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Digital management of technological processes in cattle farms: a review

Дигитално управление на технологични процеси в говедовъдни ферми. Обзор

Nikolay MARKOV (✉), Svetoslava STOYCHEVA, Miroslav HRISTOV, Lora MONDESHKA

Agricultural Academy, Research Institute of Mountain Stockbreeding and Agriculture, 5600 Troyan, Bulgaria

✉ Corresponding author: ncm64@mail.bg

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ABSTRACT

The article evaluates the development of the Internet of Things (I_oT), digital technologies, various types of biological and biometric sensors and blockchain technologies in dairy and beef cattle breeding. The peculiarities, tendencies and perspectives for digital transformation and digitalization of the cattle farms and complexes have been studied. Precise technologies (PFL) make it possible to collect a sufficient cloud of data in accordance with the physiological and technological requirements of the various categories of animals of the species Bos taurus and the welfare of cattle. Biological and biometric sensors help farmers to increase the quantity and improve the quality of their products. Blockchain technologies present cattle breeding in detail, as transparent, stable and predictable in the eyes of the consumer. Cattle breeding is a sub-sector of animal husbandry in which there is no integration, but flexible digital management is applied.

Keywords: digitalization, technology, sensors, cattle, biometrics

РЕЗЮМЕ

В статията е направена оценка на развитието на Интернет на нещата(I_oT), цифрови технологии, различни видове биологични и биометрични сензори и блокчеин технологии в млечното и месодайно говедовъдство. Проучени да особеностите, тенденциите и перспективите за цифрова трансформация и дигитализация на говедовъдните ферми и комплекси. Прецизните технологии (PFL) позволяват да се събере достатъчен облак от данни, съобразен с физиологичните и технологичните изисквания на различните категории животни на вида Bos taurus и хуманно отношение към говедата. Биологичните и биометрични сензори съдействат на фермерите да увеличат количеството и да усъвършенстват качеството на произведената продукция. Блокчейн технологиите представят детайлно говедовъдството, като прозрачно, стабилно и предвидимо в очите на потребителя. Говедовъдството е подотрасъл на животновъдството, в който липсва интеграция, но се прилага гъвкаво дигитално управление.

Ключови думи: дигитализация, технологии, сензори, говеда, биометрия

INTRODUCTION

Humanity as a population continues to grow, and cattle breeding, as a sub-sector of animal husbandry, needs to produce more cattle products of higher quality, while tendentiously respecting animal welfare, the ever-changing environment and public health (Baldy and Cotardo, 2017; Klerkh et al., 2019; Neethirajan and Kemp, 2021).

The welfare of cattle as a species of farm animal is an important indicator for the European Union and this requires the development of a number of methods and concepts for evaluation and monitoring in farms, livestock farms and livestock complexes. Precision cattle breeding provides devices, apparatus and units affecting the management, welfare and health status of cattle

Digitalization is an integral part of modern agriculture. Several digital technologies for different species of domestic animals and birds form the basis of digital animal husbandry. It is not yet clear which digital technologies are most rationally used in cattle breeding. Sensors, measuring devices, electronic controls and options for electronic processing of data clouds, give characteristics and grounds for the application with varying success of devices and robots in the development of modern technologies for dairy cows and technologies for beef cows with suckler calves. At the same time, however, digitalization poses a number of cybersecurity threats to farmers, the state and society (Berckmans, 2017; Camerlink et al., 2018; Bernabucci, 2019; Groher, 2020; Nethrajan and Kemp, 2021).

The scale of dairy farming has changed significantly in recent years with the transition to larger and more intensive, profit-oriented farms and complexes in line with market competition. Identification, non-invasive sensors are vital for the development of the next generation, cattle health monitoring system. This system will allow the automatic identification of the health of dairy cattle by mapping behavioural elements related to technology-specific diseases. The system includes: routine monitoring and veterinary dossier of dairy cows containing veterinary documents. It is divided into four subsystems, compliant with appropriate software (Li et al., 2010; Helwatkar et al., 2014; Munoz-Tamayo et al., 2019).

