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Participants: EMU, EV ILVO, KUL, ZLTO, LZA, Paragon & IfA
Author(s): David Arney, Ragnar Leming, Kristine Piccart, Deborah Piette, Janine Roemen, Sandija Zēverte-Rivža, Roberta Gall, Sara Meli and Richard Lloyd
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Executive Summary

This Dairy Sensor Research Report is a snapshot of research known to be available as at 31st August 2016.

It is a living document and will be added to in line with information provided by the Community of Practice. The updated document and the Community of Practice can be accessed at www.4D4F.eu .

Table of contents

Mastitis detection in AMS

Automatic milking systems (AMS) have gained substantial momentum in recent years. The technology was first introduced to Europe in the 1990s. Nowadays, more than 25.000 dairy farms worldwide employ AMS to milk their herds. The greatest adoption of automatic milking can be found in the Nordic countries and The Netherlands (Barkema et al., 2015). The transition from conventional milking to automatic milking is often associated with an increasing bulk milk somatic cell count. Empirical data suggests the following reasons: poor cow traffic, incomplete milkings, an ineffective systemic wash and teat preparation, and no possibility to separate cows with contagious mastitis (Landin et al., 2011).

European legislation (Regulation [EC] No.853/2004) states that all milk ought to be "checked for organoleptic or physico-chemical abnormalities by the milker or a method achieving similar results" and that abnormal milk cannot be used for human consumption. Automatic milking systems are therefore equipped with various sensors to detect macroscopic irregularities in milk (**Table 1**). The International Standard ISO/FDIS 20966 of the International Standard Organization includes an annex which describes the minimum requirements of systems for detecting abnormal milk. The test should have a minimum sensitivity of 80%, combined with a specificity of more than 99% (i.e. less than 1 false alert per 100 milkings [Hogeveen et al., 2010]). In practice, the accuracy of mastitis detection methods in AMS depends a great deal on the algorithms and the combination of multiple indicators (Hovinen et al., 2006).

Table 1. Indicators in milk used for the automatic detection of mastitis

Indicator	Description	Authors
Electrical conductivity (EC)	EC (unit: mS) is a widely used parameter to detect mastitis. The measurement is based on an increase in Na^+ and Cl^-, caused by an increased permeability of the blood-milk barrier. However, the EC can also be affected by other (non-mastitis) related factors. EC on its own is inadequate for detecting mastitis, but the accuracy can be improved by combining other detection methods.	Pyörälä (2003); Hovinen et al. (2006); Hovinen and Pyörälä (2011)

Lactate dehydrogenase (LDH)	In case of mastitis, LDH -an enzyme found in nearly all cell types- increases. The real-time, inline measurement of LDH can detect mastitis with a sensitivity of >80% and a specificity of >99% (although the results depend on the applied biomodel).	Chagunda et al. (2006)
Milk colour	Milk colour can be used to detect mastitic milk, colostrum, milk with blood, … The measurement is based on the reflection of light. The sensors are usually sensitive to red, green and blue wavelengths of light. Since the milk colour depends on the milk fat % and nutrition, yellow coloration does not always indicate mastitis.	Hovinen et al. (2006); De Koning (2013)
Somatic cell count (SCC)	Due to a massive influx of neutrophils, the SCC strongly increases following an intramammary infection. The SCC can be measured in AMS in two ways: (1) directly, by dying the nuclei of cells, or (2) indirectly, by hydrolyzing DNA and measuring the gel-formation.	Pyörälä (2003); Hogeveen et al. (2010)

References

Barkema, H. W., et al. "Invited review: Changes in the dairy industry affecting dairy cattle health and welfare." Journal of dairy science 98.11 (2015): 7426-7445.

Chagunda, M. G. G., et al. "A model for detection of individual cow mastitis based on an indicator measured in milk." Journal of dairy science 89.8 (2006): 2980-2998.

De Koning, K. “Automatic milking systems and mastitis.” IV Simpósio Nacional de Bovinocultura de Leite (2013).

Hogeveen, Henk, et al. "Sensors and clinical mastitis—The quest for the perfect alert." Sensors 10.9 (2010): 7991-8009.

Hovinen, M., A-M. Aisla, and S. Pyörälä. "Accuracy and reliability of mastitis detection with electrical conductivity and milk colour measurement in automatic milking." Acta Agriculturae Scand Section A 56.3-4 (2006): 121-127.

Hovinen, M., and S. Pyörälä. "Invited review: Udder health of dairy cows in automatic milking." Journal of dairy science 94.2 (2011): 547-562.

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Landin, H., M. Mörk, and G. Pettersson. "Udder health in herds with automatic milking." Udder Health and Communication. Wageningen Academic Publishers, 2011. 385-390.

Pohl, A., W. Heuwieser, and O. Burfeind. "Technical note: Assessment of milk temperature measured by automatic milking systems as an indicator of body temperature and fever in dairy cows." Journal of dairy science 97.7 (2014): 4333-4339.

Pyörälä, Satu. "Indicators of inflammation in the diagnosis of mastitis." Veterinary research 34.5 (2003): 565-578.

Automated lameness detection

Lameness is amongst the most costly health problems of dairy cows together with mastitis and reduced fertility. In addition, with the increasing herd sizes, farmers have less time to monitor each individual cow. This means that lame cows in the herd are often detected when they are already severely lame (if they are detected at all), compromising their health and welfare (Rutten et al. 2013, Van Nuffel et al. 2015). To date, researchers have developed a variety of lameness monitoring measurement systems to help the farmers detect lame cows in their herd. Table 2 provides a short overview of the current systems described in scientific literature. (Rutten et al. 2013, Van Nuffel et al. 2015)

Pressure mat-based systems

One type of PLF technology are the weight scales that use load cells or pressure-sensitive mats to analyse 1D or 3D ground reaction forces such as the StepMetrix, EmFit or Gaitwise. These systems require the cow walking over the weight scales, whereas other systems analyse (asymmetry in) weight distribution of standing cows in the milking robot. (Van Nuffel et al. 2015)

Camera-based systems

Researchers have also used automatic image processing techniques to detect lameness in dairy cows. For this technology cows are filmed by a 2D or 3D camera, either positioned with a side view or top view of the cow. Image processing techniques are then used to extract the shape of the cow and based on this shape features are calculated that are linked to the degree of lameness of the cow. Another camera technology is based on the infrared thermography to pick up lesions or infections in the limbs of the cows, which can be related to lameness. (Van Nuffel et al. 2015)

Accelerometer-based systems

One advantage of using the weight scales and camera technology is that only one system is required for lameness detection of an entire herd. This is in contrast with lameness detection methods that rely on activity or acceleration measures and require a system per individual cow. Although a few systems have been developed that measure 3D-head acceleration for instance using a noseband accelerometer (Beer et al. 2016), a neck accelerometer (Mottram et al. 2010) or an ear tag accelerometer (Link et al. 2016) to detect lameness, most systems measure acceleration or step counts on the limbs of the cows such as the IceTag3D accelerometer (Kokin et al. 2014, Van Nuffel et al. 2015).

