frequency identification, synergistic control, early warning

## Introduction

A pig farmer aims towards a profitable and sustainable business and simultaneously providing good care of the animals. In today's larger herds and complex markets and legislations, this requires the pig farmer to be a manager besides being an animal caretaker (Frost *et al,* 1997). Since visual monitoring of individual pigs within large groups of pigs is difficult, there is a need for automated detection of problems in the pig herd. Indeed, timely detecting, solving and treating disease and welfare problems of individual pigs can prevent decreased health, decreased growth and finally economic losses (Jensen *et al,* 2007; Maes *et al,* 2004; Maes *et al,* 2001).

In case of stress situations or upcoming illness, pigs are thought to alter their behaviour before any physiological signs can be seen (Hart, 1988). So, automated registration of animal based behavioural variables could provide the necessary information to detect problems in pigs. Alterations in pigs' feeding patterns are particularly promising warning signals for welfare-, health- and production problems (Brown-Brandl *et al,* 2011; Cornou *et al,* 2008; Hessel & Van den Weghe, 2011) and can be measured using Radio Frequency Identification (RFID) (Finkenzeller, 2010). Brown-Brandl et al (2011) and Hessel & Van den Weghe (2011) have shown that there is a large variation in feeding patterns of pigs, so determining feeding patterns of pigs on an individual basis is a necessity.

Solely registration however is not enough; there is also need for an automated data analysis system that can transform the large amounts of data into useful information for the pig farmer (Frost *et al,* 1997). The concept of Synergistic Control (SGC) provides the possibility to make a distinction between the normal variation in livestock production data (due to age differences, seasonal differences) and the abnormal variation caused by problems (Mertens *et al,* 2008; Mertens *et al,* 2009; Mertens *et al,* 2011). SGC is the combination of Engineering Process Control (EPC), used for modelling the data as a pre-treatment to remove undesired characteristics in the data, and Statistical Process Control (SPC), in which control charts are used to detect abnormal variation in the data of a production process (Mertens *et al,* 2008; Mertens *et al,* 2009). In the case of biological processes, applying SPC without pre-treatment is an almost certain fault (Montgomery, 2009). SPC requires data to be stationary, independent and normally distributed. Biological processes are not likely to fit all three criteria (Mertens *et al,* 2011). In order to address these issues, EPC is used to model the undesired trend and autocorrelation in separate steps and the residuals after model-subtraction, meeting the SPC conditions, are then used in the control chart.

By using SGC on pigs and using each pig as its own reference, individual limits for problem detection can be defined. This allows to signal problems with single pigs to the pig farmer and develop a health monitoring system for individual growing-finishing pigs based on their feeding pattern (registered using RFID) and animal-based control limits (using SGC). In this paper the first results of using RFID and SGC to monitor individual pigs are shown.

## Materials and methods

### Animals and housing

The study was carried out in an automatically ventilated experimental barn at ILVO (Institute for Agricultural and Fisheries Research, Melle, Belgium) divided in four identical pens. Each pen measured 4.3 m by 9 m with approximately 40 % slatted concrete floor and 60 % solid concrete lying area. Two hundred thirty six growing-finishing pigs (Hybrid sow x Piétrain boar) were randomly assigned to the four pens to achieve groups with equal amounts of barrows and gilts and a similar mean weight and variation. Each pen contained 30 barrows and 29 gilts. The average weight of the animals on arrival was 19.3 ± 2.0 kg (mean ± SD). Water was supplied via four nipple drinkers in each pen. Dry pelleted feed was automatically supplied using 8 Swing MIDI feeders (Big Dutchman Pig Equipment GmbH, Vechta, Germany). The pigs were fed a commercially available feed (9.3 MJ net energy and 9.2g lysine/kg feed) *ad libitum*.

### RFID Measurements

To register feeding patterns of pigs, a High Frequency (HF) RFID antenna (Custom-made, DTE Automation GmbH, Enger, Germany) was designed and attached to the feeders above the trough (Figure 1). Each antenna was connected to one of two HF long range readers (ID ISC.LR2500-A, FEIG ELECTRONIC GmbH, Weilburg, Germany) with the use of 2 multiplexers (ID ISC.ANT.MUX-A, FEIG ELECTRONIC GmbH, Weilburg, Germany). The tags used were IN Tag 300 I-Code SLI tags (ISO 15693, HID Global Corporation, California, USA) with a diameter of 30.0 mm. These passive HF transponders with a worldwide unique identification code were clipped onto the ear tags of the pigs. All the RFID registrations were continuously logged in a data file with five columns: the timestamp of the registration to the second, the unique code of the RFID tag, the antenna where it was registered and the corresponding pig and feeder.

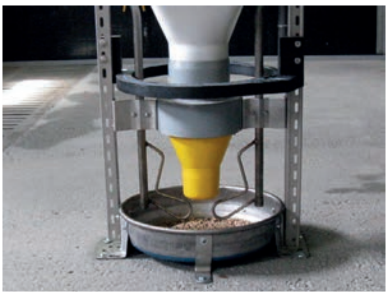

Figure 1: RFID antenna attached to the feeder above the trough.

Data analysis

To quantify the feeding pattern of the pigs, the raw RFID data was transformed into RFID based feeding pattern variables. This was done using a meal criterion of 5 min (Clifton, 1987; Gonyou, 1998), which allows calculating, amongst others, the number of meals a pig has per day, the duration of the meals and the interval between the meals.

A basic SGC procedure was post-hoc applied to the daily average intermeal interval (IMI) of the individual pigs. After checking the statistical characteristics, a simple linear regression was used to model the trend in the data in the EPC step. A small reference period of 5 days in the beginning of the production period was used to estimate the in-control model parameters and the residuals after subtracting the model from the raw data were used to calculate the process variability. With this information, control limits for the reference period were determined using a Shewhart control chart (Montgomery, 2009). Any out-of-control points in the reference period were then removed from the dataset and the procedure was repeated until the models and limits were based on 'normal-variation' points only. After the reference period a recursive approach was used. With every new data-point, the model estimation and control-limits were updated. Any out-of-control points were signalled when falling outside the limits and were not used for the recursive estimation of the model and the in-control variability (Mertens *et al,* 2008; Mertens *et al,* 2009). The alarms for points falling outside of the control-limits were compared with the problems that were noticed by the animal caretakers.

## Results and discussion

Using RFID, the feeding patterns of all 236 pigs in the stable were monitored. During the first 30 days of the period, some technical problems occurred due to set-up of the infrastructure. For this reason, the data are only shown from day 30 onwards. Data analysis has been performed for 118 days in the period.

In figure 2, the average intermeal interval of a healthy pig is shown. Even though there is a large amount of variation in this parameter, no alarms were given and all datapoints were considered in-control.

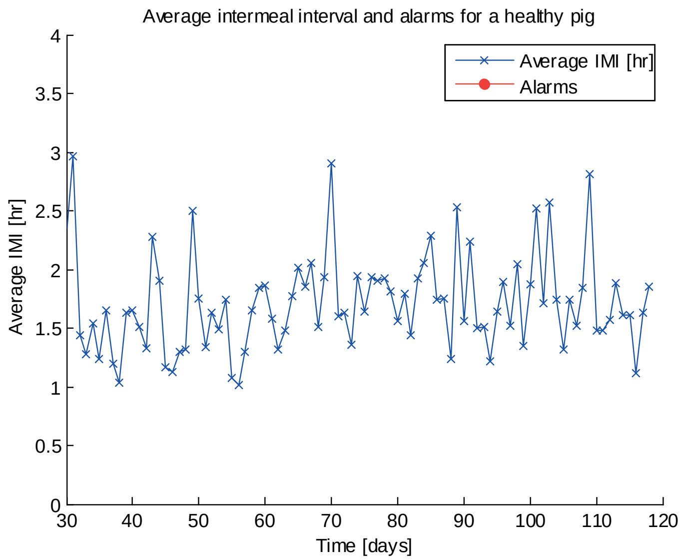


Figure 2: Average intermeal interval and alarms for a healthy pig. (The scale of the y-axis of figure 2 deviates from that of figure 3 and 4).

In figure 3, the average intermeal interval and alarms of a severely ill pig are shown. At day 68 and 69 a technical problem stopped the RFID registrations in the entire pen. This technical problem is signalled by the SGC procedure. On day 116, the caretakers noticed that this pig was diseased (it was pale, anorexic and trembling) and treated the pig accordingly. Unfortunately, the pig died two days later. As can be seen in figure 3, the feeding pattern of this pig changed drastically already 4 days before the caretakers spotted the problem.

Before day 112 (so before the average IMI goes above 10 hrs), several alarms were given. It is not sure whether these alarms from that pig indicated disease at that time. It is, however, clear that in comparison to the low and stable average IMI between day 30 and day 67, the data exhibit abnormal behaviour from day 76 onwards. Also for several other pigs alarms were generated between day 73 and day 87. At day 73, the RFID antennas were raised a couple of centimetres because some of the pigs grew too big to be able to eat comfortably underneath the antenna. Around that period, the temperature in the stable was very high as well due to high outside temperatures (maximum temperatures above 35°C on day 75 and 76). Average stable temperature was above 25 °C between day 69 and 78. Maximum temperature in the stable was even above 30 °C on day 72 and 74 to 76. The alarms between day 76 and day 87 for this pig could be explained by this high temperature or the moving of the antennas, or a combination of both. Further research is needed to give a concise conclusion on those alarms.

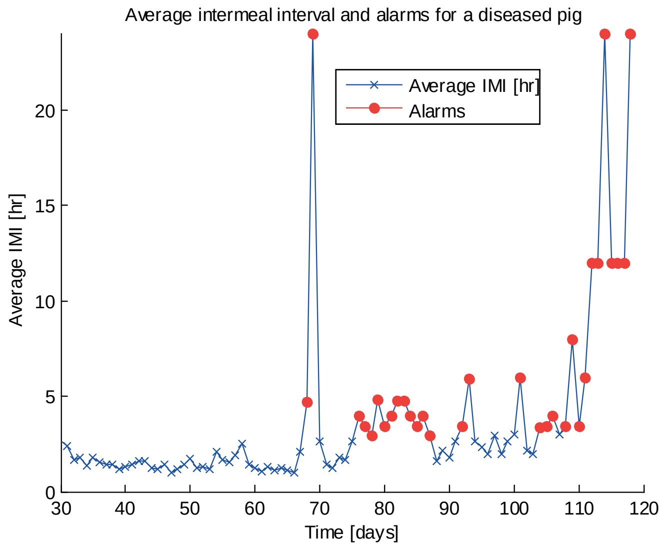


Figure 3: Average intermeal interval and alarms for a diseased pig.

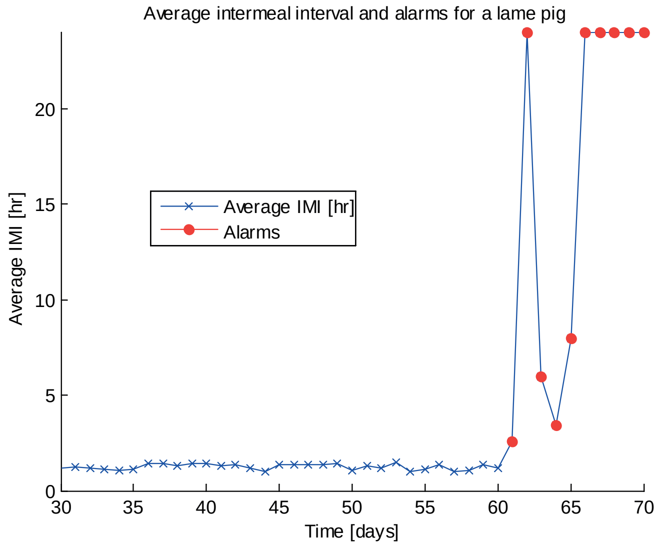


Figure 4: Average intermeal interval and alarms for a lame pig.

In figure 4 data is shown of a pig that was removed from the pens on day 65 since the caretakers spotted a severe leg problem (possibly broken leg or torn leg muscle). Already 4 days before removing the pig by the caretakers, deviating values were detected and alarms were generated using the Synergistic Control approach. This leg problem probably occurred on day 61, immediately causing an increased interval between the pig's meals.

The 2 cases detected in this experiment show the usefulness of the developed system. Three other severe health problems occurred during the fattening period. On day 16 and day 18 a pig was found to be in bad body condition and was treated. Alarms for this pig were given on day 14 and 15. Another pig was removed from the pens on day 20 due to a severe leg problem. An alarm was given already at day 19 for this pig. A third pig was suddenly found dead on day 97 without any alarms being given prior to this date. However, except for a large *hernia inguinalis*, no health problems were detected in advance by the caretakers, so it is possible that this pig suffered a sudden death. Several other pigs had minor health problems (skin irritation, *hernia inguinalis*, etc.) or were treated for lameness. Further work is necessary to investigate the changes in the feeding patterns of the pigs when subjected to these problems. In general, the number of alarms generated by the system (e.g. figure 3) was quite high in comparison to the registered problems with the pigs, but environmental and technical problems or changes are likely to have had an effect as well. More data is needed to determine the sensitivity and the specificity of the system.

The influence of technical problems or deviations in the performance of the registrations on the feeding pattern data should be identified and minimized, so that no artificial or false alarms are created due to degraded system performance. Performance testing, range measurements and validation of the RFID system are therefore mandatory. When automatically monitoring feeding pattern data of individual pigs on a day to day basis, it is important that the feeding pattern variable used reflects the true feeding pattern of the pigs. Using a subjective meal criterion to derive meals from the raw RFID data could create artefacts in the resulting data leading to false alarms. Therefore, the feeding pattern parameter used has to be validated and checked and more objective meal criteria should be determined.

Also the basic SGC procedure applied here can be further optimized by improving the trend model, adding an autocorrelation model where necessary and applying changes in the control chart (e.g. using a more sensitive cusum chart instead of the Shewhart chart). Besides the average intermeal interval, several other variables are also potential indicators for health, welfare and productivity problems (e.g duration of feeding). Analysis of each of those parameters and investigation of the results of the SGC procedure on these parameters is necessary to find the optimal variable for health monitoring. Also a combination of such parameters in a multivariate setting could provide added value.

## Conclusion

This paper shows promising results found during the development of a health monitoring system based on the feeding pattern of individual growing-finishing pigs measured with

RFID and analysed with Synergistic Control. With a basic SGC procedure a severely diseased pig and a lame pig could be signalled even before the problem was detected by the caretakers. Further work should be performed to investigate how other changes in feeding patterns of pigs can be explained. Technical influences on the measured feeding pattern should be determined and minimized. Also the extraction of the RFID based feeding pattern parameters and the SGC procedure should be further validated, optimized and analysed, so to find an optimal variable (or combination of variables) for detecting welfare, health and productivity problems and to validate this variable accordingly.

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# Session 18

# Incubators

## The impact of environment during final development of poultry embryos with special focus on acoustic signals and communication

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### Abstract

During final incubation poultry embryos have all physiological prerequisites to react on environmental influences. Its further maturation will be improved by environmental inputs. Especially during ‘critical periods’ the impact of the actual environment on the postnatal development is long-lasting (‘imprinting’ of body functions). Acoustic communication by vocalization and clicking sounds starts during final incubation. Beginning with penetrating the inner egg membrane a species-specific sound repertoire develops gradually, which might be regarded as non-specific mutual stimulation. Vice versa, a disruption of mutual vocal communication in the pre-hatching period led to lower acoustic postnatal activity and also damaged postnatal acoustic communication. It is likely that the behaviour of the breeding parent is affected by the embryonic acoustic signals. As signal of the offspring’s need for warmth from the incubating parents, cold induced vocalization (distress calls) from the embryo may help to restore normal incubation temperature. Accompanying with the development of breathing the embryos begin to regularly produce clicking sounds. Clicking sounds are accompanying noises of respiration muscle contractions and not a real vocalization, controlled by the syrinx. Clicking sound communication is an essential factor for hatching synchronization. In conclusion, commercial incubation programmes should include environmental stimulation, with temperature and light as the foremost and more silent environment to realize mutual acoustic communication between the embryos. Such conditions are near to the nature and will address also the animal welfare aspect.

**Keywords:** clicking sound, critical period, hatching synchronization, imprinting, vocalization

### The impact of environment during final embryonic development

In poultry embryos, during the last days of incubation, physiological mechanisms are well developed. Most of the regulatory systems undergo a dramatic qualitative change from an open loop system without feed back mechanisms into a closed control system with feed back mechanisms (Tzschentke & Plagemann, 2006 Tzschentke, 2007; Tzschentke & Rumpf, 2011). Sensory modalities in avian embryos develop in the following sequence: nonvisual photic sensitivity, tactile sensitivity, vestibular sensitivity, proprioception, audition and vision (based on Gottlieb, 1968; Vince, 1974). Hence, the sensory capacity for hearing and vision in bird embryos develops lastly. But audition, for instance, is functional before hatching, that the embryos are able to produce calls (Rumpf & Nichelmann, 1993) as well as to detect and encode sound (Jones *et al*., 2006). Finally, poultry embryos have all prerequisites to react on environmental influences on physiological, neuro-endocrine and with limits on behavioural level (e.g. by acoustic communication).

Maturation of body functions will be improved by environmental inputs. Especially during ‘critical periods’ the effect of the actual environment is long-lasting and may be even passed on the succeeding generations in an epigenetic fashion (Tzschentke & Plagemann, 2006). In this context ‘imprinting’ of body functions by the perinatal environment is a fundamental process of life (Tzschentke & Plagemann, 2006). During ‘critical periods’, the actual environment influences the development of the respective body function for the entire life period, especially by changes in neuroorganization and in the expression of related effector genes.

**Prenatal temperature experiences**

Temperature experiences during final incubation significantly influence postnatal temperature adaptability and/or robustness of the birds and with it the later performance. In poultry chronic and short-term changes in incubation temperature during the last days until hatch have different effects on the post-hatching performance and adaptability to the environment (Tzschentke & Halle, 2009; Halle & Tzschentke, 2011).
Chronic prenatal temperature influences may induce lifelong warm- or cold adaptation (epigenetic temperature adaptation). Birds, incubated during the last days of embryonic development at a higher (38.5°C) or lower temperature (34.5°C) than the usual 37.5°C are characterized by postnatal changes in heat production, body temperature and temperature preference, which are typical for acclimation to the respective prenatal experienced temperature (Tzschentke & Nichelmann, 1999; Loh *et al*., 2004). For instance, during the first 10 days post-hatching cold incubated birds preferred lower and warm incubated ones higher temperatures than birds incubated at the normal temperature (37.5°C). It supports the hypothesis that avian prenatal cold experience leads to a downward shift and warm incubation induces an elevation of the thermoregulatory set-point (Tzschentke & Nichelmann, 1999). For the first time, Tzschentke & Basta (2002) proved the correlation between prenatal temperature variation and long-lasting postnatal changes in neuroorganization of the central controller of thermoregulation through investigation of alterations in the hypothalamic neuronal thermosensitivity during the first 10 days post hatching. Long-lasting effect on hypothalamic neuroorganization could be found in heat-induced c-fos-expression of hypothalamic neurons, which was

significantly different between chronic warm- and cold-incubated chickens even after 8 weeks post-hatching (Janke & Tzschentke, 2010).

On the other hand, short-term mild temperature variation improves postnatal robustness and performance of the birds under standard growing conditions (Tzschentke & Halle, 2009). In Broiler chicks short-term warm stimulation improved hatchability, food intake, food conversion and body weight at slaughter age, especially in male broilers (Tzschentke & Halle, 2009). Further, the ratio of hatched female to male chicks shifted in favour of the male chicks. Compared with the non-stimulated control group, during temperature stimulation heat production of the embryos was decreased and, finally, also the embryonic body temperature (El-Sabry & Tzschentke, 2010). Postnatal, the temperature stimulated birds need less energy to keep body temperature constant than normal incubated ones, because its metabolism and body temperature are lifelong imprinted on a lower level.

**Prenatal influence of light**

In precocial birds light stimulation during embryogenesis is very important for normal brain development. Especially the specialization of the avian hemispheres (brain lateralization) depends on light exposure of the embryo during final incubation. Lateralization of the brain is fundamental for the post-hatching behaviour (Rogers, 2011). Visual information from each eye is processed to the opposite hemisphere (left eye to right hemisphere, right eye to left hemisphere). The left eye-right hemisphere preferentially controls behaviour, which is important under emergency or stressful conditions (e.g. attention to novel objects, predators, fear response). In chicken the right hemisphere is also involved in copulation behaviour (Roger *et al*., 1985) and different aspects of social learning (Daisley *et al*., 2009), which includes, e.g., the maintenance of social hierarchy (Hogue *et al*., 1996). The main functions, which are preferentially controlled by the right eye-left hemisphere, are learnt and routine behaviour under nonstressful situations. The ability to learn to distinguish between different objects (e.g. between food grains and pebbles), for instance, is a feature of the left hemisphere. In dark incubated chicken and other bird species no or weakly developed anatomical and functional brain asymmetries were found (Dharmaretnam & Rogers, 2005). During the first post-hatching weeks limitations or losses in behavioural abilities (e.g. learning, social behaviour) are typical. Whether these behavioural changes are persistent needs further validation. In comparison with light incubated chicks, dark incubated chicks develop, for instance, less stable social hierarchies (Roger & Workman, 1989). They are unable to discriminate between different conditions (Chiandetti & Vallortigara, 2009) and produce more distress calls, followed by a higher fearfulness (Dharmaretnam & Rogers, 2005). Finally, dark incubated birds are more vulnerable to post-hatching stress. To reduce this negative effect, bird embryos need light exposure, which can be an important contribution to life-long welfare (Rogers, 2011).

## Acoustic signals and communication

Along with temperature and light late-term poultry embryos need acoustic communication by clicking sounds and vocalization to ensure a proper development of post-hatching communication, learning and memory (Rumpf & Tzschentke, 2010). In the late-term chick embryos between E18 and E21 auditory structures and functions show an adult-like development in most respects (for details, see Rubel & Parks, 1988; Jones & Jones 1995; Jones *et al.*, 2006). Also in other poultry species exogenous acoustic signals are detectable at the beginning of the plateau phase of metabolism (approximately after 80% of embryonic development). In Muscovy ducks with an incubation time of 33 days, for instance, the acoustic-sensory-cardiac axis is functional from embryonic day 27 and heart rate responses to acoustic stimulation were observed (Höchel *et al.*, 2002). Whether an embryo can hear only its neighbour or all the embryos in the clutch depends on sound transmission between the eggs. Sound transmission is based on a sound-conducting medium. In a clutch, sound is conducted via the eggshell, lengthwise and crosswise. In industrial or commercial incubators a metal grid or a metal setter tray may serve as a sound-conducting medium.

<u>Vocalizations and its relevance for acoustic communication</u>
Beginning with penetrating the inner egg membrane a species-specific sound repertoire develops gradually. Higher acoustic activity might be regarded as non-specific mutual stimulation, which is supported generally by the birds` own vocalization or other stimulation within the perinatal period. Vice versa, a disruption of mutual vocal communication in the pre-hatching period led to lower acoustic postnatal activity and also damaged postnatal acoustic communication (Lauch, 1989). Pekin ducks, for instance, need embryonic experiences of a wide range of repetition rates of their contact-contentment call to develop a preference for maternal calls (Gottlieb, 1985). Also recent studies in domestic chicken (Kauser *et al.*, 2011) and the bobwhite quail (Harshaw & Lickliter, 2011) have shown that prenatal auditory stimulation with either species-specific or complex rhythmic music sounds bias postnatal responsiveness to social stimuli, facilitates spatial learning and influences memory.

Up to now it is not known if and how the embryos receive the acoustic signals of the breeding parent. But it is likely that the breeding parent receives the acoustic signals of the embryos. It may affect the behaviour of the parents (Tschanz, 1968; Lauch, 1989), for instance, egg turning, nest building or the amount of time parents spend on the nest. Embryonic vocalizations might also serve as care-soliciting signals concerning temperature regulation. Cold induced vocalization (distress calls; Fig. 3) may help to restore normal incubation temperature (Evans, 1990; Brua *et al.*, 1996; Nichelmann & Tzschentke, 1997). Under natural conditions it may be a signal of the offspring's need for warmth from the incubating parents.

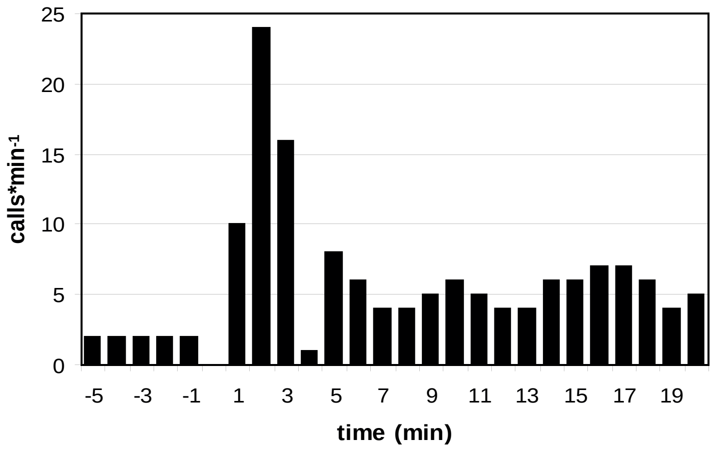


Figure 1: Distress call rate of Muscovy duck embryos before (min -5 to –1) and after a cold stimulus of 20 to 22°C (min1 to 19) from Nichelmann & Tzschentke (1997).

Clicking sounds and its relevance for hatching synchronization

Accompanying with the development of breathing the embryos begin to regularly produce so-called clicking sounds (Vince & Salter, 1967), clicks or clicking noises. Clicking sounds are accompanying noises of respiration muscle contractions and not a real vocalization, controlled by the syrinx. Investigations on the development of prenatal clicking rate are only available for Muscovy ducks (Lauch *et al*., 1988; Lauch, 1989) and quails (Vince & Salter, 1967). In the Muscovy duck first clicking sounds were observed once the inner eggshell was penetrated (Lauch *et al*., 1988). Since the investigations by Vince on quails (1964) it is known that the acoustic communication by clicking sounds is an essential factor for hatching synchronization. Vince discovered that the development and hatching time of quail embryos could be accelerated or decelerated, by clicking sounds (Vince, 1968; Vince *et al*., 1984).

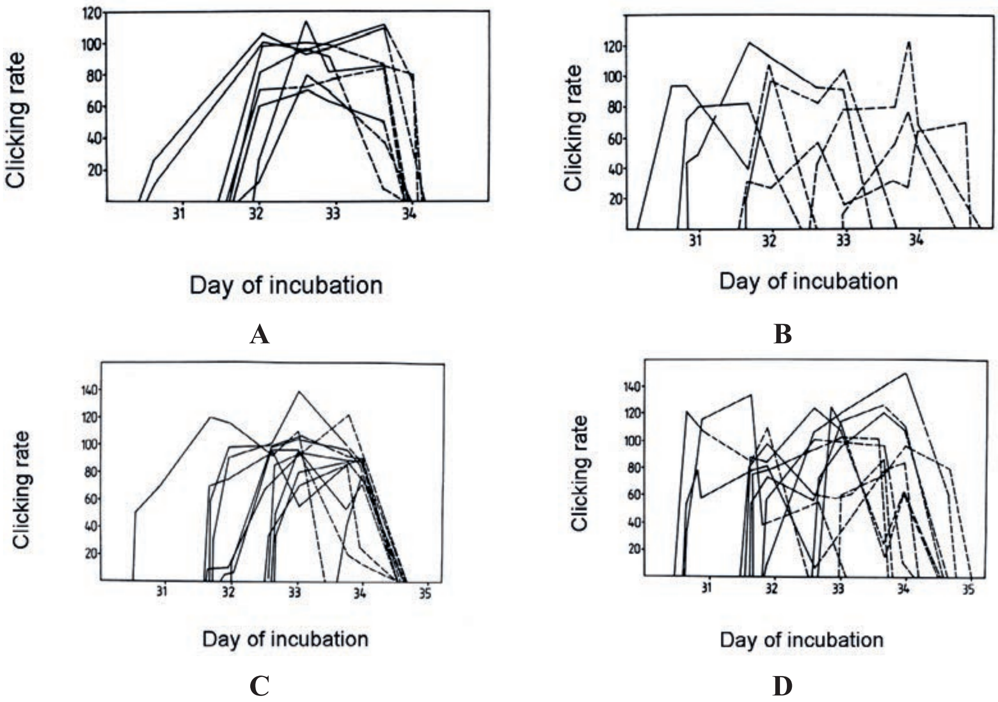


Figure 2: Synchronization of prenatal clicking rates of 8 (A) and 12 (B) Muscovy duck embryos under a sound pressure level in the laboratory incubator of 50 dB and desynchronization of prenatal clicking rates of 7 (C) and 12 (D) Muscovy duck embryos under a sound pressure level in the laboratory incubator of 80 dB, from Rumpf & Tzschentke (2010), according to Lauch (1989). (broken line=eggshell pipped, mutual eggshell contact , white noise low-pass-filter<2kHz )

In the Muscovy duck synchronization starts, when the second embryo within a clutch begins to click. Within certain, species-specific range embryos adapt their clicking rates to those of others. Towards hatching, embryos click more and more regularly. Usually, the Muscovy duck embryos in a clutch were able to synchronize their clicking rates (Fig. 2 A, B) if the surrounding sound level does not exceed about 80 dB as measured in industrial incubators. However, if the embryos had a big developmental difference to the next sibling, this embryo hatched considerably earlier or later (one example in Fig. 2 B). It can be hypothesized that small differences between the embryos as caused by, e.g., temperature can be compensated. For hatching synchronization in the Muscovy duck the mutual acoustic contact between the embryos was necessary during the whole prenatal clicking period (Lauch, 1989). Clicking rates and hatching synchronization were measured under different sound levels (steps of 5 dB). Over a sound level of 80 dB (white noise low pass filter) clicking sound communication was disturbed and Muscovy duck embryos hatched asynchronously (Fig. 2 C, D). Hatching interval under desynchronizing conditions (80 dB) was significantly, on average 4 times longer, than under synchronizing conditions (Lauch *et al*., 1988). Commercial incubation conditions seem to be more similar to desynchronized laboratory conditions, because mostly the sound level is higher than 80 dB.

## Conclusion

In poultry, during the last days of incubation physiological mechanisms are well developed. Its further maturation will be improved by environmental inputs, like temperature variations, light-dark cycle, and acoustic signals. Especially during 'critical periods' in the course of final incubation responses on environmental stimuli produce long-lasting effects, by 'imprinting' into body functions. In poultry perinatal environmetal stimulation may improve robustness and performance lifelong. Commercial incubation programmes should include environmental stimulation, with temperature and light as the foremost. To realize the acoustic communication between the embryos mutual egg contact and a silent environment (less than 80 dB) are necessary. Such conditions are near to the nature and will address also the animal welfare aspect.

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## Semi-invasive, non-contact measurements of chicken embryo heart rate using video imaging and signal processing

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### Abstract

The chicken embryo provides an excellent model organism for physiological and developmental biology studies. The chick chorioallantoic membrane (CAM) is widely used to study angiogenesis and vasculogenesis in primary tumour growth. The cardiovascular system is the first organ system to form and function in the developing embryo. Heart rate is deemed to be an important physiological parameter in such studies. The heart rate of a developing embryo can be very informative in developmental studies of cardiac rhythm. Many studies have investigated the development of techniques to measure avian embryonic heart rate from incubated eggs. However, the existing techniques disturb the incubation process and/or are sensitive to embryonic motion. A novel non-contact, semi-invasive, and motion-tolerant technique for measuring embryonic heart rate from chicken eggs using video imaging and signal processing is described and implemented in this paper. The method was developed using videos captured from 30 eggs during incubation. Heart rate was estimated using frequency analysis techniques and was in agreement with results from previous studies. The method proposed in this paper provides a real-time approach to monitoring embryonic heart rate during the development of the embryo; in addition it can provide a promising technique for monitoring the developing vasculature in primary tumour growth.

