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Overview of current methods for monitoring behavioral activities and reproduction in dairy cattle: a review

Přehled současných metod monitorování behaviorálních aktivit a reprodukce u dojnic: přehled

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ABSTRACT

The aim of the review was to create a structured overview of the available systems used for monitoring behavioral manifestations, detecting estrus, and tracking the health status of breeders, from historical to modern automated systems. Furthermore, the goal was to present the optimal system variant for monitoring dairy cows to detect occurrences of estrus and assess health status. The current trend in breeding practices undeniably moves towards the automation of observation and analysis of a large volume of data sets, which streamlines and facilitates the decision-making processes in breeding. Modern systems for monitoring estrus manifestations allow for an increase in the reproductive level in dairy herds, an increase in the percentage of detected estrus, and pregnancies in heifers and cows. The efficiency of reproduction depends on many factors such as proper conditioning, energy balance, management of the transition period, and the construction or capacity of the barn. The success of the reproductive program also depends on the ability to identify breeders suitable for insemination and then inseminate them at the correct time. In the future, methods based predominantly on precise computational principles should be used for detecting animals suitable for insemination, allowing for continuous and long-term monitoring and evaluation of animal manifestations. Other methods not based on electronic principles do not achieve the desired level of efficiency due to high production and metabolic stress, which is manifested by lower intensity and shorter duration of physiological and behavioural manifestations of estrus. As a result of these factors, a combination of automatic monitoring methods using neck responders and targeted application of hormones in justified situations appears to be optimal.

Keywords: estrus detection, cow reproduction, automatic monitoring of cow estrus, reproduction improvement, activity meter, accelerometer

ABSTRAKT

Cílem review bylo vytvořit strukturovaný přehled o dostupných sytémech využívaných ke sledování bevaiorálních projevů, vyhledávání říje a sledování zdravotního stavu plemenic od historie až po moderní automatizované systémy. Dále bylo cílem uvést optimální variantu systému pro monitorování dojnic za účelem zjištění výskytu říje a zdravotního stavu. Současný trend v chovatelské praxi nepochybně směřuje k automatizaci pozorování a analyzování velkého množství datových sestav, které zefektivní a usnadní rozhodovací procesy chovu. Moderní systémy sledování projevů říje umožnují zvýšení reprodukční úrovně v chovech dojnic, zvýšení procenta vyhledaných říjí a březosti jalovic a krav. Efektivita reprodukce je závislá na mnoha faktorech jako jsou správná kondice, energetická bilance, management tranzitního období nebo konstrukce či kapacita stáje. Úspěšnost reprodukčního programu také závisí na schopnosti identifikovat plemenice vhodné k inseminaci a ve správnou dobu je následně zapustit. Pro detekci zvířat vhodných k inseminaci by se měli v budoucnosti používat převážně metody založené na precizních výpočetních principech, umožnujicí nepřetržité a dlouhodobé sledování a vyhodnocování projevů zvířat. Ostatní metody založené na jiném než elektronickém principu nemají požadovanou míru efektivity z důvodu vysoké produkční a metabolické zátěže, což se projevuje nižší intenzitou a kratší dobou trvání fyziologických a behaviorálních projevů říje. V důsledku těchto faktorů se jako optimální jeví kombinace metod automatického monitorování pomocí krčních responderů a cílená aplikace hormonů v situacích, kde je to opodstatněné.

Klíčová slova: detekce říje, reprodukce krav, automatické sledování říje krav, zlepšení reprodukce, měřič aktivity, akcelerometr

