EIP-AGRI Focus Group

Robust & Resilient Dairy Production Systems

Mini-paper - The implication of precision livestock farming (PLF) on dairy farms robustness

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Introduction

Precision livestock farming (PLF) can be defined as the "management of livestock farming by continuous automated real-time monitoring (or controlling) of production, reproduction, health and welfare of livestock and environmental impact" (Daniel Berckmans). There is an increasing corpus of scientific and popular science literature on the use of a huge variety (continuously growing and updating) of different types of PLF systems and devices. It is expectable that in the future the price of sensors for such devices will fall, whereas the sensor will be smaller. Nevertheless, there are a number of issues common to the PLF systems that should be considered in their future development:

- Easiness of implementation and use. Not all the farmers are engineers nor are all the animals machines to be monitored; devices should be friendly-to-use and install, regardless the measurements they are intended to take.

- Integration of different data recordings in a single output system and management. The proliferation of recording systems usually comes with a number of different screens or apps to show the data recorded and to receive the early alerts when they exist. Therefore, there is a need of integration of these systems to avoid the user to get overwhelmed with different sources of information.

- Integration of different sensors to collect different data. The future development of sensors will allow collecting more data from each sensor, thus reducing the number of devices to be installed to get the maximum data.

- Data collected should be precise, reliable and representative. This is directly linked to the quality of sensors and the development of algorithms and equations to predict different parameters. It is not only a matter of engineering (hardware), but also of mathematics and software development. In fact, for some of the parameters, if data are sufficiently representative, there will be no need to monitor each animal, but only a representative sample of them.

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- Efficient alert systems that are based in the precision and reliability of sensors and linked software.
- Data ownership (once the service is finished, farmer usually does not retain any data). Migration to another company may be a complicated and (who knows) expensive nightmare that should be avoided. Therefore, the compatibility of systems is a "must" in the future development of PLF systems.
- Need for independent advisors (not only those who are commercial managers). Farmers are sometimes visited by a commercial manager trying to convince them about the necessity of implementing certain devices, whereas the real purpose of the visit is merely to sell a product. The presence of neutral advisors, with a sound knowledge of the real needs of the farms and the potential utility of any system will give the farmer confidence before making any investment.
- There is also a need for demonstration and training farms, where advisors and farmers can go and learn the utility, potential, use, recycle, installation and prices of PLF systems. These demonstration farms can be operated jointly by farmers' associations or cooperatives, research institutions, universities, foundations... and would be of great help to all the stakeholders.
- Affordability. Although it seems probable that devices will get smaller, smarter and (hopefully) cheaper, a cost benefit analysis should be carried out before taking the decision of using such systems: Will they increase productivity, resilience or robustness of the farm? How long will it take to recover the investment made? These questions are in the mind of farmers (and perhaps advisors) when they know about a potential systems for their farms.
- The last issue, but not the least is the wide variability of dairy systems (and farms) across Europe. This must be taken into account, because it constrains the potential implementation of each device depending the characteristics of the farms.

When PLF is applied to dairy farms, it aims to improve management strategies for optimizing economic, social and environmental farm performance (Eastwood et al., 2004), which is directly linked to the main objective of the focus group: increase dairy farm robustness and resilience. It is generally perceived that PLF can increase efficiency, reduce costs, improve product quality, minimize adverse environmental impacts and improve animal health and welfare (Bewley et al., 2015).
The scope of this minipaper is other than providing an extensive list of PLF systems; it aims at providing some insights on the solutions and recommendations for future development and strategies for implementation related to precision dairy farming.

Reproductive Parturition / Distocias / Reprodutive disorders (future development after parturition, monitoring vagina pH, temperature and other parameters indicative of metritis...)

It is obvious that the key to calf survivability relies on providing colostrum immediately after birth (to foster calf's immune system with immunoglobulins), which will help to protect offspring against diseases and ensure adequate growth rates in the first weeks of life. In addition, assistance to calving is compulsory whenever a difficult situation, in order to ensure calf's survival. Delayed or difficult delivery of the calf is known as dystocia, and it has a great impact on

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calf morbidity and mortality. Calving time has been considered as not predictable (unless continuous observation of the pre-parturient cow) until now.
Technology can be used to detect the onset of the calving (regardless it takes place during the day or the night), thus helping to get a healthy and safe calf delivery.
Within the range of devices devoted to detect issues related to reproduction, those related to calving onset and the possible presence of problems (delayed delivery that may require skilled assistance) are usually based on activity sensors. There are, however, recently developed intra-vaginal devices that are expulsed when the calving process starts. The vast majority of these devices is able to send text messages to the farmer, as an early alert of the onset of a calving. There are also those that also notify of a delayed delivery, thus warning about a probable problem in the farm.
The activity sensors mounted in the tail are sensitive to movement patterns associated to calving contractions. Those mounted on the leg are based on equations and algorithms that use activity patterns (walking, resting and standing) to link them to the calving itself. Information from rumination sensors (neck collars) is usually combined with that from activity sensors in order to enhance the precision of the predictions. Other kinds of devices are placed intra-vaginally (operation that must be done one or two weeks in advance to the expected calving) and measure temperature and light (these devices are pushed out when the water breaks). On balance, calving sensors help to reduce the need for direct human observation and are useful tools to improve calf survival as well as cow and calf health, which in the end will have a positive impact in farm profitability.