**Keywords:** Embryonic heart-rate, dynamic activity index (DAI), frequency decoupling, power spectrum, vasculature.

### Introduction

The chicken embryo is widely used experimentally in developmental biology research. It is often taken as a model for studying physiological responses and adaptation to altered environments (H. Tazawa 1981; H. Tazawa *et al.* 1989; Aubert *et al.* 2004). Chorioallantoic membrane (CAM) assays have been widely used to study angiogenesis, tumour cell invasion metastasis. The CAM model has many advantages, such as (a) the highly vascularised nature of the CAM greatly promotes the efficiency of tumour cell grafting; (b) high reproducibility and (c) simplicity and cost effectiveness (Lokman *et al.* 2012). Chicken eggs can be incubated to any stage of interest, simplifying experimental design. Within 2 to 3 days of laying, chick embryos gastrulate, neurulate, and fold into three-dimensional (3-D) animals with beating hearts, somites, and complex nervous systems (Tuan & Lo 1999). Moreover, chicken embryos are semi-transparent, making it possible to viewthe internal tissues and organs under the microscope. Many parameters of interest can be monitored during the development of the embryo, with heart rate (HR) being an important physiological index which reflects the embryo's natural activity.

Heart rate (HR) of chicken embryos during incubation and before hatching can be a very useful physiological parameter for evaluating the regulation mechanisms of the cardiovascular system and the development of the embryo.

To carry out such studies, a robust and accurate method of measuring heart rate is needed. In the literature, cardiogenic signals from avian embryos have been detected by various sensors noninvasively, semi-invasively or invasively while maintaining adequate gas exchange through the eggshell (Akiyama *et al.* 1999; Bamelis *et al.* 2004). In early research work by Bogue (Bogue 1932) as cited by Lazarini and Bellville (J W Bellville 1956) and Romanoff (Romanoff 1960), the heart rate of chicken embryos could only be studied using an electrocardiogram (ECG). In this technique, at least three electrodes have to be inserted into the tissues surrounding the embryo. Later, Bamelis *et al.* (Bamelis *et al.* 2004) used a technique in which the electrodes were positioned between the shell and the outer membrane. However, the exposed holes in the eggshell change the gaseous environment (i.e. water vapour, oxygen and carbon dioxide) for the embryo and thus influence the embryo’s physiology (Bamelis *et al.* 2004). Moreover, long-term recording of heart-rate in this way is risky, due to the increased possibility of bacterial infections through the exposed holes. The same concerns also arise in the case of the Impedance Cardiogram (ICG), developed by Tazawa *et al.* (H. Tazawa & G. Causey Whittow 1994) and the pulse-oximetry technique first presented by Lewin *et al.* (Lewin *et al.* 1997).

To overcome these concerns, researchers have developed various techniques to measure the heart rate. In the past, the dynamic activity index (DAI) has been developed to calculate the activity of livestock in order to relate the measurement to specific animal behaviours (Costa, A., Mentasti, T., Guarino, M., Leroy, T., Berckmans 2007; Leroy *et al.* 2008). In this work, it is shown that the activity index contains dynamic information about vessel contraction and is therefore well suited to extracting information about the heart pulse.

This paper proposes a new approach for semi-invasive, non-contact and motion tolerant cardiogenic signal measurements using video images.

## Materials and methods

Two hundred fertile eggs from a 36-week old broiler flock (breed Ross 308) were incubated in industrial forced draught incubator under standard incubation conditions until Embryonic Day (ED) 12 at a commercial hatchery (Belgabroed, Belgium). The eggs were transferred to our laboratory to be incubated in an experimental incubator (a detailed description of the experimental incubator can be found in (Van Brecht *et al.* 2005)) at 37.8oC with relative air humidity of 60% and were turned automatically every two hours. 30 eggs in total were used in this study to measure the HR of the chicken embryos during the incubation process.

Opening the eggshell

Different techniques for opening the eggshell (e.g. (Kuo 1932; R. W. Oppenheim *et al.* 1973)) were tested and compared in this study in order to select the most suitable one. During these pilot trials openings were made in 40 incubated eggs and 20 videos were captured and examined. The criteria for selecting an opening technique and procedure were that it had to provide minimal influence on the embryonic environment, especially for long observation periods (R. W. Oppenheim *et al.* 1973), and should allow a clear view of the embryo structure and egg vasculature. Hence, the eggshell lateral-opening technique was chosen (Figure 1).

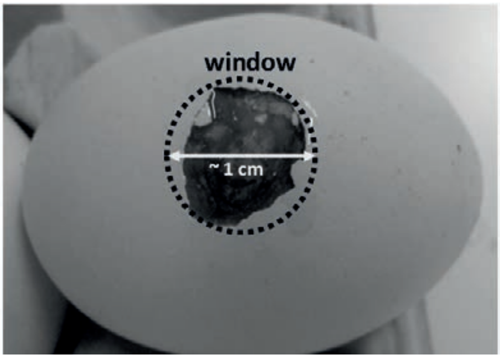



Figure 1. A windowed egg with 1 cm diameter window is opened using the *lateral-windowing technique.*

Video capturing

Videos of the embryo were captured through the eggshell window using a digital USB microscope (Veho® VMS-004D, Veho) with up to 400x magnification . Uncompressed colour videos were recorded using VirtualDub® freeware (release 1.9.11) with a pixel resolution of 320×240. The videos were collected at 10 frames per second (fps) and saved in AVI format. With this sampling frequency our collection system had a Nyquist frequency (A. V. Oppenheim *et al.* 1999) of 5 Hz and therefore allowed observation of phenomena up to this frequency. Since the maximum HR expected from the literature e.g. (Clark 1927; Bogue 1932; H. Tazawa *et al.* 1989; Akiyama *et al.* 1999) is 300 bpm (i.e. 5 Hz) it is concluded that 10 fps is an adequate sampling frequency to monitor HR. The microscope camera was fixed in the body of the egg-tray in such way as to face the eggshell window at a maximum distance of 5 mm from the egg (Figure 3). Videos were captured continuously for five hours every day, starting at 1pm, from ED 13 .

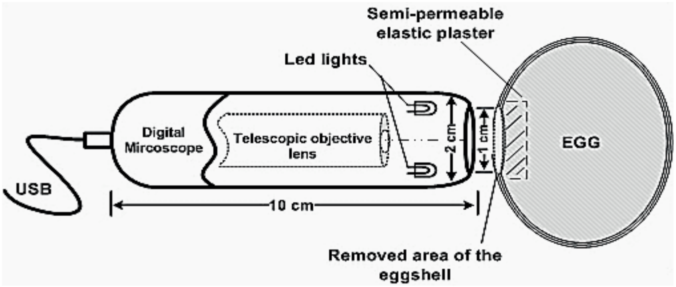



Figure 2. Schematic representation showing the dimensions of the microscope camera and its position relative to the egg.

Image processing and calculation of embryonic Dynamic Activity Index (DAI)

Image analysis was the first step to extract meaningful information from the video, such as the activity index. The first step was to segment the blood vessels from the background in order to remove the movement caused by other components of the image and therefore to reduce the error in extracting the HR. The Frangi filter (Frangi 1998) was used to enhance all the cylindrical components of the image. After the image was segmented, the second step was to extract the activity index by calculating the binary image difference between consecutive frames.

Blood-Vessel segmentation

The first step in the image processing algorithm was to discriminate the blood vessels from the other components in the image. This part is particularly important in order to remove noise from the activity value and to isolate only the activity due to vessel movement.  A multiscale enhancement filter Vf(λ) developed by Frangi *et al.* (Frangi 1998) was used to discriminate tubular structures in the image. This filter is a nonlinear combination of the eigenvalues λ_i of the Hessian matrix computed at each pixel of the image (Figure 3):

$$Vf(\lambda) = \begin{cases} 0, & if\ \lambda_2 < 0\ or\ \lambda_3 > 0 \\ (1 - e^{\frac{R_A^2}{2\alpha^2}}) e^{\frac{R_A^2}{2\alpha^2}} (1 - e^{\frac{S_A^2}{2\gamma^2}}), & otherwise \end{cases}$$

where $R_A = \frac{|\lambda_1|}{|\lambda_2|}$ is the measure of the eccentricity of the second order structure of the image, $S_A = \|H\| = \sqrt{\lambda_1^2 + \lambda_2^2}$ and α, β are thresholds which control the sensitivity of the vesselness measure.

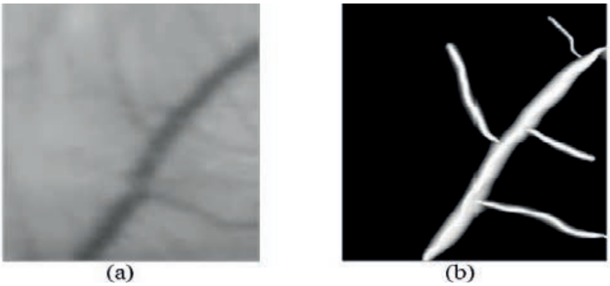



Figure 3. On the left (a) the original image captured using the digital microscope. On the right (b) the processed image with the enhanced vessel segmentation.

Activity index

Activity index is a measurement of how the pixel intensities vary between consecutive frames. The calculated consecutive activity indices (dynamic activity index, DAI) quantify different components of embryonic motion and activity including these of cardiogenic origin.

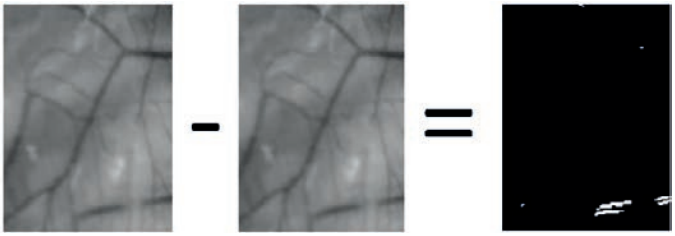
For instance, blood vessel contractions result in a change in pixel intensity in the frames. The blood flow in the vessels is pulsatile, with a rhythm of fast and slow movement. This oscillatory movement of blood vessels can be presented by a waveform of dynamic activity index. The algorithm to calculate the activity index is described in the following for each frame (Leroy *et al.* 2008):

a. Use the colour frame obtained during video recording as an input image.
b. Apply the vessels filter to the image in order to enhance the blood vessel structure.
c. Segment the blood vessels using the Otsu threshold algorithm (Otsu 1979
d. Calculate the difference $I_{diff}(x,y,t)$ of the binary image by subtracting the binary image $I(x,y,t)$ at time t and the binary image at time $t$-$1$ (Figure 4):

$$I_{diff}(x, y, t) = I(x, y, t) - I(x, y, t-1)$$

Calculate the activity index $a_i(t)$, defined as the fraction of the sum of the pixel change $I_{diff}(x,y,t)$ of each pixel of the zone to the total number of pixels in the image, from the following formula:

$$a_i(t) = \frac{\sum_{(x,y)} I_{diff}(x,y,t)}{\sum_{(x,y)} 1}$$



(a) (b) (c)

Figure 4. Activity index is the difference in number of pixels (c) between frames taken at time *t-1(b)* and at time *t (a).*

Signal processing and HR decoupling

The captured signals obtained from the image processing stage contain a number of embryonic motion and activity components as mentioned before. In this study, the underlying signal of interest is the cardiogenic periodic components of the original signal. During the cardiac cycle, volumetric changes in the CAM vasculature lead to changes in the intensity of the reflected light in a periodic pattern (pulsatile), indicating the timing of the cardiogenic events. These periodic changes can be decoupled and analysed using signal processing techniques such as unobserved component analysis (Young 2011). Processing and analysis of the signals were performed using custom software written in MATLAB (The Math Works, Inc.) and CAPTAIN toolbox (Taylor *et al*. 2007).

The waveform of the dynamic activity index was analysed by Fast Fourier Transform (FFT) and power spectral analysis. The cardiac pulses were designated as the frequency that corresponded to the highest power of the spectrum within a predefined operational range. In this study, an operational range is set to 2.5-5 Hz which corresponds to the expected minimum and maximum heart rates of 150-300 bpm (as reported for example by (H. Tazawa *et al*. 1989; Akiyama *et al*. 1999) and (Lierz *et al*. 2006)). The frequency content of the DAI signals is calculated over a one-minute window which results in the estimation of HR once every minute.

## Results and discussions

Image processing and embryonic activity detection

Figure 5 shows a typical example of the calculated embryonic dynamic activity index (DAI) from one hour video recording at ED 14. Visual observation of both the videos and the automatically extracted activity index show a wide variation in the observed activity. As can be seen in Figure 6, the activity index ranges from 0 to 0.45 units (in the complete datasets that were collected the activity index ranges from 0 to 1 unit). By comparing the activity index with the videos, it is hypothesized that a high (>0.2) activity index corresponds to high amplitude embryogenic activities (e.g. whole body movements and turning, limb and/or neck movements). Such activates can be regular and periodic in nature, quick, sudden and jerky, or irregular and unintegrated (Kuo 1932; Hamburger *et al.* 1965; R. W. Oppenheim *et al.* 1973). When the activity index is low (<0.2) it is hypothesised that this is due to weaker embryogenic activities with low amplitudes causing little modification in the reflected light intensity from the segmented blood vessels (low $I_{diff}$). Most of these movements showed an irregular pattern of occurrence or were periodic in nature throughout the whole signal. Hence, it is suggested that these patterns of activities are due to cardiogenic pulses and/or respiration (in the late stages). Irregular non-periodic activities of low amplitude were also observed and can be attributed to irregular myogenic contraction of amnion according to (Kuo 1932).

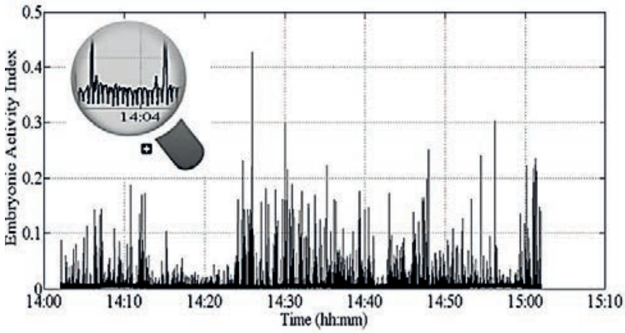


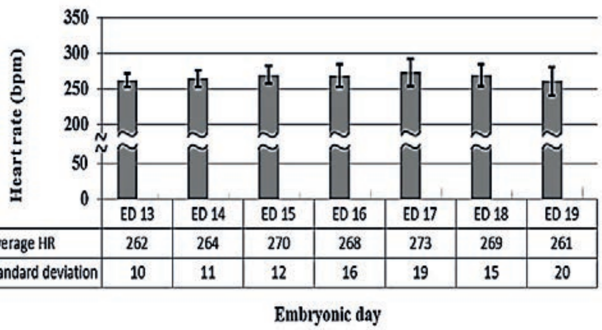

Figure 5. The calculated embryonic activity index for 1 hour of recorded video at ED 14.

<u>Signal processing and HR recovery</u>

The power spectrum of the activity index is calculated by applying the FFT algorithm to the original activity signals obtained from the captured videos.

The literature suggests than an HR of between 150 and 300 bpm can be expected (i.e. a frequency between 2.5 and 5 Hz), (Clark 1927; Bogue 1932; H. Tazawa *et al.* 1989; Akiyama *et al.* 1999; Lierz *et al.* 2006). It is hypothesised that the frequency with the highest amplitude within the 2.5-5 Hz frequency range of the spectrogram of the activity index represents the HR of the embryo.

In order to track the cardiac frequency and HR fluctuation, the power spectrum is calculated by applying the FFT algorithm to a moving window of the activity signals which is 1 min in duration. Figure 6 shows an example of the calculated embryonic HR based on a 1 minute window at ED 14. An average frequency of 4.4 ± 0.18 Hz (corresponding to an HR of 264 ± 11 bpm) was observed during one hour (from 2 pm to 3 pm) of video recording at ED14. As explained above, this is the maximum HR that can be observed using videos of 10 fps. Therefore we cannot be certain that this HR is accurate or whether the actual HR is higher. Although an HR higher than 300 bpm has not been reported in the literature, these results indicate that the instantaneous HR could be higher than 300 bpm and more research should be conducted in that direction. Figure 6 shows the average heart rate (bpm) and the standard deviation of the 30 monitored eggs at embryonic days ED13 to ED 19, calculated using the proposed technique. The resulting HR measurements are in the range of the measurements obtained by different authors (e.g. (Bogue 1932; H. Tazawa *et al.* 1989; Akiyama *et al.* 1999; Lierz *et al.* 2006)) using different techniques (e.g. ECG, ICG, Pulse-Oxmetry, and Buddy digital egg monitor).




| | ED 13 | ED 14 | ED 15 | ED 16 | ED 17 | ED 18 | ED 19 |
|---|---|---|---|---|---|---|---|
| Average HR | 262 | 264 | 270 | 268 | 273 | 269 | 261 |
| standard deviation | 10 | 11 | 12 | 16 | 19 | 15 | 20 |

Figure 6. Heart rate (mean average and standard deviation of 30 eggs) of the embryo at embryonic days ED13 to ED19 measured using the proposed video imaging technique.

## Conclusions

The present paper describes and implements a new approach for real-time estimation of the chicken embryo heart rate (HR) from video recording of the CAM through an opened window in the lateral side of the egg. The method presented is suitable for real-time and continuous monitoring of the developing embryonic vasculature. Segmentation of the blood vessels reduced the disturbing effect of other embryonic motion on the cardiogenic signals, making the method more tolerant to the different motion disturbances. The HR obtained from the video recordings for embryonic days ED13 to ED19 was within the range documented in the literature (e.g. [2], [4], [6] and [26]). The proposed approach is a novel, semi-invasive and motion-tolerant method for non-contact heart rate measurement in chicken eggs without disturbing the incubation process. The technique described in this paper is promising for the development of a real-time and continuous system for monitoring and quantification of vasculature development in the CAM for studies of tumour cell invasion metastases.

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**Effect of prenatal auditory stimulation on embryonic development and hatch performance in broiler chicks**

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**Abstract**

Previous research has reported that chicken embryos develop auditory functioning during incubation and that prenatal sound may play an important role in embryo development and alter the hatch time. To quantify the impact of sound on the development of embryo and organs and hatch window, we stimulated the incubation environment by exposing chick embryos to patterned species-specific sound by means of a speaker at 72dB for 16 hours a day: maternal calls and embryo/chick calls from day 10 to day19 and day19 until hatching, respectively. The embryos exhibited a similar growth pattern between the sound-stimulated and control groups. The onset of hatch (internal piping) was delayed and the hatch window was narrowed by 1.5 hours in the species-specific sound-stimulated group. However, the sound-stimulated embryos had a lower hatchability than the control group. The results of this study indicate that maternal calls can delay hatch time. However, we are concerned an increase in late embryonic death in sound-stimulated group, probably due to the induced stress which may be caused by sound exposure during incubation. It needs further study to identify the negative impact of sound.

**Keywords:** prenatal sound stimulation, chick, hatchability, hatch time

**Introduction**

In nature, the clutch hatches under the mother hen within a short 'hatch window' (HW) which is defined as the time between the early-hatching and late-hatching chicks. In contrast, during artificial incubation, maternally-derived components of incubation control and sound communication are excluded. In the poultry industry, the HW can be as long as 48 h due to a difference in genetics and handling (i.e. storage conditions) among the batches of eggs. As spread of hatch increases, the time of first access to feed and water also increases. A delay in access to feed for 1-d-old chicks impairs post hatch growth (Decuypere *et al.* 2001; Gonzales *et al.* 2003; Willemsen *et al.* 2010).

Several studies report that the auditory development in birds is precocious during incubation (Konishi 1973; Friauf *et al.* 1999; Rubel *et al.* 2002). In domestic chickens, the ontogeny of hearing begins with endogenous rhythms between day 13 and 14 of incubation(Jones *et al.* 2006).Research has shown that hen vocalisations delay internal piping so that all embryos reach the hatching phase well-developed and begin hatching (Greenlees 1993). This serves as an evolutionary parenting mechanism to prevent some eggs from needing additional incubation time while hatched chicks are ready to explore. It is possible that prenatal auditory stimulation may also play a role in the synchronisation of hatching (Veterany *et al.* 1999; Vergne *et al.* 2008).Avian embryos begin to regularly produce clicking sounds during EP due to the egg tooth tapping against the eggshell (Vince *et al.* 1967; Terskova 1975; Hoyt *et al.* 1980; Veterany *et al.* 1999). The acoustic communication by clicking sounds is an essential factor for hatching synchronization in many bird species by either accelerating or decelerating the hatching time of embryo (Vince 1966; Vince 1966; Vince 1973; Vince *et al.* 1984; Brua 2002). Clicking sounds are well studied in quails and Muscovy ducks, but not in the domestic chicken. In the domestic chicken, hatching occurred earlier in chicks exposed to clicking sounds than in control chicks treated with no sound stimulation or maternal calls. These results suggest that chicks accelerate hatching in response to internally generated clicks but not to external stimuli such as a maternal call (White 1984).

The aim of this study was to investigate the effects of prenatal auditory stimulation on the timing of hatching, hatch performance and chick embryo development. Hatch window, hatchability, body weight and organ weight were compared between the sound-stimulated group and control group.

## Material and Methods

Four batches of 2400 fertilized Ross 308 eggs were obtained from a local supplier (Henry Stewart & Co. Ltd, Lincolnshire, UK) and incubated in two small custom-built “BioStreamer” incubators (Petersime NV, Zulte, Belgium). Each incubator was able to set 300 eggs in 2 trays. Incubation conditions were continuously monitored and controlled by the incubator controller pc (BIO-IRIS, Petersime TM). All incubation conditions (machine temperature, humidity, $CO_2$ concentration and ventilation rate) were identical in the two incubators. The internal pipping (IP) and Hatch were detected by the SynchroHatch sensor and recorded by the incubator controller (Petersime BIO-IRISTM) which indicates the start and the end of hatching process. Hatch window (HW) in this study is defined as the duration between IP and Hatch.

In the sound-stimulated group, embryos in one incubator were exposed to a species-specific sound at 72dB for 16 hours/day: maternal calls and embryo/chick calls from day 10 to IP and IP until hatch, respectively. In the control group of another incubator, specific-species sound was excluded. The treatment was swop next batch between two incubators to exclude the incubators' effect. The species-specific sound files were built up in KU Leuven. Sounds from the hens (mainly day 15 – 18) that has most of the frequencies around 500-1000 Hz. The file was a composition of several call types with some intervals of silence that reduces gradually over time. The calls types were mainly: 1) cluck sounds, 2) beak-clapping and 3) alarm sounds. Embryo/chicks sound file was mixture of chickens' embryo sounds and chicks vocalizations. The dominant frequencies were higher between 2000 – 4500 Hz. Basically there were two main call types of the chicks: 1) distress calls and 2) pleasure calls.

Sound files were stored on a PC and played using VLC media player and a built-in speaker in the incubators.
Hatchability (the percentage of fertile eggs that hatch), early death (ED), middle death (MD), late death (LD) and mortality were determined at the end of incubation. 5 samples of each batch were collected randomly in each group at eight time points (day 10, day12, day14, day16, day18, day19, day20 and day21). Embryos or chicks were immediately decapitated and organs (heart, liver and stomach) were weighed. Animal experiments were performed with ethics approval from the Royal Veterinary College Animal Ethics Committee.
Data were expressed as mean ± standard error of the mean (SEM) and differences between control and sound-stimulated groups were analysed by Independent-samples T Test using SPSS (PASW statistics 18). The P values $< 0.05$ were considered significant.

## Results and Discussion

The IP was delayed by about 4h and average HW was narrowed by 1.5h in the sound-stimulated group compared to that of control group (Table 1). Hen vocalisations delayed internal piping and it served as an evolutionary parenting mechanism to prevent some eggs from needing additional incubation time while hatched chicks were ready to explore. At this time, it switched to embryo/chick calls which served to synchronise hatching process by either accelerating or decelerating the hatching behaviours of their siblings.

Table 1: Data of IP and HW in four incubation batches.

| Group | Hatching time data | |
|---|---|---|
| | IP[a] | HW[b] |
| Control (n=4) | 465.3±1.5 | 27.0±2.0 |
| Sound-stimulated (n=4) | 469.5±1.0 | 25.5±1.3 |
| P-value | 0.05 | 0.5 |

[a,b] present in hours of incubation time

In Figure 1, the mean values of hatchability, early death, middle death, late death and accumulated death of control group and sound-stimulated group for the four batches are presented. The sound-stimulated embryos had lower hatchability and higher late death probably due to the induced stress which may be caused by sound exposure during incubation.

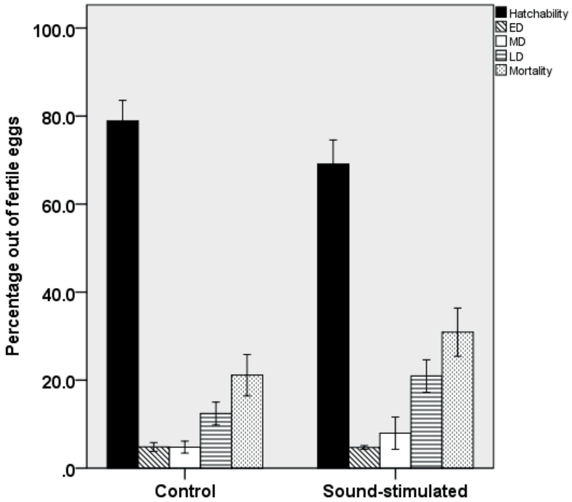


Figure 1: Data of hatch performance of the control groups and sound-stimulated groups (n=4, ED 'early death', MD 'middle death' and LD 'late death')

We haven't found any impact of prenatal auditory stimulation on embryonic development. The embryo weight, chick weight and organs weight were increasing steadily with the incubation time, but which measured at each time points did not show significant difference between control group and sound-stimulated group.

## Conclusions

We investigate the effect of prenatal auditory stimulation on embryonic development, hatchability and the timing of hatch. The sound exposure during incubation did not affect embryo development, but it delayed the start of hatch due to the hen vocalisations delay internal piping. Furthermore, more late death was observed in sound-stimulated embryos which probably due to the sound induced stress. However, further study is needed to identify the negative impact of sound on hatchability.

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# Monitoring of eggshell temperature to detect hatching time and its thermodynamic relations

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## Abstract

Monitoring incubation processes of chicken eggs demands continuous assessment of embryo status, which is usually a destructive intervention as it is necessary to break the egg open. Therefore, non-invasive methods of assessing embryo development are of interest to both research and industry. Among the existing monitoring techniques, the most widely used is eggshell temperature monitoring. This study investigated variations in eggshell temperature (EST) of broiler eggs in order to determine the precise hatch time of individual chicken embryos. Temperature sensors monitored the temperature of 40 focal eggs by registering EST every minute. The results showed temperature drops of between 2°C and 6°C during the last 3 days of incubation as an indicator of the precise individual hatch time. Video cameras were used as a reference method for validation of the results. Comparison between EST drops and the hatch time of individuals revealed time synchronisation with a 99% correlation. Since EST variations associated with fluid exchanges through the eggshell are determining factors that influence hatching, a dedicated experiment was carried out to investigate the evaporative cooling effect that caused the EST drops on the shells of chickens' eggs. Broken eggshells were sprayed with water to simulate the water vapour generated by embryonic metabolic processes. Type T thermocouples were attached to eggshells and a precision balance was used to measure EST and eggshell weight loss (ESW), respectively. Results for simultaneous heat and mass transfer in the eggshell were obtained. A model was created to estimate the amount of water on the eggshell by the measured EST. This developed model was subsequently used to infer the amount of liquid on the eggshell in real lab-scale incubation data. It was concluded that the exact hatching time can be detected by measuring EST during the hatching process, and the amount of liquid left in the broken eggshell, just after hatch, can be estimated.

**Keywords:** eggshell temperature, hatching process, hatch time, heat balance, water evaporation, modelling

## Introduction

In order to achieve maximum hatchability and post-hatch performance, continuous monitoring of chicken embryo development is desired, since hatching is a key milestone in this process. The ability to monitor embryo development events is useful for hatcheries trying to ensure that embryos are on track for proper development. Monitoring of embryonic temperature demands invasive measurements which bring a risk of potential contamination. In general, non-destructive monitoring systems for chicken embryo development are of interest to researchers and industry. Of all non-destructive techniques, the most widely used on the commercial scale is eggshell temperature (EST) monitoring, introduced by Sotherland *et al.* (1987). Measurement of EST during the setter stage of incubation is widely discussed: Lourens *et al.* (2006; 2005) studied distinct EST profiles, hatchability and posthatch performance. Molenaar *et al.* (2011) used EST treatments to explain the physiological and developmental status of chicks. Embryonic development is predominantly dependent on the interaction between environmental factors (mainly temperature) and biochemical reactions (enzymes). Under artificial incubation conditions, chemical changes in organic substances as a result of catalytic actions cannot be externally controlled. However, temperature and other secondary environmental factors (air humidity, gas concentrations, etc.) can be manipulated in order to improve the process. In practice, the air temperature in the incubator differs from the micro-environment temperature around the eggs which locally affects the embryonic temperature (French, 1997; Meijerhof and Vanbeek, 1993; Van Brecht *et al.*, 2003). EST measurements are important to monitor embryonic metabolic rates (Pulikanti *et al.*, 2011) and to understand the thermodynamics of heat exchange on chicken eggs. Heat transfer is greatly influenced by the temperature gradient between egg and microenvironment and the air velocity across the eggs. Complementary water vapour pressure gradients are the driving forces of mass transfer between eggs and their microenvironment (Meijerhof and Vanbeek, 1993; Van Brecht *et al.*, 2005) and are proved by continuous egg weight losses. Therefore, the aim of this study is to investigate EST variations and study the heat and mass transfer mechanisms during the hatching process for chicken eggs. It is believed that EST is a measurement which can accurately detect the hatching time of individual chicken embryos, and affects the magnitude of the chick's bioresponses to adverse conditions immediately post-hatch (Careghi *et al.*, 2005; van de Ven *et al.*, 2011b). The hypothesis is that simultaneous heat and mass transfer occurs in the broken eggshell due to the evaporation of water, which produces a cooling effect on the surface of the eggshell and causes the measured EST drop. As a result, EST measurements can be used to determine the precise hatch time of individual chicks (Romanini *et al.*, 2013) as well as to estimate the amount of liquid left in the eggshell by recently hatched chicks.

## Material and methods

Monitoring eggshell temperature

A total of 1800 fertilised Ross 308 eggs were randomly placed in two identical custom-built Petersime small-scale incubators with a capacity of 300 eggs each, in 3 incubation trials. Environmental incubation conditions (air temperature, air humidity and $CO_2$ concentration) followed a standard single-stage incubation programme. Subsets of 10 focal eggs out of 300 eggs were sampled. The embryonic temperature of 10 focal eggs per incubator was measured from ED1 till hatch by measuring their EST every minute using temperature sensors $T_{Sic}$™ 716 (IST, Switzerland) attached to the equator of the eggs. After transfer at ED18 the 10 focal eggs were individually placed in a specially designed area of the hatching basket, separated by a metallic mesh grid (8 x 8 x 8 cm) to allow individual monitoring of hatching. A digital colour CCD top view camera VDC 413 (Inter M, Korea) was used as a tool to record the hatching process in a video format. Pictures were taken every 5 min for 5 s (1 frame per second). Video recordings of the hatching process were used as the “gold standard” reference method for manual labelling of the exact hatching time of 10 individual focal eggs in each incubator.