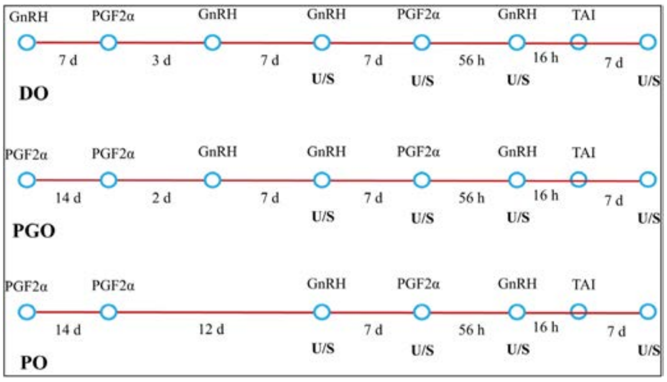
INTRODUCTION

In current dairy farms, modern technologies providing relevant data for management decisions are becoming more and more widespread. Based on this data, breeders can effectively optimize work procedures and define weak points in breeding (Fogarty et al., 2020). Among such technologies can be included, for example, automatic systems for monitoring the movement activity of animals, which can detect estrus, or reveal a reduction in movement activity and rumination time ahead of time, on the basis of which the initiation phase of the disease can be predicted. In general, it can be stated that modern elements of precision agriculture allow farm animals breeders to reduce the costs of treating farmed animals (Van De Gucht et al., 2017), for example by effectively rearing calves, optimizing their proper nutrition, or by subsidizing feed supplements with an anti–diarrheic effect, which have a positive effect influence on their health (Zábranský et al., 2015). The most widespread technology used to monitor dairy cows are nowadays monitoring systems on the neck, leg or ear of the animal. The main benefit of these systems is the automatic collection of data on the movement of the animal continuously for several years.

FROM HISTORY TO CURRENT METHODS OF MONITORING THE MANIFESTATIONS OF COWS

Monitoring different movement patterns of animals during estrus is one of the oldest monitored parameters of the suitable time for mating, the origins of which date back many years to the history of livestock reproduction management. Already in 1994, Senger (1994) described a suitable system for detecting signs of estrus based on the manifestations of animals. In the field, we can encounter various methods of searching for rutting heifers, from the original visual observation, which is a very professionally demanding and time–consuming method, to scratch tapes, to pressure-activated adhesive elements supplemented with a timing mechanism, which are placed on the spine between the iliac bones. Firk et al. (2003) indicates in his work that visual observation should not be carried out during milking or feeding, it should be carried out in the morning and with more attention compared to observation in the afternoon. We can also encounter tail–paint–marking (Dhakar et al., 2018), or chin–ball markers located on the lower jaw (Madkar, et al., 2022). We also encounter pressure–sensitive sensors KaMaR® and BeaCon heatmount detectors (Riaz et al., 2023; Saint–Dizier and Chastant–Maillard, 2012), or stickers filled with contrast dye Heat Patch Plus (Kumar et al., 2013). A less common option are androgenized cows (Moorey et al., 2022) or vasectomized teaster bulls, which represent a possible method of estrus detection in combination with other methods. The disadvantage is the higher cost of breeding such animals (Barman et al., 2022). All of these mentioned methods can be used, but the reproduction results show that in field conditions, these methods do not achieve the desired results and are not suitable for the needs of timed artificial insemination.

In recent years, modern automatic estrus detection systems, either alone or supplemented with after detection of estrus (AIE) by hormonal synchronization using PGF2α and GnRH (Cunha et al., 2021; Fricke et al., 2014), which allow sires at the right time and thereby help to increase the percentage of conception in the herd (Martins et al., 2023). The aim of the application of hormonal preparations is to induce estrus and then implant the synchronized heifers at the specified time. The most common reason for the introduction of hormonal protocols ovsynch, presynch, doubleovsynch, etc. estrus detection level is low. Another reason for using the hormonal synchronization method is the minimization of human factor errors, which is related to the reduction of costs (Islam, 2011). Timed artificial insemination (TAI) makes it possible to reduce labor costs connected with searching for estrus, further eliminate errors and shorten the length of days open (Galvão et al., 2013). There are many options for synchronizing estrus and ovulation in cows. As evident from Figure 1, the hormones common to many synchronization protocols include prostaglandin F2α (PG), gonadotropin releasing hormone (GnRH) and progestin, available in commercial products under the names: PG: estroPLAN®, Estrumate®, In–Synch®, Lutalyse®, ProstaMate®, GnRH: Cystorelin®, Factrel®, Fertagyl®, OvaCyst®, Progestin: MGA® (melengesterol acetate), CIDR® (progesterone) (Johnson et al., 2010).



A horizontal timeline with interventions marked by circles and durations specified in days or hours is presented. DO – Double–Ovsynch; PGO – Presynch–GnRH–Ovsynch; PO – Presynch–Ovsynch; U/S – ultrasonography; GnRH – Gonadotropin–releasing hormone; PGF2α – Prostaglandin F2 alpha. The mean Days in Milk (DIM) at the initiation of each protocol were as follows: DO: 38 ± 3, PGO: 32 ± 2, and PO: 29 ± 2 days (Dirandeh et al., 2015).

