Improving animal health and welfare by using sensor data in herd management and dairy cattle breeding – a joint initiative of ICAR and IDF

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Abstract

Digitalization is advancing with rapid developments in farm technologies, which has the potential to revolutionize dairy production and to improve its long-term sustainability. Farmers are increasingly using sensors and other technologies that monitor various parameters on their farms. Large amounts of data are collected, but just a small fraction is currently used along the dairy value chain. This has motivated the International Committee of Animal Recording (ICAR) and the International Dairy Federation (IDF) to start a joint initiative aiming at providing guidelines and best practices for using data from sensors across systems and applications, with a focus on functional traits such as health and animal welfare. The key partners are the ICAR Functional Traits Working Group and the IDF Standing Committee of Animal Health and Welfare who have formed a network of representatives from various stakeholders and leading scientists. Research and approaches to improve the usability of data are discussed to promote knowledge transfer and practical implementation in the dairy industry. Experiences and best practices are exchanged, and recommendations for the use of sensor data are being elaborated. The results will be broadly disseminated through ICAR and IDF avenues. Furthermore, the collaboration among multidisciplinary experts is enabling a holistic approach to the current challenges faced by the worldwide dairy industry and will facilitate cutting-edge research and innovation. The initiative will be presented, with

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a progress report on reference standards, harmonized definitions, and terminology, as well as recommendations and best practices regarding data cleaning and editing and definition of novel traits using data from sensor technologies in herd management and genetic evaluations.

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Introduction

Recent advancements in sensor technologies have significantly enhanced the capacity to technically support farmers and their advisors in monitoring the health, performance, and welfare of dairy cattle. As presented in the systematic review by Stygar *et al*. (2021) and in other focused reviews (e.g., Hogeveen *et al*., 2021), a wide range of commercially available sensor systems exists and promise significant gains in the understanding and improvement of welfare in livestock. The technologies cover the spectrum from wearable devices with multiple functions (e.g., tracking of physiological parameters) to environmental sensors that monitor housing and climatic conditions, and collectively aim to provide actionable information about animal health, reproductive status and well-being. Most wearable sensors rely on 3D accelerometers, which measure acceleration or motion to quantify cow behaviour. Manufacturers use algorithms and pattern recognition to enhance the raw accelerometer data and produce sensor systems which recognize rumination, eating, lying, standing, and other behaviours using the data from sensors on the cow's leg, neck, ear, or tail. The integration of sensor systems in livestock farming presents numerous opportunities to enhance animal health, performance and welfare, supporting farmer decision making on individual cow and group level and farm efficiency. However, while large amounts of sensor data are being collected, only a small fraction is currently used on farms, in genetic evaluation and breeding programs, or along the dairy value chain. To maximise the use and potential of data derived from sensor systems for herd health, production management, genetic and genomic selection, and welfare quality assurance programs, we need to address several challenges. Combinating sensor-derived data with routinely recorded data may be a key factor for more confidence in the use of data from advanced technologies and sensor-based herd management systems among stakeholders, including farmers, consultants, authorities, dairy processors, breeding companies, and consumers. The currently low fraction of commercially available sensor systems with independent validation (14%; Stygar *et al*. 2021) shows the clear need for more extensive validation of sensor systems in diverse farming environments, across different farm and management systems and geographical locations. Comparing different sensor systems poses a significant challenge due to the lack of standardized and agreed on criteria for evaluation and validation.

This has motivated the International Committee of Animal Recording (ICAR) and the International Dairy Federation (IDF) to start a joint initiative aiming at improved usability of data across sensor systems and applications. The initiative leaders are the ICAR Functional Traits Working Group (ICAR FTWG) and the IDF Standing Committee of Animal Health and Welfare (IDF SCAHW) in collaboration with international experts from academia and industry organizations. The primary aim of this initiative is to promote the integrated use of sensor data and derived novel traits along the dairy value chain. Standardisation and harmonisation will be supported through guidelines that include basic definitions and recommendations regarding data processing and use. Topics addressed include reference methods, data cleaning and validation, trait definitions for herd management and selective breeding, genetic improvement, and quality assurance.