The aim of the present study is to review, characterize and analyze current scientific views on existing, implemented digital technologies in dairy and beef cattle breeding and to identify prospects for the application of the most advanced, proven models and configurations.

MATERIALS AND METHODS

The research is based on scientific developments related to precision digital technologies, invasive and non-invasive, biological and biometric sensors and blockchain technologies for control of specific technological processes in animal husbandry, respectively in cattle breeding.

As a methodological basis for conducting the research, general scientific research methods, information-logical analysis of scientific and technical information, as well as materials for market research and implementation of intelligent, precise technologies for management in cattle breeding were used.

Descriptive and retrospective analysis were also provided. To achieve this goal, we studied various data on digital technologies applied in Bulgarian, European and world cattle breeding in the period 2015-2021. Structured and systematized information was used, mainly from publications of FAO, MAF, Agrostatistics, Agrarian Reports and others.

RESULTS AND DISCUSSION

According to UN estimates, 9.7 billion people will live in the world by 2050. To feed this population, according to the FAO, the UN Food Agency, there must be a colossal increase in agricultural production of 70% (FAO, 2020).

The Internet of Things (I_oT) is a set of technologies that shape the future of humanity. Its concept is based on identified, interconnected devices (sensors, computers, mechanical devices) that collect data and store it in an information cloud that is processed by intelligent algorithms (Ilyas and Achmad, 2020).

The Internet of Things (I_oT) allows for optimized monitoring of farmers mainly through intelligent sensors capable of measuring everything from solar radiation, physiological growth, changes in homeostasis and temperature of each animal and management decision-making (Chattu et al., 2019).

Knowledge and free use of digital technologies are no longer considered as "additional" skills. Everyone has to use digital technology every day. Those of us who are able to use technology to solve real problems will have an advantage in the labour market and in society. Only 29% of full-fledged Bulgarians between the ages of 16 and 74 have basic digital skills.

The creative processes in which digital technologies develop skills and create high-quality cattle products are those needed by the modern farmer - cattle breeder, farmer, agromanager (Norton et al., 2019; Papst et al., 2019; Nethrajan and Kemp, 2021).

In order to create a sustainable model, it is necessary to implement a farm, cloud cattle breeding platform.

Every farmer must have a registered personal, electronic profile.

The data cloud provides unlimited space for storing information - documents, etc., which are protected from viruses and damage.

All data is stored in a safe place. The information cloud for cattle breeding must fully comply with the requirements of the General Data Protection Regulation (also known as the GDPR).

Posting ads and other account tools are not allowed. All accounts are managed by a system administrator.

Over 60% of the farms and agricultural holdings in our country have disappeared in the last 10 years. Currently, 133.000 farms and holdings operate 3 million and 959 thousand ha. (Agricultural Report of the Ministry of Agriculture, 2021). Farmers and managers of large cattle farms in Bulgaria are most afraid of the costs they have to incur to implement digital technologies. Based on a survey in our country, it was found that there are farms that already use flexible digital technologies. They are about 14% and use mostly GPS navigation systems. No municipality in Bulgaria has developed yet a strategy for the implementation and development of digital technologies. Bulgaria ranks penultimate, together with Greece for 2021 in the Integrated Index for the introduction of digital technologies in the economy and society-DESI. It is followed only by Romania (Bachev, 2019; Fidanska, 2020; Alexandrova, 2021).

Three factors influence the application of digital technologies in cattle breeding: price, validity and response time. Precise technologies (PLF - Precision Livestock Farming), and in particular biometric sensors, leads to an objective idea obtained by observing the behaviour of cattle, which allows the farmer to identify the problem and take urgent measures.