Figure 1. Schematic of synchronization protocols and TAI (Timed Artificial Insemination)

By applying the prostaglandin PGF2α preparation and its chemical analogues, we ensure the regression of the corpus luteum (CL), decrease in the progesterone level and acceleration of the growth and maturation of the dominant follicle (Inbaraj et al., 2021), which causes a shortening of the luteal phase. One of the most widely used synchronization protocols, Ovsynch, synchronizes follicular development, CL regression and egg release (ovulation), whereby TAI is performed at a set time without the need for visual detection of estrus (Giordano et al., 2011).

Historical milestones in automated estrus detection

The origins of automatic estrus detection methods date back to 1954, when E. J. Farris (1954) developed the first system for this purpose. In 1972, Williamson et al. (1972) reported in their work several observed indicators of the beginning of estrus. In general, the period of estrus of cows lasts between 12–16 hours, but we can encounter a range of 2–30 hours. With regard to the increasing milk yield of cows, the estrus period is reduced to an average of 6–8 hours (Forde et al., 2011). The length of the estrous period is influenced by a number of endogenous and exogenous factors, such as reproductive management, nutrition and feeding, size of groups (Giordano et al., 2022), environmental temperature, temperature–humidity index (THI), amount of sunlight or season (Kumar et al., 2022). Estrus is generally defined as the period when a female can become pregnant, or when the ovaries release an oocyte (Palmer et al., 2010), which is accompanied by secondary symptoms that may vary in duration and intensity. Most often, we can observe signs of an increase in physical activity up to 4 times, a decrease in feed and water intake, attempts to jump on another cow, discharge of mucus from the vagina, sniffing at the genitalia of other cows, swelling and redness of the external parts of the reproductive system, an increase in the frequency and duration of cows spawning between and increased vocalization (Röttgen et al., 2018). Continuous monitoring of the movement activity of the heifer is essential, as signs of estrus are usually observed early in the morning (Santos et al., 2022). The method of analyzing steroid hormones (Antanaitis et al., 2021), specifically gestagens in milk such as Progesterone (P4) with the structural designation pregn–4–ene–3,20–dione (Goncharov et al., 2021; Berger et al., 2017 has expanded significantly) in recent years. It is the main protein–bound CL hormone that circulates in the blood, so it is transported to milk in the mammary gland. An important function of progestogens is to protect pregnancy by preventing uterine contractions and at the same time prepare the endometrium to receive a fertilized egg. During the luteal phase and during pregnancy, the concentration of progesterone increases rapidly up to the level of tens of ng/ml in milk (Ginther et al., 2006). Progesterone tests are performed on the basis of several milk samples in given terms. They work on the principle of evaluating the decrease in the concentration of the hormone in the body during the estrous cycle. Traditionally, biosensors based on the principle of antibodies were used, but this method was expensive and difficult to apply in practice (Zamani et al., 2022). The standard nowadays is the fully automated real-time milk progesterone analyzer Herd NavigatorTM (Lattec I/S, Hillerød, Denmark) in combination with the DeLaval milking robot (DeLaval Inc., Tumba, Sweden) (Antanaitis et al., 2020). This progesterone measurement system helps to increase key reproductive parameters but also allows assessment of luteal activity (Wiltbank et al., 2014).

Generally known indicators of the estrus phase are, in addition to generally known external manifestations, changes in behavior, such as the willingness of a female to let another female jump on her, provided there is sufficient space and suitable technical and structural conditions in the stable. Secondary indicators of estrus can also be increased nervousness of the animal, increased locomotion activity and greater interaction with other animals in the group (Higaki et al., 2019). Visual detection of estrus is time–consuming and requires a specific ability of the observer to monitor carefully behavioral manifestations. In commercial farms, being good at this can make up to 30% of the chances of impregnating heifers. The results of studies indicate that visual detection of estrus in a herd detects up to 58% of estrus, while automatic monitoring systems that continuously monitor deviations in animal behavior detect up to 80% of estrus (Tsai et al., 2020). The use of synchronization protocols has also led to an increase in the number of cows suitable for insemination and to an increase in sought estrus of inseminated animals up to approximately 85% (Yaniz et al., 2004; Van Eerdenburg et al., 2002). In high–yielding dairy cows, especially the Holstein breed, the duration of estrus is significantly shortened (Lucy, 2007), which is caused by higher milk production, resulting in an acceleration of the metabolism of the hormone estrogen and a direct influence on estrus behavior compared to heifers, in which production is not the cause of a reduction in the duration of estrus manifestations (Sartori et al., 2012). Toledo–Alvarado et al. (2018) states in their work that milk yield decreases during estrus, which they explain by increased restlessness and reduced feed intake. Roelofs et al. (2005) found that milk yield dispersion was more influenced by day of lactation than day of estrus and also that milk yield did not decrease in all estruses.

