AUTOMATED SYSTEM FOR THE MICROCLIMATE REMOTE MONITORING

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Abstract: *The authors propose the development of a system designed to control microclimate parameters at the place where grain is stored in a polymer molten bubble, diagnose changes in it and transmit information to the control center. The system is a software and hardware complex that combines grain storage tanks with a system for remote control and diagnostics of the main microclimate parameters, such as the level of oxygen* O_2*, the level of carbon dioxide* CO_2*, temperature and relative humidity. The system also monitors the integrity of the material of the melt bubbles by indirect signs.*

Key words: *automated system, remote monitoring, microclimate, grain storage, tightness, sensors, agricultural molten bubbles*

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This Publication has to be referred as: Nikonova, T[atyana]; Breido, I[osif]; Sichkarenko, A[ndrey]; Daich, L[eonid]; Kotov, E[vgeniy]; Baimuldin, M[urat] & Zharkevich, O[lga] (2022). Automated System for the Microclimate Remote Monitoring, Chapter 09 in DAAAM International Scientific Book 2022, pp.107-120, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-34-1, ISSN 1726-9687, Vienna, Austria
DOI: 10.2507/daaam.scibook.2022.09

1. Introduction

The technology of storing grain in bags is relatively new for Kazakhstan. It came to us from abroad and became popular due to the acute shortage of elevator capacities. The main advantage of the technology is the absence of capital costs for the installation of a granary: cleaned dried grain can be stored on any flat area in special sealed sleeves. Bag storage technology is used by both farmers and medium-sized agricultural firms that lack grain storage facilities, as well as large agricultural holdings that own their own network of elevators, as well as poultry and livestock companies, elevators, feed mills, oil refineries and other enterprises for which crop products are raw materials for processing (Latyshenok et al., 2021). The biggest losses of grain occur precisely at the stage of storage, so the solution to this problem is significant for the food security of any country (Laba 2022).

The basic principle of storage in plastic molten bubbles is to keep the grain in a sealed environment, in which as a result of the respiration of barn pests, microorganisms and fungi, oxygen is absorbed. In an atmosphere without access to oxygen, the vital activity of the grain slows down, the ability to reproduce parasites and fungi disappears, which leads to their death. For a short period of time, an atmosphere of carbon dioxide is formed in the bag, in which the grain is stored better and longer.

The efficiency of grain storage in polymer agricultural molten bubbles depends on several parameters, the most important of which is the preservation of the microclimate in hermetically sealed agricultural molten bubbles (Samokhvalova, 2017). This can only be ensured by ensuring the overall integrity of the materials from which the sleeves are made, consisting of three-layer high-density polyethylene. The white outer layer contains titanium dioxide to reflect the sun's rays and prevent the temperature inside the molten bubbles from rising. Two black layers on the inside protect the products from the penetration of sunlight. All three layers are inseparable, each of the layers is made of different polymers with different additives and stabilizers. The material of the sleeve is an environmentally friendly product, provides increased strength, absolute impermeability and elasticity.

Currently, the increasing digitalization of production processes is gaining importance in order to benefit from competitive enterprises, including agricultural. Digitization of the main controls, use of remote access to software and the maximum production process, optimization of technological digital system tools and architecture of firmware microprocessors and computing systems with the addition of manufacturing process control capabilities (Aryskin, 2021). Also an important component of the remote monitoring system is data visualization which is convenient for perception and further analysis (Laptev 2021).

The aim of the study is to develop a system for remote monitoring and diagnostics of the main parameters of the microclimate as the level of oxygen O_2, the level of carbon dioxide CO_2, temperature and relative humidity. The system should also monitor the integrity of the melt bubbles material by indirect signs. So a sharp increase in the oxygen concentration indicates depressurization of the polymeric agricultural melt of the bubbles.

2. Review of previous research

Scientists from all over the world are engaged in research in the field of grain storage and the choice of optimal modes, the problem of grain preservation is relevant for agriculture to this day (Afonnikov et al., 2022). The most common methods for determining the intensity of grain respiration are based on various physical and chemical methods, in each of which, the method is based on one indicator, having determined which, in the future, all components of the grain respiration process are calculated (Bazaluk et al., 2022).

Examples of this can be methods and means on the basis of which the determination of the process of grain respiration is made: on the accumulation of carbon dioxide; by reducing the oxygen content (Latyshenok et al., 2021), by the loss of dry mass of grain (Baributsa et al., 2021); by changing the pressure in a container filled with grain (manometric methods) (Aduchayev, 2015); by determining the amount of heat that was released during the study (Nyarko et al., 2021).