Success and fail factors

These systems are developed to an extent that they only provide alerts and send messages when a calving is about to start or when the delivery is taking more than expected, i.e., no big data are provided to the farmer, but only a warning on the situation. In this sense, the systems can work well on a daily basis.
Likewise, they are easy to use and implement, and a salesman or an advisor from the company (very often they are the same person) is skilled enough to teach the farmer how to install, use, recover (if such is the case), clean and reuse the devices. The farmers can easily get used to these devices.
These systems are likely to be socially accepted, because their installation does not entail any suffering or harm to the animal, thus respecting their welfare. Anyway, the problems that can arise are related to the excessive control to which the animals are submitted. On the other hand, releasing the animals from the continuous human observation is a positive factor to be taken into account, because it makes easy to the cows to rest and look for a convenient place to calf. Moreover, the farmer can have pace of mind because he knows that a phone alert (text message) will arrive as soon as a cow starts calving.
However, because each of the above mentioned systems have been developed and marketed by different companies, the challenge is the integration of the software or hardware systems, which would allow the use of several different systems to increase their predictive ability.
The lifespan and duration of batteries for such devices affects not only their applicability to an individual cow, but also the rate of renewal of devices within the farm, which entails associated costs that must be born in mind.
The cost of the different devices and the associated operating systems is another issue that constrains their application depending on the size and characteristics of the farms. While big farms will probably be able to access to different kind of detections systems, small size farms will need to rely on manpower for these activities.
When a more skilled assistance may be required (excessively delayed delivery or prolonged calving), it would be interesting to have an alert sent directly to the veterinary services to allow them to have an early alert or a prompt response or advice.
There is a clear need of all these systems to be integrated within the usual management of the farm, in order to avoid the farmers to be watch out for several different apps, screens or devices.
The usefulness of these systems is clear, because monitoring calving onset can significantly improve calving outcomes, farm profitability and overall animal health and welfare. The impact of

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these systems on farm robust and resilience seems evident, but it is obviously linked to the investment needed and the expected revenue.

Potential operational groups

Operational groups may be focused on the integration of the different systems and the improvement of their precision. In this regard, when several systems are measuring similar parameters, their complementarity should be tested in order to improve the performance (sensitivity and specificity) of the predictive models. In addition, the integration of these systems with others (software, hardware) in the farm related should be considered.
When animals are ranged outdoors, the development of positioning systems associated to the devices could help to locate the cow involved in the process that raised the alert.

Research needs from practice

Further research may focus (beyond battery duration) in the continuous monitoring throughout the different phases of the reproductive cycle and the most probable disorders in each of them (such as metritis, early abortions…).

Links to education and management

The existence, importance and way of work of these systems should be taught in veterinary schools and farmers training centres.

Systems to detect oestrus

Detection of cow in oestrus by observing behavioural signs such willingness to stand while being mounted consumes time and requires trained caretakers. Increasing herd size and increasing incidence of oestrus of low intensity and short length make it harder the visual detection of oestrus, especially in large size and high productive herds. Automated oestrus detection systems to replace visual manual detection have been developed for many years and, currently are the most used sensors in Netherland together with those for mastitis detection (Steeneveld and Hogeveen, 2015); the major systems for oestrus detection implemented at farm level are based on sensors measuring activity, activity+rumination and progesterone in milk

Activity

Activity meters (pedometers or neck collars) measures locomotive activity and uses peaks in such activity as an indicator of oestrus. These systems have become widespread in recent years.

Success and fail factors

Principal reasons of the success of systems measuring activity are:

- the systems are easy to use;
- systems are able to work on a daily basis providing simple information;
- benchmarks are known;
- information provided by systems are associated with a clear management action to do;
- in many cases, economic convenience of the investment is clear (Rutten et al., 2014,).

Major limitations to spread these systems are probably economics concerns; generally speaking, it is not easy for an individual farmer to estimate the convenience to invest in PLF technologies in his own socio-economic context;
In fact, not all automations, sensors and systems to support decision are useful in the same extent in different situations.

Implementation at farm level depending on farm type

Activity meters have been adopted especially in free stall barns and some concerns have been expressed about their use at grazing. However, Kamphuis et al. (2012) evaluated two collar-mounted activity meters in a large, pasture grazed, seasonal-calving; they demonstrated that,

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even the activity meters evaluated were unable to perform to the same level as manual detection of oestrus when used as a stand-alone system.

Challenge to integrate data

In most cases sensor to measure moving activity are accelerometers. In some case they are stand alone, but the most performing systems integrate data on activity in the informatics system used to manage the herd.
More recent systems integrate data on activity with other parameters often underestimated in the past. The most successful example of such integration is the system combining activity and rumination measures to detect oestrus.