In some cows, the estrus indicators, which represent the optimal window for insemination, are evident for 4–8 hours, whereas, all signs of estrus can be manifested for an average of 11–14 hours.

MODERN WAYS OF MONITORING MOVEMENT ACTIVITY AND THE HEALTH OF COWS

In modern high–production dairy farming systems, we meet up to 60% of cows with so–called silent heat, which means that the animal will go into heat without changing its behavior. According to the results of scientific works, silent estruses occur more in the summer months (Amin and Said, 2021). Determining the correct time for insemination requires constant observation and data evaluation of a large amount of data. The use of modern systems for detecting changes in behavior enables to find a higher percentage of estruses, which in turn leads to an increase in the percentage of inseminated cows and subsequent pregnancies. Practical experience and scientific findings consistently confirm the usefulness of implementing automatic systems as a suitable tool for improving the efficiency of reproduction in dairy farms (Gobikrushanth et al., 2014). This increases the amount of milk produced per unit of time (Vrhel et al., 2021), which will also affect the quality and ultimately the profitability of the farm.

In recent years, dairy farmers and professional agricultural societies have encountered increasingly frequent objections from the public to the excessive use of hormonal preparations in dairy farms. As a result of these concerns about overuse and increasing concentrations of hormones in the environment (Yazdan et al., 2022), new procedures and tools for the early detection of estrus are expanding and improving, allowing breeders to increase the level of reproduction (Galchenko et al., 2022). Traditional methods of monitoring the signs of estrus in heifers are beginning to be insufficient due to the high intensification of the dairy industry and welfare requirements in dairy farms. Many commercially available sensors are used to detect estrus, such as an electronic pedometer or a cow neck collar (Brehme, et al., 2008). In modern practice, these technologies are among the standard technological tools used to monitor life's economic manifestations (Shallo et al., 2022; Niloofar et al., 2021).

Smart technologies used in animal production are modern tools that can be classified as elements of precision agriculture. A comprehensive system of smart systems and technologies is widely used throughout the world, not only in high–production herds, but also in extensive farming systems. Modern technologies, such as elements for continuous monitoring of animals, allow farmers economic, social and environmental benefits (Lovarelli et al., 2020). At the same time, these new technologies require a large amount of data for relevant calculations and interpretation of observed phenomena. The continuous collection of a large amount of data and information, for example, during the feeding, watering, lying or rumination period of cows allows to better identify and subsequently eliminate the causes of stress factors that can significantly affect the welfare, level of production and reproduction of farmed animals (Wagner et al., 2021). Additionally, Riaboff et al. (2022) emphasize in their work the wide range of commercially available sensors designed to monitor animal movement. Types based on a three–dimensional accelerometric sensor currently seem to be a suitable variant of a precise animal movement sensor. Commercially available technologies are based on the principle of tracking the direction and magnitude of acceleration during animal movement. Activity meters, vital meters, and pedometers are now commonly used technology in milking herds around the world to look for heifers in heat or health problems. This system enables relatively accurate monitoring and evaluation of various aspects of activity, such as time spent walking, number of steps, lying or standing time, chewing time, etc. Information from these devices makes it possible to identify problems with, for example, cloven hooves (Halachmi et al., 2019).