Eggshell water evaporation

In order to quantify the eggshell water evaporation, a lab-scale (300 eggs) incubator installation measuring 2830 × 3240 × 1540 mm was used, which is a small section of an industrial incubator. A more detailed description of the installation is given by Van Brecht *et al.* (2005). The lab-scale incubator was set to maintain a constant air temperature and relative air humidity during the trial. The set points were 37-38°C and 32°C for dry bulb temperature and wet bulb temperature, respectively.

Eggshell temperature (EST) and eggshell water loss (ESW) measurements

A basket with 24 selected dried eggshells was placed inside the incubator installation. From this basket 4 eggshells were randomly sampled for the study. These shells were naturally broken into approximately two halves when the embryos emerged from their shells. Mechanical ventilation provided air flow around the eggshells. The incubator was set to an air temperature of 37-38°C and relative humidity of 70-80%. Calibrated type T thermocouples of 1 mm diameter with a precision of ±0.5°C in the range between -40°C to 125°C were attached on the eggshell, 5 mm from the equator of one half of each eggshell using blue tack. In addition, 2 extra type T thermocouples with the same characteristics, were placed 10 mm away from the eggshells in order to monitor the air temperature of the micro-environment around the egg. These thermocouples were connected to a DaqPRO™ 5300 (Fourier Systems Ltd.) 8-channel data acquisition and logging system in order to measure temperature in real time. The Windows® based software DaqLAB™ was used to trigger data recording by the thermocouples, at a rate of 1 measurement per second.

An A&D HM-120 digital analytical balance, physical dimensions 249 mm (W) x 330 mm (D) x 327 mm (H), with a capacity of 120 g and precision of 1 mg, was used to register the weight loss of the eggshells. WinCT software was used to transmit the weighing data from the A&D balance to the PC via an RS-232C communication port at an eggshell measurement rate of 1 measurement/s. Tested eggshells were sprayed with water at the same temperature as the microenvironment around the eggs (39 °C) to maintain the sole effect of water evaporation on EST drop. Eggshell temperature and eggshell weight data were synchronised and stored on the same PC. Data were post-processed after the end of the experiments.

## Results and discussion

<u>Hatching time identification using EST measurements</u>

Figure 1 shows that EST measurements for the focal eggs were predominantly concentrated within the reported appropriate range for embryonic development, between 37°C and 38°C. Four relevant EST drops were identified at distinct times (~ 487h, 488h, 492h and 495h).

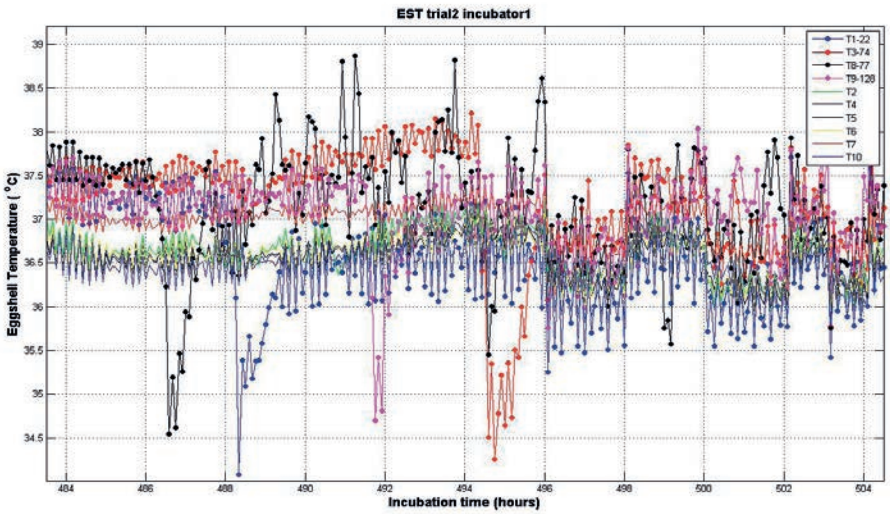


Figure 1. EST measurements of 10 focal eggs carried out during the hatching period from around 472 h to 500 h of incubation with identification of EST drops for 4 individual eggs.

The notable drops in EST (3.46 °C ± 1.23) for 4 out of 10 focal eggs were further investigated and visual observation of the videos showed that hatch only occurred in those with relevant EST drops. The exact hatching time for each individual embryo labelled in the videos coincided with the time of the EST drops. Figure 2 shows EST measurement results for two focal eggs in comparison to the labelled hatch time using the video recording as reference.

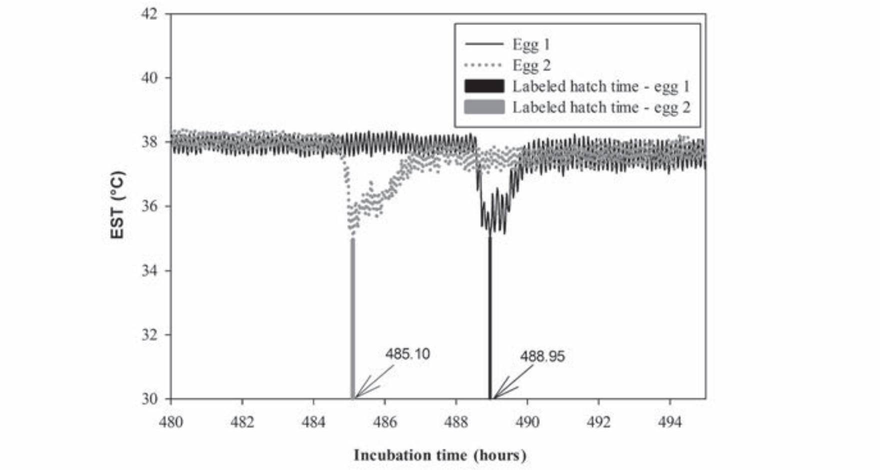


Figure 2. Example of EST measurements carried out for two focal eggs during the hatching period.

Measured EST shows that the two eggs have EST drops of 3.15 °C and 3.25 °C for egg 1 and egg 2 respectively, with the lowest EST values at distinct times during the hatching period (i.e., egg 1 at 488.9 h; and egg 2 at 485.1 h).The remaining focal eggs with dead embryos or embryos which did not hatch do not show any EST drop. Therefore, whenever there is an isolated EST drop of 2.1 °C to 5.9 °C during the hatch period, this indicates that a chick has emerged from its shell, with a correlation coefficient of R2 of 0.99 according to the linear regression model presented in Figure 3.

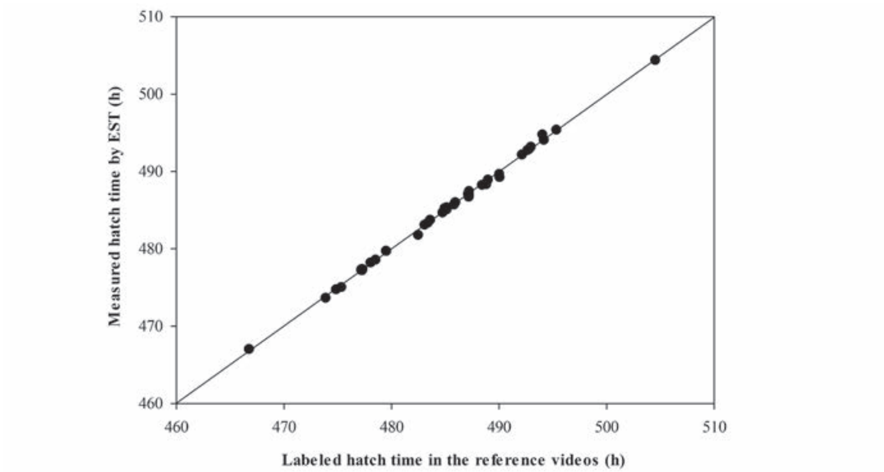


Figure 3. Linear regression model with 99% correlation coefficient between measured hatch times based on EST and their respective labelled hatch time using video recordings.

Thermodynamic relations of hatching

The hypothesis of this study was that the EST drops are an effect of evaporative cooling of the water content left in the eggshell immediately after hatch. Table 1 shows the results of calculated parameters for 4 eggshells based on an equilibrium condition between convection and evaporation heat transfer mechanisms.

Table 1. Results of EST before or after water spray ($EST_{BS}$ and $EST_{AS}$), the difference in $ESW_{BS}$ and $ESW_{AS}$, delta time (Δt), water loss rate ($\dot{m}_{Water}$) and convection coefficient (h) for 4 eggshell samples tested during the evaporation study.

| Eggshell sample | $EST_{BS}$-$EST_{AS}$ (°C) | $ESW_{AS}$ – $ESW_{BS}$ (g) | Δt (s) | $\dot{m}_{Water}$ ($g_{water}$/s) | h ($W/m^2.°C$) |
|---|---|---|---|---|---|
| 1 | 5.852 | 0,3228 | 763 | $4.23 \times 10^{-4}$ | 26,59 |
| 2 | 6.512 | 0,4214 | 907 | $4.65 \times 10^{-4}$ | 26,24 |
| 3 | 6.429 | 0,2161 | 333 | $6.49 \times 10^{-4}$ | 37,12 |
| 4 | 5.620 | 0,2342 | 284 | $8.59 \times 10^{-4}$ | 56,23 |

When the eggshell area is assumed to be a constant (A = 0.0068 m2) based on calculations by Narushin (2001), the results obtained for the convective heat transfer coefficient (h) are as shown in Table 1. The average convective coefficient (h) was 36.6 ± 12.1 W/m2 C. This experimental calculation procedure was applied to an existing lab-scale incubation data. The results are shown in Table 2.

Table 2. Magnitude of EST drops, their respective delta time (Δt), water loss rate ($\dot{m}_{Water}$) and mass of evaporated water ($M_{water}$) for lab-scale incubation.

| Trial | Repetition | Egg sample | $EST_{BH}$-$EST_{AH}$ (°C) | Δt (s) | $\dot{m}_{Water}$ ($g_{water}$/s) | $M_{Water}$ (g) |
|---|---|---|---|---|---|---|
| Trial1 | Incubator 1 | 1 | 3,26 | 720 | $3.24 \times 10^{-4}$ | 0,233 |
| | | 2 | 4,53 | 1080 | $4.50 \times 10^{-4}$ | 0,486 |
| | Incubator 2 | 3 | 2,81 | 720 | $2.79 \times 10^{-4}$ | 0,201 |
| | | 4 | 2,53 | 1080 | $2.51 \times 10^{-4}$ | 0,271 |
| | | 5 | 2,74 | 1440 | $2.72 \times 10^{-4}$ | 0,392 |
| | | 6 | 3,04 | 1080 | $3.02 \times 10^{-4}$ | 0,326 |
| Trial2 | Incubator 1 | 7 | 2,93 | 1440 | $2.91 \times 10^{-4}$ | 0,419 |
| | | 8 | 3,01 | 720 | $2.99 \times 10^{-4}$ | 0,215 |
| | | 9 | 2,68 | 1080 | $2.66 \times 10^{-4}$ | 0,287 |
| | | 10 | 3,82 | 1440 | $3.80 \times 10^{-4}$ | 0,546 |
| | Incubator 2 | - | - | - | - | - |
| Trial3 | Incubator 1 | 11 | 6,75 | 360 | $6.71 \times 10^{-4}$ | 0,241 |
| | Incubator 2 | - | - | - | - | - |

Evaporation rates of water in the eggshells just after hatch were calculated based on both the average convection coefficient and individual EST drop profile. These results were used to obtain an estimate of the mass of evaporated water, representing the amount of water left in the eggshells by the recently hatched chicks as shown in Table 2. Potentially, there could be a correlation between the estimated amount of water evaporated and some embryonic physiological factors such as egg and body weight. This supports the use of EST sensors as a tool to precisely identify individual hatching times and possibly to provide an early biological sign of a hatched bird. It is an important result, since differences in hatching time form the basis of conclusions in studies of the effect of early or late hatched chicks on post-hatch performance (Hulet *et al.*, 2007; Hulet, 2007; van de Ven *et al.*, 2011a).

## Conclusions

The results demonstrated the benefits of using EST measurement devices as a tool for accurate monitoring of hatching processes. Furthermore, EST measurements represent a safe and non-invasive method of detecting the hatching time of individual chicken embryos. Whenever there was accentuated marked drop in EST (~ 3 °C) during the hatching period (from 472 h to 500 h), it was confirmed as the hatching time in the reference videos with a 99% correlation coefficient from the linear regression model. The thermodynamic mechanisms associated with the hatching process were investigated and revealed an evaporation cooling effect on eggshells due to water left in the shell by embryos just before hatch. Such results are crucial for the optimisation of incubation processes.

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# Session 19

# Environmental Impact

# Neural predictive control of biological processes in the livestock industry

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## Abstract

Automated process control is widely used in industry, but apart from climate (temperature) control, this is not the case in the livestock industry. The introduction of new sensor technology and in particular camera based systems for measuring weight (growth) or animal activity, is providing an opportunity to actively manage growth or animal behaviour. Differential recurrent neural networks are particularly suited to model complex data sets, without in-depth knowledge of the underlying process. Using this approach, models for broiler and pig growth, broiler activity and ammonia emission in response to feed dosage, illumination and temperature change, were developed and validated using extensive data sets. The models were able to predict growth and activity accurately, but performed less well on ammonia emission due to missing inputs for the model such as heating and a lack of independent data sets.
Subsequently, the models were incorporated in nonlinear model predictive controllers, which aimed to maintain set growth curves, activity levels or emission levels, whilst minimising required resources such as feed. The validity of the controllers was tested using new data sets. The controllers for broiler and pig growth or broiler activity were able to manage feed dosage or light level to maintain growth or activity very well. However, the controller managing room temperature to lower ammonia emissions, performed poorly. Factors affecting the poor performance were insufficient data within the original data set to cover all seasons and lack of data for the effect of low temperature upon the ammonia emission.
The importance of the quantity and quality of the data sets for successful implementation of data based models has been shown clearly, with accuracy of the differential non-linear model controllers ranging from 2% to 60% for 24 to 4 data sets respectively.

**Keywords:** Predictive control, Broiler, Pig, System identification, Neural network models

## Introduction

Livestock managers deal with multiple processes associated with pig growth, animal welfare, animal health and environmental legislation. The daily challenge for farmers and stockmen is to manage these interconnected processes, whilst maintaining profitability. Where other industry sectors have embraced closed loop control systems in many forms and shapes, the livestock industry is still reliant on the knowledge of the farmer and experienced stockman (Frost *et al*., 1997). Integrated management systems, can offer tools to facilitate the decisions farmers take daily. More recently, Precision Livestock Farming (PLF) has been used as the name for automated monitoring and control techniques in the livestock sector (Wathes *et al.* 2008). However, the lack of sensor technology has prevented the emergence of control systems.

In the last decade, existing sensors to measure broiler weight have been approved and novel systems for measuring broiler activity and pig growth based on image analysis of camera images have been developed (Cangar *et al*., 2006; Doeschl-Wilson *et al*., 2004; Kristensen *et al*., 2006; Schofield *et al*., 1999). This was combined with the development of a mechanistic model of pig growth in a real time controller for pig growth (Parsons *et al*., 2007). The mechanistic model was based on the nutritional and environmental requirements of the pigs and was therefore rather complex, requiring knowledge of many parameters, rendering it less suitable for control purposes. The model was able to control the mean pig weight to within 2 kg of the target, by varying the crude protein content of the diet.

Data-based models have also been applied to livestock production (Aerts *et al*., 2000). In contrast to mechanistic models, these models estimate the unknown model parameters of any mathematical model structure from measurements of process inputs and outputs. The benefit is that no prior knowledge of the process to be modelled is required, although basic knowledge is beneficial for the selection of the correct process input and output parameters.

Data based models have been successfully applied to broiler growth using a recursive linear model (Aerts *et al*., 2003; Cangar *et al*., 2008). Differential recurrent neural network (DRNN) models have been proposed as an alternative modelling approach (Cao, 2005). In this work the latter approach was used to model broiler and pig growth, broiler activity and ammonia emission from a mechanically ventilated building. The challenge was to model and control both single and multiple processes simultaneously.

## Material and Methods

To generate data for training and validating the models, broiler chickens and pigs were grown from day-old to 51 days and 7 to 110 kg live weight, respectively, whilst being exposed to dynamic changes in the inputs, namely feed amount, light intensity, temperature and absolute humidity. To ensure a measurable response in output, the change in the input was set unrealistically high compared with normal practice. Feed amount was set at either 90% or 110% of normal dosage rates. Light intensity was set to 10 or 200 lux, temperature set to standard temperature or 5 degrees above and relative humidity at 56 or 70%. The frequency of change was set according to the time required to reach a new steady state in the output, i.e. 2-4 hours for the light intensity and 3-7 days for feed amount, temperature and absolute humidity.

With broilers, $2^3$ factorial experimental design, with three factor (growth, activity and ammonia emission) and two-levels (change or no change), repeated three times was used requiring 8 rooms. For pigs a $2^2$ factorial experimental design, with two factors (growth and ammonia emission), repeated twice, was used in two climate controlled rooms, four pens per room. These designs potentially allowed interactions between the processes (growth, activity and ammonia emission) to be identified.

Broiler chickens (Ross 308) were housed on wood shavings at a stocking density of 33 $kg.m^{-2}$. Pigs (Large White, Landrace and Pietran cross) were housed 10 to a pen, on a concave solid floor with slats either side (IC-V design, part slatted) with a small amount of straw on the solid floor. The day old chicks and pigs were acclimatized to their environment for 5 and 10 days, respectively, prior to the step changes being applied. An automated feeding system was used to dose known amounts of standard formulation commercial diets to each room/pen. Bird weight was measured continuously using a weighing platform suspended from a load cell (Fancom nv), whereas pig live weight was measured using a visual image analysis system (Osborne Ltd) validated by fortnightly manual weight measurements. Ammonia concentration, ambient and indoor air temperature and humidity, ventilation rate and feed dosage were measured continuously at six minute intervals and an average saved at half hourly intervals. Activity was measured by scanning consecutive video frames for changes in pixel colour within specified sections of the image. The number of pixel changes was a measure of activity (Kristensen *et al*., 2006). Light intensity and activity were recorded every minute.

In order to validate the newly developed process controllers incorporating the broiler or pig growth, broiler activity and ammonia emission models, fresh experiments were conducted, encompassing two further batches of growing both broilers and pigs in their respective housing systems. All measurements were as described above. Using the process controller, the lighting regime, temperature set point and daily feed dosage were calculated daily based on the previous day data.

## Results and Discussion

### Growth models

In order to develop a dynamic model to control the entire, complicated nonlinear dynamic growth, activity or emission processes with potentially variable sampling rate, the differential recurrent neural network (DRNN) and the associated automatic differentiation based training algorithm developed by Al-Seyab and Cao (2008a; 2008b) were adopted. A first order DRNN model with two hidden nodes was used to represent boiler and pig growth. The model structure was based on the intuitive assumption that from any initial weight, if the feed intake is zero, the animal's weight will gradually decay to zero. To determine the six model parameters, experimental data from the trials described above were used. The training data set for broilers consisted of six batches, two from each trial, whilst for pigs four data sets (two from each temperature treatment) were used to determine the six model parameters. Another six and four batches from the broiler and pig trials, respectively, were selected for validation of the model. The trained DRNN models were able to predict the animals weight satisfactorily, even when the actual feed intake was modulated by regular step changes. A typical mean squared error for the predicted weight compared to the actual weight for the training data was 0.007% and 0.2% for broilers and pigs respectively. The higher error for pigs was largely attributed to the lower number of data sets available for training and validating the model (Demmers *et al*., 2010).

Broiler activity model

The model for broiler activity had to capture both long-term changes in activity due to bird growth and short-term behaviours of the birds due to light level changes and feeding time. The variability of activity increased as the bird weight increased over the whole batch. On the other hand, the activity response to light level and feeding time, was very quick and similar throughout, mainly because the pattern for the main drivers, light level and feeding was constant during the batch (Figure 2). For this purpose a 1$^{st}$ order DRNN model with two inputs (light level and feeding incidence), one output (activity), two states and three hidden nodes was designed to represent activity. Broiler growth was incorporated as a scaling factor. The time-step of the model was 1 minute. The measured activity was scaled with the previous day's mean and standard deviation of measured activity.

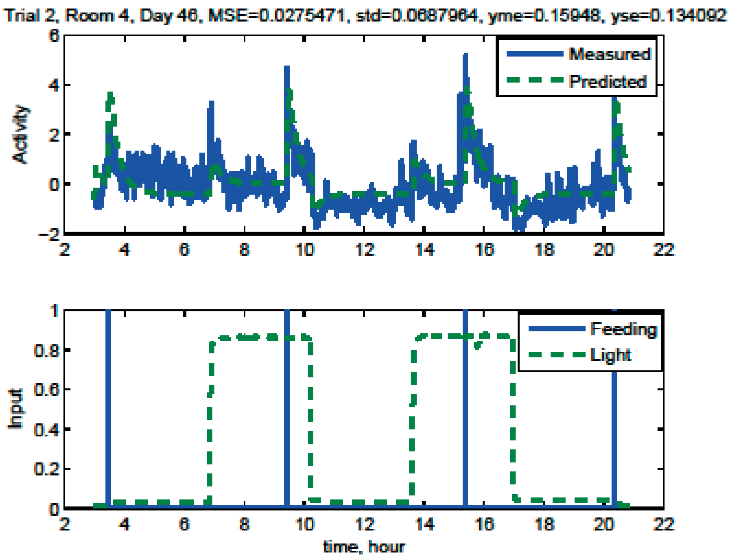


Figure 2: Actual and model prediction of scaled activity (number of pixel changes) of broilers resulting from 4 illuminance changes (0 to 200 lux) and 4 feeds a day.

The 16 model parameters of the DRNN model were determined using 9 days of data and validated using a further 54 days of the extensive data set, which comprised 864 days. The trained model was successfully applied to data for all the remaining days with satisfactory accuracy (mean squared error 1.7%). A typical result is given in Figure 2. The model predicts the sudden increase due to feeding as well as the increase in light level well in general terms (Demmers *et al.*, 2011). The slower response to reducing the light level (Kristensen *et al.*, 2006) is also properly modelled. Nevertheless, there remains a high level of variability in activity during the day that is not captured by the model.

Ammonia emission

The design of the ammonia emission model was not straightforward, because the input variables for ammonia emission, notably temperature, ventilation rate and heating are not independent. In fact they are linked by the climate control system for the building, operating in a standard fashion. The model design was 1$^{st}$ order with two hidden nodes. The inputs were ambient temperature, room air temperature, ventilation and curve day, i.e. the time from start of the experiment. The model was trained using two datasets and validated using the remaining two datasets. The model's ability to predict ammonia emission was acceptable but it was poor compared to either broiler or pig growth with a mean square error of 30%. The lack of independent data sets severely limited the number of training and validation options.
The ammonia emission DRNN model predicted that the emission would decrease with increasing temperature. This is counter intuitive and not supported by the fact that the mass transfer coefficient is directly proportional with temperature. Rom *et al.* (2000) reported a 40% lower emission when the indoor temperature was lowered from 15$^{o}$C to 5$^{o}$C. Equally, a higher indoor temperature is frequently linked to dirtier floors and slats, leading to higher emissions (Aarnink *et al.*, 1996). On the other hand the higher indoor temperature was maintained in these experiments by reducing ventilation rate resulting in lower air velocities over all emitting surfaces, which potentially increased the depth of the boundary layer, raising the resistance to ammonia evaporation and hence lowering the emission rate. The model predicts that this is the dominant effect, rather than the direct effect of temperature upon ammonia volatilization.

Process control

Using the DRNN models which were able to predict the individual processes, growth and activity and/or ammonia emission, control systems can be designed for various scenarios, i.e. grow as fast as possible whilst minimising feed usage or reach target weight at set date. Non-linear model predictive controllers (NMPC) were used to predict feed usage required to maintain pre-designed growth curves, whilst optimising for weight accuracy, feed usage and smoothness of response (Demmers *et al.*, 2010).
The thus developed NMPC for broiler and pig growth proved to be capable of predicting

the feed intake required in order to reach the required end weight whilst following the pre-set growth curves with a mean relative error less than 2% and 10%, for broilers and pigs respectively (table 1 & 2). The high maximum error for broilers at the standard -12% curve was due to a malfunction of the feeding system over a 3 day period, where feeding was erratic but in total amount correct, potentially inhibiting growth. After the problem was solved, the controller successfully returned growth to the set curve within 4 days. The substantially higher mean relative error for pig growth (10%) reflects and the smaller dataset available to develop and validate the model (table 4) and/or the lower accuracy of the estimate of pig weight (VIA camera system). For all growth curves the projected end weight was reached on time and within acceptable tolerances.

Table 1: Theoretical live weight and achieved live weight of the broilers and goodness of fit to the set growth curve as percentage of standard curve (Aviagen) over days 12-50.

| Growth curve | unit | Standard | +12% | -12% | -12% / +12% |
|---|---|---|---|---|---|
| Bird weight at 50 days | | | | | |
| Theoretical | kg | 2.85 | 3.20 | 2.51 | 2.85 |
| Actual | kg | 2.73 | 3.10 | 2.44 | 2.72 |
| Mean relative error | % | 1.8 | 1.8 | 2.8 | 1.6 |
| Maximum deviation | % | 5.2 | 6.0 | 16.3 | 5.0 |

Table 2: Theoretical live weight and achieved live weight of the pigs and goodness of fit to the set growth curve as percentage of standard curve from age 7to 21 weeks.

| Growth curve | unit | Standard | -20%/+20%/-20% |
|---|---|---|---|
| Pig weight at 21 weeks (110 days) | | | |
| Theoretical | kg | 91.8 | 88.4 |
| Actual | kg | 98.4 | 90.5 |
| Mean relative error | % | 10.5 | 10.9 |
| Maximum deviation | % | 34 | 35 |

The controller for broiler activity was based on a lookup table with feeding frequency and light level changes ranging from 3 to 6 and 2 to 6, respectively. The DRNN model successfully predicted the activity for those combinations in discrete inputs not used in the model parameter estimation and validation. Thus the controller was able to maintain broiler activity along a set curve for average daily activity, and revealed significant but small differences in daily activity. The latter implies that use of the controller for managing average daily activity is debatable, whereas the daily pattern of activity might be more important in terms of short term variation in activity levels and its effect on broiler leg health.

Table 3: Ammonia limit values and achieved ammonia emission and goodness of fit off the achieved ammonia emission compared to the predicted emission from age 7 to 21 weeks

| Ammonia emission | unit | Low | High |
|---|---|---|---|
| Threshold | mg $NH_3$-N.hr$^{-1}$ | 4000 | 8000 |
| Theoretical | mg $NH_3$-N.hr$^{-1}$ | 4520 | 10840 |
| Actual | mg $NH_3$-N.hr$^{-1}$ | 2510 | 6380 |
| Mean relative error | % | 69.5 | 61.0 |
| Maximum deviation | % | 360 | 360 |
| Mean room temperature | C | 21.5 | 22.8 |

The NMPC's for pig growth and ammonia emission were linked using a Pareto control algorithm to optimise both growth and ammonia emission for room air temperature. Both NMPC's were run separately first and for the purpose of simplicity presented the operator with responses of ammonia emission, growth and overall predicted feed usage to temperature. The operator then picked the best combination of temperature and feed dosage, optimised for lowest deviation from growth curve, lowest total feed usage and emission maintained below fixed set point, i.e. 4 and 8 g $NH_3$-N.h$^{-1}$, for the low and high set points, respectively. The Pareto control algorithm with the incorporated NMPC's predicted pig growth well (Table 2), but performed poorly for ammonia emission, consistently predicting a higher ammonia emission than actually measured (table 3). Nevertheless, in gross terms the controller was able to create a substantial difference in ammonia emission using on average a small difference in temperature. The poor performance of the controller for ammonia is most likely due to the very different ambient conditions during the test of the controller (summer) compared to the model development (autumn till spring) and hence the lack of representative data sets covering all seasons (Demmers *et al*., 2012).

Table 4: Overview of process modelled, number of datasets used for model development and validation and the accuracy (mean squared error) of the associated process controller.

| **Process** | **Data set** | **Model** | **Accuracy** | **Controller** | Accuracy |
|---|---|---|---|---|---|
| Broiler growth | 24 | 1st order, 1 state<br>2 hidden nodes | 0.07% | NMPC | 1.8% |
| Broiler Activity | 880 | 1st order, 2 states<br>3 hidden nodes | 1.7 | NMPC | 2.5% |
| Pig Growth | 16 | 1st order, 1 state<br>2 hidden nodes | 0.2% | Pareto control combining 2 NMPC | 10% |
| Ammonia emission | 4 | 1st order,1 state<br>2 hidden nodes | 30% | | 60% |

The NMPC process controllers, incorporating the above models, proved that the use of differential neural networks is a suitable approach to control biological processes. However the robustness of the models and thus the controllers depended heavily on the robustness of the dataset, both in terms of number of data collected as well as number of parameters required. Hence, growth of livestock was accurately modelled and controlled, whilst minimising overall feed intake. Equally, broiler activity was very accurately modelled and controlled. However, the accuracy of the ammonia emission model and associated pig growth and ammonia multi process controller were disappointing due to the minimal dataset available, particularly for ammonia emission.

## Conclusions

Biological processes, i.e. growth and activity as well as gaseous emissions can be modelled using differential recurrent neural network techniques and the thus developed models incorporated in non-linear model predictive controllers used to manage these processes. The importance of the quantity and quality of the data sets for successful implementation of data based models has been shown clearly, with accuracy of the differential non-linear model controllers ranging from 2% to 60% for 24 to 4 data sets respectively

## Acknowledgements

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# Precision ventilation to improve indoor air quality and reduce ammonia emission of pig production housing

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## Abstract

Indoor air quality and ammonia emission in a pig production unit with partial pit exhaust ventilation were reported. The investigations were based on the measurements of two batches of growing/finishing pig to generate additional data to validate the partial pit ventilation concept and its effects on indoor air quality and emission from pig production buildings. The negative pressure ventilation was applied with supply air via diffusion ceiling. The main exhaust fan in ceiling top chimney was automatic regulated according to indoor thermal conditions and predefined indoor air temperature reference. The pig pens had 2/3 slatted floor of 16.7% opening area and 1/3 drain floor of 8.4% opening area. In the second hold, opening area of the pen floor was reduced to investigate its effects on the pit exhaust.

The results showed that for the two experimental runs, (1) the indoor air quality was improved by the partial pit exhaust and the mean indoor ammonia concentration measured at ceiling exhaust openings were 1.8ppm and 2.2ppm respectively; (2) the total ammonia emission could be reduced about 65.5% and 61.2% respectively if an air purification system of 95% ammonia cleaning efficiency applied in the pit exhaust channel.

The partial pit exhaust air connecting to an air purification unit is feasible and effective approach to achieve optimal indoor air quality and reduce emission of livestock production housing.

**Keywords:** Precision ventilation, air quality, ammonia emission, pig production

## Introduction

Reducing the emission from agricultural become a more and more important issues in the last decades. Using the best available technology, dust, ammonia and odour emissions from mechanically ventilated livestock production buildings can be reduced by using air purification units at air exhausts (Ogink *et al.*, 2007; Ogawa *et al.*, 2011; Zhao *et al.*, 2011). However, such a cleaning system installation often requires equipping with central ventilation system and aiming at clean all ventilation air and it will result in an expensive investment and high running costs.

This investigation is based a hypothesis that applying an air purification unit only in a partial pit exhaust channel to remove that part of most pollutant air from the slurry pit. Such a negative pressure created in the pit headspace may also induce the downward motion of the air above the floor and near to the slot openings. The concept of partial pit ventilation (also in another term: differential pit ventilation) was introduced by a research project granted by the Research Agency of Danish Food, Agricultural and Fishery Ministry (Zhang, 2006a; 2006b). Some primary tests of the system concept have been previously reported (Saha *et al*., 2010; Pedersen & Kai, 2008).