Alternative methods

The previously discussed systems require that dairy farmers purchase and integrate additional lameness sensors in their daily herd management. In order to avoid these extra costs, researchers have linked lameness in dairy cows to behavioural and production data that is already being recorded on the farm. For example production data such as milk yield, milk quality, live-weight and feed supply can be measured either in the barn, milking parlour or milking robot. Behavioural data such as time spent ruminating, walking, lying and standing, can be measured using other purchased sensors. By combining these different data, it is possible to give an indication of lameness in dairy cows. However, this approach often results in lower sensitivity and or specificity compared to the previously discussed systems, which is due to a variety of influencing factors such as the lactation stage of the cow. (Van Nuffel et al. 2015)

Table 2.

Measurement system	**Principle**	**Reference**
Pressure mat-based systems	Using load cells or pressure mats features such as the weight distribution of walking or standing cows is analysed. Examples are StepMetrix, EmFit and Gaitwise.	Van Nuffel et al. 2015
Camera-based systems	The shape of the cow is extracted from 2D or 3D videos of the cows. Thermal cameras are used to detect infections or lesions in the cows' legs.	Van Nuffel et al. 2015

Accelerometer-based systems	Step counters or accelerometers are attached to the head, neck or legs of the cows to monitor their activity patterns.	Mottram et al. 2010, Van Nuffel et al. 2015, Beer et al. 2016, Link et al. 2016
Alternative methods	Data that is already available in the farm such as milk yield, feed intake and rumination time is combined to detect lameness.	Van Nuffel et al. 2015

Gaps in scientific literature

Although considerable research on automated lameness monitoring in cows has been carried out, several gaps can be identified in the scientific literature. A first gap is that the approach in using manual locomotion scores as a gold standard differs greatly between studies. This makes it difficult to compare the performance of different systems, which is often low. This low performance could be linked to the fact that most studies test a limited number of cows when developing their lameness monitoring system. In addition the test scale of most studies is limited to only one farm, which makes validation of the system more problematic and is probably part of the reason why application of lameness monitoring system in practice is difficult. Another obstacle for implementation of a lameness monitor in commercial settings is the limited available space on dairy farms to install such a system, especially when it comes to pressure-mat based systems. Perhaps a more important gap in the scientific literature on lameness monitoring systems is that so far very limited research has been done towards integrating economic information into the lameness monitoring system in order to create actual value for the farmer. However, in order to create value for the farmer, the researchers must understand the needs and demands of the farmer when developing a lameness monitoring system. Previous studies have pointed out that researchers are not sure whether farmers want the system to detect newly lame cows or severely lame cows, and whether or not they want information on their herd's lameness to be provided in real-time. Researchers should communicate more with the farmers and find out what they are looking for in a lameness monitoring system, and provide custom made systems if necessary. (Rutten et al. 2013, Van Nuffel et al. 2015)

References

Beer, G., Alsaaod, M., Starke, A., Schuepbach-Regula, G., Müller, H., Kohler, P., Steiner, A., 2016, Use of Extended Characteristics of Locomotion and Feeding Behavior for Automated Identification of Lame Dairy Cows, PlosOne, Vol 11(5).

Kokin, E., Praks, J., Veermäe, I., Poikalainen, V., Vallas, M., 2014, IceTag3D™ accelerometric device in cattle lameness detection, *Agronomy Research*, Vol. 12(1), pp 223-230.

Link., Y. C., Salau, J., Karsten, S., Krieter, J., 2016, Using classifiers based on 3D-head acceleration data for lameness detection, *Conference on Precision Dairy Farming*, Leeuwarden, Netherlands.

Mottran, T. T., Bell, N.J, 2010, A Novel Method of Monitoring Mobility of Dairy Cows, *The First North American Conference on Precision Dairy Management*.

Rutten, C. J., Velthuis, A. G. J., Steeneveld, W., Hogeveen, H., 2013, Invited review: Sensors to support health management on dairy farms, *Journal of Dairy Science*, Vol. 96, pp 1928-1958.

Van Nuffel, A., Zwertvaegher, I., Van Weyenberg, S., Pastell, M., Thorup, V. M., Bahr, C., Sonck, B., Says, W., 2015, Lameness Detection in Dairy Cows: Part 2. Use of Sensors to Automatically Register Changes in Locomotion or Behavior, *Animals*, Vol. 5, pp 861-885.

Heat detection in dairy cows

Milk production is only induced when a cow has calved en therefore reproduction is a key factor in maximizing dairy productivity and farm profitability. Milk production of the cow will decrease when lactation peak is reached and this decrease results in a feed efficiency decrease and an increase in production costs per kg of milk (Kruif in Ryckaert, Antonissen, & Winters, 2008). On average 25% of cows are replaced due to reproductive disorders (Ryckaert, Antonissen, & Winters, 2008). Several factors influence reproduction and fertility is one of the main factors. Heat detection (or oestrus detection), next to other reproduction factors as insemination, can be administered orderly by a system as cow calendar or cow map (Milkproduction.com, 2007). In order to detect heat accurately and effectively it is necessary to understand the primary and secondary signs of heat. Primary signs of heat are mounting other cows and cows moving forwards with the weight of the mounting cow. Secondary signs (mucus discharge, swelling of vulva, restlessness and others) vary in duration and intensity and may occur before, during or after heat and are not related to time of ovulation (DuPonte, 2007).

Different methods to detect heat exist. Manual heat detection methods are for example applying paint on the back of the animals, measuring body temperature or activity meters, pedometers or a combination of these methods. The combination of measuring temperature and activity will increase detection rate and reliability (Ryckaert, Antonissen, & Winters, 2008). A decrease in accuracy of heat detection on dairy farms is associated with the increase number of cows per farm, since detection of heat is a labour intensive process and in busy periods of the farmer, oestrus can be easily missed. In general, a farmer detects on average 60% of heats of cows in heat (Van Weyenberg, 2013). Automatic systems or sensors to detect heat may make it easier, replace and even excel detection of manual heat detection by the farmer and come in different forms (Ryckaert, Antonissen, & Winters, 2008). For clarity: sensors do not improve fertility but may only help detecting heat and better timing of insemination and improve fertility results on dairy farms.