Potential impact on farm robustness

Automatic detection of oestrus by activity meters can have impact on farm robustness by two ways:

- by increasing efficiency in oestrus detection. Poor efficiency in the detection of oestrus cause significant economic losses. Automatic systems increase oestrus detection (Hockey et al 2010).
- by reducing time spent observing cows; however an estimate on how much time can be saved is not known (Steeneveld and Hogeveen, 2015)

Activity +rumination

In recent years, commercial systems for monitoring rumination have become available at farm level. These systems have been studied at experimental and farm level for many years providing data reasonably correlated with those collected by visual observation. Currently, the most successful use of these system is in combination with activity to detect oestrus, in fact changes in rumination as well as feeding times around oestrus has been demonstrated useful aid for early oestrus detection. Pahl et al. (2015) found that rumination was reduced for about 30 hours around oestrus but the primary drop occurred at 6:00 am on d -1 and noon on d 0. Drops in rumination time can be caused by a number of internal and external factors, but drops around oestrus in combination with peaks of activity produce very distinctive graphs

Success and fail factors

Diffusion of such systems is still limited, but they have the potential to be widespread in the next future.

Challenge to integrate data

There is some discrepancies in the way farmers exploit these systems; most of them use the system only for oestrus detection and decide when to inseminate; only few use combination of different data (milk yield, activity, rumination) to manage herd. Monitoring rumination allow to identify nutritional problems and detect health disorders earlier. Rumination responds to stressors up to 24 h sooner than traditional measurements allowing for more effective cow management. This means that changes in rumination time combined with milk yield and moving activity can be used to detect automatically lameness and mastitis that are the most significant health problems on dairy herds. Ruminating time during the night period was found significantly lower (13 min less) for lame cows than sound cows. The night to day ratio of neck activity was higher for lame animals. (Van Hertem et al., 2013)

Potential impact on farm robustness

The systems detecting oestrus combining measures of activity and rumination have a high potential to impact robustness at individual and farm level by:

- by increasing efficiency in oestrus detection.
- reducing time spent observing cows;
- improving health and welfare

– reducing costs for health

The potential impact of these systems on farm robustness is conditioned by possessing some key characteristics that are the same that can facilitate the commercial deployment of this kind of technologies according to Banhazi et al., 2012: a) integration of sensors in a management system that ensures only the most essential procedures are carried out, they are all carried out correctly and consistently, and in a way that controls risk; b) identification of those processes which truly have a major effect on productivity, profitability and/or sustainability. c) identification of farm variables that must be measured to ensure that each essential process is being carried out correctly; d) definition of frequency at which each measurement must be made and set maximum and minimum limits for each measured variable to ensure that the process will continually remain within the optimum range and will not get out of control; e) definition and application of the most profitable pre-determined corrective action whenever measurements are outside of these limits.
These systems have also a potential impact at sector level (genetic selection) allowing an advanced phenotyping including behavioural traits.

Profitability

Improving profitability of the farm is the reason to invest in PLF and economic concerns are the main reasons for not investing. This fact emphasizes the importance of economic models helping choice, installing and management of systems. Also empirical analyses are needed to determine the economic consequences of investing in sensor systems by analysing actual farm data (Steeneveld and Hogeveen, 2015).

Beyond the oestrus detection, integration with other sensors, integration in the management system

There is a need of exploiting automatic systems currently used for oestrus detection; especially systems combining activity and rumination should be more used to monitor animal welfare, health and their interaction with feeding.
Only a full exploitation of the potential of these systems can make them really cost-effective.

Nutritional: acidosis, rumen impairment, other nutritional disorders

Reticulo-rumen boluses wear specific sensors for parameters (temperature, pH, pressure) that can be easily related to rumen function. Hence, a quick drop in pH values is related to acute acidosis, whereas the presence of moderate low values of pH correlates with subacute or chronic rumen acidosis. Likewise, rumen temperature, besides being an indicator of body temperature, is highly related with the fermentative processes in the rumen as well as with water intake (which causes a sudden drop in rumen temperature).
Neck collars that monitor animal's head movements are also used to estimate the average time spent by the cow eating and ruminating. The system is able to send pre-customized alerts when eating or ruminating declines for an individual animal. The use of boluses together with neck collars can be a suitable alternative to accurately and reliably alert farms to the signs of illness, most commonly to the early onset of acidosis and ketosis, but they are also related to the appearance of other processes, such as mastitis or lameness.
There are another number of factors that must be taken into consideration when assessing nutritional status (and adequacy of the diets formulated and provided to the animals): milk yield and composition, body condition score and body weight. Changes in milk yield are indicative of the onset of a problem (nutritional or not) whereas high or low milk fat to protein ratio can be considered as signs of metabolic diseases (ketosis and subacute acidosis, respectively). Therefore, a suitable system integrating data from milk analyses, eating and rumination and rumen conditions would be a powerful tool to provide very early alerts whenever a problem related to cows' nutrition arises, thus allowing the farm to react accordingly in real-time. This will be possible with the integration of all these systems in compatible hardware and software structures.

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In order to control and determine the most efficient feeding strategy for each cow, the use of precision feeders is the ideal alternative; these systems allocate concentrate feed to each cow on the basis of previously customized parameters (mainly milk yield and composition, but other factors such as lactation stage, pregnancy, body condition and weight, etc. are taken into account). It is known providing concentrates according to milk yield and composition is the best way of meeting cows' nutritional requirements and consequently improve lactation performance and feed efficiency. The number of available commercial devices to get such control is increasingly growing, which will, hopefully, contribute to reduce their price and ease their access to not only but also small size farms. In this regard, automatic and controlled feed and water disposals, whenever they are integrated with other monitoring systems may help to early detect feed overload, lack of consumption, water intake, approach to feeders or water without intake (what would be useful to know the animal relationships and networks, to prevent the spread of contagious processes).