Some devices detect the location of dairy cows, for example, using a GPS signal, which facilitates zootechnical work (Achour et al., 2022). Step–measurements or otherwise known as pedometers have been a generally used technology for monitoring the nature of physical activity for many years. Originally, these were simple mechanical devices. Pedometers became popular around the mid–1960s, when Professor Yoshiro Hatano, of Kyushu University, conducted research on the topic of exercise and calories, as a result of the declining health of Japanese people. The first device was the "Manpo–Kei" – 10,000 step meters, which was a simple step counting device (Watters, 2017; Tudor–Locke et al., 2008). The development of pedometers also focused on the application of these devices in the breeding industry. The first electronic pedometers intended for animals were experimentally put on in 1977 with the aim of improving the reproductive performance of farmed animals, because the effective detection of estrus and insemination at the appropriate time can influence the level of reproduction. Devices record increased movement activity during estrus or, on the contrary, reduced activity during diseases (López–Gatius et al., 2005). The first types of pedometers were based on the principle of detection using a mercury sensor, which detected movement only in the vertical direction. Depending on movement and tilt, the mercury system turns on or off, which simultaneously enabled step counting (Firk et al., 2002). At each shake above a certain level, pulses were generated, which were subsequently processed by a microprocessor. This type of sensor was placed only on the leg of the animal. The recording of the number of pulses was sent near the antenna of the milking parlour.

Every time the animal passed through the milking parlour, the number of pulses was recorded (Poborská et al., 2016). The next generation of pedometers began to use sensors equipped with a passive 3D sensor consisting of a coil and a magnetic ball that generated electrical voltage during movement. Even though these pedometers had limited sensitivity and could not recognize the direction of movement, it was possible to use them on the neck and the leg of the animal (Rutten et al., 2013). Currently, there is a wide range of technologies in breeding practice, using sophisticated devices for monitoring animal activity. These pedometers are characterized by diverse characteristics in the area of range, durability, affordability and quality of data processing. These devices are constantly active, but require an electrical power source to operate, which is somewhat of a limitation.

The operating time of these devices can range from three to ten years, and the batteries are mostly non–replaceable. It is therefore necessary to invest in a new device after the battery is discharged (Stygaret al., 2021; Grodkowski et al., 2018). In recent years, we can see a significant development of accelerometers, as they are massively used in a large number of human activities from mobile phones, watches to commercial aircraft (Chen et al., 2019). In milk cow farms, we meet them in smart technologies such as Vitalimeter, which is the commercial name for a smart device placed on the leg or neck, used to monitor the behavior of cows. The detection of signs of estrus is detected based on acceleration in individual axes and evaluated by the processor according to the detection algorithm. To evaluate the rumination time, microphones on the neck collar, among other things, were previously used, which recorded the sound level that corresponded to the level during rumination (Novotná et al., 2015). Modern methods of monitoring and evaluating the time of eating and chewing use the function of accelerometers in the Vitalimeter, which, similarly to the evaluation of movement, detects acceleration in axes and evaluates the processor based on detection algorithms (Poborská et al., 2016; Soriani et al., 2012). In their publication, Liberati and Zappavigna (2003) report the results of research comparing techniques based on tracking comparisons of commercially available activometers that measured data in three cohorts, every one hour, every 12 hours and every 5 minutes. The aim was to verify which procedure better detects estrus. In general, the authors believe that a more frequent frequency can improve the accuracy of estrus detection with respect to values that are not averaged, but mean values for each hourly or five–minute time intervals are examined. The disadvantage of such a system is the high energy consumption from the battery and thus a shorter service life. The basis of most automatic monitoring systems in animal production are various types of gyroscopic or accelerometric devices (Cornacchia et al., 2017). An electronic flywheel (gyroscope) is a sensor that allows measuring the magnitude of mass deflection in a certain direction, which is manifested as a change in electrical capacity. A gyroscope can measure angular velocity, i.e. the change in angle in radians over time. There are several classes of gyroscopes, depending on the technology and physical activity. Gyroscopes can be part of a complex system such as an inertial measurement unit (IMU), for example as a gyrocompass in a navigation system (Passaro et al., 2017). While an accelerometer is a device for measuring movement against gravity, detecting and measuring vibrations (oscillations) or measuring acceleration caused by another body (tilt) (Reguieg et al., 2019). The most common type is Micro–Electro–Mechanical Systems (MEMS), which use microscopic mechanical structures that move in response to acceleration and change electrical signals. These changes can be detected and converted into values that are further processed by computing systems (Xu et al., 2011). This type is suitable for measuring vibrations or impacts, as it achieves a high frequency response (Tian et al., 2016).