Since activity seems to increase during heat, activity meters can detect heat by measuring the (increase in) activity of the cow by using accelerometers (Graaf, Activiteitsmeter, n.d.). Algorithms will be used to detect deviation from normal individual cow activity and will detection rate have an average detection rate op 80-95%, but is heavily dependent on cow and environmental factors, as well as on how the activity meter is set. Activity meters are available in leg, neck and ear sensors, where leg sensors can have a reliability that is up to 10% higher than neck and ear sensors (Bongen, 2012).

Progesterone in milk tends to decrease as cows come into heat. Progesterone meters measure the progesterone levels in milk and can be used for heat detectors since and can therefore be compared with results from when the cow was not in heat (Graaf, LDH-meter, n.d.)

Rumination sensors are based on the principle that cows in heat ruminate less, because she is looking for a bull and eats less due to the behavioural changes following the change in oestrogen level. The rumination sensor can monitor rumination activity by sound or accelerometer based on head movements in neck or ear. By using algorithms, a deviation from ‘normal’ behaviour will be registered and the farmer will be informed (Graaf, Herkauwsensor, n.d.).

References

Bongen, J. (2012, February 2). Kiezen uit veel soorten stappentellers. Retrieved September 5, 2016, from Melkvee.nl: http://www.melkvee.nl/nieuws/1336/kiezen-uit-veel-soorten-stappentellers

DuPonte, M. (2007). The Basics of Heat (Estrus) Detection in Cattle. Livestock Management, 1-3.

Graaf, v. d. (n.d., n.d. n.d.). Activiteitsmeter. Retrieved September 5, 2016, from Groenkennisnet: Precisielandbouw: https://precisielandbouw.groenkennisnet.nl/display/SMV/Activiteitsmeter

Graaf, v. d. (n.d., n.d. n.d.). Herkauwsensor. Retrieved September 5, 2016, from Groenkennisnet: Precisielandbouw: https://precisielandbouw.groenkennisnet.nl/display/SMV/Herkauwsensor

Graaf, v. d. (n.d., n.d. n.d.). LDH-meter. Opgeroepen op September 5, 2016, van Groenkennisnet: Precisielandbouw: https://precisielandbouw.groenkennisnet.nl/display/SMV/LDH-meter

Milkproduction.com. (2007, March 18). Cow comfort: 6) Reproduction. Retrieved September 6, 2016, from Milkproduction.com: http://www.milkproduction.com/Library/Scientific-articles/Housing/Cow-comfort-6/

Ryckaert, I., Antonissen, A., & Winters, J. (2008). Vruchtbaarheid in melkvee. Brussel: Vlaamse Overheid, Departement Landbouw en Visserij, afd. Duurzame landbouwontwikkeling. Opgeroepen op 2016

Van Weyenberg, S. (2013, juni 10). Theorie vruchtbaarheid. Retrieved September 5, 2016, from Koesensor.be: http://www.koesensor.be/v1/technologie/theorie#vruchtbaarheid

Feeding and metabolic disorders

It is well known that feed is the largest cost in milk production and feeding influences directly animal performance and health status. Efficient feed management including feeding equipment, data collection technology and accurance is therefore very important for every dairy farmer. Constantly improving precision technology, automatic identification and computing have made it possible to feed individual animals regardless of the housing system or the herd size. In 2015 more than 1,250 automatic feeding systems were used worldwide (Oberschätzl-Kopp et al., 2016).

Feeding behaviour can provide an estimate of the quantity that cows are eating and refers to a collection of behaviours associated with feed consumption (Nielsen, 1999). Characteristics that are used in this subject refer to the number of chewing behavior associated jaw movements (Hirata et al., 2011, Zehner et al., 2012), dry matter intake, time at the feed trough or near the feed trough (Chapinal et al., 2007). Automatic measurement of chewing and ruminating activity can detect feeding deficiencies early and help to make changes in the ration (Zehner et al., 2012). Chewing activity has been used in the quantification of both ruminating and feeding behavior through precision technology (Borchers et al. 2016, Zehner et al., 2012).
Bikker et al. (2014) evaluated a system for monitoring rumination and feeding behavior through head movement, and Schirmann et al. (2009) evaluated a technology for quantifying rumination sounds through a microphone and microprocessor.

Monitoring body weight can be useful to predict dry matter intake as well as changes in body condition. Automated weighing systems are widespread and new technology performing automated body condition scoring (Spoliansky et al., 2016) has emerged, so frequent automated BW and BCS measurements are feasible. Van der Waaij et al. (2016) used routinely available data (cow number, concentrate, milk yield, parity, weight, rumination, lactation day, milk fat% and protein%, outdoor temperature and outdoor humidity) on the farm for predicting daily feed intake of individual dairy cows.

Individual recording of rumination time is possible by using a microphone-based sensor, which records the sound of rumination activity. The daily intake of forage NDF and starch can be estimated by rumination time (Byskov et al., 2015).

Increasing milk yield in the herd is often associated with increased risk of metabolic disorders. Ketosis, caused by excessive body fat mobilization due to severe negative energy balance, is one of the most prevalent and important production diseases. Due to the economic and welfare reasons, it is very important to diagnose subclinical ketosis in cows, especially during early lactation. Continuous, daily monitoring of the ratio between the percentage of milk fat and milk protein is commonly used to monitor the prevalence of subclinical ketosis in dairy cows. Monitoring fat-to-protein ratio is relevant for adjusting possible dietary deficiencies in cows.

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As ruminal pH is affected by the time the cow spends ruminating, then rumination behavior can be used as an indicator of rumen health. Monitoring rumination behavior can be used to detect subacute ruminal acidosis in dairy cows (DeVries et al., 2009). Ruminal temperature measured via an intraruminal telemetric sensing device (bolus), can also be used to predict of ruminal pH (AlZahal et al., 2009).

Wireless radio transmission pH measurement system is another technology that can be used to measure ruminal pH continuously and therefore help to diagnose subacute ruminal acidosis (Sato, 2016). Recent findings (Stangaferro et al., 2016) indicate that automated systems monitoring continuously rumination time and physical activity (cows were fitted with a neck-mounted electronic rumination and activity monitoring tag) could be helpful for identifying cows with metabolic and digestive disorders in the early postpartum period.

References

AlZahal, O., Steele, M.A., Valdes, E.V., McBride, B.W. 2009. Technical note: The use of a telemetric system to continuously monitor ruminal temperature and to predict ruminal pH in cattle. J. Dairy Sci. 92:5697–5701.

Bikker, J.P., van Laar, H., Rump, P., Doorenbos, J., van Meurs, K., Griffioen, G.M., Dijkstra, J. 2014. Technical note: Evaluation of an ear-attached movement sensor to record cow feeding behavior and activity. J. Dairy Sci. 97:2974-2979.