This paper's main objective is to present the methods and working strategies that the joint initiative will use to achieve its aim, using rumination as a case study.

With the increasing adoption of sensor systems in dairy farming, the number of different technologies provided by different manufacturers has increased. While the diversity offers farmers the opportunity to choose a system that best suits their own farming set-up, it has increased the variation in type of measurements, type of data generated, algorithms, sensor output, attention lists and monitoring key performance indicators. This poses challenges to advisors, researchers and other stakeholders when interpreting sensor outputs across technologies and brands and comparing herd performance. The joint ICAR/IDF initiative will provide definitions for health or behaviour situations and conditions that can be measured by sensor systems. Those definitions will be based on the primary premise that the condition of interest should be detected or quantified irrespective of the applied technologies and with a level of accuracy that enables users to make meaningful decisions based on the supplied information. To promote the use of data from sensor technologies along the dairy value chain, the collection and use of reliable data is key, emphasizing the need for validation or at least documentation of the performance against a reference standard, i.e. to show that the technology measures what it is supposed to measure. Agreement on a reference standard method is crucial as is common understanding on how to perform comparisons and report results. Furthermore, establishing a minimum level of accuracy might be helpful. Irrespective of the use of sensor data (management support, research, genetic evaluation), the processes of validation and standardization are key to ensuring that the data collected from diverse sources are comparable, reliable, and usable.

Definitions and reference methods

While developing these standards and recommendations we chose a participatory approach to address stakeholder concerns such as intellectual property considerations and achieve a common understanding with manufacturers. If, for instance, a product is offered as rumination sensor, the output should be easy understandable and reflect the actual rumination behaviour of a cow.

Harmonized terminology is fundamental to the standardization process, which comprises the development of common definitions and descriptions. The very positive experiences with the ICAR Claw Health Atlas (ICAR, 2020), presenting different lesions in the distal limb of bovine with harmonized names and descriptions, illustrates the potential for success of the current initiative on sensor data relating to health and welfare of cattle, with first results to be expected for rumination. The IDF action team on sensor-based health management recently published guidance for udder health management with sensor systems (Hogeveen *et al*, 2021). ICAR and IDF have experience in leading the standardization efforts with strong engagement to provide the crucial framework and promote a more integrated and forward-thinking approach to dairy farming technology.

Achieving agreement on a ‘gold standard’ which is appropriate across measurement approaches, is difficult for a biological phenomenon such as rumination where interactions and influences on its expression must be considered (e.g., farm environment, nutritional input, other management factors). In this case, rumination time may be the most suitable biological parameter to allow quality assessment and comparison of sensor outputs for the rumination process. Here, knowledge on the major sources of variability in rumination time (which include diet composition, breed, and health status) exists and facilitates defining standard criteria and conditions for validation. The target for a rumination sensor may be, for example, a correlation of 80% between sensor-recorded rumination time and the visually recorded rumination time in healthy cows of a given breed on a given diet. Because certain layers of complexity or specific sources of variability across herds and animals may or may not be accessible in any environment, reference standards need to be adaptable and robust enough to cope with that. A deep understanding of animal physiology and behaviour within the range of farming settings, is needed to establish baselines and thresholds for deviations that are both scientifically valid and practically applicable across diverse farming conditions.

