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AUTOMATED TECHNOLOGY OF MEASUREMENT OF PHYSIOLOGICAL PARAMETERS OF FARM ANIMALS

АВТОМАТИЗОВАНА ТЕХНОЛОГІЯ ВИМІРЮВАННЯ ФІЗІОЛОГІЧНИХ ПАРАМЕТРІВ СІЛЬСЬКОГОСПОДАРСЬКИХ ТВАРИН

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Abstract. *The development and application of automated technologies in the agricultural sector have significantly transformed the management and monitoring of farm animals. This paper presents a comprehensive analysis of existing technical systems for measuring the physiological parameters of farm animals, particularly focusing on cows. The primary goal of these technologies is to enhance the accuracy and efficiency of health monitoring and to optimize livestock management through continuous data collection and analysis.*

Key technological solutions include the use of wireless data transmission systems, radio monitoring devices, and unmanned aerial vehicles (UAVs). These technologies enable real-time tracking of animal health parameters such as body temperature, heart rate, movement patterns, and other critical indicators. The use of various sensors, including ear, neck, and intra-body sensors, plays a crucial role in collecting primary physiological data. These sensors are integrated into a broader system that includes radio modules with built-in controllers for converting raw data into digital formats, enabling wireless transmission to central systems for processing and storage.

The radio monitoring of animals allows for the continuous tracking of physiological and behavioral parameters across large areas, providing crucial insights into their well-being. It is particularly beneficial in detecting early signs of disease or health issues, ensuring timely intervention, and preventing potential economic losses for farmers. The integration of unmanned aerial vehicles (UAVs) further expands the capabilities of monitoring systems, enabling the visual assessment of animals' behavior and movement across vast pastures. Equipped with video cameras and data relays, UAVs collect video footage that is transmitted to a central processing unit for real-time analysis and storage.

The combined use of radio monitoring and UAV technology forms a comprehensive framework for livestock management, allowing farmers to make data-driven decisions, optimize resource allocation, and improve overall herd health and productivity. By leveraging these automated systems, it becomes possible to reduce the dependency on manual labor, minimize human error, and ensure that animals are closely monitored without the need for constant physical presence. This represents a significant advancement in modern animal farming, aligning with global trends toward smart farming and precision agriculture.

In conclusion, the integration of automated physiological monitoring technologies in farm animal management presents an innovative solution for enhancing animal welfare, improving farm efficiency, and reducing operational costs. These systems hold considerable potential for further advancements in the field of animal health monitoring, ultimately contributing to more sustainable and productive farming practices.

Анотація. *Розвиток і застосування автоматизованих технологій в аграрному секторі істотно змінили управління та моніторинг сільськогосподарських тварин. У цій статті представлено комплексний аналіз існуючих технічних систем вимірювання фізіологічних параметрів сільськогосподарських тварин, зокрема корів.*

Основна мета цих технологій полягає в тому, щоб підвищити точність і ефективність моніторингу здоров'я та оптимізувати управління худобою шляхом постійного збору та аналізу даних.

Основні технологічні рішення включають використання бездротових систем передачі даних, пристроїв радіомоніторингу та безпілотних літальних апаратів (БПЛА). Ці технології дозволяють у режимі реального часу відстежувати такі параметри здоров'я тварин, як температура тіла, частота серцевих скорочень, рухи та інші важливі показники. Використання різноманітних датчиків, у тому числі вушних, шийних і внутрішньотілесних, відіграє вирішальну роль у зборі первинних фізіологічних даних. Ці датчики інтегровані в більш широку систему, яка включає радіомодулі з вбудованими контролерами для перетворення необроблених даних у цифрові формати, що забезпечує бездротову передачу до центральних систем для обробки та зберігання.