Automatic weighting and body condition scoring (cameras, as used for lameness detection) in passing zones can also be useful, together with milk recordings, to adjust ration and prevent unexpected weight changes (increase or loss).

Complementary to the systems that are focused on monitoring cows' behaviour, production and activity are those intended to assess the quality of the feed provided to the animals. In this sense, there are portable NIR analysers which can be used to determine the main chemical components (particularly, but not only, dry matter, fibre and protein). Therefore, this will ensure that daily rations are prepared based on a more real knowledge of the chemical composition of the feeds that are already in the farm, and it allows the nutritionist to make the most appropriate decisions regarding the quality of the ration to be prepared. This is especially interesting in the case of feeds produced in the farm (grass, hay, silage), thus allowing to set the harvesting when the crop reaches the optimum chemical composition. These devices are developed to be handled manually, but they can also offer the possibility of being mounted on a mixed wagon, to monitor feed composition in real time (as it is being manufactured and delivered to the animals). Further development of such systems can take into account the possibility of analysing faeces samples, which can be useful to determine ration digestibility (and assimilation), but also another estimations may be foreseen (for example to detect an excess of starch or protein in faeces, and set up an alert for such situations).

Success and fail factors

One of the advantages of these systems is that, once the alerts are correctly set, there is no need for benchmarking, and each farm can be ruled (regarding nutrition monitoring) in a completely independent manner.

Most of these systems are able to work on a daily basis but, in some cases, the information provide to the user (farmer) is overwhelming. For example, looking for a drop on pH or a rise in fat to protein ratio within the data recorded from every cow would be a nightmare. Therefore, developing predictive models to set up early alerts of sudden changes or potential warning situations would be the first step in the future development.

Another issue that contributes to the lack of widespread use of these systems is their battery needs and the battery lifespan. Whereas external devices can be taken from the animals to charge batteries, internal ones (such as rumen boluses) remain in the cow for her entire life. If the bolus fail (or the battery finishes) there is no way of recovering it and the only solution is introducing another one (if this was possible and allowed) or miss the data.

There number of devices (in the case, for example, of the rumen boluses) to be used in the herd is another important question that the farmers may ask themselves. Is it necessary to monitor each animal or a sample would be enough? This would condition (or determine) the affordability for each farm. In addition, everybody knows that taking a representative sample of a herd is a complicated issue, and that the feeding behaviour of each cow can be similar to the others, but it varies greatly (even between days for the same animal).

The social acceptance of most of these systems is expected to be positive; the greatest problem can arise from the fact of introducing indwelling probes in animals. However, this operation can be done by specialized persons without any risk for the cow, and the probe itself remains in the

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rumen (without leaving it) for the cow's entire life causing no interferences with animals' behaviour and welfare.
Redundancy of data may become a problem, not only for data and apps handling, but also for the associated costs that must be assumed by the farmers. There is a clear need for integrating the different systems mentioned to get the most of them and develop more early and accurate alerts. By doing this, the complementarity (or lack of it) between systems and devices will be unveil, thus allowing future development of those with great usefulness. In this regard, farmers may ask, for example, if rumen monitoring can provide alerts earlier than milk analyses and then help to save time and money.
In the same way, if two systems provide similar information, which one would the farmer choose? The cheapest, the scalable, the compatible with previous devices?
Regarding the duration of batteries, there is a need for developing auto charging options for devices that cannot be charged otherwise given that they are located inside the animal. External or internal (based, for example in animal movement) charging systems should be developed (or increasing battery lifespan as an alternative).
Probably the main constrain for all the farmers (particularly those in small size farms) is the price of most of these systems. Farmers need to see the revenue from their investment, and this can be show in demonstration farms that can be managed by cooperatives, research centres, foundations or a joint of several of them. Price particularly matters when the number of cows to be monitored is high (or when a device must be installed in every cow present in the herd). Therefore, the need for monitoring all the animals or a sample of them must be further elucidated.
The usefulness of these systems is clear, albeit the impact on farm robustness and resilience is relative. Using these kind of monitoring systems helps the farmer to get a better knowledge on animals' physiology and behaviour and to pay early attention to changes, which in the end may result in time, feed, resources and money savings. Monitoring systems also contribute to optimize man power, hence allowing more free time (no need to continuous observation of the animals, although visiting the animals is both necessary and recommendable). However, it may be necessary to perform a cost-effectiveness analysis before deciding to implement any of these systems in the farm.

Potential operational groups

Operational groups should be oriented to not repeat data from different devices, increase robustness of algorithms and reliability of data.

Research needs from practice

The basic need is the continuous increase in the robustness of algorithms

Links to education and management

Education and management: to get know the animals, their needs and their behaviour. This would help the farmers to take the right decisions on time.