The objective of this work were (1) to generate additional data to validate the concept of partial pit ventilation and its effects to indoor air quality and emission from pig production buildings; and (2) to investigate the effects by reducing floor openings. For documentation of the air quality in room, multi-point $CO_2$ measurements were conducted in the experiments.

## Materials and Methods

<u>Experimental room</u>

The room used for the experiments had two pens and each with two third fully slatted floor and one third being drained floor. The opening area for slatted floor is 16.5% and for the drained floor is 8.5%. Slurry gutter under pen floor was 0.9m depth, with draining pipes of 0.25m and a central valve for the removal of slurry. The pen partition on the floor was up to 1.2m. In front of pig pens there was inspection alley of 1.2m width. The house was equipped with inlet duct, located at the roof above the diffuse ceiling of room. Incoming outside air passed through the screens above the duct into the attic, and entered the room through the diffuse ceiling due to negative operation pressure for room ventilation.

<u>Ventilation systems</u>

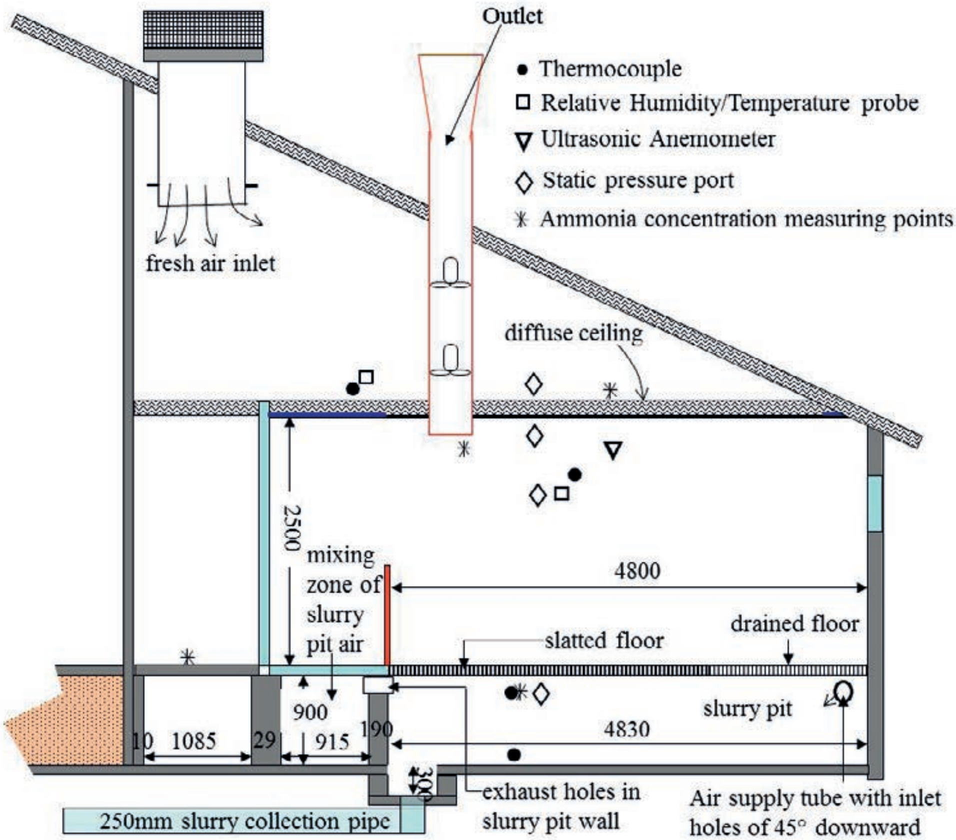
A negative pressure ventilation system with ceiling diffuse inlet and ceiling-roof-top exhaust ventilator were installed in the test unit, to represent the commonly used ventilation system in pig production in Denmark. For the research on a partial pit ventilation effects on indoor air quality and total emission from such type of buildings an extra exhaust unit and an extra air supply unit were installed under the slatted floor connected directly between the pit head space and the outdoor air, Figure 1. The system ventilation capacity was designed as 3400 $m^3\ h^{-1}$ that was equivalent to 106$m^3\ h^{-1}\ pig^{-1}$, for 32 pigs in the room.

An exhaust fan was installed in ceiling chimney of 0.4m in diameter. Under the fan, a free propeller was installed to measure the airflow rate. The outlet opening was about 0.4m beneath the ceiling at the middle of the room.

Three exhaust openings of 0.16m in diameter and made of PVC tube were installed in a slurry pit wall in between an air exhaust channel and slurry pit for each pen (see figure 1c). The air exhaust channel was located under inspection alley. A pit ventilation

of 10% of maximum system ventilation rate was pre-set for the experiments with the pit ventilation by a fan motor voltage regulator. The fresh pit air supply directly from outdoor was manually and periodically used in the second run. The pit air supply rate was controlled as 3-4 % of the system ventilation capacity.
The ceiling exhaust unit was active as the main exhaust unit during the experiments and its varied ventilation rate was controlled by the climate computer according to the indoor thermal conditions measured by a temperature sensor and the reference indoor air temperature settings. The indoor air temperature sensor used for control system was placed at 1.6m above the pig lying area.

Experimental setups
Two batches of growing/finishing pigs were used for the two experiment runs that started at April and July 2009 respectively. The average weight of pigs at start was about 30 kg and 100 kg at the end of each experimental period.



(a)

(b)

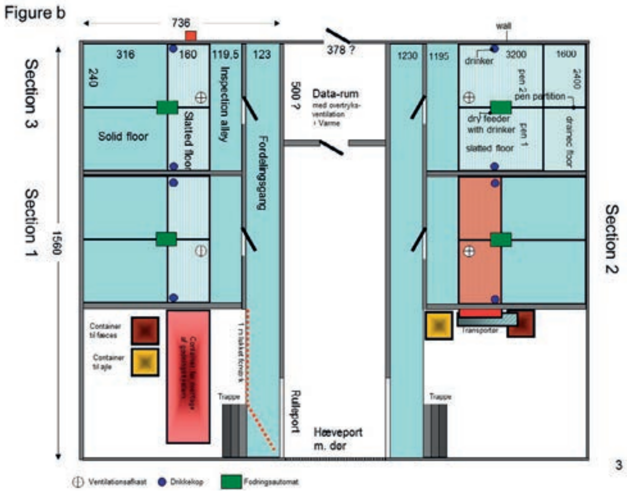



Figure 1. Cross-section of the experimental room with (a) measurement and sampling locations, (b) layout of a pen.

In the second run, extra floor cover was applied to reduce the floor opening area and exam the effects of the floor opening reduction on pit exhaust removing capacity on ammonia. Two steel plate of 1x2 m2 were used to cover the floor area of each pen, leaved 0.2 m free at each side to the partition wall and side wall and leave 0.5 m free to the end wall. The coverage gave a reduction of 52% on train floor and 26% on slatted floor, which equal to about 31% reduction of total opening area of the pen floor comparing to that without the coverage.

<u>Instrumentations and measurements</u>

*Gas concentrations*

The instrument and the locations of ammonia concentration measurements were similar to the experiments reported in Saha *et al.* (2010) and are presented in figure 1.

*Ventilation rates*

The ceiling exhaust ventilation rate was measured by a Fancom free impeller in the exhaust chimney (Fancom BV, The Netherlands). The sensor was calibrated before the experiments. The airflow rate of pit exhaust was measured using a FMU/FMDRU 200-160 flow meter (Lindab A/S, Denmark) based on an orifice taping principle and differential pressure monitoring. Using the similar measurement principle, the flow rate of pit air in-taking was measured by a pre-calibrated orifice device for the second run of the experiments

The data of the continuously measured ventilation rate and ammonia concentration were averaged over one-hour intervals and the resulting datasets were analysed in this study.

Animals, Feeding and Management

The first experiment was carried out about 75 days, form 16 April to 29 June 2009. The second experiment was run about 69 days, from 15 July to 21 September 2009. There were 32 and 34 pigs in the room for the first and second experiments respectively and the pigs was equally divided and put into the two pens in the room.

In the first experiment, the mean weight of the pigs was started as 30.6 kg and ended as 98.8 kg per pig. In the second experiment, the mean weight of the pigs was started as 35.0 kg and ended as 92.6 kg per pig.

Feed and drinking water were available all the time in ad labium. The type of feed for the pigs was ‘‘DLG Finale Plus U Fuldfoder til slagtesvin’’ (eng. DLG Finale Plus U Complete Feed) (DLG a.m.b.a., Copenhagen, Denmark) containing 40% wheat, 30% barley, 12% rapeseed, 7.45% wheat bran, 4.85% soya bean, 2.40% beet molasses, plus vitamins and minerals. The diet contained 15.5% raw protein. Feed was delivered to the two pens via a feed hopper positioned between the pens with a water nipple placed inside the feed hopper.

*Emission rate estimation and data analysis*

The emission rates via the ceiling top exhaust and the pit exhaust were computed using mass balance equation described as following:

$$E_{NH_3,Ceiling} = Q_{ceiling}(C_{ex,ceiling} - C_{in})$$

and

$$E_{NH_3,pit} = Q_{pit}(C_{ex,pit} - C_{in})$$

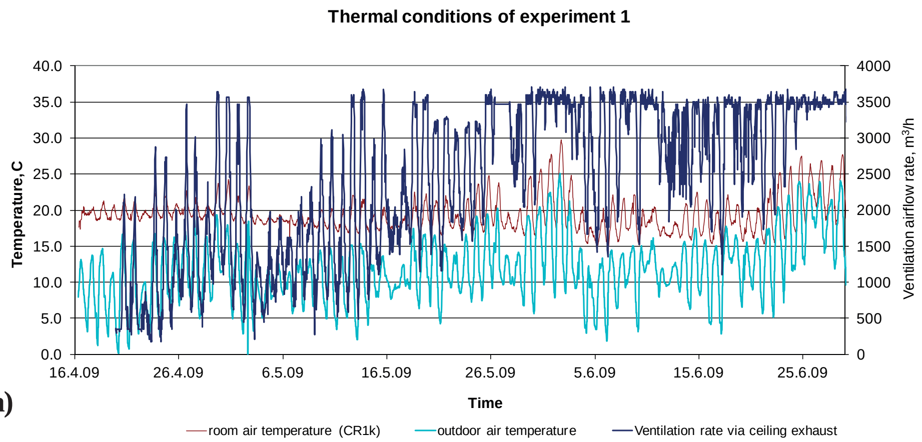
where $E_{NH3,\ ceiling}$ is the ammonia emission via ceiling ventilation mg $h^{-1}$ $pig^{-1}$ or mg $d^{-1}$ $pig^{-1}$; $Q_{ceiling}$ is the ventilation rate by ceiling exhaust fan, $m^3$ $h^{-1}$ $pig^{-1}$ or $m^3$ $d^{-1}$ $pig^{-1}$; $C_{ex,ceiling}$ is concentration of ceiling exhaust air, mg $m^{-3}$; $C_{in}$ is the inlet air concentration, mg $m^{-3}$; $E_{NH3,\ pit}$ is the ammonia emission via pit ventilation mg $h^{-1}$ $pig^{-1}$ or mg $d^{-1}$ $pig^{-1}$; $Q_{pit}$ is the ventilation rate by pit exhaust fan, $m^3$ $h^{-1}$ $pig^{-1}$ or $m^3$ $d^{-1}$ $pig^{-1}$; and $C_{ex,\ pit}$ is concentration of pit exhaust air, mg $m^{-3}$.

The emission rates achieved in the experiments were compared with the Emission Factor of Danish Livestock Production (Poulsen, 2010) in the similar production systems to evaluate the effects of the partial pit ventilation on reducing ammonia emission.

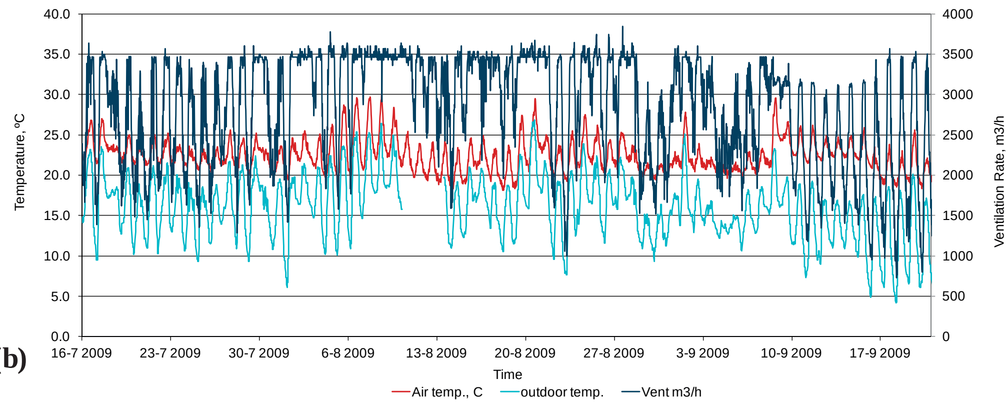
## Results and Discussion

Thermal environments and ventilation conditions

The outdoor temperature, indoor thermal conditions and ventilation rates in the two experimental periods are presented in Figure 2.




(a)

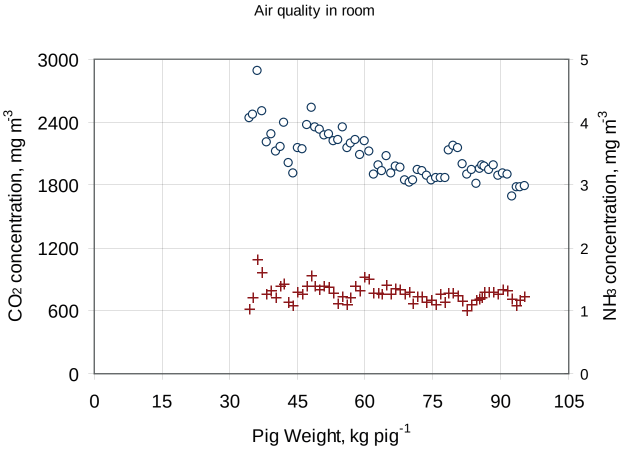



(b)

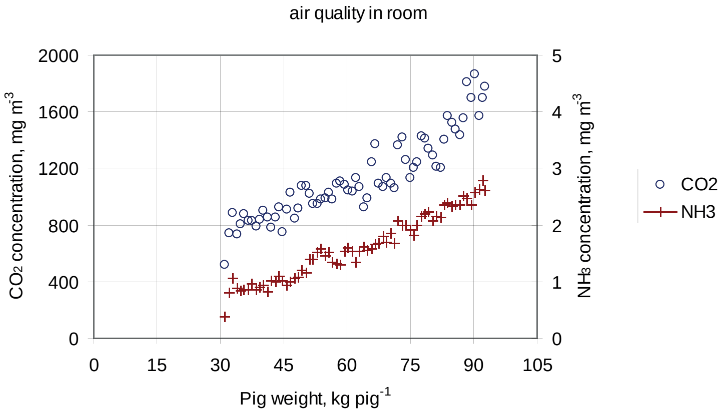
Figure 2. Thermal conditions and main ventilation rate recorded in the experimental period. (a) Experiment 1; (b) Experiment 2

The thermal environmental conditions of the two experiments were different. Although the first experimental run was also involved a period of summer climate, the mean outdoor air temperature was about 12˚C. However, in the second experimental period, the mean outdoor air temperature was about 16 ˚C. The higher outdoor temperature resulted in the higher ventilation rates to maintain the indoor climate at the setup level and consequently higher emission of ammonia via the ventilation.

The outdoor temperature in the first experimental run was significantly lower than that in the second run. And consequently it resulted in lower ventilation rates to maintain the indoor climate following the climate control system.
Lower ventilation rate could be a reason that the emission in the first run was lower comparing to the second one.




**(a)**




**(b)**

Figure 3. Indoor air quality expressed in ammonia and $CO_2$ concentrations measured at ceiling air exhaust, ○, $CO_2$; +, $NH_3$. (a), experiment 1 and (b), experiment 2

<u>Ammonia concentration and indoor air quality</u>

Indoor air quality of the production room was represented by the measured ammonia and $CO_2$ concentration at ceiling exhaust opening. These measured data in the two experiments are plotted in Figure 3 following the growth of the pigs. The mean values of the concentrations may be found in Table 1.

For the experiment 1, the mean ammonia concentration was about 1.3 mg $m^{-3}$ and $CO_2$ was about 2100 mg $m^{-3}$. For the experiment 2, the average ammonia concentration was about 1.6 mg $m^{-3}$ and $CO_2$ was about 1900 mg $m^{-3}$.

The indoor air qualities in both batches of the production are considerably better than systems without pit ventilation (Saha *et al.*, 2010; Pedersen & Jensen, 2010)

In the report by Saha *et al.* (2010) ammonia concentration of 4.3 -4.9 mg $m^{-3}$ were found in a system using a ceiling exhaust only. In a report by Pedersen & Jensen (2010), it was found that ammonia concentrations of between 5.3 and 6.6 mg m$^{-3}$ were measured in a similar production unit using the ceiling air exhaust only.

The ammonia concentration was only about 20-30% of the concentration level in a similar production system without the partial pit ventilation (Pedersen & Jensen, 2010), Table 1. This is a remarkable result for indoor air quality in finishing pig production structures.

Table 1. Overall ammonia concentration and emission at ceiling and pit exhausts

| | | Concentration | | | | $NH_3$ emission | | | | **Reduction of $NH_3$-N emission by cleaning pit exhaust air, %[**]** |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ventilation System | $NH_3$ ppm | $NH_3$ mg/m$^3$ | $CO_2$ mg/m$^3$ | Ventilation rate (mean), m$^3$/h/pig | g $NH_3$/d/pig | g $NH_3$-N/d/pig | g $NH_3$/pig | g $NH_3$-N/pig | |
| GRP2[*] | Ceiling exhaust | 9.3 | 6.6 | | 52 | 7.5 | 6.2 | 672 | **554** | **15.3%** |
| GRP3[*] | Ceiling exhaust | 2.6 | 1.8 | | 49 | 1.8 | 1.5 | 164 | 135 | **-68.3%** |
| | Pit exhaust | 20 | 14.2 | | 10 | 3.3 | 2.7 | 295 | 243 | |
| | Sum | | | | | 5.1 | 4.2 | 459 | **378** | **-21.3%** |
| RUN 1 | Ceiling exhaust | 1.8 | 1.3 | 2076 | 80 | 2.4 | 2.0 | 181 | 149 | **-65.5%** |
| | Pit exhaust | 12.5 | 8.9 | | 13 | 3.0 | 2.5 | 248 | 205 | |
| | Sum | | | | | 5.4 | 4.5 | 429 | **353** | **-26.4%** |
| RUN 2 | Ceiling exhaust | 2.3 | 1.6 | 1962 | 81 | 3.0 | 2.5 | 207 | 171 | **-61.2%** |
| | Pit exhaust | 18.6 | 13 | | 12 | 3.8 | 3.2 | 215 | 177 | |
| | Sum | | | | | 6.9 | 5.7 | 423 | **348** | **-27.5%** |

[*]Pedersen & Jensen (2010): GRP 2: 2/3 slatted floor & 1/3 drain floor, without pit ventilation;GRP 3: with a part of floor cover, pit exhaust located at the end of slatted floor/dunging area

[**]Reduction of NH$^3$-N by cleaning pit exhaust air with a purification unit of 95% ammonia removing efficiency.

## Emission from the systems

The summarised emission data are presented in Table 1, where the total emission of ammonia from the both experimental runs can be compared with the data reported by Pedersen and Jensen (2010).

Over 50% of the total ammonia emissions were removed via pit exhaust channels in the both experimental runs. The large portion of removing ratio via the pit exhaust was found in the first growing period when the average weight of the pig was below 50-60 kg. That was due to the pit exhaust rate of 10 $m^3$ $h^{-1}$ $pig^{-1}$ was relatively high comparing with the total ventilation rate. Similarly, it is expected that the removing ratio of pit ventilation for ammonia will be higher in winter period than in summer.

<u>Reduction of ammonia emission by applying air purification unit at pit exhaust</u>
From Table 1, we can see that the ammonia emission could be reduced 65.5% and 61.2% in these two experimental runs applying an air purification unit at pit exhaust channel comparing with the reference data for Danish fattening pig production. The calculations in Table 1 were based on 95% cleaning efficiency for ammonia removing.
Such reduction of ammonia emission may be different due to the ventilation required in the different season. The first run of the experiments used less ventilation rates than the second one (average ceiling ventilation rates of the two experimental periods were 75.5 and 80.6 $m^3$ $h^{-1}$ $pig^{-1}$ respectively). The later was run almost in full ventilation rate during the entire production period. Therefore, the reduction of ammonia emission in the second run was less than the first run. Similarly it is expected that the reduction in cold outdoor climate period, e.g., in winter season, may considerably larger than in summer. That may also due to the total ventilation required to maintain indoor thermal conditions deceases following outdoor temperature drop; consequently indoor concentration will increase and the portion of ammonia removed by pit exhaust will increase.

## Conclusions

Partial pit ventilation may improve indoor air quality and maintain indoor ammonia concentration at about 1-2 mg $m^{-3}$ in the two experimental runs in a semi-practical pig production unit. By applying an air purification system with 95% efficiency for pit exhaust air cleaning, the ammonia emission can be reduced about 60-65% in the test production period. Such reduction is expected to be larger if outdoor air temperature is lower in winter period, when total ventilation rate required indoor air thermal regulation is smaller.

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## Determination of nitrogen content in manure from quails raised under thermoneutral conditions and heat stress

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### Abstract

Raising quail for meat production has great potential in Brazil, creating a need for studies of the needs of this species in tropical climates with regard to the micro-environment required for bird comfort and the environmental impacts of the waste produced. It is important to know the nutrient composition of quail manure, such as nitrogen (N) concentration, so that it can be used appropriately, e.g. the use of manure as a fertiliser requires a knowledge of the specific nutrients required to meet crop needs without exceeding acceptable levels in the soil. Hence, the aim of this study was to characterise and analyse the  total N concentration in excreta collected from quails (*Coturnix coturnix coturnix*) raised in climate chambers under thermal comfort conditions and heat stress from the age of 1 day to 5 weeks. The study was conducted in two phases: in phase 1, two groups of 180 quails were raised from 1 to 21 days of age at environmental temperatures of 36, 33 and 30°C for weeks 1, 2 and 3 of age, respectively to thermal comfort conditions, and in phase 2, 180 quails were raised from 1 to 21 days of age at environmental temperatures of 42, 39 and 36°C to heat stress. In the second phase, two groups of 60 quails were raised from the age of 22 to 35 days at an environmental temperature of 26°C to thermal comfort and 33°C to heat stress. Feed was offered to the birds ad libidum and the composition was determined according to the growing phase (starter/growing ration: 1 to 21 days; growth/finisher ration: 22 to 23 days), according to the nutritional requirements and feed composition recommended by Silva and Costa (2009) and Rostagno et. al (2011).  The total N content in excreta for the two phases was analysed using the Kjeldahl method, with the addition of salicylic acid. Results indicated that there was an increase in the N content of excreta that was directly proportional to age.

**Keywords**: Quails, Manure Nutrients, Thermal Comfort

## Introduction

Quails have been available on the Brazilian market since 1997 but there is still very little information relating to the management, nutrition and environment of birds. It is often difficult to create appropriate environmental conditions, and this contributes to increases in the cost of production of this European species in hot weather conditions. Raising quail for meat production has great potential in Brazil; as a result, there is a need for studies to investigate the needs of this species in tropical climates with regard to the micro-environment required for bird comfort and the environmental impact of the waste produced. It is important to know the nutrient composition of quail manure, such as nitrogen (N) concentration, so that it can be used appropriately, e.g., the use of manure as a fertiliser requires a knowledge of the specific nutrients required to meet crop needs without exceeding acceptable levels in the soil.

The aim of this study was to characterize and analyze the total N concentration in excreta collected from quails (Coturnix coturnix coturnix) raised in climate chambers under thermal comfort conditions and heat stress from the age of 1day to 5 weeks.

## Materials and methods

This work was conducted in two climatic chamber belonging to the Center for Research in Ambience and Systems Engineering Agribusiness (Ambiagro), in the Agricultural Engineering Department of the Federal University of Viçosa (UFV), Viçosa, Minas Gerais, Brazil. UFV's campus is located at an altitude of 649 m and the predominant climate in the region, according to Koppen's classification, is Cwa (hot, rainy temperate, with a dry season in winter and hot summers).

The climatic chamber measured 2.55 x 3.25 m and was equipped with a split air conditioning system, an electrical resistance heater with 2000 W of power and a humidifier with a capacity of 4.5 l and mist flow (average value) of 300 ml $hr^{-1}$.
The heater and humidifier were controlled by an electronic controller for temperature and humidity. The study was conducted in two phases: in phase 1, two groups of 180 quails were raised from 1 to 21 days of age at environmental temperatures of 36, 33 and 30°C for weeks 1, 2 and 3 of age, respectively to thermal comfort conditions, and in phase 2, 180 quails were raised from 1 to 21 days of age at environmental temperatures of 42, 39 and 36°C to heat stress. In the second phase, two groups of 60 quails were raised from the age of 22 to 35 days at an environmental temperature of 26°C to thermal comfort and 33°C to heat stress. The relative humidity inside the climate chamber was maintained at around 60%, which is considered adequate for the birds, according to Tinoco (2003).
Feed was offered to the birds ad libidum and the composition was determined according to the growing phase (starter/growing ration: 1 to 21 days; growth/finisher ration: 22 to

23 days), according to the nutritional requirements and feed composition recommended by Silva and Costa (2009) and Rostagno et. al (2011). Feed and water were provided ad libitum and were renewed twice a day at 8 am and 4 pm throughout the experimental period so as to ensure that water and feed were always available from the drinkers and feeders. The light program used was 23 hours light and 1 hour dark, according to Abreu *et al.* (2001). The dark period was provided daily at 2 p.m.
The minimum ventilation level inside the environmental chamber was maintained with an axial exhaust system so as to permit 4 air changes per hour throughout the evaluation period. The manure samples were collected in waste deposit trays located below the cages (Figure 1).

All the trays were cleaned daily so that the samples collected on a specific day were truly representative of one day only in order to minimize biochemical changes and measure the moisture components excreted without big changes.

Figure 1: A) View of a cage with waste deposit trays. B) Collection of excreta samples.

Samples were collected three times a week throughout the experiment, in such a way that each set of three samples represented a specific week of the quails' life. We collected six single samples per treatment in order to obtain one compound sample. We removed all contaminating material such as feathers and feed during the collection of samples. After collection, the composite samples were homogenised, packed in polyethylene bags measuring 20 x 30 cm and identified, as shown in Figure 2. After sampling the samples were immediately taken for laboratory analysis.

Figure 2: Composite samples properly packed and identified

The nitrogen levels were determined by the Kjeldahl method, with the addition of salicylic acid (APHA, 2005), sulphuric digestion, distillation in an alkaline medium and subsequent titration.

**Results and discussion**

Table 1 presents the mean values for Total Nitrogen (N) levels (dag $kg^{-1}$) for the first three weeks of the experiment, and Table 3 presents the values for the fourth and fifth weeks of bird life, assessed by the Tukey test, at 5% significance level.

Table 1. Values of N, quail waste in thermal comfort conditions during the first three weeks of bird life.

| ***Treatment*** | ***N ( dag $kg^{-1}$)*** | | |
|---|---|---|---|
| | ***1º week*** | ***2º week*** | ***3º week*** |
| Thermal comfort | 5,39 A | 6,69 AB | 7,19 B |

*The mean values accompanied by the same letter do not differ in the Tukey test at 5%*

Table 2. Values of N, quail waste in thermal comfort conditions during the fourth and fifth weeks of bird life.

| ***Treatment*** | ***N (dag $kg^{-1}$)*** | |
|---|---|---|
| | ***4º week*** | ***5º week*** |
| Thermal comfort | 8.72A | 9.31A |

*The mean values accompanied by the same letter do not differ in the Tukey test at 5%*

Table 3. Values of N, quail waste in heat stress conditions during the first three weeks of bird life.

| *Treatment* | *N ( dag kg$^{-1}$)* | | |
|---|---|---|---|
| | ***1º week*** | ***2º week*** | ***3º week*** |
| Thermal comfort | 5,73A | 6,41B | 7,65C |

*The mean values accompanied by the same letter do not differ in the Tukey test at 5%*

Table 4. Values of N, quail waste in heat stress conditions during the fourth and fifth weeks of bird life.

| *Treatment* | *N (dag kg$^{-1}$)* | |
|---|---|---|
| | ***4º week*** | ***5º week*** |
| Thermal comfort | 7.91A | 8.79A |

*The mean values accompanied by the same letter do not differ in the Tukey test at 5%*

According to Albino and Barreto (2003), the average nitrogen content of quail excreta is 4.44 dag kg$^{-1}$, lower than that found in the present work. This difference may be related to the level of crude protein in the poultry feed, since, according to Cauwenberghe & Burnham (2001), only 45% of the nitrogen consumed by poultry is retained as animal protein, thereby presenting a direct relationship with the nitrogen content of the manure. Only the nitrogen content observed in the first week in thermal comfort conditions is lower than that found in broiler excreta; in characterisation studies on broiler excreta, Davalos *et al.* (2002) observed a nitrogen content of 5.6 dag kg$^{-1}$. A similar value was found by Nicholson *et al.* (1996), 6.0 dag / kg, which confirms the great polluting power of quail wastes. An increase in the nitrogen content of the manure can be observed over time, which can be explained by the increase in feed conversion ratio, since with age, the birds require larger amount of nutrients to meet their needs and continue their weight gain. Quails in heat stress thermal condition the nitrogen content observed is lower than that found in thermal comfort conditions, because under these conditions the birds consume less feed (MENDES, 2012).

## Conclusions

Quail manure exhibits high levels of nitrogen, which tend to increase with the age of the bird, and prior planning of activities using such manures will be necessary to ensure that they are handled properly.

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**Development of a simplified measuring procedure for ammonia emission from agricultural constructions**

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**Abstract**

Ammonia (NH3) is an important pollutant gas. It largely originates from agriculture, which represents about 95% of anthropogenic emissions. Releases from buildings are the main source, accounting for about 50% of pig NH3. Today, there is no low cost method available to measure ammonia emission with high accuracy from agricultural buildings. Current methods of ammonia emission factors are based on continuous measurements over a long period (up to 200 days), which make them very expensive and time consuming.

In previous studies, a reduction of the number of measuring days was tested as a strategy for a cheaper measuring method. In the development of this method, the results of a whole year of dynamic ammonia measurements from real livestock buildings were used. A selected number of data (15 days per year) was used to predict the ammonia emission on a yearly base. For this purpose a model was developed in which the ammonia emission was related to a number of easy measurable variables, such as temperature, ventilation rate, number of animals, etc. This procedure applied on the data of 15 independent measuring days was found to predict the emission factor with an accuracy of 15 %.

To further stimulate the development of a new low emission systems, a new simplified measuring technique that uses a low cost ammonia sensor in combination with the intermittent measuring procedure was developed. The idea is that the ammonia sensor is plugged into the climate control system during the required measuring days. The whole procedure runs automatically and calculates the yearly emissions with input data as number of animals, temperature and ventilation rate. The first measuring results were very promising with a maximal error of 5% compared the a reference measuring technique.

Such method allows reducing the measuring period and the cost and doing so to increase strongly the number of agricultural buildings that can be measured with one installation.