Non-invasive biometric sensors can be located in the barn, outdoor walking yards, milking parlor, hayloft, pasture. Usually, their stationary location provides data on the live weight of different categories of cattle and the rationing and feeding of different quantities and types of feed. There are also non-invasive sensors that are attached to cattle such as pedometers, GPS (global positioning systems), MEMS (micro electro-mechanical activity sensors), which can be used to monitor physiological processes in different categories of cattle. Non-invasive are also sensors designed and attached to the ear tag (Johnson et al., 2019; Nethrajan and Kemp, 2021).

Invasive sensors are less commonly used in cattle breeding. They are usually implanted with a probe in the abdomen of cattle in the form of a smart bolus. They monitor internal physiological parameters, abdominal health, vaginal pressure, body temperature and more. Invasive sensors can also be implanted subcutaneously. They are small and compact in size and measure specific physiological parameters (Berckmans, 2017; Nie et al., 2020).

The use of biological and biometric sensors in animal husbandry allows for better monitoring of major technological problems related to welfare, as well as facilitating routine activities and care and providing

valuable information on efficiency and cost-effectiveness measures.

Hosseinoorbin et al. (2021) investigated a deep neural network in connection with the presentation of data in the time-frequency range for classifying the behaviour of cattle. Their expert assessment is based on a real set of data with over 3 million samples collected from sensors with a three-axial accelerometer, magnetometer and gyroscope attached to neck belts of 10 male calves. The potential of this approach for classification is that I_oT devices operate with limited resources. The result of 94.9% is for 3 behavioural types and the result of 89.3% is for 8 behavioural types.

The welfare of different categories of cattle can be improved by using biometric sensors that examine mastitis, ovarian cyst disease, lameness and ketosis, while productivity measures measure automation, general activity, physiological condition, nutrition, estrus detection and adaptive behaviour during milking (Helvatkar et al., 2014; Neethirajan et al., 2018; Williams et al., 2020).

Blockchain technology is a decentralized or pre-encrypted transaction book, where each transaction creates a "node". Nodes, on the other hand, are organized into records known as "blocks," and they are linked by hemcodes to form a "chain." Blockchain technology has four main components: distributed, transparent, unchanging, and democratic. In cattle breeding, this is done as each cattle receives a unique, individual identification. This identification number will remain with the bovine animal throughout its existence for the purpose of collecting data on the farm or holding where it lived and kept, will register its transport to the slaughterhouse, will carry out post-mortem inspection, control of meat product transport, serviceability of packaging and characteristics of the retailer. Blockchain technologies are still at an early stage of their development. They present farmers and agricultural producers as transparently accountable to the consumer for how their products travel to the market (Tuteja et al., 2017; Nethrajan and Kemp, 2021; Motta et al., 2020).

Digitalization of dairy farms and dairy complexes – Innovative technologies with sustainable growth of dairy cattle breeding

Precise, dairy farming is defined as the use of information and communication technologies for detailed control of the productivity of lactating animals and an efficient resource for optimizing the economic, social and environmental reserves of dairy farms (Eastwod et al., 2019; Klerkh et al., 2019).

In Bulgaria, solutions are being sought for the transformation of the existing building stock and reorganization of the technological process. An example of this is the old farm in the village of Zlatovrah, Asenovgrad municipality, where on the basis of existing brick-concrete buildings a farm for 100 dairy cows is organized - a complete cycle using digital technologies. The village is located on flat terrain and surrounded by fertile fields and pastures. A photovoltaic system will be installed on the roof of the future cow farm. The breeding technology will be free box breeding, and the animals will be divided into 4 groups of 25. Milking will be robotic, in a modern milking parlor. The feeding will be carried out normally, according to the food path, according to the submitted data. The cows will have ear tags with sensors to monitor health, fertility and suspected lameness. Sensors will also be placed on the abdomen, in the form of smart mini-boluses (smaXtec) to measure temperature and active movement. The bolus sends updates every 10 minuties, and then the information is stored in the information cloud, via broadband or 4G network. Stationary sensors will monitor the microclimate in the rooms: humidity, dust, air temperature, lighting, the presence of harmful gases, ventilation, noise and more (Tools for the evaluation of the welfare). The cleaning of the manure will be mechanized with a tractor with a bulldozer shovel with subsequent covering with straw (Alexandrova, 2021).