Радіомоніторинг тварин дозволяє безперервно відстежувати фізіологічні та поведінкові параметри на великих територіях, надаючи важливу інформацію про їхнє благополуччя. Це особливо корисно для виявлення ранніх ознак захворювання або проблем зі здоров'ям, забезпечення своєчасного втручання та запобігання потенційним економічним збиткам для фермерів. Інтеграція безпілотних літальних апаратів (БПЛА) ще більше розширює можливості систем моніторингу, дозволяючи візуально оцінювати поведінку тварин і пересування по величезних пасовищах. Оснащені відеокамерами та реле даних, БПЛА збирають відеозапис, який передається на центральний процесор для аналізу та зберігання в реальному часі.

Комбіноване використання радіомоніторингу та технології БПЛА формує комплексну основу для управління худобою, дозволяючи фермерам приймати рішення на основі даних, оптимізувати розподіл ресурсів і покращити загальний стан здоров'я та продуктивність стада. Використовуючи ці автоматизовані системи, стає можливим зменшити залежність від ручної праці, мінімізувати людські помилки та забезпечити ретельний нагляд за тваринами без потреби в постійній фізичній присутності. Це являє собою значний прогрес у сучасному тваринництві, що відповідає світовим тенденціям до розумного землеробства та точного землеробства.

Підсумовуючи, інтеграція автоматизованих технологій фізіологічного моніторингу в управління сільськогосподарськими тваринами представляє інноваційне рішення для покращення добробуту тварин, підвищення ефективності ферми та зниження експлуатаційних витрат. Ці системи містять значний потенціал для подальшого прогресу в галузі моніторингу здоров'я тварин, зрештою сприяючи більш стійким і продуктивним методам ведення сільського господарства.

Key words: cow (farm animal), physiological parameters, UAV, RTM, monitoring, radio modules, wireless transmission, sensors

Ключові слова: корова (сільськогосподарська тварина), фізіологічні показники, БПЛА, РТМ, моніторинг, радіомодулі, бездротова передача, датчики

Introduction

Agriculture is characterized by all groups of automation objects: automated technologies and automation objects [1 – 4]. The analysis of the physiological parameters of cattle shows that for increasing the level of realization of the genetic potential of animals, not only the usual technological processes of milking and individual feeding are the most significant and informative, but also such as monitoring the location of the animal, the main indicators of vital activity (heart rate, breathing, mobility), timely detection of sexual activity of cows, especially on pasture [5 – 6].

Reproduction is one of the most important factors in the rational production of both dairy and meat livestock products. If a cow has a disturbed sexual cycle, remains barren and does not produce a healthy calf every year, then all its other high qualities are of no importance. There are still few opportunities to increase the efficiency of reproduction by traditional methods of breeding, feeding and keeping animals. In this regard, it is necessary to introduce modern automated systems for monitoring the sexual activity of cows in the pasture, one of which is the activity system.

Monitoring of other important physiological indicators of cows in real time in free grazing conditions is one of the main requirements of successful management of modern "precision animal husbandry". That is why the implementation of the latest automated systems for individual recording of the vital activity of cows on the pasture is becoming more and more important [6 – 8].

Analysis of literary data and statement of the problem

Features of production on modern farms are the need to minimize labor costs and prompt response to emerging production problems. With the increase in the size of farms and the increase in the workload of the farmer, there is a need to automate the remote control of each animal in real time.

It is known that cows "send signals" by their behavior, body position and other manifestations, which can be used to draw conclusions about their health and physiological state [1 – 4].

There are many animal physiological parameters and pasture data that need to be monitored in various livestock production processes. This includes data such as: temperature, monitoring of cows in lactation; detection of cows in heat and control of the sexual cycle of heifers and cows; detection of the optimal time of fertilization, etc. [5 – 8].