# Section 20

# Hens -Broilers

# Automatic quantification of laying-hen behaviors using a 3D vision sensor and Radio Frequency Identification technology

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## Abstract

Stocking density of laying hens in egg production remains an area of investigation from the standpoints of ensuring hen's ability to perform natural behaviors and production economic efficiency. It is therefore of socio-economic importance to quantify the effect of stocking density on laying hens behaviors and thus wellbeing. Video recording and manual video analysis is the most common approach used to track and register laying hen behaviors. However, such manual video analyses are resource intensive and are prone to human error. The number of target objects that can be tracked simultaneously is also limited to a small number. In this study, we explore a novel method for automatic quantification of certain behaviors of individual laying hens in a group-housed setting (1.2 m × 1.2 m pen), such as locomotion, perching, feeding, drinking and nesting. Image processing techniques are employed on top-view images captured with a state-of-the-art time-of-flight (ToF) of light based 3D vision camera for identification as well as tracking of individual birds in the group with a passive Radio Frequency Identification (RFID) system. Each hen is tagged with a unique RFID transponder attached to the lower part of her leg. A RFID sensor grid consisting of 20 antennas installed underneath the pen floor is used as a recovery system in situations where the imaging system fails to maintain identities of the birds. Spatial as well as temporal data are used to extract the afore-mentioned behaviors of each bird. To test the performance of the tracking system, we examined the effects of two stocking densities and perching space on bird behaviors, 2880 $cm^2$-$hen^{-1}$ vs. 1440 $cm^2$-$hen^{-1}$ and 24.4 cm vs. 12.2 cm per hen perch, corresponding to five hens vs. ten hens in the 1.2 m × 1.2 m pen, respectively.
The system is able to discern the impact of the physical environment (space allocation) on behaviors of the birds. Of particular interest is that the two stocking densities tested did not affect the characteristics of hen's movement.

**Keywords:** Laying hen, Stocking density, Behavior monitoring, 3D vision, RFID

## Introduction

Spatial requirement for laying hens and its impact on their welfare remains one of the most debatable topics among egg producers and advocates of animal welfare. With the 2012 European Union ban on conventional cages for laying hens and recent developments in the U.S., non-cage or alternative housing systems are likely to become more predominant (Zimmerman *et al.*, 2006). The United Egg Producers (UEP) and consumer food chain McDonald's put forward welfare guidelines in 2000. The UEP guidelines recommended that cage floor space be increased over a five-year period ending in 2008 from the U.S. industry standard of 348 $cm^2$-$hen^{-1}$ to a range of 432 to 555 $cm^2$-$hen^{-1}$ (UEP, 2000). While McDonald's Recommended Welfare Practices call for cage floor space of 465 $cm^2$-$hen^{-1}$ (McDonald's, 2000). The European Union (EU) on the other hand, recommended cage floor space for conventional cages to be 550 $cm^2$-$hen^{-1}$ until 2012 (Hy-Line, 2003). Without large-scale experiments, it is difficult to assert if increasing the cage floor space actually improves the welfare of laying hens. A broad range of different potential indicators of welfare needs to be considered before the effect of stocking density (SD) can be assessed.

Researchers have explored many possible indicators of welfare and methods of measurement. Behavior is one such important indicator of animal welfare. Xin and Ikeguchi (2001) developed a measurement system to quantify feeding behavior of individual poultry in order to study effects of biophysical factors such as light, ration, noise, and thermal variables. Gates and Xin (2001) developed and tested algorithms for determining individual feeding statistics and pecking behavior from time-series recordings of feed weight. Puma *et al.* (2001) developed an instrumentation system to study dynamic feeding and drinking behaviors of individual birds. Persyn *et al.* (2004) used the measurement system and computational algorithm developed by Xin and Ikeguchi (2001) to quantify feeding behaviors of pullets and laying hens with or without beak trimming. Cook *et al.* (2006) adapted and expanded the behavior measurement system and analytical algorithm developed by Persyn *et al.* (2004) to investigate stocking density effects on feeding behavior of group-housed laying hens. Liu *et al.* (2013) developed an instrumentation system to study perching behaviors of group-housed laying hens.

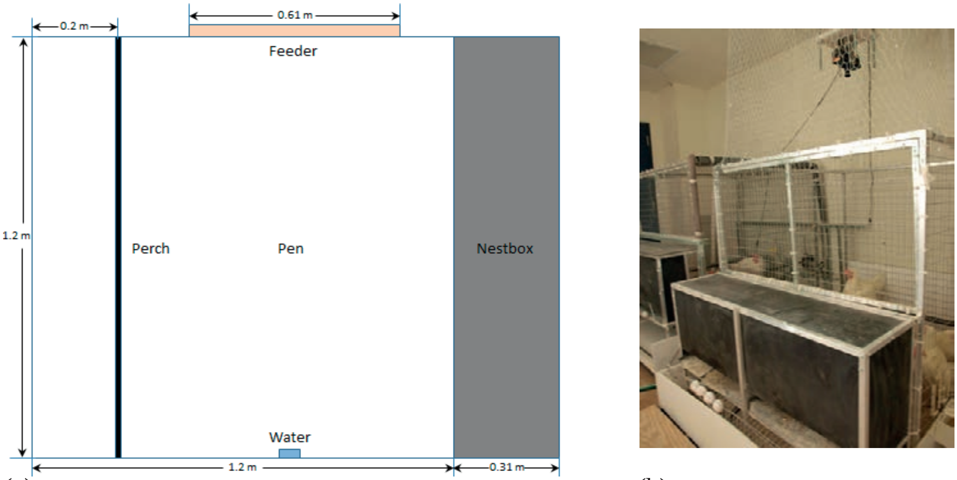
Behavioral characteristics are usually evaluated using audio-visual tools by a human observer which is time and labor intensive, subjective to human judgment and only applicable for a limited observation period (Abrahamsson, 1996). Quantification of animal behavior, and hence animal welfare, in livestock using image processing brings along specific problems. Animal appearance varies according to their posture, which makes processing and interpretation of images difficult (Van der Stuyft, 1991). Researchers have used visual monitoring to study group behaviors of animals. Image processing techniques have been used to monitor the weight distribution in poultry flocks (De Wet *et al.*, 2003; Chedad *et al.*, 2003), spatial distribution of pigs (Shao *et al.*, 1998; Hu and Xin, 2000), and trajectory of a flock of poultry (Vaughan *et al*, 2000). Monitoring behavior of an individual animal within a group requires tracking of the animal. This problem can be alleviated by constraining the animal of interest so that it is in a standard position with no other animals around. This has been applied on pigs to monitor the weight (Schofield *et al.*, 1999) and back fat (Frost *et al.*, 2004). Leroy *et al.* (2005) developed automatic computer vision technique to track individual laying hen and detect six different behavior phenotypes, namely standing, sitting, sitting, sleeping, grooming, scratching and pecking. The system study, however, was still conducted to monitor behaviors of individually caged hen. However, for freely moving animals such as laying hens in a cage, constraints are impractical. Sergeant *et al.* (1998) used an adaptive image segmentation technique to estimate the trajectory of a limited number of broiler chickens in video images. The correspondences of animals between two subsequent images were determined using a set of simple heuristics. These techniques were further enhanced as model-based tracking, which allows for more robust and accurate shape tracking, including locations on the animal body which are not detectable through image features (Tillett *et al.*, 1997).

The objective of the study was to develop an automatic tracking and behavior monitoring system of individual hens housed in groups. For experimental purpose, the hens were housed in groups of five or ten, where each hen was tracked, and her perching, nesting, feeding/drinking and movement behaviors were monitored.

## Materials and methods

<u>Experimental equipment and setup</u>

A 1.2 m by 1.2 m pen was designed to house multiple laying hens (figure 1). A 61 cm long feeder was attached outside the north wall, and a water source (two nipple drinkers) was mounted on the inside of the south wall. A 1.2 m by 0.31 m nestbox was placed just outside the east wall. Entrances (exits) to the nestbox were kept at the north and the south side. The nestbox entrances were 15 cm above the floor. A perch was placed inside the pen 20 cm from the west wall and 25 cm above the floor. Saw dust was used as bedding material of the pen floor. An identical pen was made to house hens before moving into the test pen for data collection. Fluorescent lighting at the intensity 10-12 lux in the open area and 1-2 lux in the next box was on at 06:00h and off at 22:00h, i.e., 16L:8D. Resource allowance for hens in the experiment is shown in table 1.




(a) (b)

Figure 1: A schematic and photographical representation of the experimental pen.

Table 1. Resource allowance for hens in the experimental pen compared to conventional cage, aviary, and enriched colony houses

| Parameter | Experimental | | Conventional | Aviary | Enriched |
|---|---|---|---|---|---|
| | SD5 | SD10 | | | |
| Wire mesh floor space ($cm^2$ $hen^{-1}$) | - | - | 568 | 633 | 643 |
| Litter floor space ($cm^2$ $hen^{-1}$) | 2880 | 1400 | - | 505 | - |
| Nest space ($cm^2$ $hen^{-1}$) | 743.2 | 371.6 | - | 86 | 58 |
| Perch space (cm $hen^{-1}$) | 24.4 | 12.2 | - | 12.5 | 11.0 |
| Feed trough space (cm $hen^{-1}$) | 12.2 | 6.1 | 10.2 | 10.2 | 12.0 |
| Nipple drinker (hens $drinker^{-1}$) | 2.5 | 5 | 6 | 8.9 | 7.5 |

Laying hens used in this study were 32 weeks old White Leghorns weighing approximately 1.4 kg at procurement. A total of 15 hens were housed in groups of five and ten, respectively, in two identical pens. First, five birds were housed in the test pen and ten birds were housed in the holding pen. After three days of data collection, five other birds from the holding pen were moved into the primary pen, and data were collected for three days with ten birds in the test pen as well. The hens were acclimatized for at least five days between data collection. The hens were fed twice a day at 09:00h and 17:00h. Eggs were collected once a day at 17:00h. The litter was cleaned every 2 weeks.

The images were captured for 18 hours per day, with ten hours of light time and eight hours of dark time. Images were not captured while feeding the hens and collecting eggs from the pen. It was observed that not all eggs were laid in the nest box and occurrence of egg eating was noticed. Therefore, it was necessary for eggs laid on the floor to be collected every day. The hens were then given enough time to settle down before the images were captured. During the capture of each frame, tags read by RFID sensor network were also recorded. The records were stored in the database and accessed later during image processing phase to determine hen locations and identities.

A total of 20 antennas (RI-ANT-G02E-30, Texas Instruments, USA) were used to create an antenna grid with 18 antennas laid underneath the pen floor and the remaining two antennas were mounted beneath the entrances to the nest box. The 18 antennas on the floor were 30 cm apart from each other. Five clusters of 4-antenna were created which were then connected to a RFID reader (RI-STU-251B, Texas Instruments, USA) via a 4-channel multiplexer (RI-MOD-TX8A, Texas Instruments, USA). Figure 3(a) shows a layout of the clusters and their interfacing with other devices used in the RFID system. The readers were configured to work in Master/Slave synchronization scheme, with the first reader working as the Master and all others as the slaves. This configuration allowed the system to read all 20 antennas in less than 0.5 s. With the 4-channel multiplexers connected to each of the RFID reader, five antennas, one per cluster, could be read simultaneously. The read time per channel of the multiplexer was 0.1 s. The RFID readers were connected to serial to Ethernet servers (VESR901, B&B Electronics, USA), and finally interfaced to the computer using an off-the-shelf Ethernet hub.

A state-of-the-art 3D imaging sensor, Cambube3 (PMDTec, Germany), based on TOF (time of flight) of light principle was mounted above a 1.2 m by 1.2 m pen. The camera was used to capture distance images at ~5 FPS (frames per second). The system was developed in Microsoft Visual Studio 2010 using C#.Net as the primary programming language and Microsoft SQL Server 2008 as the backend database management system.

<u>Overview of the algorithm</u>

The acquired images were processed offline to detect individual birds in the pen. Each hen was tracked and its activity at each frame was extracted and stored in the database for further analysis. The development of the automatic algorithm for behavior extraction consisted of three steps as shown in figure 2. In the image pre-processing step, the acquired images were treated with Complex Diffusion Filter (Perona and Malik, 1990) to reduce image noise while maintaining edge features. The filtered images were then subject to background subtraction to extract foreground objects. Gradient magnitudes of foreground images were then computed. In the second step, Watershed segmentation algorithm based on immersion was employed on gradient magnitude images to divide foreground images into partitions with similar heights. Size of the foreground object was used as the primary criterion to determine whether it was used for Watershed segmentation. Simple heuristics based on centroid, height similarity, orientation, size and major axis length were used to group close by partitions to form hen regions. In the next step, overlapping of the partitions in consecutive images was then utilized to track individual hens. In the last step, spatial information along with heading direction was used to determine hen activity in a given frame. In situations where the visual system was unable to keep track of the hens due to quick sudden movements of the hen, RFID sensor network was used to recover hen identities. For the RFID sensor network to recover the hen identities, the system should already have read the tags attached to the hens. Depending on initial hen locations with respect to RFID antennas, it would take several frames to several hundred frames before all the tags were read. If a hen was on perch, inside next box, or outside the reading range (10 cm radius from the center of the antenna) of its closest RFID antenna, it would not be detected. When more than one hen was inside the next box and one of them exited, the vision system could not determine its identity. The system then maintained a separate list of the unidentified hens. As the unidentified hen moved along and RFID network read its tag, its identity was then recovered, and the corresponding data were saved (Nakarmi *et al.*, 2013).

Centroid of each detected hen area was computed and compared with corresponding centroids in subsequent frames to calculate hen movements. A list of centroids was maintained for each hen. When the movement between the centroid in hand and the last centroid in the list was larger than 5 cm, it was added to the centroid list. The 5 cm threshold was used to filter out smaller movements, which were considered to be noise due to erroneous centroid extraction.

(a)

(b)

(c) (d) (e)


(f) (g) (h)

Figure 2: (a) Distance image; (b) Background image; (c) Noise reduced image; (d) Foreground image; (e) Gradient magnitude image; (f) Watershed partitions; (g) Detected hens; (h) Uniquely identified hens

## Results and Discussion

The system was able to track individual hens and extract their behaviors such as perching, nesting, feeding, drinking and movement. The SD effect was examined by comparing behavioral data of the same 5 hens used in both the SD levels. Figure 3 shows the time spent by the hens in feeding area on different days. The graph clearly indicates that the hens spent more time in feeding area when housed in a group of 5 than when housed in a group of 10.

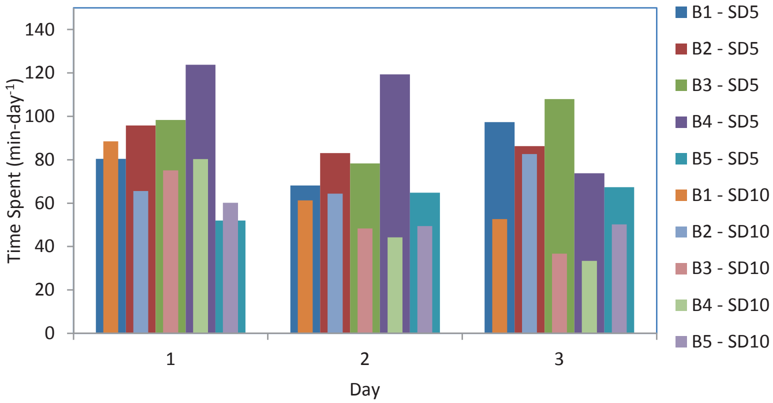



Figure 3: Time spent at feeder by 5 hens on different days when housed at SD5 or SD10.

Figures 4, 5, 6 and 7 depict time budgets of perching, nesting, feeding and drinking behaviors, respectively. The shaded block along the horizontal axis indicates the dark hours of the day. Figure 4 clearly shows that the hens spent longer time on perch at night than during the day. The data also show that the hens spent 348 ± 240 min-hen$^{-1}$-day$^{-1}$ and 265 ± 158 min-hen$^{-1}$-day$^{-1}$ on perch when housed at SD5 and SD10, respectively, presumably due to the available perch space. Similarly, figure 5 depicts time budget of nesting behavior. The hens spent longer time in nest box between 10:00h and 11:00h and the time spent in nest box slowly declined. It was observed that only 3-4 hens spent most of their time on perch at night, while some hens spent entire time in nest box or on floor at night despite having enough perch space. The data revealed that the hens spent 99 ± 165 min-hen$^{-1}$-day$^{-1}$ and 78 ± 142 min-hen$^{-1}$-day$^{-1}$ in nest box when housed at SD5 and SD10, respectively. Figure 6 shows time budget of feeding behavior. The feeding behavior seems consistent throughout the day, with nearly zero activity at night. It can be seen that the hens spent 87 ± 21 min-hen$^{-1}$-day$^{-1}$ and 60 ± 17 min-hen$^{-1}$-day$^{-1}$ in feeding area when housed in groups of 5 and 10, respectively. Similarly, as shown in figure 7, drinking behavior seems consistent throughout the day and was nearly zero at night. The hens spent 32 ± 12 min-hen$^{-1}$-day$^{-1}$ and 27 ± 11 min-hen$^{-1}$-day$^{-1}$ in drinking area when housed at SD5 and SD10, respectively.

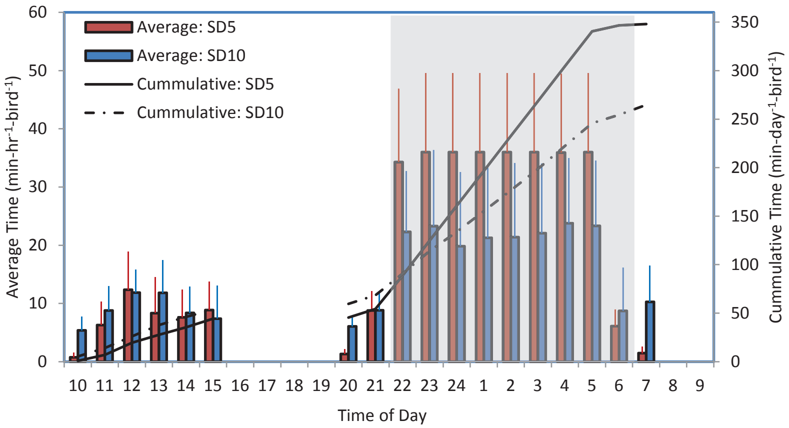



Figure 4: Perching-behavior time budget of hens housed in group of 5 or 10 hens.

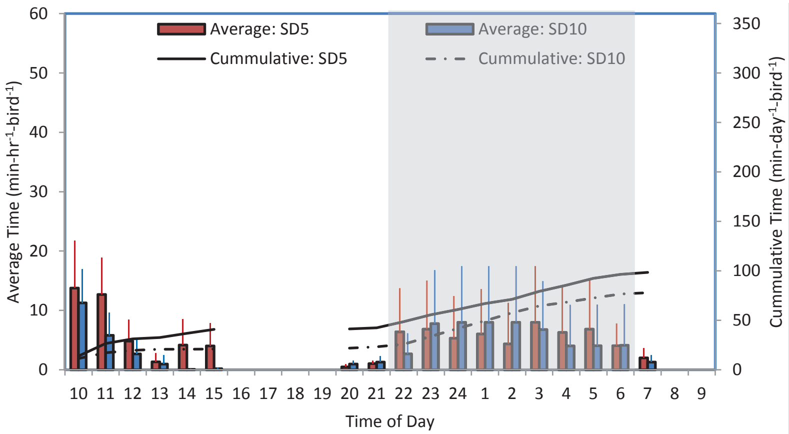



Figure 5: Nesting-behavior time budget of hens housed in group of 5 or 10 hens.

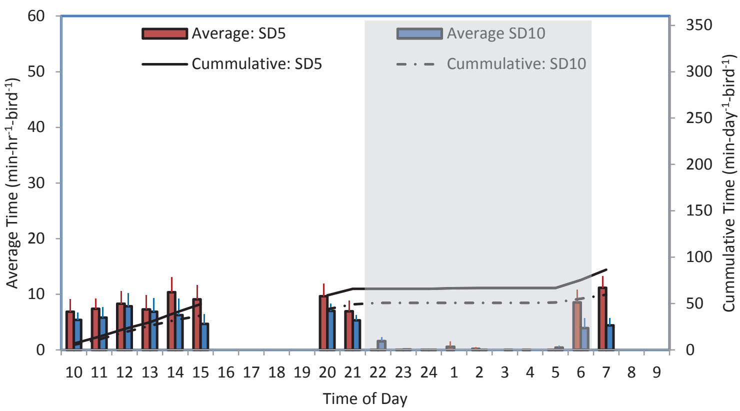



Figure 6: Feeding-behavior time budget of hens housed in group of 5 or 10 hens.

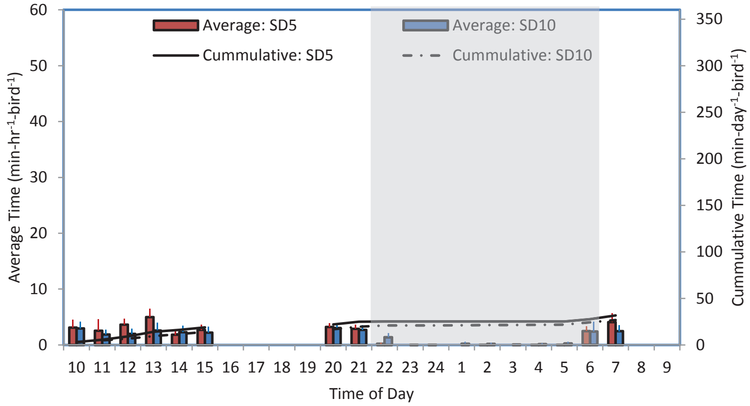



Figure 7: Drinking-behavior time budget of hens housed in group of 5 or 10 hens.

Figure 8 depicts time budget of movement. The hens seemed to move 499 ± 236 m-hen$^{-1}$-day$^{-1}$ and 540 ± 160 m-hen$^{-1}$-day$^{-1}$ when housed in group of 5 and 10, respectively.

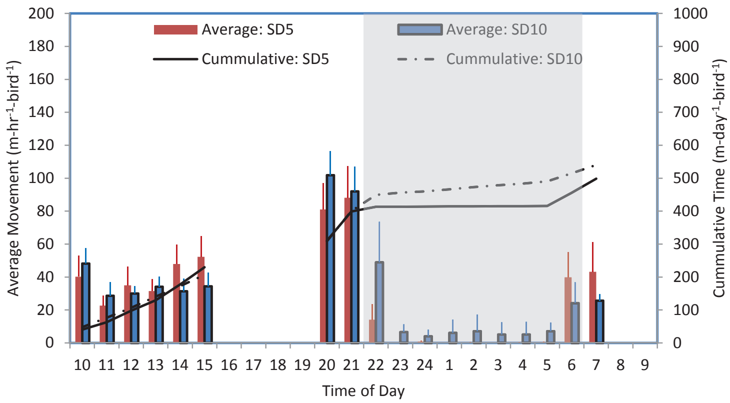



Figure 8: Movement time budget of hens housed in group of 5 or 10 hens in a 1.2 m × 1.2 m pen.

Figure 9 shows comparison between distributions of movement by the hens housed at SD5 and SD10 filtered at 5 cm to ignore smaller movements which could be the result of erroneous centroid extraction. It was observed that about 90% of the movements made by the hens during the day (10 hr-day$^{-1}$) were less than 10 cm long when they were housed in group of 5, while about 85% of the movements were less than 10 cm long when housed in group of 10.

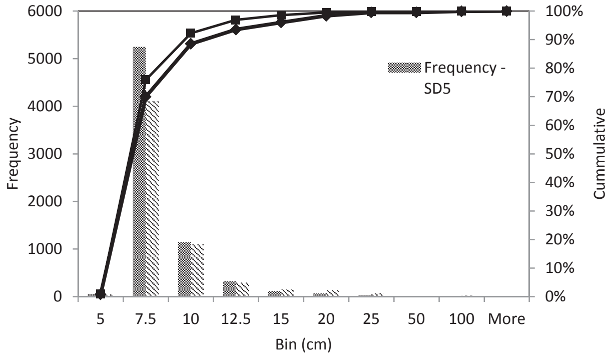



Figure 9. Comparison of movement by hens housed at stocking density of 5 or 10 in a 1.2 m × 1.2 m pen.

Figure 10 shows average time spent by the hens performing different activities. The same 5 hens on average spent 32% and 25% of their time on perch when housed in groups of 5 and 10, respectively. Similarly, the hens on average spent 9% and 7% of their time in nest box, and 8% and 6% of their time in feeding area when housed in groups of 5 and 10, respectively. The hens spent 3% of their time in drinking area in both the stocking densities. For the remaining of the time, 48% and 60%, the hens performed activities such as standing, walking and sitting when housed at SD5 and SD10, respectively.

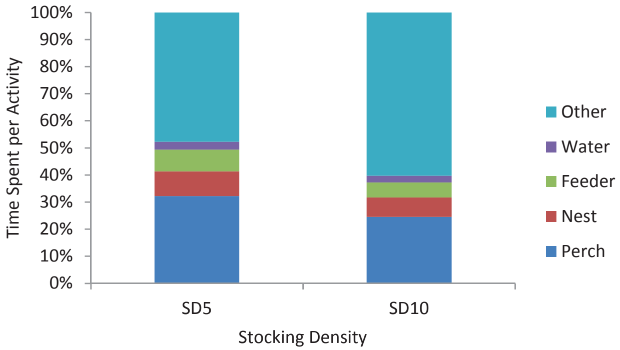



Figure 10: Average time spent by birds performing different activities

The statistical analysis of the data showed that SD effect was significant on perching behavior of the laying hens ($P = 0.0023$). The hens spent more time on perch at SD5 (348 min) compared to SD10 (265 min). This is not surprising because of the limited perch space. Similarly, SD effect was prominent on feeding behavior ($P < 0.0001$), 87 min at SD5 and 60 min at SD10. The increased pressure for feeding space was seen on hens in SD10. On the other hand, SD effect was insignificant on nesting or drinking behaviors ($P = 0.3597$ and 0.1366, respectively). The result also show that SD did not affect movement of the hens for the given floor space of 1.2 m × 1.2 m ($P = 0.2422$).

Table 2. Stocking density effect on laying hen behaviors.

| Behavior | Stocking Density Effect |
|---|---|
| Perching | Yes ($p=0.0023$) |
| Nesting | No ($p=0.3597$) |
| Feeding | Yes ($p<0.0001$) |
| Drinking | No ($p=0.1366$) |
| Movement | No ($p=0.2422$) |

## Conclusions

In this study, we developed a system that automatically extracts behaviors, such as locomotion, perching, nesting, feeding and drinking, of hens housed in groups of 5 and 10, thereby quantifying stocking density effects on their behaviors. The system has been demonstrated to track and maintain identities of individual hens, which is critical for extraction of time budgets of individual hen behaviors. This unique tracking system will enhance researchers' ability to examine the impact of physical and management factors on behaviors and well-being of group-housed animals.

## Acknowledgements

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## Modelling of spatial variation of floor eggs in an aviary house for laying hens

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### Abstract

A problem in loose housing systems for layers is laying eggs on the floor, which need manual collection. To automate this, it is desired to know the location of floor eggs for planning a collection path. As this information is not available, we constructed a spatial model to indicate the probability on floor eggs, based on housing properties. This model is mainly determined by parameters relating probability to position in the house. Validation against floor egg locations from poultry practice indicated that underlying model assumptions match with practice, making the model a suitable start for further work in this field.

**Keywords:** Alternative Poultry housing, Laying hens, Floor Laying, Floor Eggs, Laying Behaviour.

### Introduction

History

The EC issued a ban on egg production in traditional battery cages by 2012. Alternative loose housing systems were developed, e.g. aviary systems containing multiple elevated tiers that maintained productivity while improving behavioural freedom and welfare for the animals. This also introduced problems, like the presence of floor eggs. Such eggs are laid on the floor, which is covered with litter for scratching and dust bathing. Floor eggs have a twofold influence on the farming practice: Yield is reduced due to degraded quality and lost eggs (which result from floor conditions and pecking by other animals) while demand for (manual) labour increases from the need to collect the eggs (Appleby, 1984; Emous *et al.*, 2001). The presence of floor eggs mainly results from four factors: 1) Inability of the hen to reach the nest (Appleby, 1984; Emous and Fiks - van Niekerk, 2003); 2) A mismatch between the properties of the nest and the hens preferences (Zupan *et al.*, 2008); 3) The unfamiliarity with laying, especially for younger hens (Appleby, 1984; Emous and Fiks - van Niekerk, 2003); 4) Presence of other eggs on the floor, inducing additive laying (Emous and Fiks - van Niekerk, 2003). All of these result in placing the egg outside the nest box, in the litter on the floor or on elevated tiers in the housing. As collection of the latter already can be automated, we focus in this paper only on floor eggs. Research already came up with three solutions: A) Appropriate training of the birds; B) Improvements in management of the farmer, housing layout and strain selection; C) Frequent collection of floor eggs to limit the chance on additional floor eggs (Emous and Fiks - van Niekerk, 2003). With these solutions, current poultry practice is able to reach floor egg percentages below 1%. However, it is expected that floor laying will remain, as a result of variation between flocks and specific preferences of the hens on their nesting places (Appleby, 1984; Zupan *et al.*, 2008). Furthermore, this 1% remains a problem due to farm scale, labour costs and the labour demand to reach this level.

<u>The problem</u>

Since manual collection of floor eggs is a demanding task, recent advances in mobile robots (FRE, Darpa Challenges) gave rise to the idea of developing an autonomous vehicle for collecting floor eggs in commercial poultry houses. Benefits are reduction of the problem by more frequent collection of floor eggs and easing the farmer's work, without fixed installations in the poultry house. Main purpose of (manual) collection of floor eggs is to remove them as soon as possible to prevent laying of other eggs near these floor eggs. To fully exploit a mobile robot's capabilities, goal-oriented path planning is required, taking into account the spatial characteristics of the floor egg distribution. As neither such path a planning method nor a (formalised) model describing the floor egg problem exists, we developed and validated such a model.

<u>Floor egg distribution</u>

Past research mainly focused on the decrease of the total number of floor eggs. The amount of eggs and their exact locations are not described, only (Emous *et al.*, 2001) gave explicit (but qualitative) information on the number of floor eggs on a limited number of specific locations. According to Van Niekerk (2013), hens search an enclosed and recognizable place, to feel safe and return there for the next egg. Farmers also indicate that in general, the more surrounded a location is, the higher the risk on floor eggs. This means that locations near walls and under interior elements and darker areas are preferred for floor laying. Besides, more animals will lay their eggs towards the front side of the housing (Emous and Fiks - van Niekerk, 2003).

The available knowledge and information seems sufficient to build a spatial egg distribution model based on qualitative relationships, but quantitative data for validation are missing. We hypothesize that it is possible to build a probabilistic model for a single multi-tier aviary house that describes the probability of floor eggs being present at each location, for a general situation without time- or flock specific aspects. We constructed such a model, tested the sensitivity of the model output for model parameters and validated the model results against spatial floor egg data gathered in practice.