Cattle pose a number of specific challenges for farmers and agricultural producers. Each individual animal is an investment for the farmer or agricultural producer with a high value and a wide range of factors that affect the overall profitability of the herd. The ability

to measure time in fertility cycles (estrus) with real-time results is important for herd maintenance, while precise control of nutrition and energy is crucial to increase milk productivity. The use of biometric estrus detection sensors combined with classical pedometers has shown success in dairy cow breeding (Helvatkar et al., 2014; Nethrajan and Kemp, 2021).

Röttgen et al., (2020) investigated and analyzed automated detection and recording of vocalizations (roar) of an individual cow in the herd, with reported sensitivity of 87% and characteristic specificity of 94%, as a potentially important method for monitoring the estrous status of dairy cows.

The metabolic energy balance in this species of animal has different parts: basic metabolism, physical metabolism, metabolism of production (milk, meat, skin), neuro-mental metabolism and others. (Tornton, 2010; Johnson et al., 2019; Müller et al., 2019; Lu et al., 2020; Nie et al., 2020).

Nutrition and energy balance are important for the efficient production of milk from dairy cattle. Circulating levels of non-esterified fatty acids (NEFA) show a negative energy balance and can be a symptom of significant health risks that need to be checked. Metabolic disorders associated with high levels of NEFA in the blood lead to loss of appetite, decreased milk production, reproductive problems, breast infections and immune system dysfunction (Tools for the management of the nutrition). The biosensors monitored by NEFA are still under development and have the potential to be extremely useful in dairy farms (Tuteja et al., 2017).

Ketosis is another health status problem in dairy farms. It is often preceded by elevated levels of beta-hydroxybutyrate (BHBA). This disease can be detected by a quantum dot-based biosensor developed by (Weng et al., 2015). An alternative approach has been adopted by Tuteja et al., (2017) using electrochemical immunosensors based on 2D MoS_2 nanostructure to detect BHBA in dairy cows. This method showed high specificity and sensitivity and was comparable to commercially available configurations. BHBA field devices and smartphone-based technologies will soon allow for rapid testing and response on the farm.

Young et al., (2017) demonstrated a portable diagnostic reader that can detect progesterone in milk. The development of biosensors that would allow the rapid detection of markers and the active response of the farmer would ultimately improve the health and well-being of dairy cattle, while reducing the use of monetary resources (Tools for the evaluation of the estrus).

Innovative methods include the TIR-based eye imaging system used for non-invasive stress monitoring in various categories of cattle, as well as several new approaches that deserve attention:

MooMonitor is a portable biometric sensor designed specifically to measure behavioural levels during the grazing of dairy cows, which demonstrates a high correlation with traditional monitoring methods (Werner et al., 2019).

Biometric sensors successfully monitor the intake of water from cattle. A study by Williams et al., (2020), using RFID tags and accelerometers, showed with 95% accuracy the correct classification of bovine behaviour patterns.

Sensor technologies have the ability to give cattle some autonomy by replacing some of the technological tasks, and this is mainly the case with robotic milking systems for dairy cows. Robotic milking systems apply sensors to record a cow's behaviour during milking and feeding (Neethirajan, 2017; Nethrajan and Kemp, 2021).