Borchers, M.R., Chang, Y.M., Tsai, I.C., Wadsworth, B.A., Bewley, J.M. 2016. A validation of technologies monitoring dairy cow feeding, ruminating, and lying behaviors. J. Dairy Sci. 99:7458-7466.

Byskov, M.V., Nadeau, E., Johansson, B.E.O., Nørgaard, P. 2015. Variations in automatically recorded rumination time as explained by variations in intake of dietary fractions and milk production, and between-cow variation. J. Dairy Sci. 98:3926-3937.

Chapinal, N., Veira, D.M., Weary, D.M., von Keyserlingk, M.A. 2007. Technical note: Validation of a system for monitoring individual feeding and drinking behavior and intake in group-housed cattle. J. Dairy Sci. 90:5732–5736

DeVries, T.J., Beauchemin, K.A., Dohme, F., Schwartzkopf-Genswein, K.S. 2009. Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: Feeding, ruminating, and lying behavior. J. Dairy Sci. 92:5067-5078.

Hirata, M., Tanikawa, T., Tobisa, M. 2011. Quantifying short-term foraging behavior of cattle grazing a tall grass: A preliminary study with maize. Livestock Sci. 138: 220-228.

Nielsen, B.L. 1999. On the interpretation of feeding behaviour measures and the use of feeding rate as an indicator of social constraint. Appl. Anim. Behav. Sci. 63:79-91.

Oberschätzl-Kopp, R., Haidn, B., Peis, R., Reiter, K., Bernhardt, H. 2016. Effects of an automatic feeding system with dynamic feeding times on the behaviour of dairy cows. In Proceeding of the Precision Dairy Farming 2016. Ed. C. Kamphuis and W. Steeneveld. The Netherlands: Wageningen Academic Publishers, 363−369.

Sato, S. 2016. Pathophysiological evaluation of subacute ruminal acidosis (SARA) by continuous ruminal pH monitoring. Anim. Sci. J. 87:168–177.

Schirmann, K., von Keyserlingk, M.A., Weary, D.M., Veira, D.M., Heuwieser, W. 2009. Technical note: Validation of a system for monitoring rumination in dairy cows. J. Dairy Sci. 92:6052-6055.

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Spoliansky, R., Edan, Y., Parmet, Y., Halachmi, I. 2016. Development of automatic body condition scoring using a low-cost 3-dimensional Kinect camera. J. Dairy Sci. 99:7714-7725.

Stangaferro, M.L., Wijma, R., Caixeta, L.S., Al-Abri, M.A., Giordano, J.O. 2016. Use of rumination and activity monitoring for the identification of dairy cows with health disorders: Part I. Metabolic and digestive disorders. J. Dairy Sci. 99:7395-7410.

Van der Waaij, B.D., Feldbrugge, R.L., Veerkamp, R.F. 2016. Cow feed intake prediction with machine learning. In Proceeding of the Precision Dairy Farming 2016. Ed. , C. Kamphuis and W. Steeneveld. The Netherlands: Wageningen Academic Publishers, 377−381.

Zehner, N., Niederhauser, J.J., Nydegger, F., Grothmann, A. Keller, M., Hoch, M., Schick, M. 2012. Validation of a new health monitoring system (RumiWatch) for combined automatic measurement of rumination, feed intake, water intake and locomotion in dairy cows. In: Proceedings of International Conference of Agricultural Engineering CIGR-Ageng 2012.

Grazing

Identification of changes in the behaviour of animals, both normal and abnormal, and the diurnal patterns of such behaviours and positional data can be reliable indicators of the health and welfare of dairy cows and also their production levels. While it is relatively uncomplicated to make such assessments within housing, especially in smaller herds, by direct observation or video camera recording, at pasture, with a greater area occupied by the animals and obstacles obstructing sight lines, this is more complex. It is important to know this not only from the viewpoint of the animal, but also to inform grazing management decisions, to reduce undergrazing and overgrazing of the sward as a whole, but also to identify localised areas within the pasture where over or undergrazing may take place. However, a mathematical model has been proposed to enable such evaluation from direct observation of animals while grazing, although the validity of this method has only been shown for small groups of cows. It is also possible to use GPS systems to track the positional and time data of cows at pasture (Turner et al., 2000) although, as Barvella et al. (2016) points out, unless all the cows are thus tagged, the assumptions made based on these data may only be valid for the tagged cows as individuals and not for the grazing herd as a whole. Using precision tools and concepts to aid grazing management have been reviewed by Laca (2009). Actual time spent grazing by cows can be estimated using the Kenz Lifecorder Plus device (LCP, Suzuken Co. Ltd., Nagoya, Japan), as described by Delagarde and Lamberton (2015). This device was designed to measure human activity but gives apparently accurate results when attached to the necks of cows. The recording of the kind of activity involved in simply walking, from the housing or milking parlour to the pasture, was sufficiently different from that of grazing activity that it could be filtered out and excluded.

The RumiWatch Pedometer (ITIN+HOCH GmbH, Switzerland) has been validated for indoor conditions (Kajava et al., 2014), and although there are some concerns about its reliability for accurately measuring walking times, it seems that lying and standing times are reliable, and this device could be used outdoors at grazing to investigate behaviour and behaviour changes at pasture.

Feed intakes are also more easily and reliably estimated indoors than outside at pasture, in conventional systems at least. Cows can be fed rations of known quality and we can estimate, through individual weighed feed bins, quantities of feed taken within a given time period, although this can be less accurate than we hope (Soonberg and Arney, 2014). At pasture the estimation of intakes is much more difficult.

Feed intakes can be estimated from feeding behaviour, perhaps in particular by chewing behaviour. It has been claimed that the different jaw movements involved in biting (apprehension and cutting of the herbage from the grassland), chewing (crushing and grinding of the herbage), and movements indicating a combination of these two, both biting and chewing, can be identified using measurement of acoustic signals (Milone et al. 2012). De Boever et al. (1990) proposed that such movements could be related to intakes and Chelottia et al. (2016) have presented data presenting a proposed algorithm using real-time analysis of sound signals to effect such estimation, with a suggested accuracy of estimation of 97% and a level of correct identification of the type of jaw movements of 84%. This method also appears to be accurate for estimating bites by calves (Nadin et al., 2012). Earlier, Rutter et al. (1997) proposed a device that registered jaw movements mechanically and could identify chews, bites and the number of boluses processed while ruminating, although this work was carried out with sheep. Similar use of accelerometers to estimate herbage intakes has been reported by Oudshoorn (2014), who combined number of bites and grazing time to estimate intakes. They also reported that it did not appear to be of significant moment whether the devices (Lifecorder Plus, as described in the opening paragraph above) were strapped tightly to the head or hung loosely from the necks of the cows.