Monitoring of animals using image analysis

Automatic monitoring and image analysis suggest potential possibilities for more efficient management of farm animals, due to a significant reduction in the workload of the manager (Chung et al., 2014). Modern breeders have a variety of options for detecting estrous heifers, but research shows that commercially available systems do not achieve the desired results, as they can still report false alerts of estrus. In addition, these detection systems are relatively expensive and labor–intensive for large farms, as workers must verify all individual devices individually. Various image monitoring systems based on image analysis can be a suitable alternative. This issue was dealt with by the author's team (Achour et al., 2020), who investigated the individual recognition of animals by image analysis and followed the eating of dairy cows using Convolutional Neural Networks (CNN). For each animal, the upper part of the head was loaded as a Region of Interest (ROI), which served as classifiers based on the models (CNN). The evaluation was made on the basis of 7265 images of 17 Holstein dairy cows. In conclusion, the authors show that the use of CNN is very practical in complex environments, such as agricultural complexes, where image disturbances such as dynamic backgrounds, poor lighting, etc. are often present. The authors of the study believe that the most suitable classifier with the highest accuracy to identify dairy cows is a Clustering–multiples CNN. The authors managed to achieve 97% accuracy in the identification of cows on a selected sample of cows, which can be considered a valuable basis for further expansion of knowledge.

The infrared method, introduced in the work of Wang et al. (2023b), presents new ways of interpreting changes in the infrared imagery of selected parts of cows, such as the temperature around the eyes or vulva, which in the future could contribute to a more precise search for estrus heifers. Based on the LOGISTIC model, they achieve up to 82.37% estrus detection rate when using the so–called segmentation contour. The results indicate that the chosen method could be useful, as the temperature in the eye and vulva of rutting cows was increased compared to anestrous cows, which could be due to the higher level of estrogens and prostaglandins and the vasodilation effect, due to which the temperature increased by 1 – 2 °C in cows in estrus (Bertoni et al., 2020). In the conclusion of the work, the authors state that the applicability is for the time being rather for observations on a smaller scale due to the limitation of taking images (Dela Rue et al., 2013).

Other modern methods of monitoring and evaluating rutting heifers include the use of an automated system with a side–view camera at a height of 1.5 to 1.9 m above the ground and an applied computer program that can recognize and identify cows that jump on others or cows that let them jump on each other. The installed camera had a resolution of 640 × 480 pixels. The main idea behind the side camera monitoring system is that the camera detects a sudden change in movement (i.e. upward movement, i.e. jumping on another cow (more than 40 cm within 0.5 second) (Chung et al., 2015). These types of movement patterns can be detected using the Optical Flow method, which is a movement estimation method (Tamgade et al., 2009).

The authors Yildiz and Özgüven (2022) dealt in their work with detecting the appropriate time of insemination using Artificial Neural Networks (ANN) based on mobility and environmental data. The authors of the work included data on cow movement, data on movement in the previous period, number of days since the previous heat, temperature, and humidity of the environment in the models. In conclusion, the authors confirm that the accuracy of estrous time prediction is increased by evaluating movement data together with environmental data. The use of big data, artificial intelligence, and machine learning can help reduce costs and the effectiveness of managerial decisions or increase the welfare of animals (Neethirajan, 2020).

The findings of Chung et al. (2013) suggest that the microphone system can be deployed as an independent solution for estrus detection, achieving a precision rate of 94%, and can also serve as an adjunct to established methodologies. Audio data was extracted using Mel–Frequency Cepstrum (MFC) coefficients with feature dimension reduction, and vector data description was used as an anomaly detector.

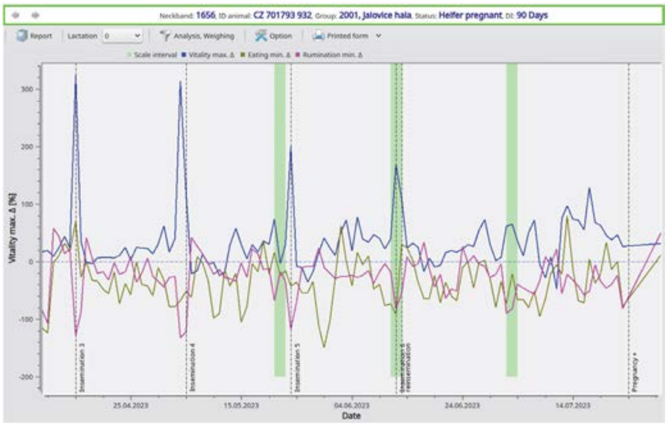
Based on findings and trend monitoring, it can be stated that dairy herd breeders around the world should make more use of modern elements of precision agriculture, because investments in automatic monitoring systems will affect not only profitability and sustainability, but also the competitiveness of the agricultural enterprise (Borchers and Bewley, 2015).