Health

Respiratory diseases

Success and fail factors:

Big data is necessary at this time since to detect respiratory problems on distance various types of data are needed:

- Changes in body temperature: Rumen T°C boluses, IRT, ear mounted thermometers
- Changes in feeding behavior: Growsafe system, ENGS system (characteristic of illness is anorexia or loss of appetite (Konsman et al., 2002).
- Changes in physical activity: pedometers, accelerometers to monitor lying behaviors

Another approach:
Cough can be a biomarker in case of respiratory diseases. By monitoring and analyzing cough sounds through automatic devices, the farmer can obtain an early warning about a developing

outbreak of respiratory infections. Cough sounds can be characterized by particular acoustic features (amplitude, frequency and duration) that are obtained by sound recording, labeling and analytic procedures. Based on these features, it might be possible to develop an automated cough recognition system. Currently in experimental conditions it is it is possible discriminate cough sounds from other sounds and that cough sound can be used as a non-invasively diagnostic tool for respiratory diseases in young stock groups.
Why are health-monitoring systems not currently used in feedlots?

- 1st explanation = costs $$$
  - •Rumen temperature bolus = $35-100
  - •Infrared camera = $7000
  - •Growsafe system = $25 per head
- 2nd explanation = low specificity!
  - •Numerous "false-positive" detection

Lack of specificity of fever and abnormal feeding behavior:
1) Study of Timsit et al. (2011b): Up to 75% of the fever episode detected by rumen T°C bolus lasted less than 47 hours without any treatment => viral infection only? Successful immune response? Hyperthermia? Vaccination?
2) Study of Wolfger et al. (2012): Pulling cattle only based on abnormal feeding behavior during the first weeks on feed could lead to pull as much as 90% of the healthy animals=> Adaptation to the bunk?
Schaefer et al., 2011: Automated, RFID driven, noninvasive infrared thermography technology
True positive animals for BRD based on a gold standard including core temperature, clinical score, white blood cell number and neutrophil/lymphocyte ratio displayed higher peak infrared thermal values of 35.7 ± 0.35 C compared to true negative animals 34.9 ± 0.22 C ($P < 0.01$). The study also demonstrated that such biometric data can be non-invasively and automatically collected based on a system developed around the animal's water station.
Large due to noninvasiveness of all the suggested systems and potential to improve health and welfare of the cows.
Automated, wireless collection of biometric data of respiratory diseases is useful for bio-security and bio-surveillance purposes. The use of a non-invasive, automated, remote sensing system such as the infrared scanning station technology, lends itself to easier collection and oversight for early indicators of animal health aberrations.
The economic losses through lower weight gains and treatment costs for bovine respiratory diseases in cattle equals USD14 per animal, not including labor and associated handling costs (Snowder et al., 2006).
For early detection, continuous animal observation is basic but it also requires substantial manpower that is not available in large dairy farms. As a consequence, animals are treated only in case of clinical signs when the infection has already developed to a late stage. Cough sound analysis might be a valuable PLF tool in early detection of respiratory disease where pathological coughs can be a marker of infection;
Prediction system could track the evolution of the disease and be useful to improve the prevention of respiratory diseases when used in synergy with good management practices (colostrum and vaccine administration, stables hygiene), to save costs for single animal treatments and to reduce weight losses and drop of production (Gardner et al., 1998; Apley, 2006).
Bovine respiratory disease complex (BRD) causes considerable economic loss and biosecurity cost to the industry globally and also results in significant degradation to the welfare of affected animals. Early detection i) limits impact of on performance, ii) maximizes clinical and bacterial cure and iii) reduces emergence of bacterial resistances

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Research needs from practice

Still a huge lack of knowledge on coughs sound analysis and interpretation. In order to obtain punctual and early diagnosis, in real field conditions, it is necessary to study, as first, the association of a certain type of cough to its corresponding disease. It is also important to consider that farming conditions offer a wide range of sounds which, even if acoustically very different from coughs, may interfere with a correct cough recognition and the automatic analysis of these sounds may result in a false quantification of coughs.

Knowledge gap (research needs, potential operational groups)

Capability to automatically select and distinguish the cough sounds produced by infected animals from all the other sounds present in cattle stables. By rejecting any kind of other sounds but coughs, using an automatic system, we will be able to avoid false positives cough sounds detections increasing the reliability of the detection system. By an objective sanitary quantification and qualification of the disease together with sound analysis of all coughs and “non coughs” sounds we may expand our knowledge about animals acoustic and the way to use it for diagnostic purposes.

Lameness

Success and fail factors:

Comparison between the different approaches is impeded by the wide range of practical settings used to measure the gait or behavioral characteristic (e.g., measurements during normal farming routine or during experiments; cows guided or walking at their own speed) and by the different definitions of lame cows.

Despite the research on opportunities to automatically measure lameness in cattle, lameness detection systems are not widely available commercially and are only used on a few dairy farms (Van Nuffel et al., 2015).

Early detection of lameness should be used only if it is relevant to the farmer, which suggests that there may be a need for custom-made detection systems. For a farmer with low herd lameness prevalence and a good general lameness management, early detection of new cases of lameness or mildly lame cows might create an added value. However, such farmers are rare. Most farmers hugely underestimate not only the prevalence of the lame cows in their herds but also the severity of the lameness cases. The majority of farmers prefer a detection system which only creates alarms for the severe cases (specificity of >99%), as shown for automated detection of mastitis. Severe cases can be divided into new cases or chronic cases (i.e., those that cause recurring alarms).