Such agreed references and standards are indispensable for the validation and calibration of sensor outputs, because they help to ensure that accurate and actionable data is used across the dairy value chain, that products and services within the industry are comparable, and uniform approaches to data interpretation and decision-making can be used. Thus, the efforts of ICAR and IDF to harmonize definitions and develop industry-wide standards and guidelines are not merely procedural but are vital for the advancement and sustainability of dairy production on a global scale. The interdisciplinary approach and wider exchange with stakeholders will contribute to acceptance and adoption of standards despite the operational challenges which may be substantial. ICAR is offering tests for milk (recording) devices according to agreed standards, which are described in the ICAR guidelines (www.icar.org). Devices that pass such test receive an ICAR certificate. One of the aims of this initiative is to elaborate and recommend options for validation of sensor systems.

Data cleaning and quality of sensor data

Sensor data can be noisy, and the output variables that are presented are the result of the use of an algorithm that transforms raw sensor values into variables such as rumination time or activity level. Typical errors in sensor data include outliers, missing data, bias, drift, noise, constant value, uncertainty, and stuck-at-zero conditions (Teh *et al*, 2020). Examples for cleaning sensor data can be found in Schodl *et al* (2022). Proper data integration and interpretation is dependent on reliable assignment of records to individual animals and on coordination of times of recording. Furthermore, whenever working with sensor data, it must be considered that the processes used for cleaning, procedures and transformation of raw sensor data into variables such as rumination time or activity values are usually proprietary to the sensor companies, which means that these procedures cannot normally be shared or used by others. Analyses of data structure and quality require an understanding of the type of measurements, i.e. single-shot measurement at a certain point in time versus already summarized or averaged figure (Bouchon *et al*, 2019). Visualisation of the data is helpful in understanding the type of distribution, patterns, gaps, outliers, etc. (Unwin, 2020). Detecting and removing outliers is a very important step in the data cleaning process. Another important aspect is the detection of technology -related noise such as measurement drift (Giannoni *et al*, 2018; Munirathinam 2021). The same is the case for sensor calibrations or replacement and software updates and ideally this information should be available from the sensor companies. Finally, all data cleaning steps should be documented and reported. The integration and availability of other data sources (calving date, breed, events like in heat etc.) is beneficial for data cleaning and validation.

Use of sensor technology for herd management and welfare assurance

Rumination behaviour data from sensors has been used successfully on working dairies around the world, implying availability of mature technology with proven results across multiple manufacturers. Changes in rumination are linked to feed intake, and a reduction may indicate health issues (including metabolic and non-metabolic disorders, like mastitis or pneumonia). Identification of drops in rumination can help identify individual cows which require manager or veterinary intervention. Especially in early lactation, monitoring of rumination patterns is of high value for timely disease detection and proper intervention and treatment. At the group level, rumination data is a useful tool to monitor and manage feeding during the lactation or to identify stressful situations in the herd. The particular value of rumination data from early lactation is obvious due to the increased risk of metabolic diseases. Early identification of affected cows can facilitate a successful intervention through therapeutic treatment. Whereas research often focuses on the sensitivity and specificity of sensor-based alerts for identifying disease, high false positive rates (where unaffected animals are identified as a positive case) may have practical benefits in larger operations through reducing labor costs.

As rumination decreases around the time of an estrus event, the accuracy of estrus detection can be improved by including rumination data. In general, sensor-based alerts rely on deviations from each individual cow's baseline. Thus, consistency within a technology from the farmer's perspective may be at least as important, or even more important than the relationship to a 'gold standard'. However, direct comparisons of rumination times across technologies can lead to false conclusions. Studies with multiple rumination technologies attached to the same cows have shown that differences in rumination time across technologies can be large (Zambelis *et al*., 2019). Guidelines, video tutorials and protocols for visual assessment of rumination are available and support collection of observation data.

To date, sensor technologies are rarely used for welfare assessment in quality schemes (Stygar *et al*, 2022). However, research efforts have been made to develop algorithms which classify dairy cow welfare into good, moderate, and poor using data from various sensors (Stygar *et al*, 2023). Standardization of rumination definitions across manufacturers is necessary for the development of a global welfare assessment algorithm from a technical point of view. Common implementation practices will also be beneficial in terms of reducing the cost of sensor-based welfare assessment.