Feeding and activity data together have been measured using a single accelerometer-based method with collars, on wild horses and wild sheep, although these were problematic and not terribly reliable.

References:

Barcella M., Filipponi F. and Assini S. (2016). A simple model to support grazing management by direct field observation. *Agriculture, Ecosystems & Environment* (in press).

Chelottia J.O., Vanrella S.R., Milonea D.H., Utsumib S.A., Gallic J.R., Leonardo H. Leonardo R.D. and Giovaninia L. (2016). A real-time algorithm for acoustic monitoring of ingestive behavior of grazing cattle. Computers and Electronics in Agriculture. Vol.127, pp-64-75

De Boever J., Andries J., De Brabander D., Cottyn B., and Buysse F. (1990). Chewing activity of ruminants as a measure of physical structure-a review of factors affecting it. *Anim. Feed Sci. Technol*., Vol. 27 (4) pp. 281–291

Delagarde R. and Lamberton P. (2015). Daily grazing time of dairy cows is recorded accurately using the Lifecorder Plus device. *Applied Animal Behaviour Science.* Vol. 165, pp. 25–32

Kajava S., Frondelius L. , Mononen J., Mughal M., Ruuska S. and Zehner N. (2014) Validation of RumiWatch pedometers measuring lying, standing and walking of cattle. *Proceedings International Conference of Agricultural Engineering, Zurich*.
http://www.geyseco.es/geystiona/adjs/comunicaciones/304/C06830001.pdf

Laca E.A. (2009). New Approaches and Tools for Grazing Management. *Rangeland Ecology & Management.* Vol. 62, Issue 5, pp. 407–417

Milone D.H., Galli J.R., Cangiano C.A., Rufiner H.L. and Laca E.A. (2012). Automatic recognition of ingestive sounds of cattle based on hidden Markov models. *Comput. Electron. Agric*., 87 (1) (2012), pp. 51–55

Nadin L.B., Chopa F.S., Gibb M.J., Trindade J.K.D., Amaral G.A.D., Carvalho P.C.F. and Gonda H.L. (2012). Comparison of methods to quantify the number of bites in calves grazing winter oats with different sward heights*. Applied Animal Behaviour Science,* Vol. 139, pp. 50–57

Oudshoorn F.W., Cornou C., Hellwing A.L.F,. Hansen H.H., Munksgaard L., Lund P., and Kristensen T. (2013). Estimation of grass intake on pasture for dairy cows using tightly and loosely mounted di- and tri-axial accelerometers combined with bite count. *Comput. Electron. Agric*., Vol. 99, pp. 227–235

Rutter S.M., Champion R.A and Penning P.D. (1997). An automatic system to record foraging behaviour in free-ranging ruminants. Appl. Anim. Behav. Sci., Vol. 54, pp. 185–195

Scheibe K.M., Schleusner T., Berger A., Eichhorn K., Langbein J., Dal Zotto L. and Streich W.J. (1998). ETHOSYS (R) new system for recording and analysis of behaviour of free-ranging domestic animals and wildlife. *Applied Animal Behaviour Science*, 55, pp. 195–211

Soonberg, M. and Arney, D. (2014). Dairy Cow Behaviour at Individual Feeding Bins, Can We Estimate Intakes From Behavioural Observations ? Research for Rural Development, 1: RESEARCH FOR RURAL DEVELOPMENT 2014 Annual 20th International Scientific Conference Proceedings. Jelgava.. Ed. Santa Treija and Signe Skujeniece. Jelgava, Latvia.: Latvia University of Agriculture, 114−117.

Turner L.W., Udal M.C., Larson B.T, and Shearer S.A. (2000). Monitoring cattle behavior and pasture use with GPS and GIS. *Can. J. Anim. Sci*., Vol. 80, pp. 405–413

Welfare and behaviour detection

In the last few decades there are significant increases within the dairy industry – an increase of dairy cow productivity of more than 50% and also an increase of the size of dairy herds. Thereby studies about cow welfare and behaviour are proving their importance. In animal welfare there are three main questions that need to be answered: is the animal functioning well; is the animal feeling well and comfortable and is the animal able to live a natural life up to certain limit (Fraser et al., 1997).

Farmers need to have at least a basic knowledge about animal natural behaviour to reach the desired step of animal welfare. This knowledge allows more effective identification and treatment of ill animals, allows making precise decisions of which animals can be more suitable for breeding purposes and also gives an impression for the basic principles of animal housing systems. The main point in animal welfare is to maximally reduce animal stress by reducing factors that may be the source of stress.

Monitoring and analysis of activity

As technologies develop, more and more often the newest scientific achievements and modern technologies are used to assess dairy cow welfare and behaviour, which allows the automation of animal monitoring. The behavioural pattern of dairy cows more often is evaluated with different bio-telemetric devices. Frequently used technologies are global positioning (GPS) trackers, different location sensors, proximity loggers, and accelerometers for animal behaviour monitoring. The main advantages of sensors are their light weight and small size, and the ability to record high precision animal behaviour data.

The precise behavioural monitoring system in dairy cow herds can provide farmers and scientists with valuable information about cow behavioural patterns that can serve as a signal for poor welfare conditions in the farm. If there is a behavioural monitoring system in herds, farmers can collect data about cow individual and social behaviour, which can later be used to evaluate cow health, welfare and determine the reproductive status.

One of the simplest animal behaviour monitoring systems is automatic feeders, which can help to determine different health risks occurred in farms (animal eating behaviour).

For animal moving behaviour monitoring one of most used systems are pedometers, which can be used to analyse cow health, reproduction phase, sleeping and eating patterns etc. In international study (Italy and Israel) in year 2013 by using two different cow pedometers cow sleeping behaviour was monitored. In conclusions the team of scientists confirmed that by using pedometers farmers can better monitor and improve understanding of comfort and welfare of dairy cows especially in modern dairy farms with loose housing system (Mattachini et al., 2013).

In the study by Essex scientists (UK), an algorithm that can be used in precise animal husbandry for cow health and welfare assessment was developed by assessing dairy cow behaviour using collar transponders fitted with a tri-axial accelerometer (Vázquez Diosdado et al., 2015).

Stress indicators

Stress as physiological mechanism is not inherently a bad thing, for example different hormones, that releases in cow organism also appear in time of courtship, copulation and hunting (Broom & Johnson, 1993). For dairy cows there are many stressors that not only can affect cow productivity and health, but can be one of main reason for impaired physiological and reproduction cycles. One of the accessible methods to evaluate stressors and cow stress level is the analysis of cow hormones that releases when there is one or more stress factors. Austrian scientists in their study determined the most precise methods of determination of stressor effect on different hormone release in cow body (Möstl & Palme, 2002). The hormones that are one of the strongest indicators for dairy cow stress level are ACTH, glucocorticoids, catecholamine, prolactin and others, that are involved in the stress response. The adrenaline secretion is one of strongest indicators of presence of different factors and it triggers the increase of glucocorticoid and/or catecholamine secretion. One of the easiest achievable hormone level assessment method is the analysis of fecal cortisol metabolites that can serve as the indicator of adrenocortical activity in cows.