## Materials and methods

Model

On a laying hen farm in Opheusden, The Netherlands, two identical aviary houses were selected as reference situation for this research. Each house accommodated 36000 laying hens and was equipped with 5 rows of the Farmer Automatic Aviary (model year 2003, Farmer Automatic GmbH & Co. KG, Germany). A cross-section of the housing is shown in Figure 1, while a top view can be observed in Figure 2. On the four outer rows (A, B, D and E), Van Gent group laying nests (Van Gent International BV, The Netherlands) were provided. The front of the house was opposite to the wall where the ventilation fans were placed. The housing was longitudinally divided by mesh wire

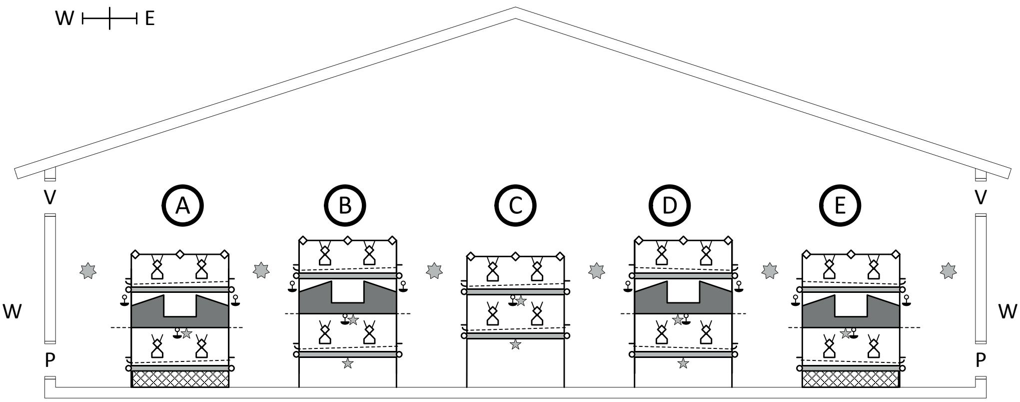


Figure 1: Cross-section of the reference poultry house. On both sides of the housing a Winter Garden (W) was present, accessible via pop holes (P). In the aviary house, rows with elevated tiers (indicated A to E) with feeding lines, drinkers, perches and laying nests were present. The whole floor was covered with litter for scratching and dust bathing, except for the rows on the outside (A and E), below which the floor area was not accessible

fences into six sections, which were considered to be equal and thus the model was developed for a single section only. The Winter Garden was not included in the model as hens only got access to the Winter Garden after laying. Spatial resolution of the model was 0.1 by 0.1 meter, which can hold approximately 1 egg at a time. For each location, a probability ($P$) between 0 (never a floor egg) and 1 (every day a floor egg) was calculated. The value of *P(floor egg)* was determined by the housing layout, being the sum of three components, which are explained below: 1) distance to corners ($P_{corners}$);

2) shelter offered by a location ($P_{shelter}$); and 3) proximity of interior elements ($P_{proximity}$). It was expected that floor egg probability decreases with distance from a corner. Also, literature indicated that there might be slightly more eggs towards the front of the housing. Thus, it was decided to use an exponential decay function to determine the floor egg probability for each corner of a section separately and combine this to $P_{corners}$. The value for a single corner depended on the distance to the walls in *x* (cross sectional) direction and *y* (longitudinal) direction.

$$P_{corners}(x, y) = e^{-\left(\frac{x}{c_1}+\frac{y}{c_2}\right)} \tag{1}$$

Here *x* and *y* are distances in meters to the walls in the cross sectional and longitudinal direction respectively. Furthermore, model parameters *c1*=2.5 and *c2*=5 for corners on the front side of the house and *c1*=*c2*=2.5 for corners on the rear side of the house. Due to draught from the pop holes the origins of the corners were moved inwards in cross-sectional direction of the house, and the probabilities on the outside were lowered with a factor 10. By selecting the values for the weight factors, it was assured that the probability in the front was higher compared with the rear of the housing. The probabilities of the four corners were then combined according to:

$$P_{corners}(x, y) = \frac{\sum Front/_{0.8} + \sum Rear/_{2}}{1.3} \tag{2}$$

$P_{shelter}$ depended on the free height above a location ($h_{free}$). Literature indicated that enclosed or shaded areas favour floor laying, where less free height above a surface is a good indicator for more shelter and shade. Therefore, $P_{shelter}$ was determined by:

$$\begin{array}{lll} P_{shelter} = 0.2 & if & h_{free} < 0.4m \\ P_{shelter} = 0.15 & if & h_{free} < 0.7m \\ P_{shelter} = 0.1 & if & h_{free} < 1.0m \\ P_{shelter} = 0 & if & h_{free} \geq 1.0m \end{array} \tag{3}$$

With $h_{free}$ the height in meters between floor and the obstacle above it.
$P_{proximity}$ accounted for the effect of interior elements in the proximity of a location in cross-sectional direction of the housing, which might favour the presence of floor eggs as well. This effect was modelled as function of the distance to the interior element:

$$P_{proximity} = (d_{max} - d) * c_3 \tag{4}$$

With *d* the distance to the object in meters, $d_{max}$ the maximum distance to have effect (0.5m for walls and 0.3 for elevated tiers) and model parameter $c_3$ the contribution of the interior element (0.3 for walls and 0.2 for elevated tiers).
*P(floor egg)* now becomes:

$$P(floor\ egg) = P_{corners} + P_{shelter} + P_{proximity} \tag{5}$$

Finally, *P(floor egg)* was limited to 0.98, since it is never completely sure that an egg is found on a specific location. Furthermore, *P(floor egg)* was set to 0 for locations that could not be accessed by animals (row A and E). To represent the full housing, results of a single section were replicated six times to form a map of the complete house.

Model Sensitivity

To determine the sensitivity of the model for its parameters, their contribution was investigated using a full factorial sensitivity analysis (Montgomery, 2009; Snoek *et al*., 2012). This analysis contained all possible combinations of a high and low value (-50% and +50% of the original value) for each parameter. For 8 locations that represents areas with different properties (front, middle, rear, in corners and below elevated tiers) in the house, the contribution of model parameters and their interactions (up to 5 parameters) was assessed using a Sum of Squares measure. The locations can be found in Figure 2.

Model Validation

To validate the model, data was collected from the two reference poultry houses. In both houses, the location of each floor egg was recorded. Recordings were done once a week by a human observer which followed the farmer during his daily collection round, which took place between 9:00h and 11:00h. Floor egg locations were manually registered on a map of the house, consisting of 6 similar sections. On the map, each section was longitudinally divided into 39 cells of 0.4m, and crosswise into 38 cells of about 0.45m (see Figure 2). Data was collected on two flocks of white hens (Dekalb White) in two houses, from 30 until 34 weeks of age and from 40 until 44 weeks of age. Data from all recordings (over time) and sections (in space) were considered to be independent, and were combined in the analysis to form a single distribution for each measurement period of 5 weeks. Each distribution contains the sum of 2 houses, 6 sections per house and 5 observations in time.

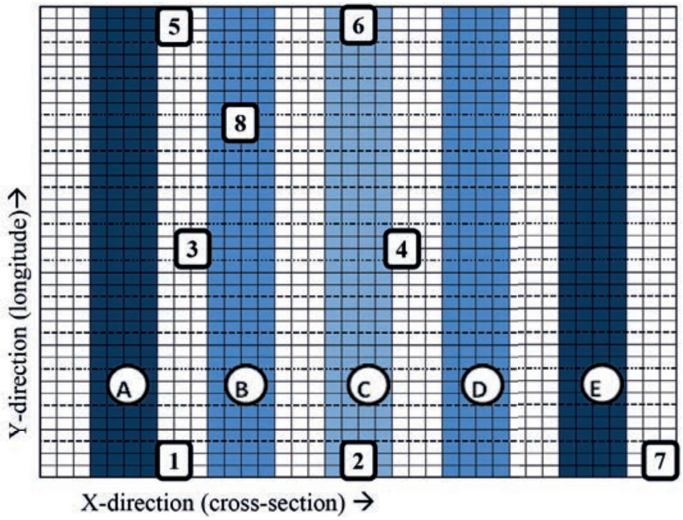


Figure 2: Map of a housing section, as used in the validation measurements. Letters A to E refer to the aviary rows in Figure 1, while the numbers indicate the locations that are evaluated in the sensitivity analysis.

**Results**

<u>Model</u>

Figure 3 shows the map produced by the model, where the aviary rows on the outside (A and E) are visible as the dark blue horizontal lines (*P(floor egg)*=0) and the six sections can be recognised as the replication of the pattern in horizontal direction. Furthermore, it can be seen that probabilities were highest in the front corners, as well as raised for locations below and near aviary rows.

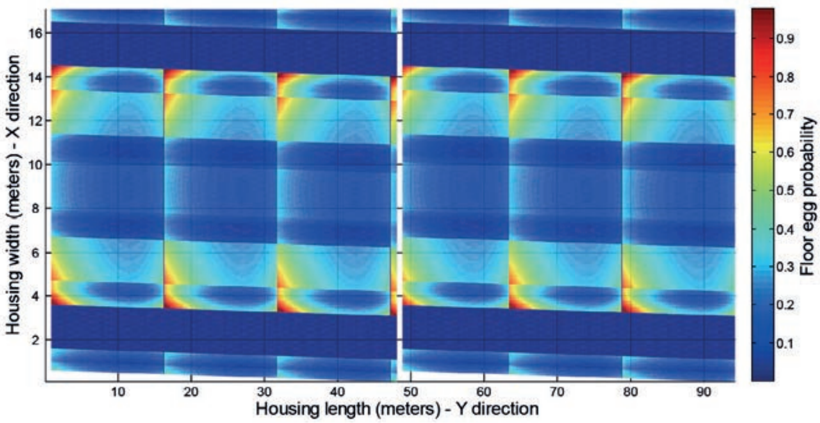


Figure 3: The map resulting from the floor egg model, indicating the probability on a floor egg for each location in the housing. The dark blue lines refer to A and E in Figure 1**.**

Model Sensitivity

Contribution of parameters is varying among the selected locations, but *P(floor egg)* is mainly determined by the parameters of $P_{corners}$, with a total contribution between 50% and 96%. In corners, locations 1 and 5, $P_{corners}$ is determined by the weight factors of the single probabilities, with contributions of 96% and 85%. On other locations factors determining the single probabilities, *c1* and *c2*, play a larger role with a contribution between 40% and 50%. For most locations, the contribution to *P(floor egg)* of parameters from the front is larger than from the rear. Elevated tiers, walls and obstacles had a limited contribution of less than 5% to *P(floor egg).* Only for locations with a low probability from $P_{corners}$, like location 8, they showed a higher contribution which is reaching almost 30%.

Model Validation

Validation results can be found in Figure 4 and Figure 5. To match model output with measurement results, the probability distribution in the model was converted into the expected floor egg distribution. Figure 4 shows the floor egg distribution along the cross section of the house, which qualitatively matched the model rather well. Highest numbers, between 4 and 11%, were found on the outside of the litter area (between rows A-B and D-E) and below elevated tiers with limited height (rows B and D). Lower numbers of less than 1% were found in the middle region and in the outside corridors. Figure 5 shows the floor egg distribution in longitudinal direction, with considerable

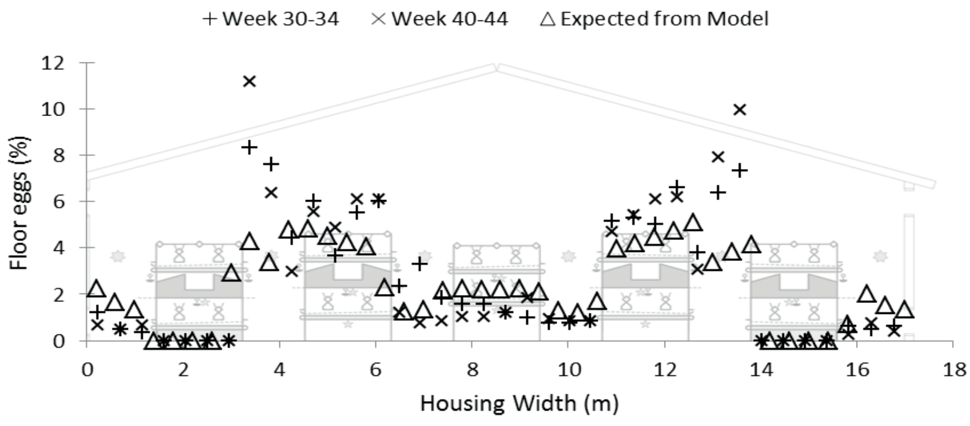


Figure 4: Distribution of floor eggs as percentage of total floor eggs along cross-section of the house. Data was collected in two periods of 5 weeks. Series names indicate animal age in weeks during these periods.

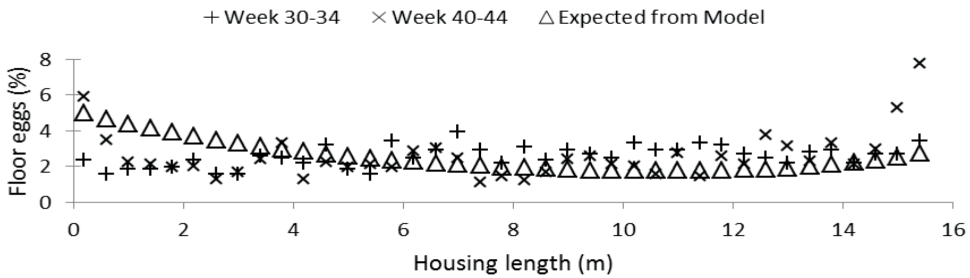


Figure 5: Distribution of floor eggs as percentage of total floor eggs along longitudinal direction of the house. Data was collected in two periods of 5 weeks. Series names indicate animal age in weeks during these periods

variation around a certain level (about 2% for each location), and an increase at the front and rear of the house (especially for Week 40-44). Furthermore, it can be observed from both figures that the distribution has shifted between the two measurement series.

## Discussion

Model

The probability model was constructed based on qualitative knowledge and calibrated intuitively. Therefore the assumptions taken, for example on the chosen representation (a probabilistic model), might be discussed as other representations might yield better results. The same holds for the initial choice of parameters, functions and parameter values that are used in this model to construct to *P(floor egg)*. However, the results of the used model match well to the available literature and findings in practice, making the model suitable for further use. Still, we recommend more research on the choices that have been made, to ensure the correctness of the model.

Model Sensitivity

The results of the sensitivity analysis match with expectations, in that location within the house ($P_{corners}$) contributed most, followed by the effect of shelter ($P_{shelter}$). Selection of parameter values determining $P_{corners}$ needs to be done carefully, since $P_{corners}$ contributes over 50% to the probability on floor eggs. A further check on the correctness of these values is thus advised. The limited effect of obstacles ($P_{proximity}$) on the probability indicates that their role in the model needs more attention. This can be done in two ways: by increasing the effect or by removing this parameter from the model. Both require an evaluation of the role of obstacles on the floor egg probability.

Model Validation

With respect to the validation experiment, it should be noted that only a single housing type with a single animal breed was tested during a short period with a very low percentage of floor eggs (0.3% ≈ 2000 eggs collected in the experiment). Performing experiments on a larger scale might give a more representative result. However, measurement results agree qualitatively with available literature and practical experiences, indicating that observations resemble common poultry practice.

The conversion from model probability to expected floor egg distribution has introduced some round-off errors, so that some of the values in the graph are lower compared to the real model. Also the resolution of the sampling map should be noted here, which was taken as small as practically feasible. As there was no exact position measurement, floor egg locations were registered with a deviation from reality of less than 0.3 meter. This resulted in loss of specific information, like the presence of clusters over multiple cells or the exact location of an egg within a cell. Both were observed during the measurement but partly disappeared in the measurement map as result of its resolution. Thus, higher accuracy in the registration might have slightly changed the distribution (without affecting the results or the model), most likely by placing the location of the eggs more close to the obstacles and indicate a certain degree of clustering of the eggs. The personnel on the reference farm confirmed that the probability model qualitatively described the distribution of the floor eggs in a general way. Still, for each flock adaptations might be required to resemble their specific behaviour.

This holds also for the application of management measures like the use of (electric) fencing. Adaption might also be required to account for variation over time, as can be observed from the shift in distribution between the first and second measurement period shown in Figure 4 and Figure 5. Thus, adding adaptability on flocks and over time is highly recommended, especially when using this model for planning floor egg collection paths and other practical applications.

## Conclusion

It was possible to build a model describing spatial floor egg distribution by 3 components: 1) Position in the poultry house; 2) Free height above the floor; 3) Proximity of obstacles. These components were combined in a model resembling floor egg probability with a value between 0 and 1. The floor egg probability in the model is mainly determined by the position in the poultry house (1). Less dominant are free height above the floor (2) and distance to interior elements (3). The validation experiment shows that the model qualitatively agrees with the spatial floor egg distribution found under practical circumstances. The model is more than sufficient to be used in the evaluation of floor egg collection paths.

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## An Innovative Monitoring System to Measure the Feed Intake of Broiler Chickens using Pecking Sounds

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### Abstract

Technological developments have provided us with a variety of tools that can be used to monitor behaviour automatically, and these have great potential to improve our ability to monitor animal welfare indicators on-farm. In this study, a fully-automatic monitoring technique was developed to analyse the pecking sounds of broiler chickens.
In this research, an algorithm is developed to detect individual pecking sounds while the relationship between pecking sounds and feed uptake is investigated. The results of the algorithm were compared with reference weighing system measurements and video observations. The pecking sounds of 12 individual, 28-day old, male broiler chickens were recorded by a microphone that was attached to the feeding pen in laboratory conditions. Feed uptake measurements were automatically recorded using a weighing system. Feed spoilage was manually collected and weighed after each experiment. Based on the measurements of feed uptake and feed loss, the feed intake was calculated and used to validate the proposed algorithm. It was found that 93% of the pecking sounds were correctly identified by the algorithm, whereas 7% of the identification results were false positives. A linear regression test was performed to define the determination coefficient between the number of pecks and feed uptake in chickens, which resulted in $R^2 = 0.995$. In addition to that high correlation, 90% of feed intake events were correctly monitored using sound analysis.
Since the correlation between the number of pecks and feed uptake of chickens was $R^2 = 0.995$ the results suggest that this feed uptake detection system has the potential to be used as a tool to monitor the feed intake of chickens on commercial farms. The advantage is that measurements can be made continuously throughout the life of a flock, in a fully automated, completely non-invasive and non-intrusive way.

**Keywords:** Sound analysis, peck detection, feed intake, poultry, broiler.

### Introduction

Researchers are trying to investigate which responses should be measured and whether bird responses are correlated with well-being. One means of assessing bird response to stimuli involves careful analysis of individuals or group characteristics over time.

Monitoring individual behaviour during research trials is typically performed using a type of video imaging system. For poultry, behavioural activities are categorised into events such as eating, drinking, preening, resting, and stereotyped activities directed at different targets. This assessment methodology is time-consuming, hence costly, tedious and prone to errors, even with modern commercially available research systems that compile the statistics semi-autonomously. Therefore, there is an increasing need for methods of further automating the collection of event-based behavioural responses (Gates *et al*., 1995; Gates and Xin, 2001; Persyn *et al*., 2004; Xin *et al*., 1993). For this purpose, computer and modern electronic technologies have been applied to monitoring of bird feed intake, body weight and feed conversion ratio (FCR) (Hulsey and Martin, 1991; Xin *et al*., 1993; Yo *et al*., 1997; Savory and Mann, 1999; Puma *et al*., 2001). For example, algorithms for determining individual bird feeding statistics and stereotyped pecking behaviour from time-series recordings of feed weight were developed and compared to video observations by Gates and Xin (2008). In another study, focusing on turkey breeding, a structured query language (SQL) database management system was developed by Xuyong *et al*., (2011) to record and manage the dynamic feed intake and body weight gain data of individual birds. The system developed also provides a powerful research tool for studying poultry feeding behaviour under group housing conditions (Xuyong *et al*., 2011). Up to now, however, the same methodology has been applied by defining poultry feed intake based on weighing scale data from the literature. In contrast to previous studies, this is the first time that a sound detection system has been used in the feeding pen instead of a device attached to each bird. In this research, a novel method is investigated by using a sound detection system to calculate the feed uptake and feed intake of chickens. A major advantage of this sound detection system is that measurements can be made continuously throughout the life of a flock, in a fully automated, completely non-invasive and non-intrusive way.

The objective of this research is to test, develop and validate an algorithm by detecting individual bird pecking sounds to estimate feed uptake and feed intake of broiler chickens.

## Materials and Methods

<u>Experimental Design, Video Recordings and Birds</u>

The recordings were carried out with 12 broiler chickens over three consecutive days. Three experiments were conducted with each broiler, giving a total of 36 experiments. Each individual chicken was housed in a different cage for four hours before the experiment without access to feed and water so that they were hungry before the experiment. Each experiment lasted for 15 minutes. During the experiment an individual bird was placed in a separate cage (50x50x50 cm). All sounds such as pecking, singing and environmental sounds were continuously recorded. At the same time, video images were captured and the feed uptake of the chicken was continuously recorded (sampling frequency of 10 Hz) by a weighing system, which was connected to the PC via RS-232 cable. Once all the data had been recorded, sound data were analysed by a pecking detection algorithm in MATLAB® (Mathworks). For validation of the proposed algorithm, the chicken pecks in the image data were manually labelled using the labelling tool developed by Leroy *et al.* (2005). A second validation based on the measured weighing data was used. For the sound recording, an electret microphone (Monacor ECM 3005) was positioned under and attached to the bottom of the feeding pan (Figure 1). The microphone had a frequency response of 30–20,000 Hz and was connected to a PC via a preamplifier (Monacor SPR-6). All recordings were sampled at 44.1 kHz with 16 bit resolution. For the video recordings, a USB webcam (Logitech Webcam Pro 9000) with 3.7 mm Carl Zeiss® lens was mounted next to the cage at a distance of 50 cm with its lens pointing towards the cage to give a side view of the feeder (Figure 1).

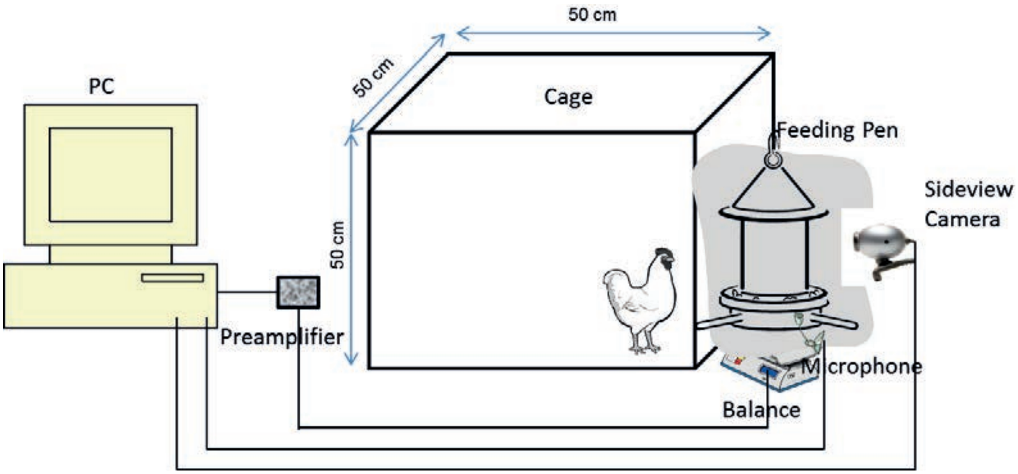


Figure 1. Laboratory setup for sound recordings of an individual chicken
Images were captured with a resolution of 640 horizontal by 480 vertical pixels at a sample rate of 15 frames per second. During the video recordings, the light level was maintained at 10 lux. The feeding pan was placed on a precision balance (KERN PCB-250-3, with a weighing range of 250g and accuracy of 0.001g)

Definition of the frequency ranges

Before sound extraction was applied, the recorded data was pre-processed to define the best frequency differences between pecking and other sounds. Afterwards, the individual sounds (pecking and other sounds) were manually extracted from the continuous recordings and stored as individual sounds. The resulting data set of 100 individual pecking sounds and 100 other sounds was used to define the best frequency differences between pecking and other sounds.

2.3.2. Filtering

To eliminate low-frequency noise, produced mainly by the ventilation system in the laboratory, the signal was initially band pass-filtered (6th order Butterworth filter) with cut-off frequencies of 1 kHz and 5 kHz (figure 2).

The pecking sound signals that need to be recognised are not affected by this filter as they have large low-frequency components and the frequency range between 1 kHz and 5 kHz holds enough information for the purpose of this study.

Figure 2 shows a filtered sound signal between 1 kHz and 5 kHz.

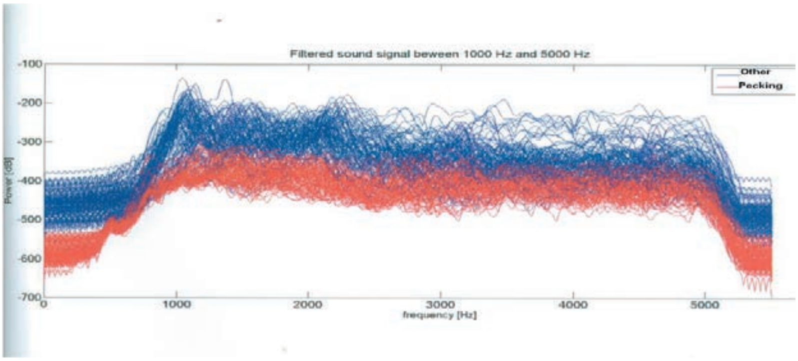


Figure 2. Filtered sound signal (pecking and other) between 1 kHz and 5 kHz

After band pass filtering, the signal was down sampled from 44.1 to 11.025 kHz to reduce processing time. The flowchart for the proposed signal processing procedure is shown in Figure 3.

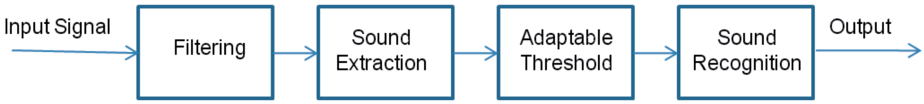


Figure 3. The flowchart used for the proposed algorithm.

<u>Sound extraction</u>

The algorithm consists of two major parts: first, the individual sounds are extracted from a continuous recording, and afterwards each sound is classified as pecking or other sound. Each part of the algorithm is presented in detail in the following sections.

Extraction of individual sounds from a continuous recording is based on the energy envelope of the signal and is automatically selected by applying a specific threshold (Exadaktylos *et al*., 2008a). The mean value of the envelope over the complete recording is used for this application, on the assumption that it is adequate for extracting most of the signals that are of interest. To automatically calculate the envelope of the continuously recorded signal, the Hilbert transform of a discrete time signal s[k] is defined as

$$H\{s[k]\} = \sum_{n=-N/2}^{N/2} s[k-n]h[n]\sin^2\left(\frac{n\pi}{2}\right), \qquad (1)$$

where h_k_=2/k_, for k=_1,_2, . . . ,_N/2 and h_0_=0.

The Hilbert transform provides a 90° phase shift to the original signal and is used according to the following algorithm procedure:

1. calculation of the signal energy, calculation of the Hilbert transform of the energy,
2. calculation of the square root of the sum of the energy and its Hilbert transform, and
3. calculation of the moving average of the result to get a smoothed estimate of the envelope of the initial signal.

The result of this procedure is presented in Figure 4, which presents a continuous sound signal and shows the extracted pecking sounds.

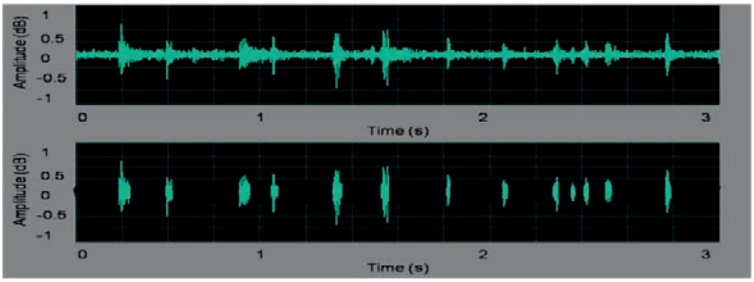


Figure 4. Continuous recording of sounds (top) and individual pecking sounds (bottom) as extracted by the algorithm.

<u>Sound classification</u>

The sum of the power spectral density vector is calculated for a frequency range between 1 and 5 kHz in order to identify whether the sound is a peck or not. The frequency range was identified because the pecking and other sound signals have considerably different frequency content. Based on this, the threshold value can be chosen in the ranges that differentiate the other sound from the pecking sound signal. In this research, an adaptable threshold was chosen instead of the fixed threshold, due to the frequency contents of pecking and other sound signals, which are not stable and not easily distinguishable. Every single sound signal was automatically calculated by the algorithm to obtain a new and correct threshold value. Each threshold was defined as 0.8 per cent of the maximum signal. However, it should be noted that the noise level and acoustics of a commercial broiler are different from the laboratory environment, which can affect the resulting signal. Therefore the threshold should be chosen taking this into account.

After threshold definition, the algorithm classified the sound based on a sudden increase of amplitude in both spectrogram(s) and wave forms together with a subsequent decrease. Fig. 5 shows a spectrogram of a continuous sound consisting of several individual pecks. If the sum of the density is below the threshold in the frequency band, the signal is characterised as a peck.

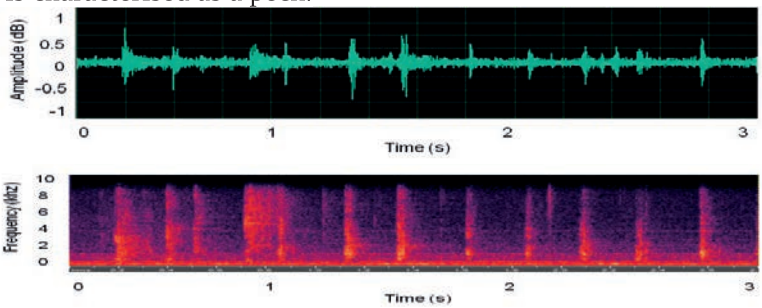


Figure 5. Spectrogram of a continuous sound (consisting of 13 pecking hits) represented in the time domain (above) and frequency domain (below).

<u>Calculation of feed intake of chickens</u>

The feed uptake was automatically calculated by a sound algorithm detecting the pecking sounds of broiler chickens. At the same time, it was continuously recorded by a weighing system while the feed wastage was collected and weighed manually after each experiment (see Table 2). Afterwards, the feed intake per experiment (FIPE) was defined as:

$$\mathrm{FIPE} = \mathrm{FUPE} - \mathrm{FWPE} \quad (1)$$

The feed intake per experiment (FIPE) is the quantity (g) of feed ingested by chickens during the experiment. This value was calculated by subtracting the feed wastage per experiment (FWPE) (quantity (g) of feed spilled on the ground) from the feed uptake per experiment (FUPE) (quantity (g) of feed removed from the feeding pan by the chicken during the experiment).

The calculation of average feed intake per peck (FIPP) is therefore defined as;

$$FIPP = \frac{FIPE}{NPPE} \qquad (2)$$

The feed intake per peck is the quantity (g) of feed ingested by chickens with each peck. This value was calculated as the ratio between the total feed intake per experiment (FIPE) and the total number of pecks per experiment (NPPE).

## Results and Discussions

The first main goal of this study was to develop an accurate algorithm to detect broiler pecking sounds. All sounds were processed and classified as either "pecking" or "other sound" using the algorithm presented. Table 1 shows the total number of pecking sounds identified automatically by the algorithm and the total number of pecking sounds labelled visually by using the video reference. False positives were obtained when a sound of another kind was falsely identified as a peck. As can be seen in Table 1, 93.0% of the pecking sounds were correctly identified, while the false positive results remained low at 7%.

Table1. Accuracy results of the proposed algorithm

| Data Set | Number of pecks (Algorithm) | Number of pecks (Video Labelling) | Accuracy of Algorithm (%) | True Positive | False Positive |
|---|---|---|---|---|---|
| 1 | 113 | 105 | 93 | 105 | 8 |
| 2 | 99 | 95 | 96 | 95 | 4 |
| 3 | 109 | 106 | 98 | 106 | 3 |
| 4 | 98 | 91 | 93 | 91 | 7 |
| 35 | 98 | 91 | 93 | 91 | 7 |
| 36 | 95 | 88 | 92 | 88 | 7 |
| Total-Average | 3707 | 3447 | 93 | 3447 | 7 |

The results presented are based on sounds recorded in laboratory conditions using 12 birds in total. The second main goal of this research was to investigate the relationship between pecking sounds and feed intake of chickens. To detect the total number of pecks in each experiment, all sound data were analysed by the algorithm (see Table 2). Additionally, feed uptake (FUPE and FUPP) was measured by the weighing system and the data were linked to the results of the sound algorithm (see Table 2). The lowest feed intake per peck was 0.023 g in the second experiment using the eleventh chicken (see Table 2). The highest feed intake per peck was 0.028 g in the third experiment using the fourth chicken (see Table 2). The average feed intake per peck was 0.025 g.