A common disadvantage of these methods is that when using each of them, only one of the indicators of the grain respiration process is determined, and, based on the calculation and subsequent analysis of the numerical values of this indicator, found directly or indirectly, conclusions are drawn about all the complex biochemical processes occurring in the grain mass during its respiration. In addition, the use of these techniques does not allow one to study all types of breathing according to one scheme, i.e. aerobic respiration is studied according to one scheme, and anaerobic respiration according to another scheme. The effect of this significantly increases the error in the results of both the study itself according to one of the schemes, and the ratio of the results of studies conducted by different methods. Sometimes the ability to compare the results obtained by different methods is generally lost.

Known system for remote monitoring of the state of grain during storage, protected by patent RU2555794C1 (Zakladnoy 2021). The system includes temperature sensors, relative air humidity sensors and an insect counting sensor and contains grain mass parameters meters equipped with lifting mechanisms and junction boxes with measuring digital blocks placed in them, interconnected in parallel and connected to a power supply unit and a computer. The disadvantage of this system is the inability to measure such parameters as the level of oxygen and carbon dioxide in the storage atmosphere, as well as the lack of remote monitoring, which does not allow receiving operational data from remote objects. Also known is a complex system for remote monitoring and diagnostics of the state of grain during storage (Zakladnoy 2021), which contains a system for remote monitoring of the state of grain during storage, a system for recirculating grain fumigation and a system for preserving grain from pests. The disadvantage of the system is the complexity of its installation and the lack of remote monitoring, which does not allow receiving operational data from remote objects.

Thus, the development of a system for monitoring microclimate parameters at a storage location in a polymer sleeve, diagnosing microclimate changes and transmitting information to a control room is an urgent task for the development of agriculture.

3. Development process and results

The developed automated system for remote monitoring and diagnostics of the microclimate in polymeric agricultural sleeves combines grain storage tanks with a remote monitoring and diagnostics system for the main parameters of the microclimate, such as the level of oxygen O_2, carbon dioxide (CO_2), temperature and humidity. Also, the software and hardware complex will monitor the integrity of the hose material and transmit information from sensors to the operator's monitor in real time using modern communication systems. It will signal unacceptable values of the measured parameters and ensure the use of autonomous power sources, power supply of sensors and communication systems for the entire period of use of the agricultural molten bubbles.

The principle of operation developed by the authors is as follows: sensors, being in the sealed compartment of the polymer sleeve, measure the parameters of the gas composition, temperature and humidity. The received data are sent to the control room in real time in the form of tabular and graphical reports. An alarm is also implemented at critical values of oxygen, temperature or humidity.

The system represents the hardware-software complex consisting of an industrial controller for collecting information from sensors located inside the polymeric agricultural sleeve, processing information in accordance with the developed program, storing operational data and transmitting information to the central dispatching console; oxygen sensors to monitor the dynamics of oxygen concentration in the gas-air mixture inside the polymeric agricultural sleeve. The system includes CO_2 sensors for monitoring the dynamics of carbon dioxide concentration in the gas-air mixture inside the polymeric agricultural sleeve. The system also contains temperature sensors to control the temperature of the gas-air mixture inside the polymeric agricultural sleeve. The system has humidity sensors to control the dynamics of the humidity level inside the polymeric agricultural sleeve. The system has a battery (an electrochemical energy source) to provide the system with electricity during the entire grain storage cycle in the agricultural sleeve. The system also has a communication controller to provide wireless communication with the control room to transfer technological information about grain storage conditions. Additionally, the system has a control room equipped with a computer for storing and displaying technological information about grain storage conditions.

This arrangement of system components makes it easy to change the number of sensors depending on the measured space and fulfill the conditions for creating flexible production systems (Mulc 2021).

The data collection and transmission device, according to the developed block diagram (Figure 1), transmits the measured indicators to the control room, where graphs of parameter changes are displayed on the operator panel, the measured values are archived in memory, and these readings are analyzed to identify an emergency.