If the animal is indoors, for example, in a cowshed, then it is not difficult to measure such parameters. For this, there are special barriers and portable or stationary measuring devices [9 – 15]. A veterinary specialist has the opportunity to assess the animal's physiological condition and make the necessary decisions regarding further diagnosis and treatment [1, 2, 6 – 8, 10, 16]. However, all the advantages of technical systems of bioveterinary control of the animal's condition lose their significance in pasture conditions. An animal that is in pasture conditions is exposed to external conditions, may get sick or get a digestive tract disorder. In addition, animals have natural physiological cycles. For example, cows that need to be inseminated in time. Therefore, there is a need for constant monitoring of animals that are in free grazing far from the point of veterinary control with measuring equipment. Monitoring tasks can be solved using automated ground or air-based systems [16 – 20]. This is, respectively, a method of radio monitoring of animals on pasture and a method of monitoring using unmanned aerial vehicles (UAVs). At the same time, both methods and their technical means will be able to ensure the transmission of data from any sensors located on the animal's body or inside, to the main point of information reception for the purpose of processing and decision-making by a veterinary specialist or zootechnician. Such a specialist will be able to go to the pasture and promptly provide assistance to the animal or perform other procedures.

As an example, we can consider the sensors of physiological and other parameters produced by different companies. One such device is manufactured by TekVet. The measuring device is supplied with an internal battery that is designed to last the lifetime of the animal. Once the measuring device is attached, the TekVet Health monitoring system [21] will automatically pick up the electronic data transfer, including temperature and animal ID information.

The length and size of the device were designed to be placed on the ears. During installation, the thermistor (electronic thermometer) is slipped into the animal's ear canal. Cattle naturally secrete a significant amount of earwax, which forms a natural seal around the thermistor, protecting it from weather conditions.

The company Quantified Ag [22] has developed an ear tag that monitors not only temperature and other vital signs, but also the movement of the animal. The data is transmitted wirelessly to a central server where violations are analyzed. When animal parameters are outside the normal range, they can be pulled out and reviewed. If a cow starts to get sick, for example with a fever, it cannot be as active as usual.

"Silent Herdsman" has made a collar for animals. It monitors the level of food consumption and fattening of the cow, and also monitors their temperature, which is an important indicator of health. But it requires the Internet to work.

In Austin, Texas, the "e-pil" [22], a sensor pill that is placed in one of the cow's stomachs, has been developed. Once a pill is fed down the cow's esophagus, the device begins reading metrics such as heart rate, respiration rate, stomach acid and hormone levels, and notifies workers via text message if a problem is detected. This device is designed mostly for dairy herds.

To detect cows ready for insemination and at rest, a system for detecting heat based on motor activity was developed [23]. This system, firstly, surpasses the best Western proposals in terms of functionality (it is possible to provide a longer communication range, as well as deep adjustment of the detection algorithm to the conditions of a specific farm, identifying all cows that have at least some external manifestations of sexual behavior), secondly, more convenient to use, "Ovi-bovi" sensors hang freely on standard cow collars without requiring orientation; software is in Ukrainian; reading information from the sensors does not require a system of readers that is connected to other equipment on the farm, thirdly, the sensors are twice as cheap as foreign analogues.

The sensors have a state-of-the-art circuit, a high-quality shock-resistant housing and are controlled by simple and convenient software. The electronic circuit of the "Ovi-bovi" sensor contains three basic elements: a triaxial accelerometer-magnetometer FXOS8700CQ (Freescale Semiconductor, USA), which measures the movement activity of a cow at a frequency of 1,56 Hz; a microcontroller of the Cortex-M family (STMicroelectronics, Switzerland), which collects data from the accelerometer, pre-processes and packages it for forwarding; the Si4460 transceiver (Silicon Labs, USA), whose characteristics allow for a communication range from 500 m to 5 km, depending on the settings of the receiving node.

One of the dynamically developing areas of electronics is the development of wireless data transmission systems. They are based on the use of functional radio modules that work at a distance of one to several hundred meters from each other. Usually, radio modules consist of a microcontroller, a receiver, a transmitter and a small number of external components [24]. The market of radio modules is represented by manufacturers who offer products with different functionality and in different frequency ranges, from hundreds of megahertz to units of gigahertz. Next, we will consider some existing radio modules that may be suitable for the project of automated monitoring of a herd of cows.