Other than indicators that don't appear with visible signs, there are vocal responses to stressors. Cattle vocalization is not always a sign of stress as it is also a communication method between animals and can serve as a dominance indicator. The stressors that might lead to intensive vocalization of dairy cows are: isolation, expression of pain, reproductive status, age (young calves are more likely to vocalize than fully grown cows), sex, dominance status, reproductive status, lack of fitness and need for resources (Watts, 2000).

The changes in cow behaviour also may indicate of different stressor presence in cow farm. The rapid aggression, tongue rolling and head shaking without apparent reason can indicate a higher stress level for monitored animals. In the study where 12 cows were fed and 12 cows were food deprived results showed that 10 of food deprived cows showed rapid aggression, 4 cows rolled tongue, 6 cows shook head and 5 showed uncharacteristic vocalization. The cows that were properly fed showed none of previously mentioned stress indicators (Sandem, Braastad, & Bøe, 2002).

One of visible stress indicators of dairy cows is the percentage of eye-white. As introduced to stress cow eye white significantly increases of up to 60% of all eye area in just 4 minutes and starts to regain its normal size 6 minutes after stressors end (Sandem, Braastad, & Bøe, 2002).

A prolonged influence of stressors can result in a decrease of cow productivity and also a decrease of cow health performance. A study, where loud noise was used as a stressor, determined that in some cases after prolonged exposure to loud noise cows suffer from increased abortion frequency, foetus resorption, reduced foetus weight etc. (Algers et al., 1978). In different studies determined that cow productivity reduced when they were exposed to the sound of 80 – 100 dB for 1.4 hours. The phenomenon in different studies is explained with reduced appetite and lower feed intake in stressful situations (Algers et al., 1978; Kauke and Savary, 2010; Cwynar and Kolacz, 2011).

Social behaviour

Cows naturally are typical herd animals with a strong hierarchy and behavioural pattern. It is believed that one cow can recognize 50 -70 different cows (Fraser, 1997). The

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cow social behaviour traits are important in cases when animal holders – farmers – need to manage their herds, in those cases it is significant to know cow communication and basic social necessities to avoid probable risks of handling and in the meantime improving their welfare.

In the wild the herds usually consist of mothers and young calves, but males join to the herd only in the mating period (Keeling, 2001). In modern dairy farming, cows are separated from calves and bulls so dairy cows rarely shows territorial defence. In modern dairy farms signs of territorial defence usually show that in the farm there is a significant lack of space (feeding, drinking or sleeping space).

There are 4 basic cow behavioural characteristics that affect social structure in the herds: likeness, individual space, hierarchy, and domination. As it comes to the likeness of cows, they are usually choosing some other cows from the same group to favour their relationship. This quality can be observed in farms where cows are in close contact without significant aggressive interactions and it is usually established at a young age (first 6 months of age) and is stronger for animals that are reared together from a young age. The main advantage of likeness is the reduction of competitive behaviour among animals and also development of the hierarchical formation of the herd (Bouissou, 2001; Shahhosseini, 2013).

The individual space or flight zone varies between different cows and refers to the space around the cow that should be avoided to interfere with other cows or humans. In case of intrusion of individual space, depending from its social rank, the cow could move away or show aggression. The main advantage of individual space behaviour is the possibility to control the direction of cow movement by stepping in their flight zone that can also decrease possible aggression, injury or damage between herd animals (Grandin, 1997).

In cow herds there is typically hierarchical relationship between animals. The herd hierarchy could be simple like a straight line (each cow have her own place in hierarchical chain limiting two different animals to have the same hierarchal status), but also there might be more complex hierarchies. Usually cow superiority is determined by various factors – age, level of productivity, time of joining to herd, etc. (Berstein, 1981). About 25% of all cows in their life can lose their hierarchal status, but only in the way that a subordinate cow can step up and become dominant over other cows (Philips, 1993).

Dominance is one cow`s ability to suppress behaviour of other cows in the herd. The main factors that determine the level of dominance are: body size, inheritance, age, sex, animal temper and early age experiences (Albright & Arave, 1997). Dominant cows usually are first that takes place to the feed and water, also has betters access to resting zone, so from the view of welfare, dominant cows have far better welfare conditions than low ranked animal (Phillips, 2002).

Non-invasive system for monitoring sleep

Cow sleeping pattern is one of the most important factors that affect cow welfare, because not only it shows cow attitude towards pen bedding, but also, when cows are sleeping all metabolic processes conducts much faster. Before the use of technologies, cow sleep monitoring was conducted manually, but this can lead to human error in the collected data. Nowadays there are systems that monitor each step of the cows and collect the information for further analysis.

There are some invasive methods for monitoring cow`s sleep such as electroencephalography (EEG) that can monitor brain activity, eye movement and muscle activity (with electromyography (EMG)), but using such invasive methods can make it hard to evaluate cow`s natural behaviour, because while the equipment has been set up there is a possibility to intrude cows sleep. In that case all occurred sleeping patterns are not accurate and therefore they are not usable in further studies.

The non-invasive sleep recording technologies in comparison with invasive ones are already attached to the cow before she goes to sleep and the recordings begin when the desired activity is occurring (Ternman et al., 2012).

Heat and cold stress

In regions with different weather conditions in summer and winter, when air temperatures reach somewhat critical values, there is a large possibility that in one points in cow`s life she will suffer from heat or cold stress. Heat or cold stress is not only a major welfare problems, but also in times of stress cows suffer from decrease of productivity, which can lead to major financial loss for the farmer.

Dairy cattle can withstand temperatures as low as -37˚C, but temperatures above 23 ˚C can cause stress in combination with high humidity, low air movement or direct sun. The main signs of heat stress are: reduced feed intake, change of feeding patterns (more grazing at cooler times of the day), cows rather stand than lay down, bunching in shade (if it is available), rapid and shallow breathing (also open mouth breathing with panting), increased water intake (100 – 130 l per day), sweating and increased saliva production and lack of coordination (OACC, 2008).

The heat stress can reduce dry matter intake by 8 – 12% and reduce period of digestion by 4 – 6 hours, which is one of the main reasons to decreased milk productivity. Cow`s milk productivity decreases by 10% at 27 - 32 ˚C with the air humidity of 50 – 90%, but by 25% at the air temperature of 32 - 38 ˚C with 50 – 90% air humidity. The effect is more significant in high productivity level cows (OACC, 2008). Milk dry matter compositions are also affected by heat stress – the milk fat content can decrease up to 2%, but milk protein up to 1.5%.