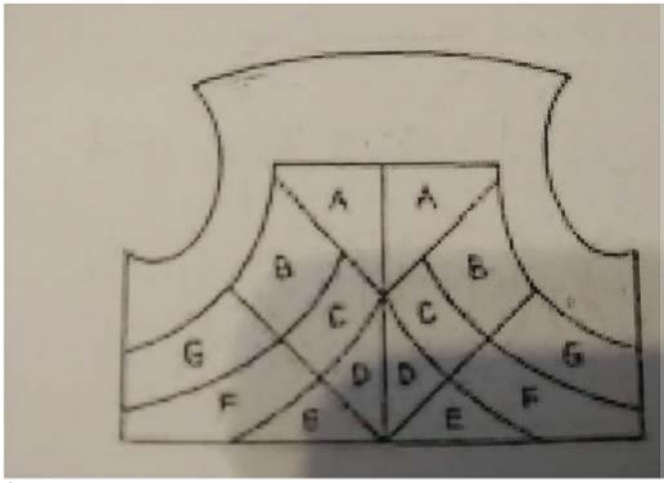
Precision technologies are becoming popular in the dairy industry as they apply remote monitoring of cow health and allow a timely response to a pathogen (Klerkx et al., 2019). Large amounts of data (data set), followed by error checking and quality control must be applied to ensure the quality of the same (Wurtz et al., 2019; Nethrajan and Kemp, 2021).

Digitalization of meat-producing farms and meat-producing complexes – Innovative technologies with sustainable growth of beef cattle breeding

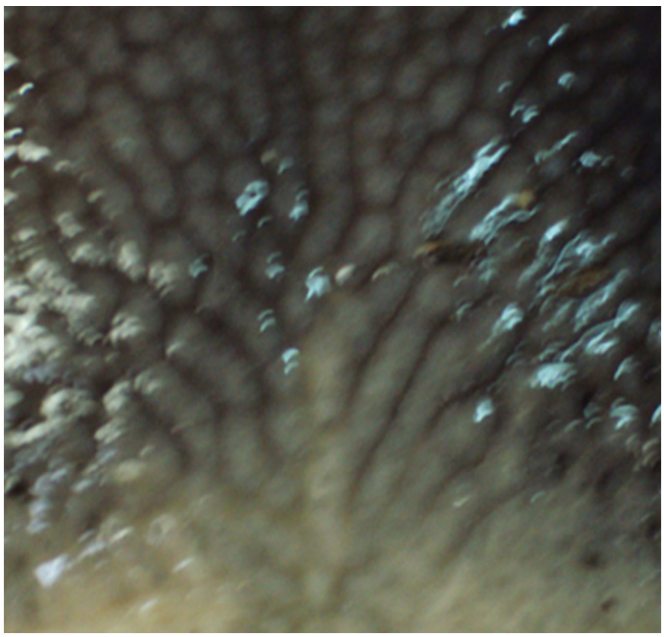
Solutions for high-resolution digital cameras are sought in Europe and around the world, which give consistent, accurate results and automatic weighing of animals (bulls, cows, heifers, suckling calves) on pasture in certain, flat areas that they visit regularly: watering places trays and equipment, lollipops with microelements and salt, fences, etc. The data is collected in an information cloud, where it is stored, preserved and analyzed and will be used for the selection, growth physiology, analysis of average daily growth, health status and more. On the smartphone of the farmer or the head of the cattle breeding enterprise there will be information with the data of each animal at any time (Agroplovdiv, 2019).

At the University of Melbourne in Australia, La Troube University, the Infusion Center is developing an advanced, new, sensory technology for collecting and systematizing data on the behaviour of cattle in pastures, the health status of each cattle in the group / herd. The sensors used are lighter, more convenient and cheaper, while collecting more processed information. This data helps farmers to act operatively depending on the observed behaviour of individual animals. This way the reasons for the poor growth in recent years, the nature of endoparasitic diseases, lack of micro elements, the impact of droughts on suckling calves, etc. are understood (Demirev, 2018).