The "Gamma" radio module is intended for the organization of automated complexes in large areas, the organization of communication between remote objects and information collection and analysis points [25].

With the help of "Gamma" modules, it is possible to transmit digital information from telemetric sensors of measuring, control and technological equipment, which is also installed on stationary objects. Basic technical characteristics: carrier frequency 433,92 MHz ± 0,2%; transmitter power (max) 10 mW; supply voltage (nominal / permissible range) 10 / 5...15 V; load current (reception / transmission) 40/70 mA; overall dimensions 40x102x24 mm, weight 40 g.

The RFM12BP module [26] is designed to work in conjunction with the RFM12 frequency modulated (FC) transceiver module. In the 433 MHz range, with this configuration, it is possible to achieve stable communication at a distance of up to 3000 m with direct line of sight.

The main characteristics of the RFM12BP radio module. Bands: 433, 868, 915 MHz; internal data filtering and clock frequency recovery; support for very short data packets up to 3 bytes; supply voltage 2,2...3,8 V - for the FM transceiver, 8...12 V – for the output power amplifier; current consumption in transmission mode 260 mA; current consumption in reception mode 20 mA; receiver sensitivity 121 dBm; transmitter output power 100 mW; transmission speed on the radio channel up to 250 kbps; dimensions 52x30x10 mm; weight with antenna 20 g.

Radio modules operating in the 433 MHz band from Hope Microelectronics (Hope RF) use FM (frequency modulation). These devices have a low price and small dimensions (no more than 3 cm^2). Radio modules are manufactured as a board with installed components and a device for connecting to external circuits. Specialized radio modules of the

HM series [27] are successfully used to create wireless data transmission systems. It is known that FM communication systems with many parameters are superior to systems with amplitude modulation.

HM-R is a compact FM receiver module. Supporting a fairly high speed of data reception in the range of 600...9600 bps (300 bps – 100 kbps with an external filter) and having good sensitivity, HM-R radio modules are able to ensure reliable communication with HM-T transmitters over long distances from 160 to 370 m. The modules are characterized by high efficiency in a wide range of supply voltage 2,5...5 V, while consuming a current is 9...11 mA. The devices are small in size. Parameters of the HM-R radio module: range 433 MHz; sensitivity 98 dBm; supply voltage 2,5...5 V; current consumption in working mode 11 mA.

HM-T is a compact radio module of the FM transmitter. HM-T transmitter modules provide a data transfer rate in the range of 600...9600 bps or 300 bps - 100 kbit/s using an external filter, which corresponds to the same bandwidth of HM-R receiver radio modules. With an output radiated power of several milliwatts, they are able to provide reliable communication at a distance of up to 370 m with direct line of sight. HM-T devices work efficiently in the supply voltage range of 2,5...5 V, while consuming a current of only 25...31 mA. Parameters of HM-T radio modules: range 433 MHz; output power 7 dBm; supply voltage range 2,5...5 V; current consumption 31 mA. Radio modules of HM-R receivers and HM-T transmitters are made in the form of printed circuit boards with overall dimensions of 26,0x21,3x7,14 mm. These radio modules are the most suitable parameters for use in this research.

It can be concluded that currently there are many different sensors for automated determination of physiological parameters of animals and data transmission via wireless communication to a central computer. In addition, in Ukraine, several measuring systems have been developed to determine physiological parameters at the cell level using electrical conductivity and membrane electroporation in a pulsed field of increasing intensity [28 – 31]. The sensors of these conductometric systems can also be used for the automated determination of physiological parameters of animals at the cellular level, which is certainly decisive in the formation of the physiological homeostasis of the animal's organism. Therefore, the choice of one or another type of sensors depends on the conditions of cow grazing, the requirements of the farmer, and the scientific and practical problems that are posed and solved during the testing of new technical devices which are being developed.