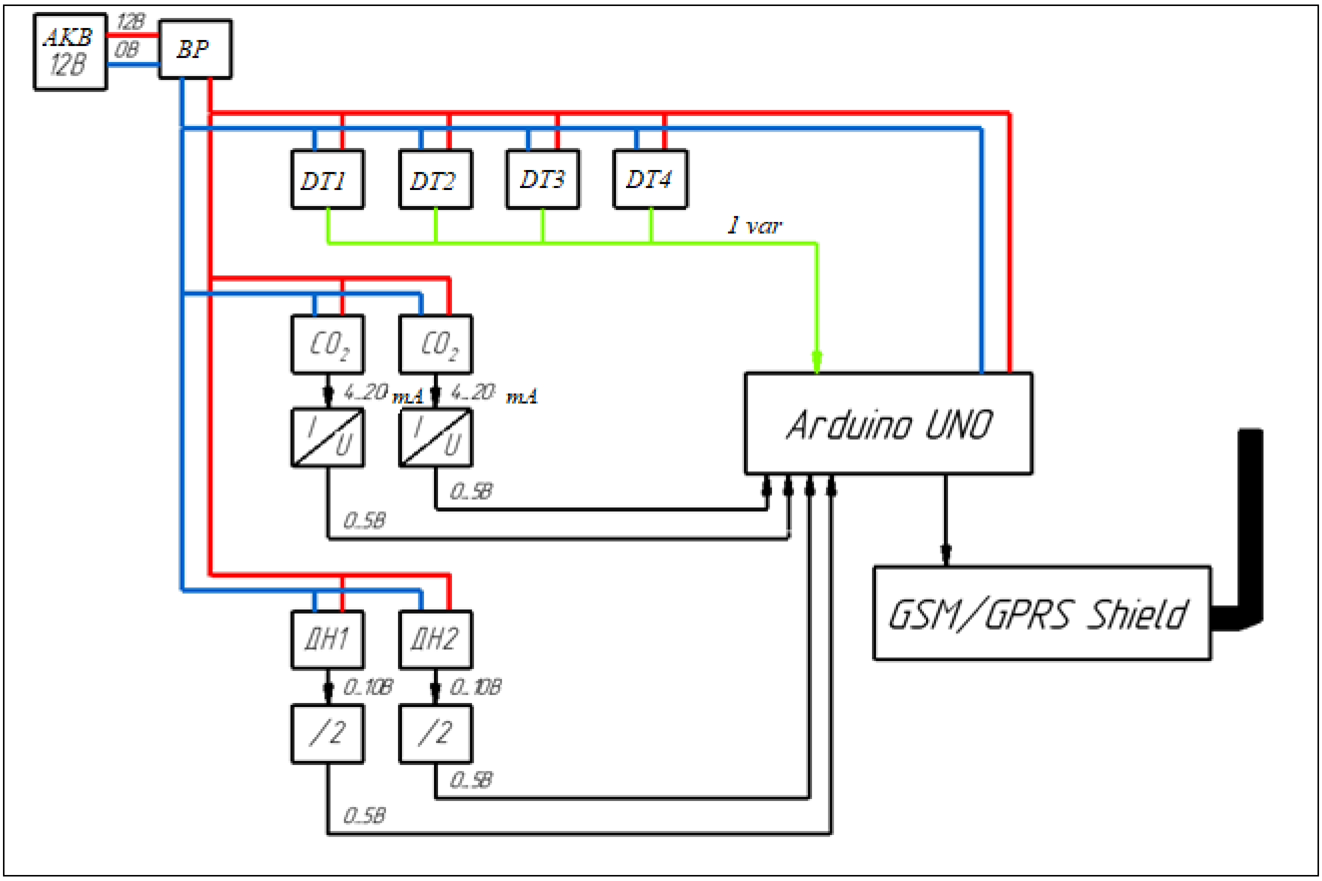

Fig. 1. Structural diagram of the microclimate system in a polymer sleeve for grain storage.

Figures 2 and 3 show the schematic diagrams of the control box and the system as a whole. Description of the circuit diagram of the system (Figure 2). The heart of the system is the control unit - A4, through which power is supplied, as well as collecting information from sensors. So, block A1, the solar panel controller, supplies voltage to block A4 through connector X1, which in turn receives voltage from the solar panel - block A2.

Through connector X2, block A4 communicates with the antenna - block A3. Using connector X3, the control box communicates with digital sensors DS18B20 - blocks A5, A6, A7, A8, thereby supplying power at a rate of 5V and taking readings. Using the X4 connector, the A4 block communicates with the A9 block - the OWEN PKG100-CO2 carbon dioxide sensor, supplying power at a rate of 12V and taking readings. In a similar way, it communicates through: connector X5 of block A4 with block A11; connector X6 block A4 with block A10; connector X7 of block A4 with block A12.