Heat stress can cause reproductive problems (lower birth weights, compromise of the immune system). In times of heats stress clinical and subclinical mastitis and lameness often occurs, which sometimes are not treatable. In the case of heat stress there is a significant lack of Ca and K because of disturbed metabolism processes. The somatic cell count (SCC) also increases up to 300 – 700 thousands ml^{-1}, that doesn't pass for quality milk.

The heat stress might occur even if all animal welfare conditions are satisfied, but in order to reduce heat stress symptoms there are some recommendations: increase the amount of cold water, use fans more efficiently, use water sprinklers in different places in the farm, minimize time spent in pens before milking, avoid grazing in the hot periods of the day (OACC, 2008; Black, et al., 2014).

Cold stress on the other hand is observed in winters during critically low temperatures and it is not as widely studied as heat stress because European cattle tend to be more tolerant to low temperatures. The main indicators of cold stress are: increased - dry matter intake, rumination, maintenance of energy requirements, body oxygen consumption, cardiac output, adrenaline, cortisol and growth hormone levels, and hepatic glycose output – and decreased – rumen volume, dry matter digestibility, temperature of skin, ears and legs, insulin response to a glucose infusion (Angrecka & Herbut, 2015)

When in case of heat stress there are fewer options how to cool down cow body temperature, but in the case of cold stress there are possibilities to make a suitable shelter for dairy cattle, keep their hair coat dry and clean so it can protect animals from low temperatures.

Time budgets

Certain components in cow's life are fixed and non-negotiable. There are few positions of the time management that takes large proportion of cow's day. The cow has to spend significant proportion of the day eating, lying, in social interactions, ruminating, drinking and also there is time for management activities (milking, grooming, veterinary procedures). In average a dairy cow, dependent on her productivity, spends approximately 3 to 5 hours per day eating, from 12 to 14 lying, 2 to three hours socializing, 7 to 10 hours ruminating, approximately 0.5 hours drinking and the time left for management activities is 2.5 – 3.5 hours (Lindgren, 2009; Krawczel & Grant, 2009). In the pen cows usually spend approximately 17 hours per day, which are spent mainly by three activities – lying down, standing in an alley and standing in a stall. Average freestall cow by socializing and moving between feed bunk and stalls spend 2.4 hours per day, in stall a cow spends 2.9 hours standing and 11.3 hours per day lying (Cook et al., 2005).

The time budget concerns not only the time that cows spend doing certain activities, but also the times that cows visit each of the strategic points (pen, feed bunk, milking station etc.). The average cow visits sleeping (lying) areas approximately 7.2 times per day with an average 13.6 lying bouts (time spent lying). The average duration for one high yielding dairy cow is 1.2 hours; most of the cows spend time between bouts at the defecation area and eating. It is a commonly known fact that cows produce more milk when they are lying down because of increased blood flow thru pudic artery (when cow lies down, blood flow increases by 24 – 28% (Metcalf et al., 1992; Rulquin and Caudal, 1992). Some researchers determined that there is a linear relationship between milk productivity and time spent lying down, but those results in different studies are proven to be inconclusive (Grant, 2004; Hill et al., 2007).

Cow behavioural pattern shows that in different cases cows can sacrifice eating time if lying time is not satisfied, so farmers need to balance animal feed to make it easier to eat (not too many small fractions that can make eating difficult) but also to make animal feed more balanced and concentrated to reduce the time cows spend eating. If cows are not satisfied with all the nutrition they need, a significant productivity loss could occur, loss of body weight and consequential metabolic diseases.

Ear-based real-time location systems

The main target of real-time location systems are loose housing systems when cow behaviour needs to be monitored and one of the main aims for those systems is to measure social behaviour and interactions between different animals. There are 4 different types of real-time location systems – collar transponder, ear tag, injectable transponder and rumen bolus (Finkenzeller, 2003). Different systems are adaptable to different species of animals, for dairy cows it is easier to apply ear tags and collar transponders. Rumen bolus is hardly accessible after insertion, but ear tags and collar transponders are easily fixable in case of some problems. In Latvian farms the mostly used system is collar transponders, but this system has some negative sides, for example, collar transponders could be removed by other cows in conflict, cows can damage transponder parts, and some of collar transponders are designed only to access and read information about cow productivity and fodder intake. The information about the cow is collected at the choke points, such as gateways and feed stations. The ear tagging on the other hand is more suitable for dairy cattle, because there is a standard ear tagging procedure which is mandatory of all European Union (EU) countries and which determines that all cattle must be marked with an ear tags until 20th day of their life. There are some downsides with ear tags also. About 10% of dairy cattle lose one, but in 2% of cases cows lose both of their ear tags. This causes problems in identifying animals (Tractech, 2009)

Usually real-time location systems are used for tracking cow movements, studying their behaviour and feed management. The use of real-time location system tags in animal production not only provides management and welfare benefits, but also increases accuracy in traceability. Before such animal tracing systems manual labour was used, which wasn't as accurate due to lack of labour and human factor.

With different real-time location systems it is possible to monitor the movement of the individual animals if it is necessary and also track the location of a specific animal.

References

Albright, J.L. & Arave, C.W. 1997. The Behaviour of Cattle, CAB International. Wallingford, UK.

Algers, B., Ekesbo, I., Stromberg, S., (1978) The impact of continuous noise on animal health. Acta Veterinaria Scandinavica, Suppl. 67, 1978, p. 1-26.

Angrecka, S., & Herbut, P. (2015). Conditions for cold stress development in dairy cattle kept in free stall barn during severe frosts. *Czech Journal of Animal Science*, *60*(2), 81–87. http://doi.org/10.17221/7978-CJAS

Berstein, T.S. 1981. Dominance: the baby and the bathwater. Behav. Brain Sci. 4:419-457.

Black, B. R., Amaral-phillips, D., Ph, D., Heersche, G., & Bewley, J. (2014). Effect of Heat Stress on Reproduction.

Bouissou, M.F., Boissy, A., Le-Neindre & P. Veissier, I. 2001. Social behaviour of farm animals. CABI International, Wallingford, UK, 113-145.

Broom DM, Johnson KG. Stress and animal welfare. London: Chapman & Hall, 1993.

Cook, N.B., T.B. Bennett, and K. V. Nordlund. 2005. Monitoring indices of cow comfort in a free-stall-housed dairy herds. J. Dairy Sci. 88:3876-3885.