The reviewed examples of radio modules have a small power and, for their use over long distances in the pasture, a repeater-amplifier needs to be connected. It can be placed on the animal's collar together with its individual code.

The purpose and objectives of the research

To conduct an analysis of existing systems for monitoring the physiological parameters of cows, to determine directions for improving the assessment of physiological parameters of cows by automating this process with the help of modern technical means of remote monitoring, to substantiate the main elements in the composition of technical systems for automated monitoring of a herd of cows on a pasture based on means of ground and aerial surveillance and wireless data transfer.

Research methods and materials

Elements of automated animal monitoring systems in operation include one of the varieties of traditional radio communication subsystems, namely, radio telemetry (RTM), i.e. measurement of physical quantities at a distance with transmission of measurement results via radio communication channels [32 – 34].

A set of devices located on the biological object of observation and at the point of reception of telemetric information forms the RTM system. Sensors, analog-to-digital converters, data encoding devices, radio transmitters are placed on the transmitting side of the system (on the biological object); radio receivers, data decoding devices, equipment for data processing and registration are installed on the receiving side (at the receiving point). Multi-channel radio communication lines are used to transmit information. The necessary accuracy and stability of data transmission are ensured by the use of digital methods of transmission and processing of information, as well as methods of protecting information from errors. RTM methods and systems are widely used for automated monitoring of the functional (physiological) state of biological objects, including animals [35].

Since this project considers the process of remote automated measurement of the physiological parameters of cows on a pasture, which in general can have quite extensive dimensions and some natural irregularities (obstacles), it is advisable to consider the basic theoretical provisions relating to the influence of some external factors and radio signal parameters on the range communication through the RTM channel.

To build radio communication in RTM systems, VHF is mainly used: decimeter (UHF), centimeter (SHF). The main factor affecting the communication range is the wavelength (or, in other words, the frequency) on which the reception-transmission is conducted. As is known, the radiation frequency is related to the wavelength by the following ratio [36]:

$$\lambda = vT = \frac{v}{f} \tag{1}$$

where: λ – the wavelength, m; v – speed of its propagation (speed of light), km/s; T – oscillation period, s; f – frequency, Hz.

With an error of about 0,1%, you can calculate the length of a radio wave in free space as follows:

$$\lambda = \frac{300}{f} \quad (2)$$

where: λ – the wavelength, m; f – frequency, MHz.

If we consider the propagation of a radio wave in free space, it can be found that the wave easily goes around a small obstacle and overcomes it, but cannot go around a large obstacle - a kind of "radio shadow" is formed behind it, there are practically no waves there, if we neglect the small edge effect of the wave's penetration beyond the edge obstacles. These processes are explained taking into account the ratio of the wavelength and the size of the obstacle. Therefore, for long radio waves of more than 1...10 km, the natural unevenness of the Earth does not constitute a significant obstacle, and such waves relatively easily go around the Earth's surface. For short (1...100 m) and especially ultra-short (less than 1 m) UHF, SHF radio waves, the Earth with its numerous irregularities is too big obstacle. These waves almost do not go around the earth's surface and practically do not go beyond the horizon line. They extend in a straight line within line of sight to the first insurmountable obstacle larger than a wavelength.

So, the lower the frequency at which the RTM system works, the greater the communication range. On the other hand, the higher the frequency, the shorter the distance between RTM base stations and the better the quality of communication. In addition, as the frequency increases, the dimensions and weight of RTM equipment, especially antenna-feeder devices, significantly decrease. Also, the cost and energy consumption are reduced, the portability and mobility of the entire RTM system as a whole are increased, and all this in the aggregate is extremely important for automated monitoring of animals in the field. Therefore, it is most expedient to use the frequency range UHF and higher in RTM systems.

Thus, radio communication at frequencies above 300 MHz (i.e. wavelength less than 1 m) is possible, mainly, only within the radio horizon, that is, the distance of direct passage of radio waves taking into account the sphericity of the earth's surface, the so-called direct or optical visibility. In this case, the range D of RTM communication will depend on the height of the receiver antenna and is determined by the following formula [36]:

$$D = 3,85 \cdot \left(\sqrt{h_1} + \sqrt{h_2}\right) \quad (3)$$

where h_1 and h_2 – the heights of RTM receiver and transmitter antennas, m.