The influence of monitoring technologies on the health status of farmed animals

The incidence of lameness in dairy cows is one of the most serious traumas impairing the welfare and production potential of reared cows (De Mol et al., 2013). Conventional methods use an estimate of the animal's back curvature/posture as the only statistically measurable trait. The principle of these evaluations is that traumatized cows have an arched back (Poursaberi et al., 2010). This method of monitoring was extended by Van Hertem et al. (2014) with an automated lameness detection system based on posterior arch measurement using 3-dimensional (3D) video. According to the outcomes reported by Viazzi et al. (2014), there exists no commercially viable method to date that accurately classifies lameness in a timely fashion and is appropriate for routine application in dairy farm settings.

In their study, Wang et al. (2023a) empirically demonstrate that the application of three-dimensional computer vision monitoring for cows significantly enhances the efficiency and accuracy of quantifying and assessing body weight gain. To analyze the three–dimensional data, we used Kinect sensors, fixed in the nadir position, to monitor in detail the shape and proportions of the dorsal line of each individual. With the progressive development of machine vision and artificial intelligence technologies, it is possible to evaluate behavioral patterns without the need for human intervention (Zhuang and Zhang, 2019).

To illustrate the modern way of monitoring and evaluating the activity of cows, below we present an example of the output from monitoring system of the physical activity and health using the Vitalimeter FA22 neck responder technology (Farmtec, a. s.), which are shown in Figure 2. (Farmtec, a.s. 2010). Evaluation and graphical interpretation of data from the Vitalimeter is processed by the zootechnical program Farmsoft. The program displays a graph of estrus, where deviations in the cow's behavior are also visible.



Above the graph, the basic record data about the cow are shown: Neckband – cow's collar identification number; ID animal – the cow's unique identifier; Group – group of the herd; Location – where the cow is housed; Status – category within the farm; Scale interval – represents the 21 days of estrus; Yield – amount of milk; Yield MPR – Milk Yield by Monthly Production Record; Weight – the cow's weight. The main part of Figure 2 shows the graph, which includes movement activity deviation (Vitality max. Δ (%)), feeding time deviation (Eating min. Δ (%)), and rumination time deviation (Rumination min. Δ (%)), with regular estrous cycles at an interval of every 21 ± 2 days (green vertical stripes). This is supplemented with a record of insemination and re-insemination performed (dashed vertical line).

Figure 2. The movement activity, eating, and rumination time of a cow during her estrus cycle from March 17, 2023, to June 15, 2023, along with insemination records

Table 1 shows a comparison of the current methods of observing and detecting estrus of heifers, which we can normally encounter in breeding practice. Table 1 shows the methods of visual observation, Vitalimeter, image analysis, synchronization protocols and progesterone test assessed according to selected process automation parameters, time required, reliability, level of development, accessibility, mobile application, other uses and price. As a result of the comparison, it can be stated that the most accurate system for detecting estrus is the progesterone test, which reaches up to 95% reliability ($P < 0.05$). While the most expensive method for searching for estrus is Visual monitoring, which is at the same time the least reliable up to 60% ($P < 0.05$), but on the other hand, in the case of an experienced observer, the largest range of information about the reared animal can be obtained with this method, for example the time of food intake, time rumination, incidence of lameness, qualitative behavior assessment (QBA), where appropriate, the level of welfare and the degree of behavioral manifestations in the breeding environment can be evaluated. The method of monitoring estrus using the Vitalimeter can be performed automatically, i.e. the system itself evaluates which individuals are suitable for insemination and sends this information to the user's mobile device. This functionality is also made possible by image analysis, when they install camera systems in the barn, which achieve a comparable scale of use as visual observation with a more precise ability to detect heat up to 90% (P < 0.05) and with the possibility of automating this method. The last compared method is synchronizing hormone protocols + SONO (Ultrasonographic examination). This method achieves a similar reliability of up to 95% (P < 0.05), but it is time–consuming.