Description of the circuit diagram of the control unit (Fig. 3). Inside the control unit are:

- block A1 - voltage stabilizer;
- block A2 - Arduino Uno controller;
- block A3 – transmitter GSM/GPRS Shield Sim800F.

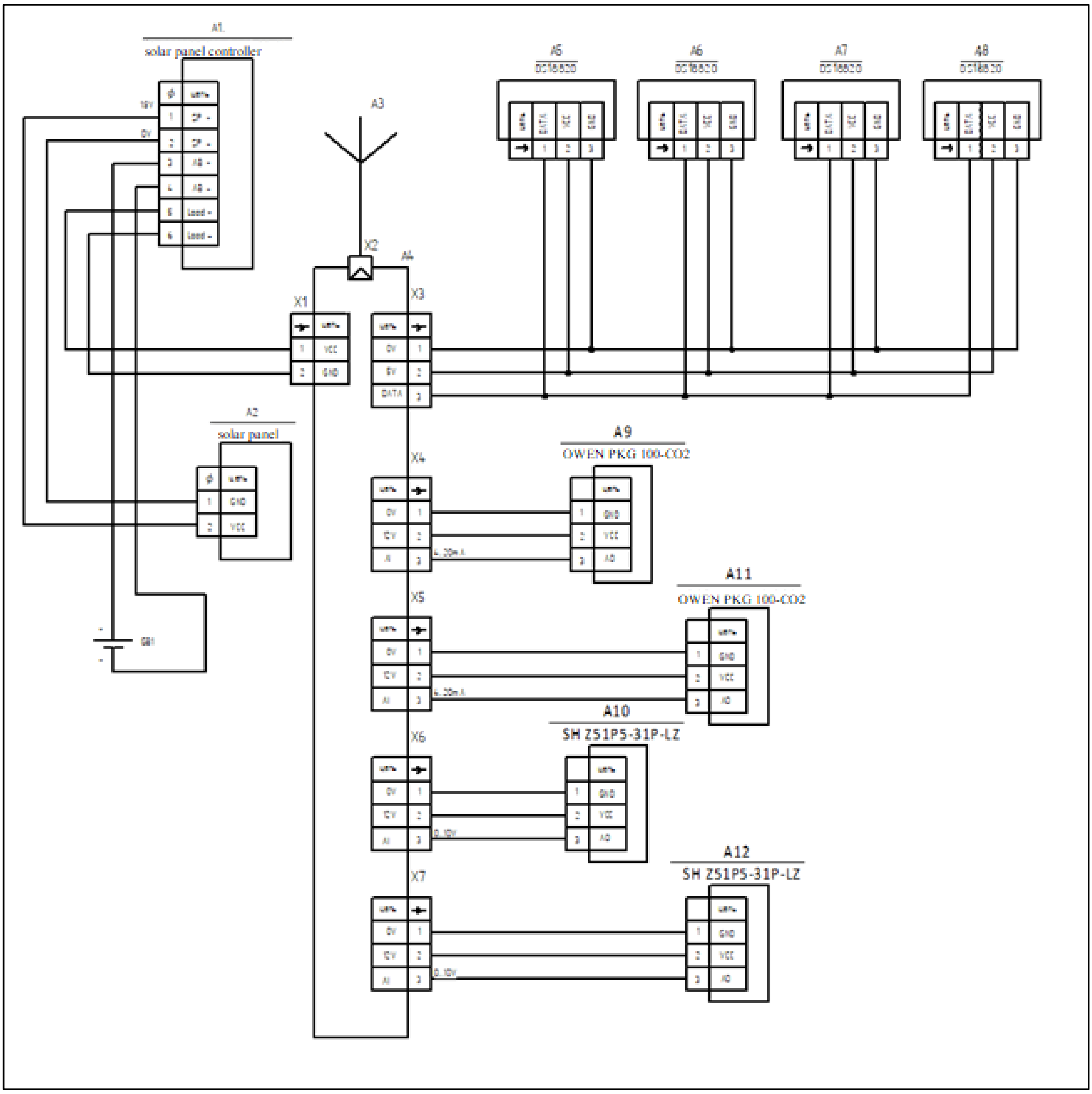

Fig. 2. Schematic diagram of the system.

Through the connector X1 of the control unit, the external supply voltage is supplied to the connector X1 of the unit A1, stabilizing, which exits the connector X2 of the unit A1, after which it goes to the connectors X4, X5, X6, X7 of the control unit, as well as to the connector X3 of the unit A2. By this action, blocks A2, A3 are powered, as well as external carbon dioxide sensors and moisture meters. The digital temperature sensors are powered through connector X1 of blocks A2 and A3.