In addition to "radio shadow" which reduces the range of communication and reduces its quality, other influencing factors include the following: fading, reflection and scattering of the radio signal; diffraction on an obstacle and interference with a reflected signal; transmitter power and receiver sensitivity.

One of the important parameters of a radio signal is its attenuation (weakening) with distance from the transmitter. However, this parameter is determined by the operating frequency of the receiving and transmitting system, so it can be reduced by selecting the appropriate frequency. There is such a relationship - the higher the frequency of the signal, the greater the attenuation. Attenuation can be compensated by increasing the transmitter power and receiver sensitivity, as well as by using antennas with a high gain. The graph of the dependence of the attenuation (weakening) of the signal of three different frequencies in free space on the distance, presented in Fig. 1 [36].

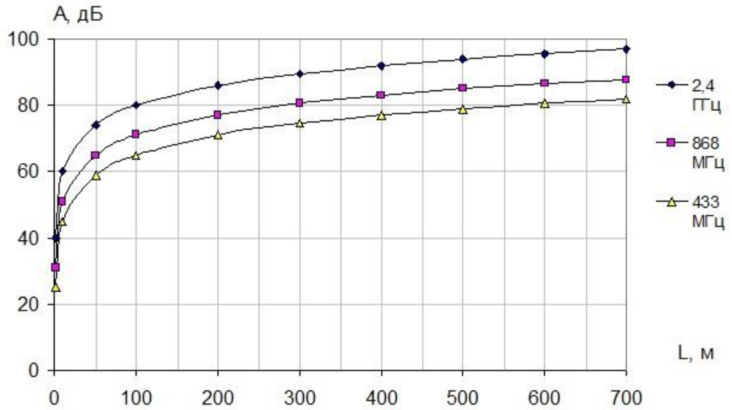

Fig. 1 – Dependence of signal attenuation of three allowed frequencies in free space from the distance to the radiation source

It follows from Fig. 1 that the most acceptable frequency for the RTM-based monitoring system from the specified three permitted frequencies, from the point of view of minimum attenuation, is the frequency of 433 MHz.

Therefore, scattering is an inevitable consequence of the spread of energy from one point, which is the source of radio signal radiation (at a distance much larger than the size of the emitter). The principle of propagation of some radio waves is similar to the principle of propagation of light. Therefore, in order to obtain a large coverage area (equal to the area of the pasture), it is necessary to direct the radiation in all directions, that is, to use a non-directional antenna.

Scattering cannot be reduced, but can be partially compensated for. For example, by using directional antennas that focus the radio beam in one direction. But then the coverage area will narrow, which is undesirable in our case of monitoring animals on pasture. Another way to compensate for scattering can be to increase the power of the transmitter. However, it should be noted that increasing the output power of the transmitter is the least effective way to increase the communication range. So, to increase the range by 2 times in the presence of direct visibility, it is necessary to increase the power of the transmitter by 4 times, and in the absence of visibility by 8 times.

The influence of the radiation power [36, 37] on the communication range can also be estimated by the voltage of the electric field at the point of reception according to the following Vvedenskyi formula:

$$E = \frac{4\pi \cdot \sqrt{60 \cdot P \cdot G} \cdot h_1 \cdot h_2}{\lambda \cdot r^2}, \quad (4)$$

where E – the amplitude of the field strength at the reception point, V/m; P – radiation power of the radio transmitter, kW; G – the gain of the antenna transmitting the signal, dB; λ – wavelength, m; r – the length of the radio communication line, km; h_1 , h_2 – the height of the antenna transmitting the signal and the receiving radio station, respectively, m.