Farmers willing and flexible enough to treat lame cows every day may benefit from real-time measurements. Farmers planning fixed weekly treatment days may not need real-time systems because cows that were identified lame in the past week could be selected and separated on one specific day. One might also suggest that based on the list with attention cows, a farmer should decide which cow should be examined and hence which cows have to be separated from the group after next milking. For the top managers with smaller herds or fewer problems, this approach might indeed create less frustration as such farmers have the skills and knowledge to decide which cow should or should not receive treatment. On the other hand, an automatically separated cow would force the farmer to attend to the separated cow before releasing her back into the barn. This would enhance the chance of that cow getting proper treatment.

In practice, no free space is available in dairy barns to install any lameness detection system. This might create drawbacks for those sensor technologies that need an alley set-up where measurements are performed (walk-over devices, e.g., the Gaitwise system, StepMetrixTM) or where video can be recorded (vision techniques). Therefore, measurement systems that need less space or that can be included in the existing farm infrastructure, like measurements of weight differences in the milking robot or measurements with accelerometers, might be more feasible in practice. If not, additional space could be incorporated in the plans for new barns. However, creating sufficient space in any existing barn is challenging, especially as cows should preferably pass this measurement zone daily—if possible, after milking—and should be identified simultaneously. This requires a free zone inside the barn after the milking parlor, rotary or milking robot or even at the exit to the pasture for measurements during the grazing season. This drawback however, is especially present in the smaller dairy farms. In larger dairies, which are the kind of farms which would benefit hugely from this technology, installing a lameness detection system might be easier. However, the most important thing is to ensure good cow traffic, especially if a system is installed after the milking parlor or milking robot. Cows blocking the area around the measurement zone will disrupt the measurements and create measurement failures and might even affect the milking routine

Very large social acceptability of the systems. Tool to support better health and welfare of the cows while reducing use of the antibiotics and reducing mortality due to leg issues.

Automated measurements can gather data continuously, such that cows can be monitored on a daily basis. In addition, their major advantage is the lack of need for herding the cows. As cows have a stoic nature, guiding them can bias the measurements, because they will try to hide their weakness and pain compared to measurements during normal routine without the presence of a human or predator. Ideally, measurements should therefore be fully automated, so no interference of an operator is necessary.

As several hoof lesions take some time to develop, it might also be difficult for hoof trimmers or veterinarians to define the lesion causing the lameness and give accurate treatment at such early stages. Identification of problems in hoof shape, on the other hand, might provide information for the optimal timing to apply preventive hoof trimming. However, early detection of lameness is a prerequisite for effective treatment, which again may prevent the lameness from becoming chronic

Throughout the past 20 years of research on dairy cow lameness and automatic lameness detection systems, scientists have claimed that early detection of lameness signs is beneficial in treating affected animals before the problem becomes too severe. In doing so, long lasting and costly treatments, production losses and reduced welfare long term can be avoided.

Research needs from practice

To answer:

- What is early detection?

- When is it needed or when does a farmer perceive it as an added value?

Links to education and management

Supporting the farmer in monitoring the individual cows.

In the next step, after prevention and treatment programs have successfully resulted in lower lameness prevalence at the herd, the threshold settings of the detection system could be changed to also detect the mildly lame cows to further decrease the lameness prevalence to a lower level. In general, it is very important to convince the farmer to trust the lameness detection system. Many farmers may be reluctant to rely on the judgement of an automatic system rather than their own. The farmer's suspicion might be even worse for early lameness detection, especially if he or she cannot diagnose a treatable problem. In general, a lameness detection system should provide the ideal balance between detecting almost every lame cow (high sensitivity) and having as few false detections as possible (high specificity). Farmers might be more reluctant about a high number of false alerts compared to a missed lame cow, as false alerts create unnecessary labor and time to check the cows on the alert list. However, research on the expectations and use of farmers for a lameness detection system might provide more information on the requested sensitivity and specificity of lameness detection systems.

Knowledge gap (research needs, potential operational groups)

In order for automated measurements to be used in a detection system, algorithms to distinguish between non-lame and mildly or severely lame cows need to be developed and validated.

The biggest challenge for any lameness detection system is the detection of early onset.

Whether or not measurements of a lameness detection system should be in real-time at this stage of the development process remains unclear. If the detection could be performed in real-time, i.e., immediately after the cow was measured by the system, it becomes possible to automatically separate a cow that is identified as lame by the software and needs extra attention

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from the farmer. Such decisions made on the spot must be done in less than five seconds, requiring technology with high-speed calculations.

Metabolic diseases

Determination of ruminal pH, temperature and pressure in animals can be crucial to suppress the occurrence of health problems such as sub-acute rumen acidosis and bloat. Owen et al. reported that rumen acidosis is a serious problem in dairy and feed-lot sectors, resulting in animal deaths, morbidity and diminished productivity.

- A bolus containing a mote (temperature sensor, processor and radio) was placed in the rumen of a fistulated cow to monitor body temperature. Rumen temperature was measured every minute and stored in the internal buffer of the mote.

- Rumen motility can be assessed by measuring changes in rumen pressure. Thus rumen pressure can be used to determine bloat in ruminants. There is not a lot of rumen pressure data for cattle. Therefore, the boluses would be a very useful tool for assessing the relationship between rumen pressures on bloat in cattle.