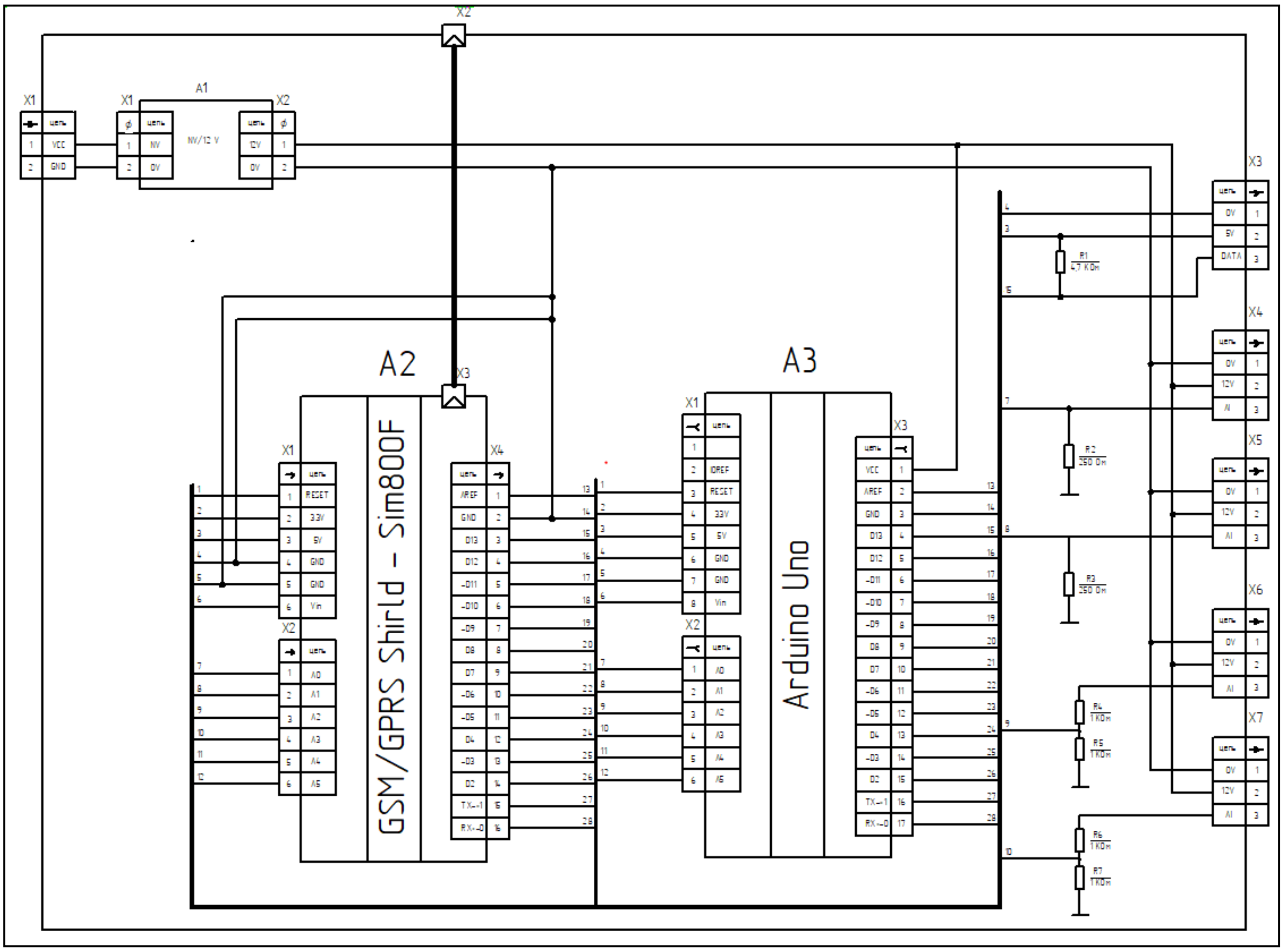

Fig. 3. Schematic diagram of the control unit.

The connection of blocks A2 and A3 is carried out directly, this is noticeable in view of the partial duplication of connectors.

Signals from sensors are received using connectors X3, X4, X5, X6, X7. Connector X3 of the control unit is responsible for communication with digital temperature sensors, receiving a signal and transmitting it to connector X3 of block A3 and connector X4 of block A2. A 4.7kΩ resistor is connected between the DATA line and the 5V line of the X3 connector, this is due to the peculiarity of connecting a digital sensor.