The range of communication is affected by interference. In real conditions, due to the reflection of waves from various obstacles at the reception point, many waves with shifted phases relative to each other can be received and, therefore, the resulting signal can change randomly or disappear. When building RTM systems, digital technologies of pulse-code frequency modulation are usually used, and partial loss of information can be easily restored according to the Kotelnikov (or Nyquist-Shannon) theorem [37].

On large livestock farms, cattle are often driven out to graze freely. As a result, farmers face a problem - the issue of livestock safety. Therefore, it is important to provide timely veterinary care to the animal in the pasture and control the movement of animals. Undoubtedly, one of the most accurate and operational ways to control the herd is the use of UAVs. Compared to conventional small aircraft controlled by a person, UAVs are much more affordable, fully pay off with the results obtained and allow for aerial surveying and analysis of a significant amount of areas in a shorter period of time.

To control the herd, these devices are equipped with a photo and video camera or an infrared sensor and fly over possible locations of animals along a predetermined route. It can be adjusted at any time at the ground control station, which takes into account all the technical characteristics of the unmanned complex. Battery-powered devices can stay in the air for up to five hours and fly up to 100 km. Battery replacement time for continued flights is no more than 10 minutes, which allows you to monitor for almost a whole day, at night you can use an infrared camera capable of distinguishing living objects in complete darkness. During the flight, a photo or video recording of the understory surface is taken. Then the received data is processed and decrypted automatically with the use of special software developed for this equipment.

The use of a special program provides simplicity and convenience to the method of controlling the herd using a UAV because the operator does not need to personally view all the data obtained as a result of the shooting, the number of which can reach tens of thousands of photos and occupy hundreds of gigabytes on the hard disk. When manually analyzing such volumes, the time for processing information can reach several days, while the probability of operator error increases significantly, since animals often almost completely merge with the underlying surface. Thus, the herd control technique using UAVs consists of three stages. On the first one, the area is photographed using a camera installed on the equipment. After that, the results of the survey are processed with the use of the animal recognition program, and at the final stage, the obtained information is analyzed and further management decisions are made.

A special recognition program displays on the screen only those pictures where animals were detected, while the coordinates of each individual are automatically determined. With a different species composition of the herd and the presence of characteristic distinctive features of individual types, the program automatically recognizes the animal's belonging to each species and displays this data in its interface. Such a function allows timely detection of dangerous objects, such as robbers, before their direct approach to the herd and time to react to their appearance. Based on the results of the program, an electronic map of the location of livestock on the controlled area can be compiled, on which individuals of various species are marked with points, which allows to visually assess the location of each animal. In addition, with the help of a UAV, permanent video monitoring of the herd in automatic mode is possible. If there is an installed video camera, the object tracking mode is turned on and the desired individuals are selected, the device is able to follow them automatically and adjust its route independently if it is necessary. Thus, surveillance of animals from the air with the help of UAVs and the developed software complex makes it possible to significantly improve the preservation of herds on pasture.

Research results

There are many different systems for automated monitoring of animals from the air, including using UAVs. Thanks to the mobility and automation of unmanned vehicles, for example, the process of accounting for the number of livestock is greatly simplified in huge territories. With the development of digital means of observation and fixation installed on board UAVs, the accuracy and efficiency of monitoring animals on pastures has increased.

The use of radio beacons allows you to accurately determine the geographical coordinates of the location of the animal, you can monitor the movement and length of the daily transition. In the absence of beacons, the route task for the UAV is prepared in advance. The task depends on the area and length of the pasture. After landing, all received images are downloaded from the plane. The area of shooting in one working day can be from 4 to 8 thousand hectares. Nowadays, the use of UAVs is the most effective method of monitoring the number and movement of cows, both in terms of financial costs and time spent.

Standard radio modules can be used for wireless transmission of data received from the animal to the UAV and further to the main PC. Common functional radio modules that work in connection at a distance of one to several hundred meters from each other have already been considered above. The use of transceivers made on one crystal simplifies the process of applied development. Usually, systems based on such microcircuits consist of a microcontroller, a receiver and a transmitter, and a small number of external components.