- Monitoring ruminal fluid pH is a reliable method to determine acute acidosis or SARA. I. Success and fail factors:

The system could work on a daily basis monitoring individual cow data, however main problem is the acquisition of the data. Currently developed methods are very invasive and require fistulation of the animals, which significantly increases the costs, reducing ability to collect data as well as is potentially inacceptable by the society, even though benefits from reducing metabolic disorders could be major.
Potential implementation for larger farms due to costs. On those farms managers have less time to look at individual cows – the system would help them to manage.
The social acceptability may be low due to invasive methods
The role of these systems at farm level is large since a major health and welfare issue, reason for culling could be prevented. Veterinary costs would be reduced. Cow suffering would be reduced. Use of antibiotics would be reduced. Furthermore methane emissions could be better monitored and in the future optimized per cow.

Research needs from practice

Need to develop a system which is not invasive

Links to education and management

The system needs much development and work and afterword could be translated to educational and management purposes.

Knowledge gap (research needs, potential operational groups)

For monitoring of rumen a permanent device in the rumen is required managed remotely without interfering with the normal behavior of the animal which currently is very difficult.

Milk yield and quality

Milk is one of the endproducts the cow biology. In the milk there are some stamps of these processes. This means that through different analysis of the milk it is possible to say of the cow is sick, in heat, pregnant, in negative energy balance, producing increased amount of methane, etc.
Fourier transform infrared (FTIR) spectroscopy is used globally at commercial milk recording agencies and dairies for decades for routine quantification of major milk components fat, protein and lactose content. Several studies have investigated the potential use of milk FT-IR spectroscopy to predict detailed milk quality traits, such as individual milk fatty acids and proteins (De Marchi et al., 2014).
Recently, the quantification of FA contents of bovine milk by mid-infrared spectrometry (MIR) was developed (Soyeurt et al., 2006, Rutten et al., 2009, Soyeurt et al., 2011). As the FA prediction by MIR is feasible and as the CH4 production is correlated to the milk FA profile and

potentially other milk components such as lactose, there is an interest to quantify directly the CH_4 eructed by lactating cows from the milk MIR spectra. In 2012, Dehareng et al. published the first article on this topic. The equation was developed by combining 77 MIR milk spectra and their corresponding reference SF_6 CH_4 data. Even if this study was based on a limited number of records, it showed the feasibility to use milk MIR spectra to evaluate the CH_4 eructed by dairy cows.
Positive genetic correlations were observed between MIR predicted MP in g/day and FPCM, fat yield, and protein yield (Kandel et al., 2013). This means that a decrease of CH_4 should have negative impacts on milk, fat and protein yields. However, since many years, the breeding selection is not any more based only on the milk production, but on several traits combined in a breeding selection index. Studying the impact of the introduction of MIR CH_4 trait in the breeding selection index is therefore interesting.
The concept of selecting for improved feed efficiency or RFI is highly attractive, but practical implementation might be challenging, primarily because individual feed intake records are unavailable in commercial dairy herds. Dry matter intake is the key component to calculate feed efficiency. Genetic assessment of dairy cows requires reasonably large data sets. However, only small data sets are generally available for feed intake because of the difficulty and expense involved in measuring DMI. A promising option could be use of Fourier transform mid-infrared (FT-IR) spectroscopy on milk samples to predict DMI or RFI traits; FT-IR spectroscopy is a rapid and cost-effective tool for recording phenotypes at the population level and is already widespread for standard milk sample analysis. Fourier transform mid-infrared spectroscopy studies the interactions between light and matter and is method of choice worldwide to quantify milk components, including fat, protein, and lactose during routine milk analyses.
McParland et al. (2011, 2012, 2014) reported that energy status (intake and balance) and RFI can be predicted phenotypically using FTIR. The additional benefit of using milk FT-IR is that spectral data are routinely generated for all individual milk samples, and DMI or RFI can be predicted on all milk-recorded animals at no additional cost.

Welfare: BCS and weight, environmental conditions

The welfare of dairy cows is important for their health and productivity. Therefore, it is useful for the farmer to get information about the welfare status of the cows and an early warning if something is wrong with one cow. Beside health indicators it is also a good hint to get daily information about the body condition score (BCS) and the weight of dairy cows. By now, sensors and technologies were developed to get this information automatically every day (without leading each cow to a scale or evaluating the BCS of each cow with your eyes). This helps the farmer to save a lot of time. Furthermore, due to daily and objective measurements, it is possible to get at once the information if something is significant different to the days / weeks before.
An automatic weight measurement can be integrated in the ground of an automatic milking system or in the ground of a gate (where every cow has to stop shortly) after the milking parlour during the way back to the herd. Every cow will be recognized there per RFID so that the measured weight can be saved animal individual. Body condition scoring is possible with 3D imaging (DeLaval BCS, Tumba, Sweden). DeLaval BCS eliminates the guesswork and the inaccuracies of visual and tactile evaluation. The BCS camera is mounted on a DeLaval sort gate or on DeLaval VMS™. It takes a 3D image of your cows' lower backs every time they pass under the camera. It then calculates the body condition score of each cow and sends it to DeLaval DelPro Farm Manager where you can view graphs of individual animals, groups or the entire herd. DelPro Farm Manager can be set to notify you if a cow falls below a certain score. There is already a smartphone application (BCS Cowdition, Bayer Animal Health, Leverkusen, Germany) available to get the BCS of a cow objectively by taking pictures of her.
The welfare of the animals is also influenced by the barn climate. Heat stress conditions can have a negative influence on the wellbeing, the behaviour and the productivity of dairy cows. It is possible to make it more comfortable due to the use of cooling systems (e.g., fans, open the side walls or water sprinklers). But up to now, the farm staff takes the decisions when to use these cooling systems. It would be helpful to measure the temperature and the relative humidity with a sensor to calculate the temperature-humidity index (THI). In the future it is also thinkable to