Connectors X4, X5 of the control box are responsible for communication with carbon dioxide sensors. The reception of the analog signal from the sensors goes directly to the connectors X2 of blocks A2, A3. Resistors R2, R3 of 250 Ohm are connected to the AI communication lines of connectors X4, X5, which converts a 4 ... 20 mA signal into a 0 ... 5V signal.

The resistance of resistors R2, R3 was selected based on the following equation:

$$R = \frac{U}{I} = \frac{5B}{0{,}02A} = 250 \text{ohms} \quad (1)$$

Connectors X6, X7 of the control box are responsible for communication with humidity sensors. Reception of the analog signal from the sensors goes directly to the connectors X2 of blocks A2, A3. Voltage dividers with resistors R4, R5 are connected to the communication lines of the AI connectors X6, X7; R6, R7 to 1 kOhm, which converts a 0 ... 10V signal into a 0 ... 5V signal. Resistance of resistors R4, R5; R6, R7 was selected based on the following equation:

$$U_{input} * \frac{R_n}{R_m + R_n} = U_{output} \tag{2}$$

The antenna is connected via connector X2 of the control box to X3 of the A2 unit. Table 1 provides a verbal description of each operand.

№	Operator	Action
1	Operator - 1	The beginning of the algorithm. Further transition to block 2.
2	Operator - 2	Starting the system, which is a sub-algorithm with sequential reading of readings from sensors, as they are ready. Continue to block 3.
3	Operator - 3	Checking the temperature values from temperature sensors for failure by comparing with a previously set alarm range. If the condition is true, it goes to block 4, otherwise to block 5.
4	Operator - 4	Recording readings from temperature sensors in an emergency array. It erases the readings in a regular array. Continue to block 6.
5	Operator - 5	Recording readings from temperature sensors in a regular array. It erases the readings in the emergency array. Continue to block 6.
6	Operator - 6	Checking moisture values from moisture meters for accidents by comparing with a previously set alarm range. If the condition is true, it goes to block 7, otherwise to block 8.
7	Operator - 7	Recording readings from temperature sensors in an emergency array. It erases the readings in a regular array. Further transition to block 9.
8	Operator - 8	Recording readings from temperature sensors in a regular array. Erases the readings in the emergency array. Further transition to block 9.
9	Operator - 9	Checking the readings from the carbon dioxide sensor for accidents by comparing with a previously set alarm range. If the condition is true, it goes to block 10, otherwise to block 11.
10	Operator - 10	Recording readings from temperature sensors in an emergency array. It erases the readings in a regular array. Further transition to block 12.

11	Operator - 11	Recording readings from temperature sensors in a regular array. It erases the readings in the emergency array. Further transition to block 12.
12	Operator - 12	Checking for a request for readings by the operator. If there is a request, there is a transition to block 13, otherwise to block 14.
13	Operator - 13	Reading current readings of sensors with further recording in arrays. Continue to block 16.
14	Operator - 14	Checking the passage of the day. If the condition is true, it goes to block 13, otherwise to block 15.
15	Operator - 15	Check for an accident. If the condition is true, it goes to block 16, otherwise to block 17.
16	Operator - 16	Check for an accident. If the condition is true, it goes to block 16, otherwise to block 17.
17	Operator - 17	Check for a system shutdown signal. If the condition is true, it goes to block 18, otherwise to block 3.
18	Operator - 18	It performs shutdown of the entire system. Further transition to block 19.
19	Operator - 19	The end of the algorithm.

Tab. 1. Description of the algorithm.

For programming an automated system for remote monitoring of the microclimate in polymer agricultural molten bubbles during grain storage, an algorithm was developed (Figure 4)

The technical result from the use of an automated system for remote monitoring of the microclimate in polymer agricultural molten bubbles during grain storage is the constant monitoring of the microclimate in grain storage tanks and its remote monitoring, signaling violations of the specified limit levels of oxygen, carbon dioxide, temperature and relative humidity (Figure 5).

This result is achieved in that the microclimate control and remote monitoring system in polymeric agricultural molten bubbles for grain storage contains at least three groups of sensors 1 for measuring changes in microclimate parameters in various places of the agricultural sleeve at a distance of 1-2 meters from each edge of the molten bubble and In the middle. All groups of sensors 1 installed in the grain mound are interconnected by bus 3 and connected to the inputs of industrial controller 2. Industrial controller 2 is connected to switching controller 5. Industrial controller 2, communication controller 5 and sensors are connected to power supply 4.