Table 2. Number of pecks, feed uptake, feed loss and feed intake of chickens

| Birds | Exp | NPPE | FUPE (g) | FLPE (g) | FIPE (g) | FIPP (g) | FIPP (Mean) | FLPE (%) |
|---|---|---|---|---|---|---|---|---|
| | 1 | 1193 | 28,63 | 0,325 | 28,31 | 0,024 | | 1,14 |
| 1 | 2 | 759 | 18,98 | 0,198 | 18,78 | 0,025 | 0.025 0.0015[a] | 1,04 |
| | 3 | 895 | 24,17 | 0,222 | 23,94 | 0,027 | | 0,92 |
| | 1 | 1250 | 32,50 | 0,236 | 32,26 | 0,026 | | 0,73 |
| 2 | 2 | 1283 | 30,79 | 0,365 | 30,43 | 0,024 | 0.025[a] | 1,19 |
| | 3 | 1460 | 35,04 | 0,348 | 34,69 | 0,024 | | 0,99 |
| | 1 | 583 | 13,99 | 0,145 | 13,85 | 0,024 | | 1,04 |
| 12 | 2 | 654 | 16,35 | 0,165 | 16,19 | 0,025 | 0.025[a] | 1,01 |
| | 3 | 573 | 15,47 | 0,155 | 15,32 | 0,027 | | 1,00 |
| Total-Average | | 25285 | 633,26 | 6,22 | 627,04 | **0,025** | 0.025[a] | **0,98** |

Before estimating the absolute amount of feed intake by chickens from the pecking sounds algorithm, the relationship between the number of pecks and feed uptake by chickens was investigated. A linear relationship between the variables was identified (see Figure 6).

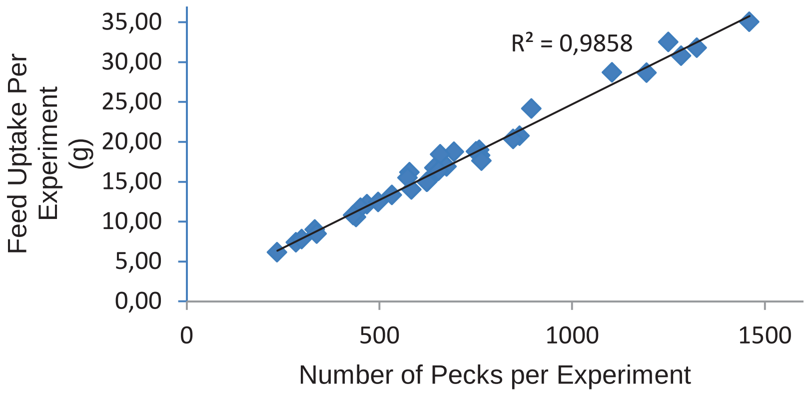


Figure 6. The relationship between feed uptake and number of pecks by chickens per experiment

In addition to that high correlation, 90% of feed intake was correctly monitored through sound analysis.

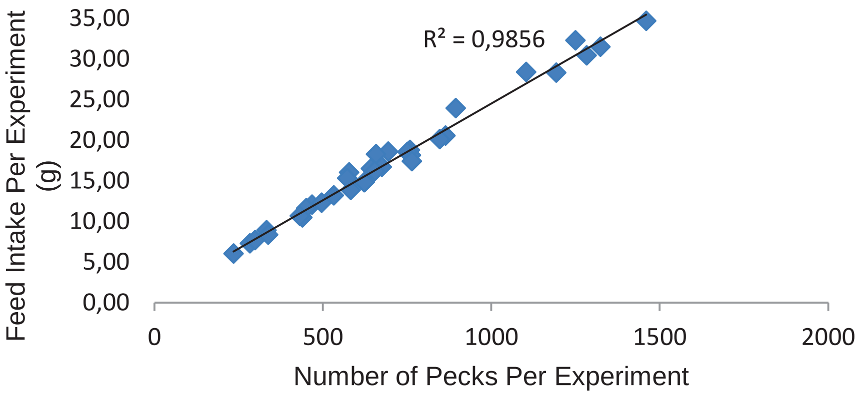


Figure 7. The relationship between feed intake per experiment and number of pecks per experiment.

Furthermore, the results for individual feed intake per peck were statistically compared. The results show that there are no significant differences between the feed intake of individual chickens (see Table 2).
As the correlation between the number of pecks and feed intake by chickens was $R^2 = 0.995$, the results suggest that this feed uptake detection system has the potential to be used as a tool to monitor the feed intake of chickens on commercial farms. The advantage is that measurements can be made continuously throughout the life of a flock, in a fully automated, completely non-invasive and non-intrusive way.

However, a number of technical challenges must be overcome if the algorithm presented is to be developed to work under field conditions. The most important of these challenges was that each feeding pan on the farm might be easily modified by a very cheap microphone to rapidly and correctly calculate the feed intake of chickens. The real-time nature of the algorithm presented makes it an attractive tool for measuring the absolute feed intake by chickens on commercial broiler farms. This is the case in broiler houses where it is important to measure feed intake reliably in order to achieve the correct feed conversion rate, to calculate the food wastage in each pen, to define the feeding period and to define the dynamic feeding behaviour of chickens. In any case the applicability of the approach presented should be tested under farm conditions in order to obtain a more accurate evaluation. It should also be stressed that although the algorithm was tested on individual animals under laboratory conditions, the results showed that the algorithm is potentially of great value to study the feeding behaviour of chickens objectively in future research.

## Conclusions

This paper proposed a novel algorithm for detecting broiler pecking sounds. The results showed that the majority of sounds were correctly identified as pecks with 93% accuracy. Furthermore, the relation between feed intake and pecking sounds by broiler chickens was investigated and the results revealed that there was a very strong correlation between these two variables ($R^2$=0.9950). In addition to that high correlations, 90% of feed intake events were correctly monitored by sound analysis. However, applying the method under field conditions will probably introduce problems that can affect the accuracy of the algorithm. For example, the competition between birds to reach the food, ventilation or feeder sounds will introduce a variety of sounds besides pecking. This will affect the frequency content evaluated by the algorithm. However, such a problem can be solved by studying and estimating the expected noise sequence and subsequent fine-tuning of the algorithm. Furthermore, animal age and different pathological conditions are believed to affect the frequency content of pecking signals and need further investigation. It is concluded that sound monitoring could be used to define the feed intake of broilers. Apart from sound monitoring of broiler chickens housed in groups for breeding purposes, the real-time dynamic data for feed intake provide an important basis for research on broiler feeding behaviour and welfare. Thus, further research should be aimed at defining dynamic feed intake, eating period, food wastage and feeding behaviour of broilers by sound analysis under different commercial farm conditions.

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# Assessment of human-animal relationship in broilers with automatic recording of activity

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## Abstract

In broiler production birds are kept in large flocks of thousands of animals. The farmer walks among the birds daily, but has in comparison with other livestock little physical contact with individual animals. Even with this limited contact, studies show that qualitative aspects of the relationship between the caretaker and the poultry flock can affect both the animals' welfare and the productivity. In this pilot study, the possibility to assess human-animal relationship in a broiler flock using the techniques of precision livestock farming was investigated. Automatic tracking of the activity level of the flock was compared to the human-animal relationship as assessed by a human observer.

Two small groups of broilers (Ross 308) were reared for 36 days. One of the groups was treated with additional human contact every day to make the birds more familiar to humans. Welfare assessment according to the Welfare Quality® protocol for poultry (2009) was carried out once a week, with special emphasis on human-animal relationship using the Avoidance Distance Test (ADT). Video recording of the birds' response to the presence of a human was carried out once a week in both groups. The recordings started when a human began walking through the flock. Analysis of the activity of the birds after the human had left the pen was carried out using image analysis software. Activity was for each second expressed as an index between 0 and 1.

Results show that the additional human contact group had different values on the ADT-test than the control group: 91 % of total number of birds could be touched compared to 65 %. At week 5 the activity level after a human had left the pen, was lower for the additional human contact group than for the control group (average index level 0.06 compared to 0.09). The results from this pilot study show a potential of using automatic recording of activity of broiler to assess the human-animal relationship but this needs further development.

**Keywords:** Broiler, human-animal relationship, automatic recording, activity

## Introduction

The Welfare Quality® project started in 2004 to monitor and improve animal welfare in livestock production (Blokhuis *et al.* 2010, www.welfarequality.net). The project was the largest integrated European research project on animal welfare ever and involved 17 countries (13 European and 4 Latin American countries). Approximately 250 scientists and 44 organizations participated in this collaborative effort. Welfare Quality® developed standardised science-based, on-farm welfare assessment systems for broilers, laying hens, sows with piglets, fattening pigs, beef and dairy cattle and calves. This included reliable and feasible measures of animal welfare to assess the level of welfare on farm and at slaughter as well as a method to integrate the measures into an overall classification per facility. The emphasis was placed on the use of animal-based measures, in contrast to resource based measures, in an attempt to estimate more directly the actual welfare state of the animals in terms of their behaviour, fearfulness, health or physical condition and thereby combine the effect of resources and management.

This pilot study focused on investigating the possibilities to develop an automatic system for the assessment of the "human-animal relationship" which is one of the parameters in the Welfare Quality® protocol for broilers (Welfare Quality®, 2009). Broiler production takes place in large flocks of thousands of animals. The farmer walks among the birds daily, but has in comparison with other livestock little physical contact with individual animals. Even with this limited contact, studies show that the quality of the relationship between the caretaker and the poultry flock can affect both the animals' welfare and their productivity (Hemsworth *et al.* 1994, Barnett *et al.* 1994, Cransberg *et al.* 2000, Waiblinger *et al.* 2006).

The objective with this pilot study was to get a better idea regarding the potential of automatic measuring of the welfare criterion "good human-animal relationship" using video recording and image analysis. The automatic output measured was animal activity and the results from the Avoidance Distance Test (ADT) as assessed by a human observer were used as a golden standard.

## Material and methods

The experiment was performed at the Swedish Livestock Research Centre in Uppsala, Sweden. Broiler chickens of the hybrid Ross 308 were floor reared in two pens, each one of 6 $m^2$ (3 meters x 2 meters). Each pen contained 100 broilers which were reared for 35 days. The animals were fed *ad lib* during the whole growing period. Video recording was done using two network surveillance cameras (Axis P3344), which were controlled using the computer software Mirasys (www.mirasys.com).

The hypothesis in this pilot was that broilers that are used to human contact during rearing will be less fearful during contact and less aroused afterwards. They will then show less activity in the pen after a human has been present, compared to broilers which have had less contact with humans. Broilers that have been used to human contact during rearing will show less avoidance from the assessor in the Avoidance Distance Test (ADT), compared to broilers that had less contact with humans. To create a difference in human-animal relationship one group was treated with additional human contact according to table 1. The other group of birds had as little human contact as possible (but still at least twice a day during daily management activities) and was used as a control group.

Table 1. Treatment schedule

| **Treatment** | **Control group** | **Additional human contact group** |
|---|---|---|
| Daily check for feed, water and dead/sick birds | Two times every day. Morning and afternoon | Two times every day. Morning and afternoon. |
| Human contact | None | 1 hour during weekdays |

The additional human contact session took place once a day on weekdays for a total duration of 1 hour. The test person entered the pen, kept a standing position for 5 minutes and then sat down for 5 minutes and then repeated the procedure on two more locations in the pen (see figure 1). After one 30 minutes session the birds were left alone for one hour before the session was repeated once more.

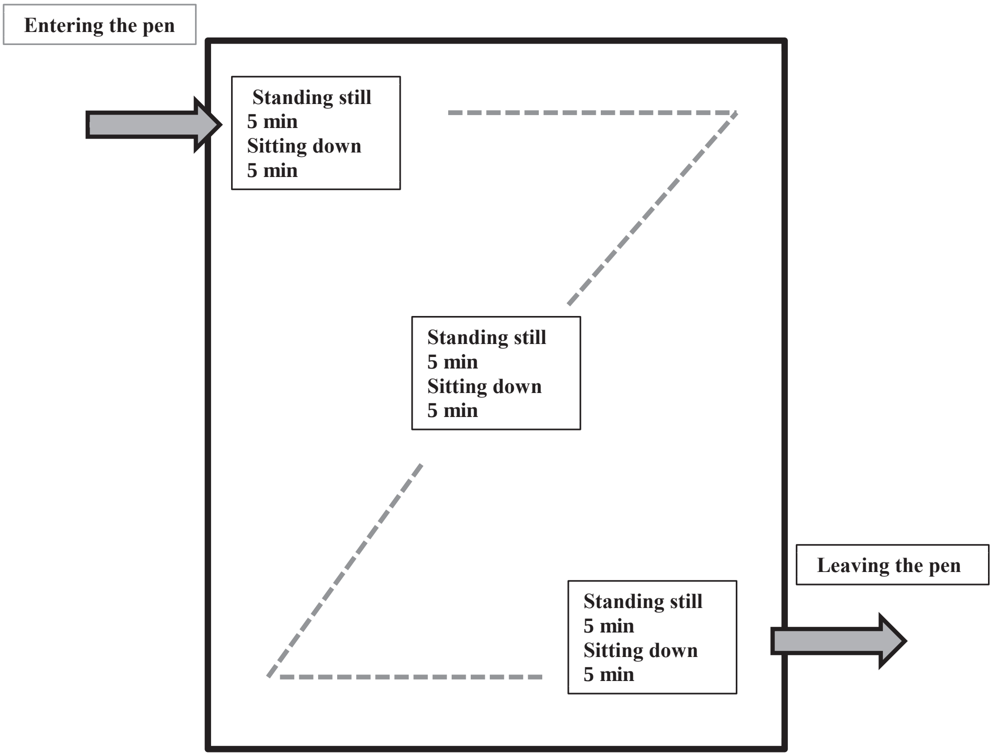


Figure 1. Additional human contact procedure

To assess the human-animal relationship the Avoidance Distance Test was used as it is described in the welfare assessment protocol for broilers (Welfare Quality®, 2009). The birds were tested once a week starting in week 1. The assessor approached a group of at least 3 birds, sat down for 10 seconds and then counted the number of birds within an arm's length. The assessor then counted the number of birds that actually could be touched. This was repeated 5 times in each testing session.

Video recordings were made once a week during the whole rearing period. Recording started when a test person entered the pen (and then walked through the flock and then left the pen). Analysis of activity of the birds started when the human had left the pen and continued for a period of 1 hour. Activity was expressed each second as an index between 0 and 1.

## Results and Discussion

The results show that the additional human contact group had different values on the ADT-test than the control group: 91 % of total number of birds could be touched compared to 65 %. At week 5 the activity level after a human had left the pen, was lower for the additional human contact group than for the control group (average index level 0.06 compared to 0.09). More research is needed to investigate the underlying reason for the difference in activity. The increased activity in the control group may be due to the level of arousal in the flock and the time it takes for them to settle down again. It may also be due to the fact that the control birds move further away from the human and therefore take longer time to move back to an even distribution of animals in the pen when the human has left.

Regarding the Avoidance Distance test the pen size used in this pilot may have been a limiting factor affecting the accuracy of the test. The test is developed to be used in commercial flocks with much more space/area. For future research a complimentary test for human-animal relationship could be used to validate the Avoidance Distance Test under the experimental conditions applied. A suitable test for this purpose which is not depending on pen size, may be the Stationary Person Test, described by Raubeck *et al.* (2007) and Graml *et al.* (2008).

Since the activity analyzing software is recording movements in the pen. It is important that the only things moving in the pen are the chickens. Drinkers, feeders and so forth must be fixed to prevent errors in the activity data. The cameras must also be placed top viewed to exclude any perspective differences in the recordings.

## Conclusions

The results from this pilot study show a potential of using automatic recording of activity of broilers to assess the human-animal relationship and this warrants further development.

## Acknowledgements

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# Session 21

# Animal response to climate

# Sensor placement to reach thermal comfort and air quality in broiler housing

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## Abstract

A knowledge of the spatial variability of climatic attributes and the use of kriging maps can help environment management of housed animals. The goal of this research was to evaluate the homogeneity of the environment inside a totally closed broiler house to help in the placement of sensors for better environmental control of the building, using a geostatistics technique. The following environmental data were evaluated: dry bulb temperature (ºC) and relative humidity (%) with a THDL 400 (Instrument®) device and carbon dioxide concentration (ppm) measured with GasAlertMIcro 5 BW Technologies® equipment. Data were collected at 52 equidistant points inside the barn at 21, 28, 35 and 42 days old at 2 p.m. A model adjustment was carried out for each of the variables analysed to develop semivariograms using GS+ software and a data interpolation technique (kriging) using Surfer 8.0 software. The semivariograms were adjusted in the following models: Gaussian, Spherical, and Exponential. The nugget did not occur. Sanos® software was used to simulate different numbers of sensors inside the building. The results show maps of the broiler houses with the recommended sensors. The Sanos® software was able to set the number and placement of sensors for the different bird ages. Geostatistics proved to be a good tool for sensor placement inside broiler houses.

**Keywords:** Animal welfare, Poultry, Environmental control, Sensors position

## Introduction

Recent developments in sensors and computer modelling, such as geostatistics and artificial intelligence, allow higher precision in data measurement, modelling and decision making for climate control in broiler houses (Carvalho *et al.*, 2010). Precision Livestock Farming aims to control the management of individual animals, but at the same time environmental control of a broiler house has to be achieved in a sectorised way, making appropriate decisions for each part of the house instead of using a single sensor to control the environment of the whole house (Wathes *et al.*, 2008). The goal of this research was to evaluate the homogeneity of the environment inside a totally closed broiler house to help in the placement of sensors for better environmental control of the building, using a geostatistics technique.

## Material and methods

Broiler house description

The broiler house evaluated was located in the north-east of Sao Paulo state. The broiler house was tunnel ventilated, with sidewall inlets for minimum ventilation and pad cooling for evaporative cooling. Six exhaust fans were located at the end of the building and five on each side wall (Figure 1). The side walls were built from concrete bricks, with a fibre cement roof and a polyethylene ceiling. The dimensions of the broiler house were 12.0m x 120.0m.

(a) (b) (c)

Figure 1. View of the broiler house– inside (a) and outside (b, c).

Experimental data

The environmental variables evaluated were as follows:

- dry bulb temperature was measured with a Velocicalc® thermo-anemometer , TSI™ (Figure 2, a).
- relative humidity was measured with a THDL 400, Instrument® (Figure 2, b)
- carbon dioxide concentration was measured by a GasAlertMIcro 5 BW Technologies® (Figure 2, c).

(a) (b) (c)

Figure 2. Equipment for data collection.

Data were collected during the summer at 2 p.m., at 52 equidistant points inside the building at bird height. The data were collected when birds were 21, 28, 35 and 42 days old (Figure 3).

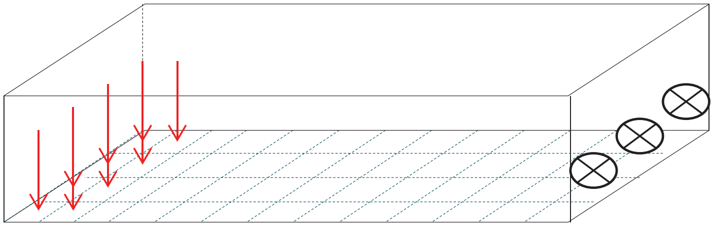

Figure 3. Data collection.

Data analysis

For each variable an adjustment was made using mathematical models to fit the semivariograms using the GS + software. The data interpolation technique (kriging) was carried out using the Surfer 8.0 software.

## Results and Discussion

Analysis of all the ambient variables showed, as presented in Figure 1, that the dry bulb temperature values were above the values recommended by the literature, Cobb (2008) between 18 and 23°C and Nicholson *et al.* (2004) 22°C. These results indicate a need for better ventilation and cooling systems, as well as better insulation of the roof and ceiling, to protect the building from solar radiation. A single fibre cement sheet is not enough to insulate a building like this. A higher R value for both roof and ceiling is needed to reduce the inside temperatures and increase the birds' performance (Oliveira *et al.*, 2000).

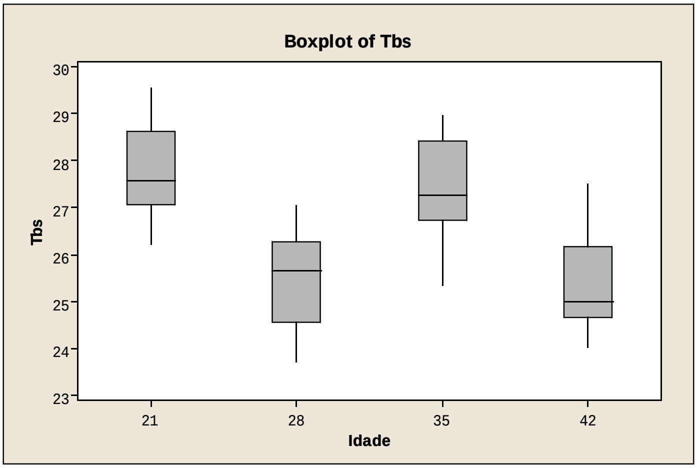


Figure 4. Box plot of dry bulb temperature against bird age.

The relative humidity (RH) average was within the recommended values (Cobb, 2008) of between 50 and 70%, when the birds were 21 days old; after this the RH increased above the recommended levels (Figure 5).

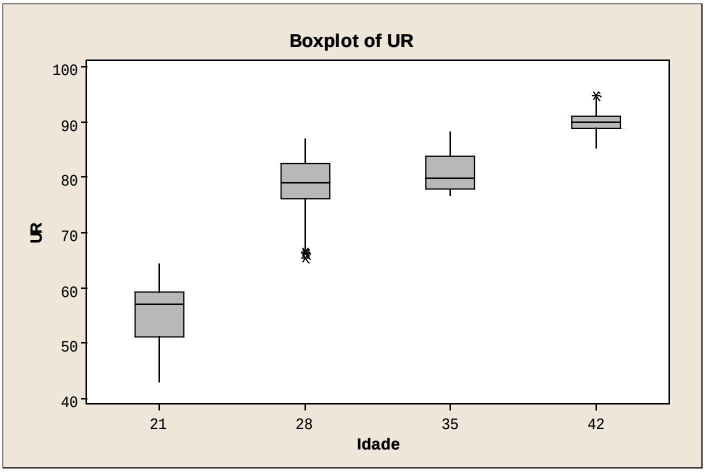


Figure 5. Box plot of relative humidity against bird age.

The air quality, measured by the $CO_2$ concentration and presented in Figure 6, was below the recommended levels for all bird ages according to Globalgap (2007). The results show that the ventilation system was able to change the air inside the building to control the gas concentration but was not able to control thermal comfort.

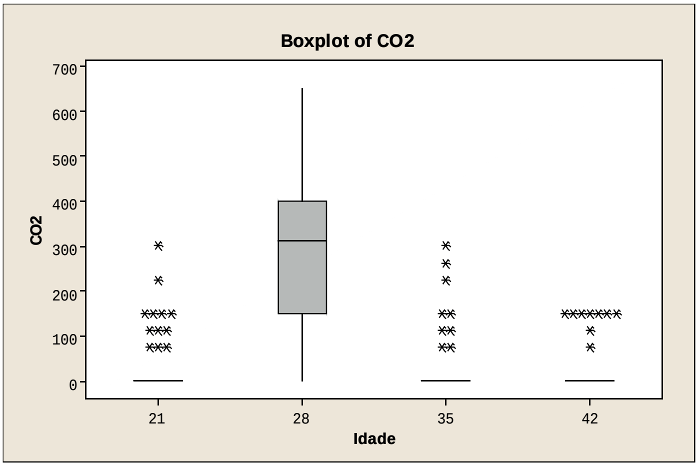


Figure 6. Box plot of carbon dioxide concentration against bird age.

Figure 7 presents maps of the temperatures inside the buildings for all bird ages. As expected, lower temperatures were observed near the cooling system and higher temperatures near the exaust fans. The temperature variation was 3.2°C for 21 and 35 day old birds, 2.8°C for 28 day old birds and 3.6°C for 42 day old birds. This variation is close to the ideal variation recommended by the literature in tunnel ventilated barns (3°C).

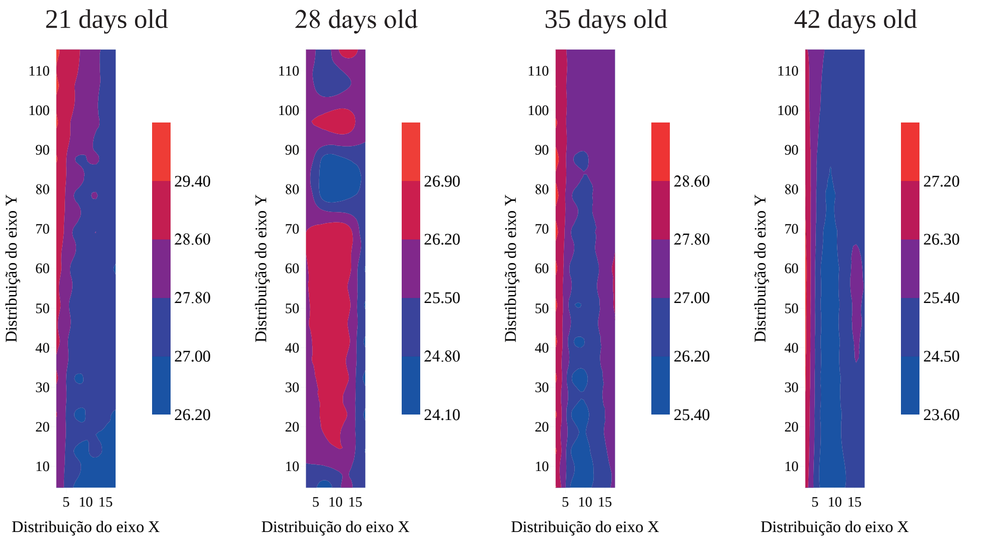


Figure 7. Dry bulb temperature distribution using geostatistical analysis.

The relative humidity was higher next to the exhaust fans where the heat, humidity and gases usually accumulate (Carvalho *et al.*, 2012). The highest level was found when the birds were 42 days old, at 95%. (Figure 3)

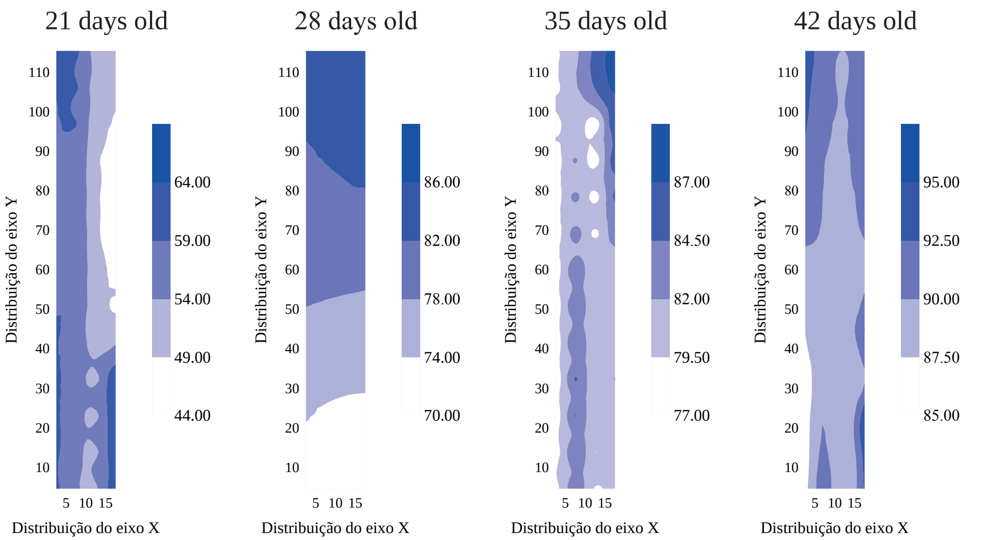


Figure 8. Relative humidity distribution using geostatistical analysis.

As expected the higher levels of $CO_2$ were also located near the exhaust fans but were always below critical levels. Some heterogeneity in $CO_2$ distribution was observed, indicating problems with operation of the ventilation system.

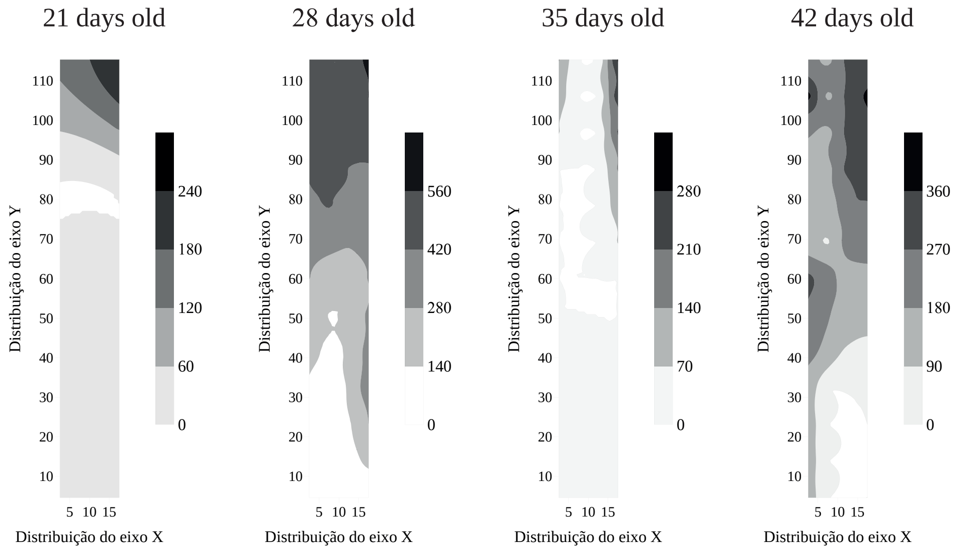


Figure 9. Carbon dioxide concentration distribution using geostatistical analysis.

The semivariograms for the temperature and relative humidity variables for 21 and 35 day old birds, as well as temperature and $CO_2$ for 28 day old birds, were fitted in spherical models. The semivariograms for $CO_2$ for 21 day old birds, as well as RH for 28 day old birds, and all variables for 42 day old birds were fitted in Gaussian models. The exponential model was fitted for $CO_2$ only for 35 day old birds. (Table 1).

Tabel 1. Models and estimated semivariogram parameters for all climate variables and bird ages.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | **21 days old – 2 p.m. – Summer** | | | | | |
| **Variable** | **Model** | **c0** | **c** | **c0+c** | **A** | **c0/c0+c1** | **R²** |
| DbT | Spherical | 0.01 | 0.81 | 0.82 | 22.00 | 0.98 | 0.89 |
| RH | Spherical | 0.01 | 25.68 | 25.69 | 19.50 | 1.00 | 0.97 |
| $CO_2$ | Gaussian | 390.00 | 4763 | 5153 | 51.96 | 0.92 | 0.98 |
| | | **28 days old – 2 p.m. – Summer** | | | | | |
| **Variable** | **Model** | **c0** | **c** | **c0+c** | **A** | **c0/c0+c1** | **R²** |
| DbT | Spherical | 0.04 | 0.77 | 0.81 | 15.20 | 0.94 | 0.87 |
| RH | Gaussian | 4.94 | 25.93 | 30.87 | 77.94 | 0.84 | 0.96 |
| $CO_2$ | Spherical | 1070.00 | 21010 | 22080 | 55.06 | 0.95 | 0.99 |
| | | **35 days old – 2 p.m.– Summer** | | | | | |
| DbT | Spherical | 0.01 | 1.06 | 1.06 | 16.60 | 0.99 | 0.92 |
| RH | Spherical | 0.05 | 10.48 | 10.53 | 15.10 | 0.99 | 0.66 |
| $CO_2$ | Exponential | 10.00 | 4288.000 | 4298 | 36.00 | 0.99 | 0.92 |
| | | **42 days old – 2 p.m.– Summer** | | | | | |
| Tbs | Gaussian | 0.01 | 1.30 | 1.30 | 14.89 | 0.99 | 0.92 |
| UR | Gaussian | 0.01 | 3.49 | 3.49 | 15.59 | 0.99 | 0.88 |
| $CO_2$ | Gaussian | 10.00 | 3168 | 3178 | 18.71 | 0.99 | 0.95 |

Afterwards the Sanos® software was used to simulate different sensor numbers and locations inside the building, taking all bird ages as an average. Figure 10 shows maps of the broiler houses with the recommended sensors, for each variable and then for both of them in a single sensor. As recommended by the literature, each 1/3 of the building needed a separate sensor.