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have intelligent cooling systems which will be controlled automatically if a predefined heat stress value is achieved.

Proposals for future development of FADN

The FADN commits

The Farm Accountancy Data Network (FADN) is a European system of sample surveys that take place each year to collect structural and accountancy data relating to farms; the aim is to monitor the income and business activities of agricultural holdings and to evaluate the impacts of the Common Agricultural Policy (CAP).
The FADN survey covers only those farms exceeding a minimum economic size (threshold) so that only the most relevant part of the agricultural activity in each EU Member State is covered, i.e. at least 90 % of the Standard Output and 90 % of Utilised Agricultural Area covered in the Farm Structure Survey (FSS, Eurostat).
The survey provides representative data by: region, economic size and type of farming activity.
The FADN is the only harmonised source of micro-economic data, which means that the accounting principles are the same in all EU Member States.
A significant change in the FADN methodology entered into force in 2010 where the revised EU-typology of farms (replacing standard gross margin by the standard output) was integrated into the FADN database.
FADN releases annual dairy reports about dairy farms of EU member states.
The report provides an analysis of the economic situation of EU dairy farms. Describes the **sample of dairy farms** on which the results presented in the report are based. Provides an **analysis of milk margin** by EU group and Member State. Presenting **an income analysis at EU and national level and provides an analysis of the competitiveness** of the dairy sector in Europe. Detailed data by EU group, Member State and region are provided in Annex, together with explanations on the methodology.
If we define competitiveness as the capacity to keep and extend your market share, an analysis of the competitiveness of the dairy sector based on FADN data will look at the main strengths and weaknesses of the different Member States that will define their final competitive advantage.
Based on specialized dairy literature, in the dairy sector, the main **competitive advantages** are linked to the existence of natural resources, infrastructures, high population density, economies of scale and of scope and market orientation.
Apart from the existence of national infrastructures (e.g. roads, ports etc...), **the existence of suitable farm infrastructures** will also have a positive impact in the competitiveness, in particular in the ability to increase future milk deliveries at national and at EU level.

FOCUS GROUP's statement:

PLFs are special infrastructural features of the future's dairy farms, which can have effects the competitiveness of the milk production. Competitiveness and profitability are the key issues of the robust and resilient milk sector.
Using PLFs can result better management and gain profitability. But different farms (with different environmental conditions and technical background) might need different PLF solutions.
It would be useful to be able to compare different farms in the economical point of view, which are implementing PLF systems.

Possibility

FADN could collect some specific data from the dairy farms, focusing on the technical background. Information can be collected on what PLF system or other management tools are implemented on the given dairy farms. (For development of the FADN a study was introduced in 2015: “Cost of and good practice in FADN data collection” - **EUROPEAN COMMISSION**, Directorate-General for Agriculture and Rural Development, Directorate E — Economic analysis, perspectives and evaluation by Dr B. Dylan Bradley and Professor Berkeley Hill).
Also other sources can be integrated into the survey. If some specific data are too detailed for a system like FADN professional organizations can be involved in, for example EDF (European Dairy

Federation). Specific analyzes can be carried out by these organizations. Even the EU MMO service can take role in the evaluations or can get some feedback.

Proposal

Milk sector is already a well monitored part of agriculture. Because of the early CAP Milk CMO, well developed systems are introduced for observation, and the "Milk-package" enforced more detailed observation of the sector. So the bases of the sector-level analysis are given. Based on that, there is possibility to improve the FADN system concerning milk sector and to make survey on the level of management of the dairy farms. Also possible to link different database and knowledge to each other like EDF or MMO.

To make improvement in the milk sector – in the meaning of robustness and resilience – more information should be evaluate in the future. This information should be more specific and should focus on the level of the farm-management more than earlier.

Therefore, it can be recommended to develop the FADN system as below:

- In the frame of structural database some specific information should be collected, focusing on specific production parameters (replacement, first calving age, culling rate etc.)
- In the frame of structural database some specific information should be collected, focusing on management level (used management tools, integrated monitoring, PLFs etc.)
- In the frame of public database specific reporting should be available focusing on the connection between the specific production parameter and management level and margins of the dairy farms.
- Link should be built up between different sources like Milk Market Observatory and European Dairy Farmers or other NGOs.
- DG-Agri should encourage the different professional bodies like FADN's national institutes or national Inter-branch Organizations (IBOs) or EU level public organizations (EDF) to make voluntary surveys on concerning of the connection between farm management level and margins. Some specific subsidies can be provided for that type of activities.

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