The control system and remote monitoring of the microclimate in polymeric agricultural molten bubbles for grain storage is made as follows.

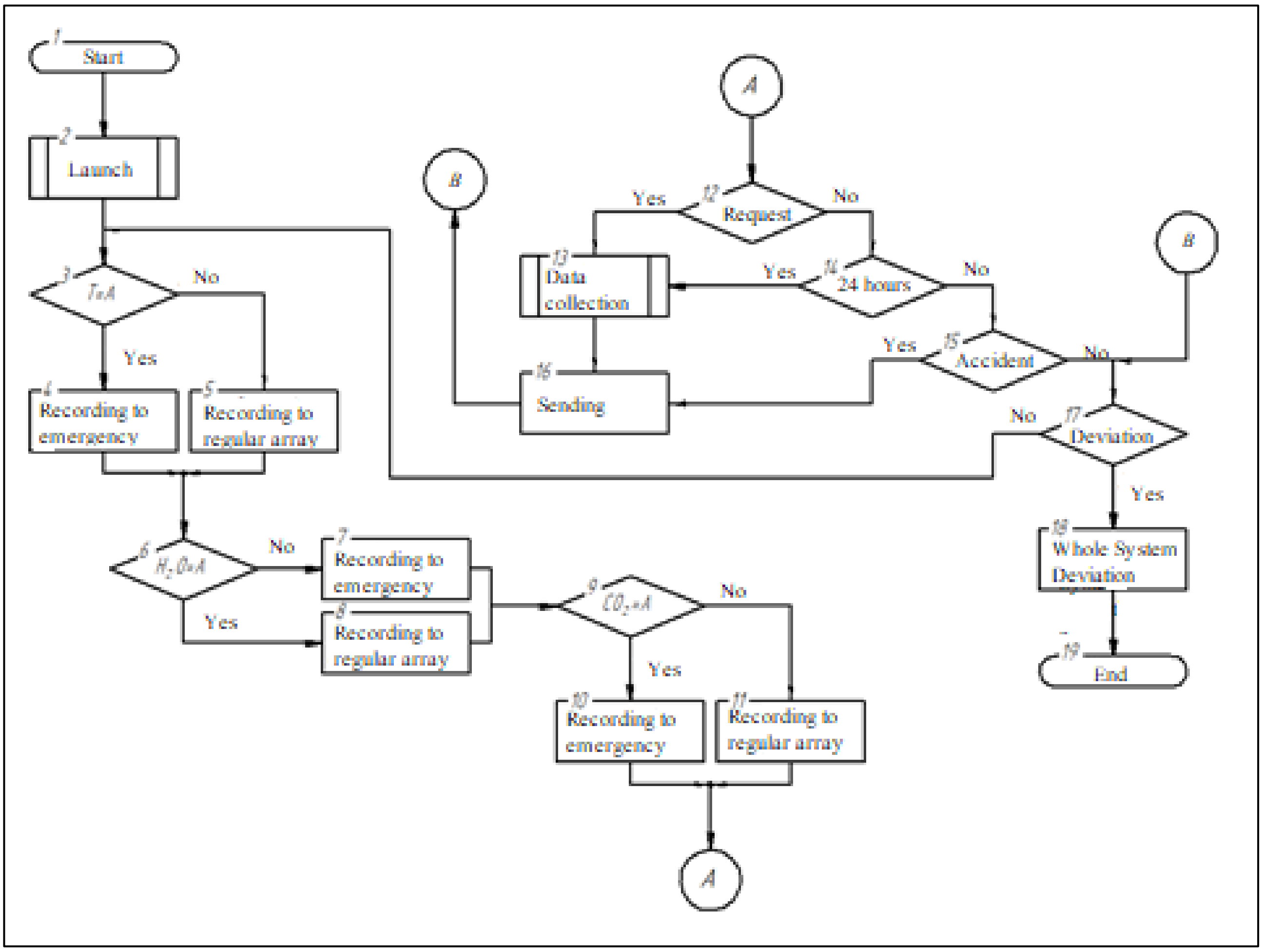

Fig. 4. The algorithm of the automated system for remote monitoring of the microclimate in polymer agricultural molten bubbles during grain storage.