In Udmurtia, the Autonomous Republic of the Russian Federation, in the capital Izhevsk, Volga Administrative District, the local agricultural company STSH LL with President Alexei Safaulin has developed an advanced, intelligent cattle identification system based on scanning the relief of the nose mirror SAIS. The image of the area and relief of the nasal mirror are unique to each ruminant, they do not change during ontogenetic development, and are comparable to fingerprints and palm prints in primates and humans (Trofimenko, 1991). This is a kind of Face ID of cattle. The image cannot be falsified, cannot be lost or destroyed and is completely harmless and natural. It is enough to point only the smartphone to the muzzle and take a "snapshot" and immediately get a complete set of data related to the inspected animal, which are used in the management of technological processes.



A



B

Figure 1. A-diagram of the relief of a cow's mirror; B-picture (image of the relief of the nasal frost) of cattle

Large cloud analysis of data, machining and modeling

The use of biometric and biosensors to monitor the health and welfare of cattle leads to the production of vast amounts of data that need to be processed and analyzed to provide meaningful information on animal management. This justifies technological advances in the acquisition and analysis of large, complex data sets (Wolfert et al., 2017).

Large amounts of data are defined as a set of data with a huge number of rows and columns that do not allow visual inspection, and many variables or predictors that make them cluttered and unsuitable for traditional statistical techniques and programs (Morota et al., 2018).

Large amounts of data are characterized by four attributes, commonly known as the "4 Vs" model: (1) volume, amount of data (2) velocity, speed of access or use of data (3) variety of different forms of data and (4) veritableness, cleaning and editing of data (Wolfert et al., 2017; Morota et al., 2018).

Precision animal husbandry relies on the proper use, processing, analysis of large amounts of data and modeling to inform the farmer or agronomist about food needs, reproductive status and trends in reducing production costs (Neethirajan and Kemp, 2021).

Cloud computing is a technological solution that has long been used in agriculture and industry. The concept is quite vague in space. The data cloud is a set of connected servers. The server is a program or machine on which the processed data is stored - text, images, files on websites. Servers can be connected to a private, public or hybrid cloud network. The cloud is not only a server location, but also a set of various services. The name cloud comes from a drawing used by the first engineers (pioneers) of the cloud-like network (Nie et al., 2020; Nethrajan and Kemp, 2021).

Large cloud data models extract information from sensors, process it, and then use it to detect data anomalies that can affect cattle. Large data models contribute to the effectiveness of sensor technology by sorting it to provide meaningful results for farms, including forecasting the likelihood of future events, improving farmers' response and decision-making, and may even allow farmers to group animals based on needs, leading to greater use of available resources (Morota et al., 2018).

Sensor data can be divided into animal-oriented data (by phenotype) and environmental-oriented data. These two types of data need to be monitored and analyzed simultaneously, as they affect animal health and productivity (Neethirajan and Kemp, 2021).

The digitalization of livestock through the use of animal and environmental data means improving the overall management of health, nutrition, genetics, reproduction, welfare, biosecurity and greenhouse gas emissions (Pineiro et al., 2019).

Machining is a branch of artificial intelligence that uses algorithms for statistical predictions and inferences (Morota et al., 2018).

There are two main types of data modeling: exploratory and predictive. Survey models take data from past events and determine which factors were influential, while forecast models use data to predict future events based on certain criteria (Sasaky, 2020).

Proper use and modeling of data is important when using large data sets; data variability means that there are a number of variables that need to be considered in the models and the data will need to be cleaned to eliminate noise (Koltes et al., 2018).

Forecast models and configurations

The use of forecasting models allows farmers to predict future results and apply an active, pragmatic approach to management (Wolfert et al., 2017).

Large data technologies can be useful in monitoring the transmission of a number of diseases, by establishing contact networks and identifying high-risk populations (Wurtz et al., 2019).

Data mining is similar, but the focus is on processing model identification databases to generate information. Machine learning (ML) - a user of big data is showing increasing interest in precision cattle breeding, as it allows computer algorithms to gradually process sensory arrays of big data and improve accordingly, eliminating the need for human factor analysis (Benjamin and Yik, 2019).