Cwynar, P., Kolacz, R. (2011) The effect of sound emmission on sheep welfare. XV ISAH Congress 2011. Proceedings of the XVth International Congress of the International Society for Animal Hygiene, Vienna, Eds. Prof. Josef Köfer, Dr. Hermann Schobesberger First Edition, 2011, vol. III, p. 1059-1061

Finkenzeller K. 2003. RFID handbook, fundamentals and Applications in contactless smart cards and identification, Sussex, England, ISBN 0-470- 84402

Fraser, D., D. M. Weary, E. A. Pajor, and B. N. Milligan. (1997). A scientific conception of animal welfare that reflects ethical concerns. Anim. Welf. 6:187–205

Grandin, T., 1997. The design and construction of facilities for handling cattle. Liv. Pro. Sci. 49: 103-119.

Grant, R. 2004. Taking advantage of natural behavior improves dairy cow performance. Accessed 08/22/08 at http://www.extension.org .

Hill, C.T., P.D. Krawczel, H.M. Dann, C.S. Ballard, R.C. Hovey, and R.J. Grant. 2007. Effect of stocking density on the short-term behavior of dairy cows. J. Dairy Sci. 90 (Suppl. 1):244.

Kauke, M., Savary, P. (2010). Lärm und Vibrationen im Melkstand – Auswirkungen auf das Tier. Agrarforschung Schweiz, vol. 1, 2010, 3, p. 96-101.

Krawczel, P., & Grant, R. (2009). Effects of cow comfort on milk quality, productivity and behavior. *NMC Annuals Meeting Proceedings*, 15–24.

Lindgren, E. (2009). Validation of rumination measurement equipment and the role of rumination in dairy cow time budgets. *Swedish University of Agricultural Sciences: Department of Animal Nutrition and Management.*, 26.

Mattachini G., A. Antler, E. Riva, A. Arbel, G. Provolo (2013). Automated measurement of lying behavior for monitoring the comfort and welfare of lactating dairy cows. Livestock Science 158 (2013) 145–150.

Metcalf, J.A., S.J. Roberts, and J.D. Sutton. 1992. Variations in blood flow to and from the bovine mammary gland measured using transit time ultrasound and dye dilution. Res. Vet. Sci. 53:59-63

Möstl, E., & Palme, R. (2002). Hormones as indicator of stress. Domestic Animal and Endocrinology, 23, 67–74.

OACC. (2008). Heat stress in ruminants, 1–4.

Phillips, C. J. C. and Rind, M. I. 2002. The Effects of Social Dominance on the Production and Behavior of Grazing Dairy Cows Offered Forage Supplements Journal of Dairy Sci. 85 (1), 51-59.

Phillips, C.J.C. 1993. Cattle Behaviour. Farming Press, Ipswich.

Rulquin, H., and J.P. Caudal. 1992. Effects of lying or standing on mammary blood flow and heart rate of dairy cows. Ann. Zootech. (Paris) 41:101. Schefers,

Sandem, A. I., Braastad, B. O., & Bøe, K. E. (2002). Eye white may indicate emotional state on a frustration-contentedness axis in dairy cows. *Applied Animal Behaviour Science*, *79*(1), 1–10. http://doi.org/10.1016/S0168-1591(02)00029-1

Shahhosseini, Y. (2013). Cattle behaviour Appearance of behaviour in wild and confinement, 1–28.

Ternman, E., Hänninen, L., Pastell, M., Agenäs, S., & Nielsen, P. P. (2012). Sleep in dairy cows recorded with a non-invasive EEG technique. *Applied Animal Behaviour Science*, *140*(1-2), 25–32. http://doi.org/10.1016/j.applanim.2012.05.005

Tractech 2009; http://www.tractechnology.se/files/MeatTracBreeder_SWE.pdf; 2009-09-14

Vatts J.,M., (2000) Vocal Behaviour As an Indicator of Welfare in Cattle., Retrieved from http://pisces.boku.ac.at/han/bokusummon/ecommons.usask.ca/bitstream/handle/10388/etd-10212004-002304/NQ63938.pdf?sequence=1

Vázquez Jorge A. Diosdado, Zoe E. Barker, Holly R. Hodges, Jonathan R. Amory, Darren P. Croft, Nick J. Bell and Edward A. Codling. (2015) Classification of behaviour in housed dairy cows using an accelerometer-based activity monitoring system. Animal Biotelemetry 2015, 3:15, DOI: 10.1186/s40317-015-0045-8

Cow Traffic

The ease of movement of cows through their environment is important in increasing the accessibility of the cows to feed, water, milking and other resources (comfortable lying area, grooming brush, social avoidance, perceived danger). Restricting such access can impair production, health and welfare.

Using video recording, and a programme to automatically analyse social interactions, Guzhva et al. (2016) looked at the effect of disruption of the movement of cows to an automatic milking system by observed social interactions, and compared to actual observation records this method had an accuracy of 85%.

Not only the movement of cow traffic is important, recording automatically the structure of such movement, such as the order of cows into the milking parlour can be a useful tool in assessing welfare and health problems. Those cows that change their position in the order of entry can be red flagged by an automatic system as being likely to be suffering from a health problem (Polikarpus et al, 2015).

Wireless sensors have been used to estimate activity behaviour Nadimi et al.(2014), albeit with sheep as experimental animal, and this might be useful in assessing the ease of movement of a herd indoors. If the activity at a herd level is reduced over a short time period this might suggest a check of the ease of movement of the cows. The IceQube accelerometer (IceRobotics Ltd., Edinburgh, UK) could also be used for this purpose; Charlton et al. (2015) used these devices for the purpose of lameness detection but other cow traffic problems could be identified in this way. But if the device is not attached to each cow in the herd there might be problems of assumptions from a small sample size of cow traffic effects in the whole herd.

References

Charlton G.L., Rutter S.M., Bleach E.C.L. and Boyce R. (2015). Validation of the CowAlert system to automatically detect lameness in dairy cattle.Proceedings of the Second DairyCare Conference. p.29. Cordoba.

Guzhva O., Ardö H., Herlin A., Nilsson M., Åström K., and Bergsten C. (2016). Feasibility study for the implementation of an automatic system for the detection of social interactions in the waiting area of automatic milking stations by using a video surveillance system. *Computers and Electronics in Agriculture*. Vol 127, pp. 506–509.

Nadimi E.S., Jørgensen R.N., Blanes-Vidal V. and Christensen S. (2014). Monitoring and classifying animal behavior using ZigBee-based mobile ad hoc wireless sensor networks and artificial neural networks. *Computers and Electronics in Agriculture*. Vol 82, pp. 44–54

Polikarpus A., Kaart T., Mootse H., De Rosa G. and Arney D. (2015). Influences of various factors on cows' entrance order into the milking parlour. *Applied Animal Behaviour Science*. Vol. 166, pp. 20–24