The optimal variant of technologies for estrus detection in dairy cows

The best combination and variants for monitoring dairy cows to detect the occurrence of estrus depend on the specific needs, budget, and goals of each agricultural operation. The progesterone test offers high reliability (Ø 95%) and low time requirements, making it an ideal choice for farms prioritizing accuracy and efficiency, assuming cost is not the main limiting factor. For operations seeking a cost-effective yet efficient solution with a good compromise between automation and additional utility, the Vitalimeter represents an attractive option, offering solid reliability results (Ø 80%) at low costs and the capability of further monitoring animal health and behavior. In situations where more resources

Table 1. Comparison of methods of monitoring heifers to determine the occurrence of estrus in agricultural operations

Assessed parameters	Visual monitoring	Vitalimeter	Image analysis	Synchronization protocols+sono	Progesterone test
Process automation	No	Yes	Yes	According To the supplier	Yes
Time requirement	High	Low	Low	High	Low
Reliability	Ø 60%*	Ø 80%*	Ø 90%*	Ø 95%*	Ø 95%*
Stage of development	In practical use	In practical use	Testing	In practical use	Put in operation
Reachability	Demanding	Easy	After Completion Of Development	Medium Demanding	Only In The Producer´s Device
Mobile application	No	Yes	Yes	According To the supplier	Yes
Other uses	Food intake, rumination, limping, QBA, welfare	Food intake, rumination, limping	Food intake, rumination, limping, QBA, welfare	Cysts, abort, anaestrus	Mastitis, Cysts
Price	High	Low	Medium	Medium	High

* P < 0.05; Process Automation – shows whether the process is automated; Time Requirement – expresses the time complexity of the method; Reliability – reliability of the method; Stage of Development – stage of development of the method; Reachability – accessibility of technology; Mobile Application – indicates whether there is a mobile application for the given technology; Other Uses – Other applications of technologies beyond the main purpose; Price – price of the technology.

are available and a broader application of technologies is desired, combining methods such as synchronization protocols with supplementary use of image analysis or mobile applications according to the supplier can provide a comprehensive overview of the herd's health and behavior while maximizing estrus detection accuracy and efficiency. In conclusion, within the context of current capabilities and economic demands, the optimal system appears to be the implementation of Vitalimetrů complemented by the hormonal prophylaxis of pathological manifestations of the bovine reproductive system.

Figure 3. Vitalimeter FA22, a device for monitoring and evaluating the behavioural activity of dairy cows (Source: Farmtec, a.s., 2010)

Figure 3. illustrates the device depicted as the Vitalimeter FA22 neck responder, designed for the comprehensive monitoring of dairy cows' health and behavior. It tracks the animals' behavioral activities, including deviations in eating and rumination patterns, which are crucial for precision livestock farming. The device's advanced sensors enhance estrus detection, improving the timing of inseminations. Additionally, it serves a vital role in early illness detection by identifying the initial stages of diseases, thereby potentially improving herd health management. The Vitalimeter also signals the onset of labor, facilitating timely intervention. Its monitoring capabilities include alerts for decreased feed intake, aiding in maintaining optimal nutritional status. By promoting improved cow comfort and overall animal welfare, this device, manufactured in the Czech Republic, signifies a considerable progression in animal husbandry technology.

CONCLUSION

In modern dairy farms, we can already meet modern technologies using the principles of big data, IoT, or robotics, which facilitate everyday zootechnical work. These systems make it possible to collect and evaluate data on farmed animals and thereby streamline work processes and increase the profitability of production. However, the possibilities of modern technologies allow us to obtain much more important data from devices such as boluses, thermal cameras, microphones, etc. The most used systems include smart collars or pedometers, which are most often used for accurate detection of estrus, thus the appropriate time of insemination of heifers and monitoring of health status based on physical activity, time of eating and rumination. In recent years, we can observe the trend of image processing and data evaluation by artificial intelligence, deep learning and CNN for the purposes of managing the reproduction and health of farmed animals. Current scientific knowledge opens up new possibilities for farm animal breeders. There are still irreplaceable activities that must be performed by humans, but they can make optimized management decisions based on collected data and calculations. It is important that breeders are informed about modern technologies that they can use effectively.

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