ML techniques are often used in studies of genetics and selection of cattle, to predict phenotypes based on genotypic information, to identify deviations in the population. ML-technologies are also used to detect

mastitis (inflammation of the udder) by automated technologies for milking on dairy farms, to assess physical condition, to analyze images and to monitor the health of cattle (Morota et al., 2018).

ML and large data analyzes have the potential to improve the welfare and productivity of dairy cattle. They can be used to predict the likelihood of developing motor problems (lameness) and mastitis in dairy cows and heifers, as these conditions are particularly problematic for the technology used, and can have serious negative effects on milk production (Ebrahimi et al., 2019; Taneja et al., 2020; Warmer et al., 2020).

Large data analysis techniques can be used to aggregate and integrate specific data sets in farms and holdings in order to optimize production processes and systems (Aiken et al., 2019; Nethrajan and Kemp, 2021).

The value of large data sets depends on automation, availability and accuracy. As PLF technologies become more applicable on farms, it will be necessary to develop appropriate software, quality control mechanisms, database systems and statistical methods to summarize and visualize data and identify the most appropriate models of data (Koltes et al., 2018).

Another challenge with the large amounts of data obtained in farms and complexes is confidentiality and security (Wolfert et al., 2017).

The collection of data on farms and complexes is currently not used effectively, as farmers and agricultural producers give priority to confidentiality and have a certain fear of cyberattacks (Table 1, by Nethrajan and Kemp, 2021).

Table 1. Companies that use, process and apply large amounts of data in cattle breeding according to Nethrajan and Kemp (2021)

Name	Technology using a large array of data	Website	Location
Cargill Inc	Dairy Enteligen cloud-based analytics service; Decision making for cattle breeding	https://www.cargill.com/animal-nutrition/feed-4-thought/industry-insights	Italy
Cattle-watch	It uses a system to track the location of large data needed to count the animals in the herd and to enable users to determine the location of individual animals.	http://www.cattle-watch.com/	Israel
Wreath	Artificial intelligence, sensors and sensor-based large data sets to control animal movement, monitor welfare and create virtual fencing lines during grazing	http://vence.io/	USA
Connecterra	Large array of data for real-time prediction of the behaviour of dairy cows using sensors and cloud-based application	https://www.connecterra.io/	The Netherlands
Cainthus	Computer monitoring and analysis of animal behaviour	https://www.cainthus.com	Ireland
Rex Animal Health	Large amounts of data on precision veterinary medicine	http://rexanimalhealth.com/	USA
Chitaledaity	RFID biosensors and sensors to collect data on how much feed the dairy cow consumes and monitor physiological and health	http://www.chitaledairy.com/	India
Smart Shepherd	Data from sensors based on an information belt to build maternal pedigree by identifying relationships between animals.	https://www.smartshepherd.com.au/	Australia
Merck Animal Health	Biometric and behaviourally based large amounts of data from ear tag sensors to identify abnormalities in sick animals	https://quantifiedag.com/	USA
Alan-it	Cloud-based analytics service Smart4Agro; Decision making for animal husbandry	https://www.alan-it.ru/wkpages/default.aspx	Russia

By integrating sensors for the Internet of Things (I_oT) and large datasets model for predicting MooCare was developed and implemented to help farmers in the management of dairy cattle by predicting milk production (Righi et al., 2020).

CONCLUSIONS

We can conclude that in the sub-sector of cattle breeding it is possible to apply flexible digital management. The collection, storage and analysis of large volumes of data, through precision technology (PFL), allows farmers to more precisely and remotely control and manage physiological and technological parameters in different categories of the species, in relation to the health and welfare of the animals. Biological and biometric sensors assist farmers in managing the quantity and improvement of their production. Blockchain technologies make it easier to control the breeding process in cattle and it becomes more predictable.

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