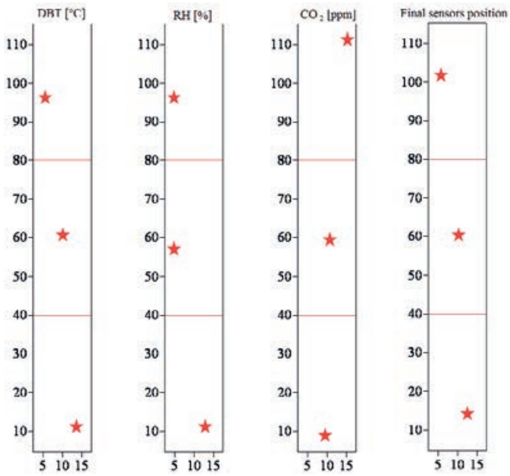


Figure 10. Sensor positions.

## Conclusions

The Sanos® software was able to determine the number and placement of sensors for the different bird ages. Geostatistics proved to be a good tool for sensor placement inside broiler houses.


## Acknowledgements

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# Characterizing Individual Animal Response to Environmental Changes

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**Abstract**

Heat stress in feedlot cattle is a concern. A study was conducted to characterize heat stress in feedlot cattle and to determine the impact of providing shade. To characterize the response to heat stress, linear equations were developed for each of 384 heifers relating 8 different indicators. In unshaded feedlot cattle, it was determined that the lower categories of responsiveness had more lighter colored breeds and the higher categories of responsiveness had more darker colored breeds of cattle. However, it was noted that there were lighter colored animals with high responsiveness and darker breeds with low responsiveness.

**Keywords:** Heat stress, respiration rate, panting score, responsiveness, animal susceptibility

## Introduction

Periods of extreme heat have negative impacts on an animal's growth, performance, well-being, and ultimately can cause death in the most severe cases. Economic losses associated with heat stress for the United States in a single summer average $2.4 billion over all livestock species; $369 million of that is associated with feedlot cattle (St-Pierre *et al.* 2003). Further, losses accrue from direct animal losses and indirect performance losses and vary from regional to localized impacts (Busby & Loy, 1996; Hahn, 1999; Hubbard, *et al.*, 1999).

The total impact of a heat wave is dependent on the interaction of several factors including environmental factors, animal susceptibility, and management of animals. These factors are interactive and each needs to be considered when making management decisions.

Weather conditions typically are described using dry-bulb temperature (Tdb). Attempts have been made to summarize environmental parameters (including two or more of the following: solar radiation, wind speed, humidity, and dry-bulb temperature) into a single index (Eigenberg *et al.*, 2005; Gaughan, *et al.*, 2008; Mader *et al.*, 2006). Those of most interest include Temperature-Humidity Index (THI), a variation of THI known as Adjusted Temperature-Humidity Index (AdjTHI), and Heat Load Index (HLI). Each of these parameters attempts to capture the composite impact of weather on feedlot cattle (Gaughan *et al.*, 2008; Hahn *et al.*, 1999; Hubbard *et al.*, 1999; Nienaber *et al.*, 2007).

Brown-Brandl & Jones (2011 & 2012) reported that individual animal response is quite varied given the same environmental conditions. When animal heat stress data (e.g., RR in breaths per minute) are viewed in relation to environmental parameters (dry-bulb temperature, °C), the variation in responses is evident (Figure. 1). For example, at an ambient temperature of 32.9°C, the response in RR for an entire collection of feedlot cattle varies between 78 and 167 breaths/min.

While Brown-Brandl & Jones (2011) studied this specialized management concept, it was apparent that the need to better understand which relationships among risk factors and between risk factors and management options was apparent. Also, it was apparent that a single measurement or parameter was needed to summarize the response of an individual animal over the entire summer season. Brown-Brandl and Jones (2012) offered RR and Tdb as the variables sufficient to summarize individual animal response. This work expands that view and investigates the use of panting score (PS) and as a measure of animal response and, along with Tdb, THI, AdjTHI, and HLI as a measure of the animal environment.

PS is a candidate measure for a variety of reasons. It is evident that a single measurement is not sufficient to describe animal response, whether it be RR, PS or any other measure. PS is a worth investigating because it is quicker to measure/observe than RR. The rate of data collection is important when attempting to make observations of many animals in a short period of time. PS is measured on a 0 – 4 scale with 0 being no indication of stress and 4 being extremely stressed. The score is based upon the activity and breathing characteristics of the animal. A more complete treatment of PS is available in Mader *et al.* (2006) and Gaughan *et al.* (2008).

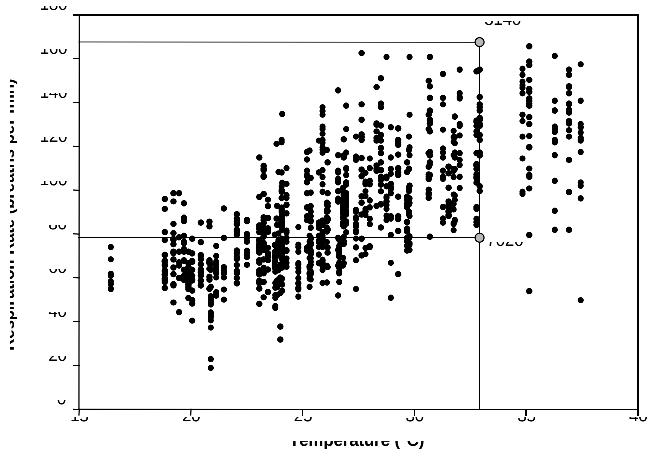

Figure 1: Response in respiration rate (RR) of multiple feedlot heifers over a 3-month summer period exposed to a variety of different environmental conditions.  The two gray points, labeled 3140 and 7020, represent the varied responses of two individual heifers exposed to the same environmental conditions on the same day (Brown-Brandl & Jones, 2012).

In order to summarize an animal's response to heat stress, it was hypothesized that using the slope from a regression line fit to an individual animal's RR (or PS) data over a range of summertime conditions could be such a parameter.  The parameter would represent an individual animal's responsiveness to ambient temperatures (Figure. 2).  Brown-Brandl & Jones (2012) expounded on the rationale of this approach and suggested that such an approach would capture at least a portion of the dynamic response inherent in the system.

## Objectives

The overall objectives of this study were to characterize the responsiveness of beef cattle to environments prone to induce heat stress and the mitigating effects of shade.

## Material and Methods

A study was conducted over three consecutive summers (May – Aug) at the USDA-ARS Meat Animal Research Center (MARC) feedlot (-98.055 Longitude, 42.522 Latitude).  Three hundred eighty four feedlot heifers from the MARC populations were selected for this study (128 heifers/year).  Four distinct breeds/composite were selected based on their hide color and included: Angus (black), MARC III composite (dark red) [¼ Pinzgauer, ¼ Red Poll, ¼ Hereford, and ¼ Angus], MARC I composite (tan) [¼ Charolais, ¼ Braunvieh, ¼ Limousin, ⅛ Angus, and ⅛ Hereford], and Charolais (white). Additional details of the pen, bunk, and shade construction; animal allocation in each pen; data collection schemes; and data processing techniques; etc. are available in Brown-Brandl & Jones (2012).

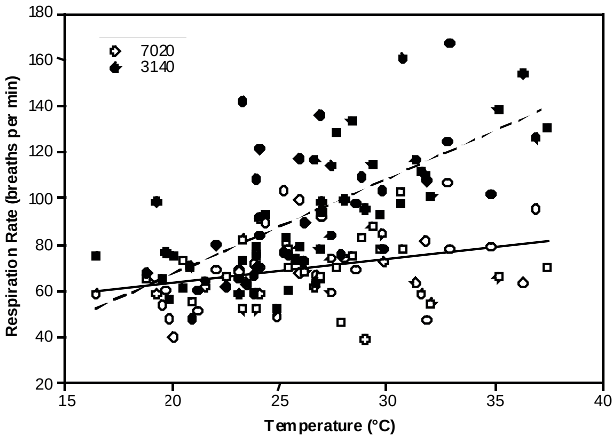


Figure 2: Respiration rate (RR) response of two feedlot heifers over a 3-month summer period exposed to a variety of environmental conditions. White points represent the response of heifer 7020, a Charolais heifer. Black points represent heifer 3140, a dark red composite breed Bos taurus heifer. The two animals were under the same management scheme, and their respiration rates were recorded at the same times throughout the summer (Brown-Brandl & Jones, 2012).

The responsiveness of the animal is determined using eight (8) different indicators. The indicators are:

1. Slope of RR and dry bulb temperature (RR/Tdb)
2. Slope of RR and Temperature Humidity Index (RR/THI)
3. Slope of RR and adjusted Temperature Humidity Index (RR/aTHI)
4. Slope of RR and Heat Load Index (RR/HLI)
5. Slope of PS and dry bulb temperature (PS/Tdb)
6. Slope of PS and Temperature Humidity Index (PS /THI)
7. Slope of PS and adjusted Temperature Humidity Index (PS /aTHI)
8. Slope of PS and Heat Load Index (PS /HLI)

In order to visualize the distribution, histograms were created for different subsets of the populations. Histograms were used to visually describe the distribution of and the effects of breed and treatment (shade/unshaded).

## Results and Discussion

Weather in the summer of 2004 was cooler on average than either the 2005 or 2006 summer-time period. The average temperature in 2004 was 20.7 °C (min 5.5 °C - max 35.4 °C), 2005 was 24.1 °C (min 8.7 °C - max 37.7 °C), and in 2006 was 23.0 °C (min

4.9 °C - max 39.6 °C). RR during 2004 were collected at dry-bulb temperatures ranging from 13.8 – 36.2 °C, while the temperature range from data collection during 2005 was 22.7 – 39.5 °C and 16.9 – 40.8 °C during 2006.

Each animal's data set contained between 23 and 43 points and was dependent on the year. Data collected during 2004 contained between 24 and 26 data points collected at different temperatures. There were a similar number of points collected for each animal during 2005 (22 - 27 point/animal). The experiment was conducted longer during 2006 due to some added objectives not reported in the manuscript; therefore more data points were collected (40 - 43 points/animal). A linear regression line was fit to each animal's responsiveness as determined by each of the 8 indicators.

Understanding the distributions of responsiveness proved useful in understanding factors that affected heat stress. The histogram shown in Figure 3 illustrates the distribution of responsiveness of all animals observed as part of this study in both shaded and unshaded treatments. The majority of animals (352/384) have a responsiveness value between 3 and 6 breaths/min/°C. Twenty-nine animals had a responsiveness greater than 6.5 breaths/min/°C, while only 3 animals had a responsiveness less than 2.5 breaths/min/°C.

Shade significantly reduced the responsiveness of cattle, 3.74 ± 0.08 breaths/min/°C compared to 4.47 ± 0.08 breaths/min/°C. While this provides some information and agrees with other literature data (Blackshaw & Blackshaw, 1994; Brown-Brandl *et al.*, 2005; Eigenberg & Brown-Brandl, 2011; Gaughan *et al.*, 2010), the fact remains we know little about the change in distribution and which of the animals are most impacted by shade.

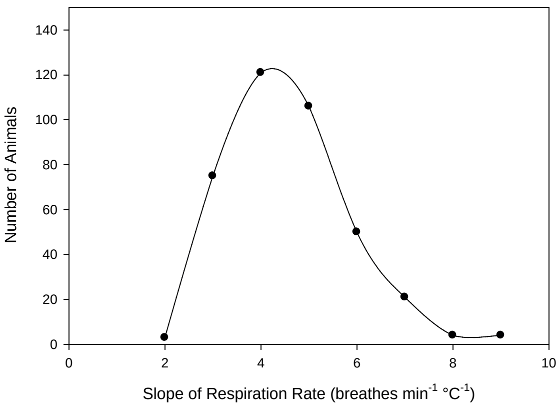


Figure 3: The distribution of responsiveness (slope of individual animal respiration rates (RR) with dry-bulb temperatures) of 384 feedlot heifers to increases in ambient temperature. Animals in this project were equally distributed among four *bos taurus* breed/composite breeds, and two treatments (shaded and unshaded pens).

The two histograms shown in Figure 4 are more evidence that the shaded animals have a nearly perfect normal distribution of responsiveness ranging from 2 to 7 breaths/min/°C with all but 4 animals having a responsiveness between 3 and 6 breaths/min/°C. The unshaded animals have a much larger range of responsiveness ranging from 2 to over 9 breaths/min/°C. The interesting fact is that it appears that shade is having more of an impact on the animals with high responsiveness than animals with a lower responsiveness. While the lower values of responsiveness were the same in both shaded and unshaded treatments, it appears that shade moderates stress in highly responsive animals.

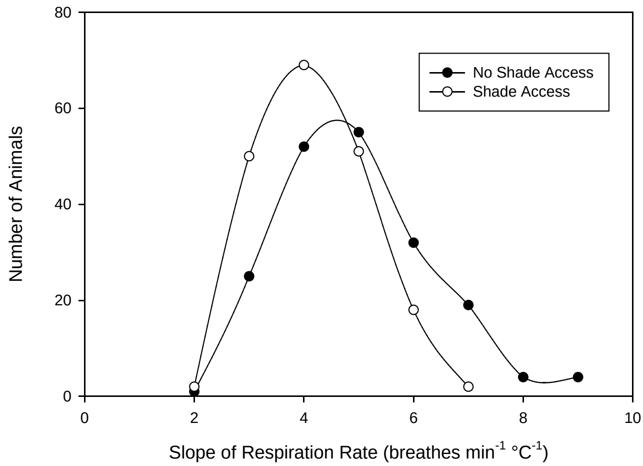


Figure 4: Distribution of responsiveness of feedlot heifers to increased temperature both when provided with access to shade and not provided with access to shade. A total of 192 heifers were in each of the two groups – data was collected over three summers (64 heifers each summer).

Indicators using Respiration Rate (RR)
The indicator of slope of RR and dry bulb temperature (RR/Tdb) is an extension of work presented by Brown-Brand & Jones (2012) and is repeated (in part) here for clarity. The histograms presented in Figure 5 indicate that the animals with lighter coat colors were impacted less when having access to shade (compared to not having access to shade) when compared to animals with dark coat colors.

Similarly, the indicators of slope of RR and Temperature Humidity Index (RR/THI), slope of RR and Adjusted Temperature Humidity Index (RR/AdjTHI), slope of RR and Heat Load Index (RR/HLI) are shown in Figures 6, 7, and 8.

In general, there is greater differences in RR between the dark coated animals based upon access to shade than that of animals with lighter colored coats. Further, AdjHLI and THI are indicators fail to allow for a differentiation of shade v no shade treatments.

Indicators using Panting Score Rate (PS)

The indicator of slope of PS and dry bulb temperature (PS/Tdb) is in Figure 9. The histograms presented in Figure 9 indicate that the animals with lighter coat colors were impacted less when having access to shade (compared to not having access to shade) when compared to animals with dark coat colors.

It is interesting to notice that the magnitude of the slope is small. This feature likely is expressed because the animals did not exhibit elevated PS at nominal temperatures. Had the data been analyzed by restricting the analysis to the use of higher values of the variable attempting to describe environment (Tdb, THI, AdjTHI, HLI), the slope would likely have increased in a more linear fashion. Such an analysis is appropriate for future work.

Similarly, the indicators of slope of PS and Temperature Humidity Index (PS/THI), slope of PS and Adjusted Temperature Humidity Index (PS/AdjTHI), slope of PS and Heat Load Index (PS/HLI) are shown in Figures 10, 11, and 12.

Shade is one of many management options available feedlot managers to reduce heat stress. This research shows that shade preferentially provides relief to cattle with darker colored hides and has less relief to cattle with lighter colored hides.

## Conclusion

A study was conducted to characterize the stress in feedlot cattle and to determine the impact of providing shade. To characterize the response to heat stress, linear equations were developed for each of 384 heifers relating 8 different indicators. In unshaded feedlot cattle, it was determined that the lower categories of responsiveness had more lighter colored breeds and the higher categories of responsiveness had more darker colored breeds of cattle. However, it was noted that there were lighter colored animals with high responsiveness and darker breeds with low responsiveness.

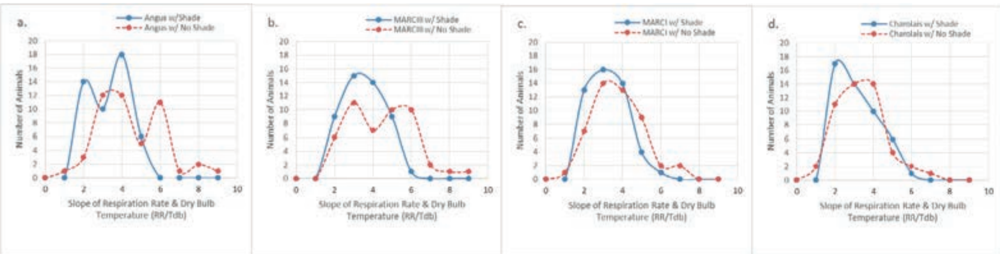


Figure 5: Distribution of responsiveness of different breeds of cattle provided with access to shade. a. Angus heifers, b. MARC III Composite heifers, c. MARC I Composite heifers, d. Charolais heifers. Each breed/treatment group is represented by 48 heifers. Responsiveness is defined as the slope of Respiration Rate and dry bulb temperature (RR/Tdb).

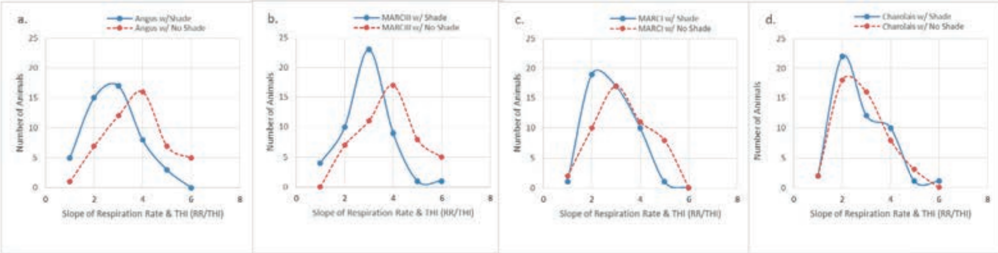


Figure 6: Distribution of responsiveness of different breeds of cattle provided with access to shade. a. Angus heifers, b. MARC III Composite heifers, c. MARC I Composite heifers, d. Charolais heifers. Each breed/treatment group is represented by 48 heifers. Responsiveness is defined as the slope of Respiration Rate and Temperature Humidity Index (RR/THI).

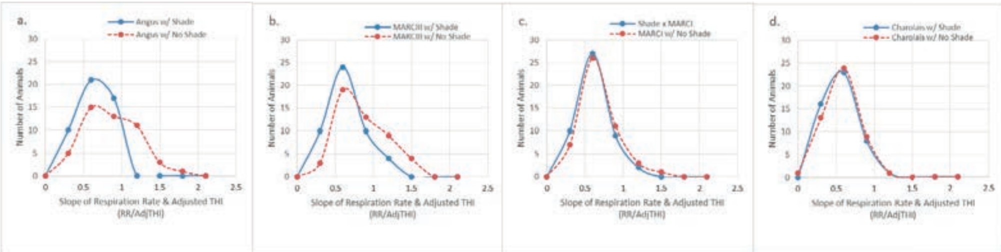


Figure 7: Distribution of responsiveness of different breeds of cattle provided with access to shade. a. Angus heifers, b. MARC III Composite heifers, c. MARC I Composite heifers, d. Charolais heifers. Each breed/treatment group is represented by 48 heifers. Responsiveness is defined as the slope of Respiration Rate and Adjusted Temperature Humidity Index (RR/AdjTHI).

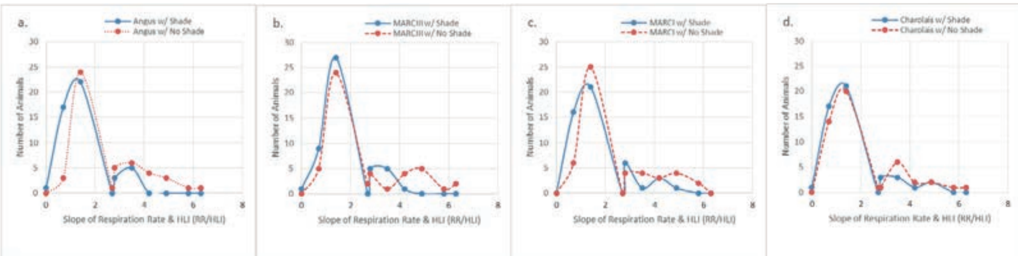


Figure 8: Distribution of responsiveness of different breeds of cattle provided with access to shade. a. Angus heifers, b. MARC III Composite heifers, c. MARC I Composite heifers, d. Charolais heifers. Each breed/treatment group is represented by 48 heifers. Responsiveness is defined as the slope of Respiration Rate and Heat Load Index (RR/HLI).

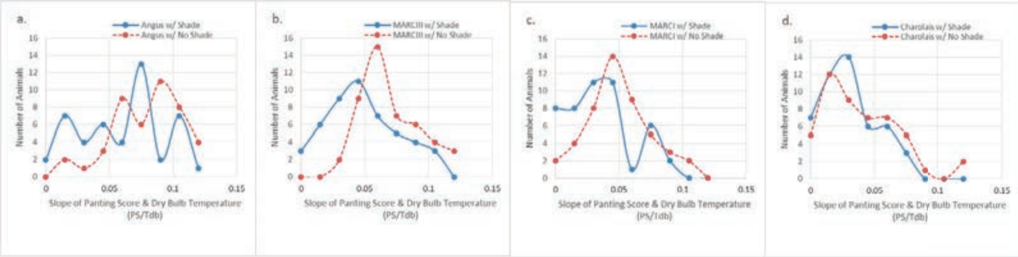


Figure 9: Distribution of responsiveness of different breeds of cattle provided with access to shade. a. Angus heifers, b. MARC III Composite heifers, c. MARC I Composite heifers, d. Charolais heifers. Each breed/treatment group is represented by 48 heifers. Responsiveness is defined as the slope of Panting Score and Dry Bulb Temperature (PS/Tdb).

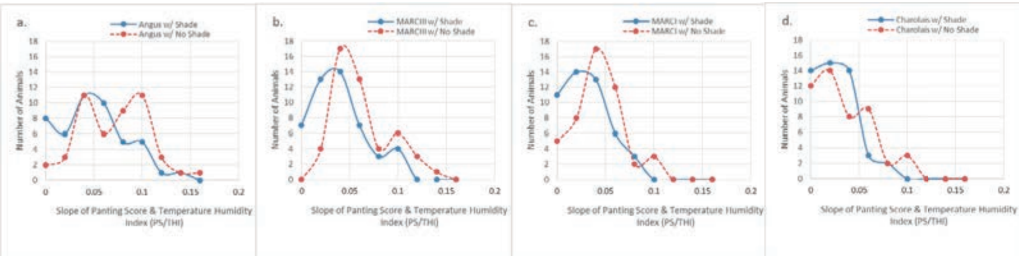


Figure 10: Distribution of responsiveness of different breeds of cattle provided with access to shade. a. Angus heifers, b. MARC III Composite heifers, c. MARC I Composite heifers, d. Charolais heifers. Each breed/treatment group is represented by 48 heifers. Responsiveness is defined as the slope of Panting Score and Temperature Humidity Index (PS/THI).

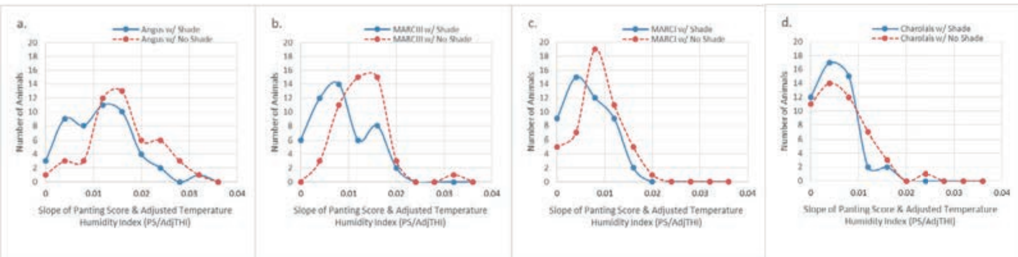


Figure 11: Distribution of responsiveness of different breeds of cattle provided with access to shade. a. Angus heifers, b. MARC III Composite heifers, c. MARC I Composite heifers, d. Charolais heifers. Each breed/treatment group is represented by 48 heifers. Responsiveness is defined as the slope of Panting Score and Adjusted Temperature Humidity Index (PS/AdjTHI).

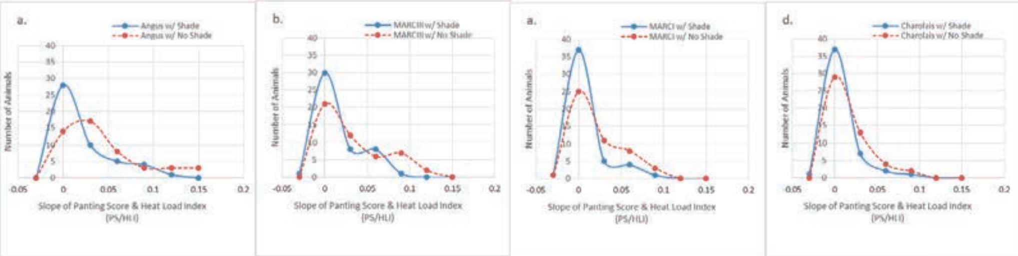


Figure 12: Distribution of responsiveness of different breeds of cattle provided with access to shade. a. Angus heifers, b. MARC III Composite heifers, c. MARC I Composite heifers, d. Charolais heifers. Each breed/treatment group is represented by 48 heifers. Responsiveness is defined as the slope of Panting Score and Heat Load Index (PS/HLI).

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**Control System for Positioning of Broilers Using Infrared Heating and Thermal Camera**

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Temperature is commonly assumed to be the most important environmental factor influencing chicken health, behaviour and production. All homeothermic living organisms, including broilers, attempt to maintain their body temperature by preserving a dynamic balance between metabolic heat production and heat loss to the environment using their internal thermoregulatory system. In Broilers, heat production is affected is affected is affected by heat losses, body weight, food intake and activity level.

The possibility of controlling the position and activity of broiler chickens may provide an inexpensive tool with the potential to improve broiler welfare and production.

The main objective of this work is to examine the possibility to control the position of group of young chickens (6-7 days old) in small ventilated chamber via controlling their micro-environmental temperature using infrared heaters as actuators. A small ventilated test chamber (0.70×0.65×0.4 meters) of 0.15 $m^3$ equipped with inlet and outlet fans and a heater in the inlet was used (Figure 1). Nine small infrared curved-shaped heaters (0.06 × 0.06 × 0.01 m) with 100W power each was installed in a 2D array (3 × 3) and suspended from the top of the chamber facing the bottom (0.15 m above the chicken head-level). The IR heaters could be controlled individually providing IR heat to motivate the chickens to move to the desired direction/location by separately heating zones close to them. Because of the IR thermal phenomena, the heaters were able to heat the surface of the chickens much more than the surrounding environment (air). On the top of the chamber (Figure 1) a thermal camera of 640×480 thermal resolutions was installed. The lens of the camera was pointed downwards to get a top view image of the chamber and the chickens' surface body temperatures. Sequences of thermal images of the chamber together of the chicken surfaces were captured with frequency of one frame per second. The ventilation rate was kept constant at 17$m^3$/h.

Step changes in the power to each of the IR heaters were applied and the dynamic responses of the chicken body temperatures were modelled. The time constants of the chicken body temperature and change in their positions were calculated.

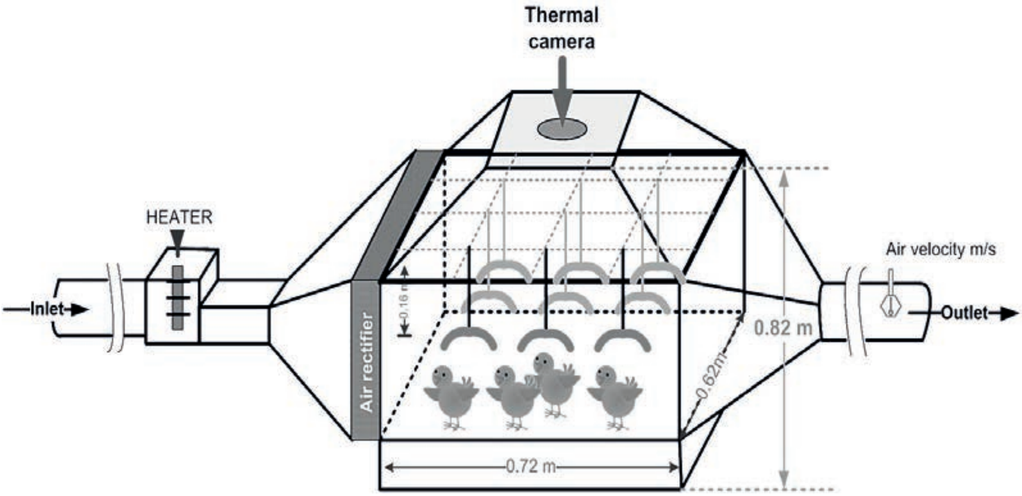


Figure 1. Schematic 3D diagram of the test chamber showing: the 2D array of the IR heaters (3×3) suspended from the top, the position of the thermal camera in the top of the chamber and the inlet/outlet fans.

## Author index

**Precision Livestock Farming 2013**

To date, PLF research has been presented in over 650 papers at previous conferences and another 111 at this conference. It is good to see that PLF conferences, workshops and sessions are being organised worldwide and that PLF now forms an integral part of conferences in other disciplines which extend beyond the field of engineering.

This is encouraging and is, in fact, essential if we are to make progress since PLF currently only offers a technology and a support tool for those who are engaged in animal monitoring and management. Technical experts who are developing PLF technology need to collaborate with colleagues from different disciplines and have to ask them what variables they want to measure and control by PLF solutions. Only then will we achieve more sustainable, ethical and economically viable livestock production.

The first commercial PLF products are already in the field and services to the farmer and other stakeholders are being developed; this is essential if we are to create a new service industry around the farmer of the future. Before we reach this point it will be necessary to attract more industrial partners and persuade more innovative SMEs to engage with the sector. The leading companies in PLF technology are working hard to translate the technology to mature products, and researchers should support this. There is also a need to develop new technology and new business models.

It is clear that PLF technology is applicable to larger farms but we must demonstrate that it can also create added value in small-scale alternative farming. How can this technology be applied in less productive areas with a totally different way of farming? The key element is to achieve improvements through collaboration between many disciplines and stakeholders. We must all engage with this approach in order to succeed.

**Leuven 2013**

SEVENTH FRAMEWORK PROGRAMME