However, wider use of the rumination data as for welfare quality programmes, breeding purposes require interoperability of data from various sensor systems, such that definition of the rumination trait(s) can be performed across data sources. Agreement on standards and common definitions is prerequisite.

Use of sensor data for genetic improvement of novel traits

The large number of variables recorded by sensor technologies can be integrated with routinely collected variables for deriving novel welfare indicators for management and breeding purposes (Brito *et al*., 2020). Ideally, the derived traits should capture the biological mechanisms of interest, be heritable and repeatable, and be clearly defined and evaluated in a standard way across breeding programs. After identifying the variables of interest (e.g., rumination time), statistical models need to be developed for the genetic analyses. Modelling systematic effects (e.g., parity, lactation stage, herd, season, diet, reproductive stage, housing time) that significantly influence the target trait is enabled by integrating sensor data into the established data infrastructure for dairy cattle. Comprehensive genetic analyses of the target trait(s) and possible correlated traits provide the genetic parameters for setting up genetic and genomic evaluations: additive genetic (co)variances, heritability, repeatability, genetic correlations. In the context of sensor-based measures of health and welfare, multiple trait analyses may include, e.g., direct health traits, feed efficiency, methane emissions, milk production and composition, productive life, reproductive performance. Additional genome-wide association studies and functional genomic analyses can contribute to better understanding the genomic background of the target trait.

Functional traits are integral parts of the breeding goals and breeding programs of dairy cattle. However, the main challenge for health- and welfare-related traits is the often limited availability of phenotypic data (e.g., veterinary diagnoses, farmer observations, records from hoof trimming) and mostly low heritabilities. The continuous data collection provided by sensor technologies offer new possibilities for multiple trait solutions with the potential for integrated data usage in future genetic evaluation routines. Key challenges to be overcome include access to data, protocols for integrating data from different data sources, many different data providers, tools with different information from different data providers and different resolution of the information, a lack of background information on the data, regular updates with respective needs to adjust the data pipelines for genetic analyses, and the large amount of data (Egger-Danner *et al*. 2022).

However, research on the use of sensor data for breeding is ongoing, with publications on fertility (Heringstad and Wethal, 2023), resilience traits (Poppe *et al*. 2022) and others. With regards to rumination, focus has been mainly on 'Rumination Time (RT; min/day)' which represents the time per day a cow spends ruminating. Derived variables that have been proposed include daily average RT, 2-hour averages of RT (Hut *et al*., 2022), changes in RT during specific time periods as well as trait definitions based on deviations and more recently, longitudinal measurements of RT have been suggested as measure of overall resilience. For RT, heritability estimates of 0.14 - 0.45 have been reported (Byskov *et al*., 2017; Lopes *et al*., 2022). Future research will show whether breeding and management purposes will benefit from combined use of several sensor-derived traits (e.g., rumination together with activity).

Conclusions

Both ICAR and IDF see great benefit in providing standards and recommendations for the use of sensor data to improve cow health and welfare to the benefit of farmers, manufacturers, dairy herd improvement and breeding organizations, consultants, researchers, dairy processors and consumers. Leveraging the synergies of both organizations will facilitate communication, collaboration between stakeholders and implementation along the dairy chain, e.g. herd management, breeding and welfare quality assurance programs. A participatory approach involving researchers and industry is key to understanding the interests, needs, concerns, and expertise of different stakeholders and develop standards that would benefit all. Expanding our discussion to all stakeholders will bring together the different aspects and approaches, lessons learned and recommendations. The aim is to develop harmonized definitions and terminology that are feasible, acceptable, beneficial, and implementable for the different stakeholders. Improving the quality and comparability of data will encourage use beyond current applications and the development of more accurate tools, thereby contributing to increased sustainability through productivity and economic performance, improved animal health and welfare, and better use of resources and reduced environmental footprint.

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