Flying over an animal or a herd on a pasture, a UAV takes photos and videos in both automatic and semi-automatic modes, as well as receives and relays data on the physiological state of animals to a PC. The result of such work is a series of high-quality pictures with reference to geographic coordinates and a set of primary data from sensors placed on the animal. After processing the entire array of data in specialized software, the received data is analyzed in accordance with the assigned tasks.

For automated monitoring of a herd that moves slowly on a pasture, the most effective is the use of a helicopter-type UAV. The use of UAV in the form of an airplane to monitor animals in the pasture is impractical because the following technical requirements must be met for these devices: the presence of a runway; high flight speed to provide lift; the need to have a supply of fuel and lubricants; A UAV in the form of an airplane cannot hover and make a clear video recording.

In view of this, it should be added that at a higher flight speed of such an apparatus, the Doppler effect will be observed. This effect will lead to a shift in the frequency of the on-board transmitter radio signal and, as a result, narrowband receiver on the ground, which will lead to a partial or complete loss of information. It is advisable to use devices with a low speed of movement in space, preferably with a hover function. Helicopter-type UAVs have such properties. The comparative characteristics of the UAV are presented in Table 1.

Table 1 – Comparative characteristics of UAVs

Technical characteristics of the UAV	ZALA 421-22	ZALA 421-02X
1. Range of video/radio channel	5 km / 5 km	25 km / 50 km
2. Flight duration	35 min	1.5...2 hours
3. Frame dimensions	1060x1060x165 mm	750x2860x1180 mm
4. Speed	up to 30 km/h	up to 60 km/h
5. Maximum take-off weight	8 kg	90 kg
6. Load mass	2 kg	25 kg
7. Navigation	GPS/GLONASS	GPS/GLONASS
8. Target loads	Type "16E+"	Type "16E+"
9. Additional target loads	Installation of a 10 W LED	Installation of a 50 W LED
10. Temperature range	-30°C...+40°C	-30°C...+40°C
11. Launch	Vertical - automatic	Vertical
12. Landing	Vertical - automatic	Vertical
13. Engine type	Electric - eight-rotor scheme	Internal combustion engine (Wankel)
14. Maximum height	1000 m	3000 m

Discussion of results

Table 1 shows that the ZALA 421-02X has better technical characteristics, but for this project it is impractical to choose this type of UAV for the following reasons: internal combustion engine (ICE), not electric; fire hazard, in the event of a malfunctioning device falling onto the pasture; heavy weight; danger to animals, as the blade of a UAV with an internal combustion engine has a higher rotation frequency and moment of inertia; high cost compared to an electric UAV. Despite the huge prospects, the use of UAVs for automated monitoring of the physiological state of animals in the current global practice of pasture livestock breeding is just beginning. In our country, these technical means for monitoring the condition of animals on pastures are not used at all. Therefore, according to experts, this promising direction of automation of pasture livestock breeding will have an undoubted novelty and relevance for the next 4...5 years. After conducting theoretical studies, it should be noted that the following technical means can be used for automated monitoring of physiological parameters of cows: various types of ear sensors (tags) and neck or intra-body sensors to obtain primary physiological data about the animal; miniature radio modules as part of the RTM system with a built-in controller for converting primary data into a digital code and transmitting it via a radio channel, a UAV with a video camera and repeater (possibly also a pasture condition sensor system) on board for video recording of animals and RTM data transfer to the main computer for processing and storage.

Conclusion

It is possible to solve the task of automated monitoring of the state of cows in the pasture using one of two (or their combination) methods with the appropriate technical equipment: using automated ground and/or air-based systems. These are, respectively, radio monitoring of animals and monitoring using UAVs. At the same time, both automated monitoring systems together with technical means of radio telemetry (RTM) will be able to provide data transmission from any sensors located on the animal's body or inside, to the main information reception point for processing on a PC.

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