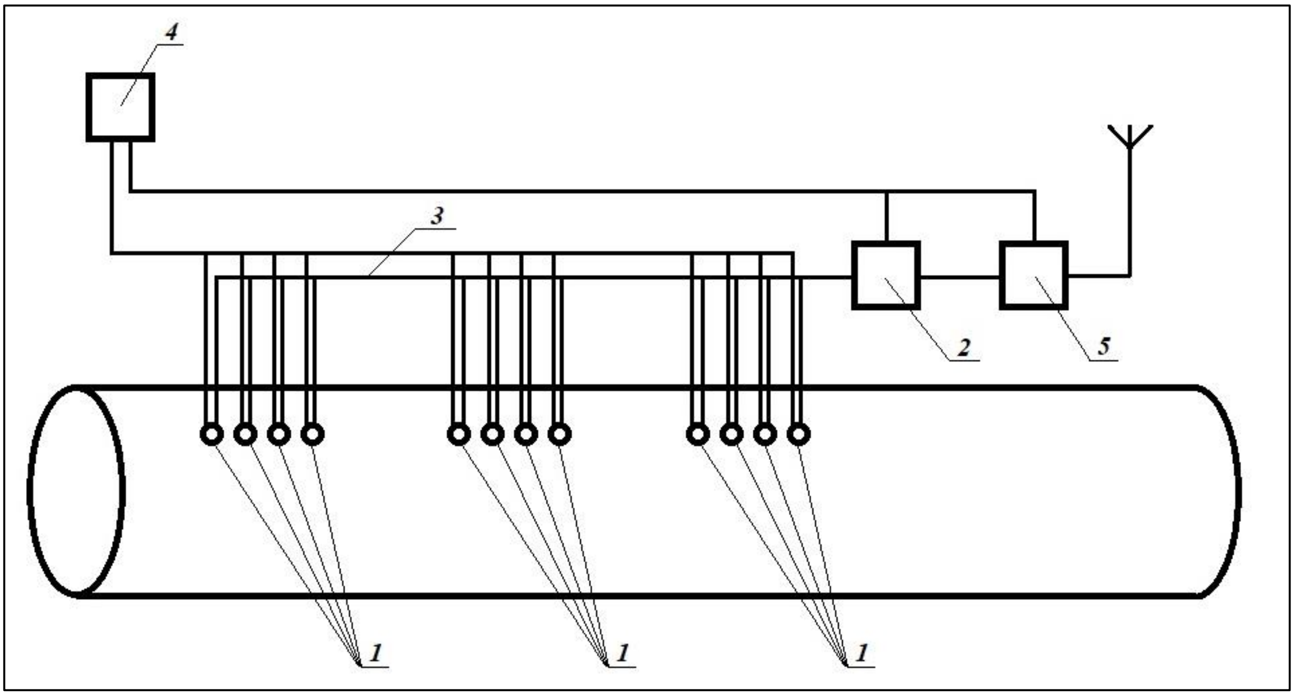

Fig. 5. Schematic representation of the system for remote monitoring of the microclimate in polymeric agricultural molten bubbles during grain storage.

Groups of sensors 1 are installed in the grain mass in polymeric agricultural molten bubbles when the sleeve is filled. Analog signals from sensors of oxygen, carbon dioxide, temperature and relative humidity, which contain current indicators of the level of oxygen, carbon dioxide, temperature and relative humidity of the air are transmitted to the industrial controller. The industrial controller 2 converts the data into a digital signal. By means of the communication controller 5, data on grain storage conditions are transmitted to the control room computer via a GSM channel. Thus, in the proposed system of control and remote monitoring of the microclimate in polymeric agricultural molten bubbles for grain storage, in comparison with the prototype, automatic control is carried out with the display of microclimate characteristics on the monitor screen simultaneously in terms of oxygen, carbon dioxide, temperature and humidity.

An oxygen sensor ADT-93-1195 can be used as an oxygen sensor. The carbon dioxide sensor OVEN PKG100-H4.CO2 can be used as a carbon dioxide sensor. To measure temperature and relative humidity, the SHT Z51P5-41P-LZ relative humidity and temperature sensor in a sealed IP65 plastic case can be used.

An industrial controller can be Arduino modular controllers in an IP67 case (Figure 6). The communication controller is made in the form of a GLONASS + GPS controller Azimuth GSM 5.1. Power supply is carried out from accumulators SVC AV7.5-12, 7.5Ah/12V. The GSM Shield is connected directly to the Arduino Uno board (Figure 6). To check the functionality of the Sim800F module after connecting the GSM / GPRS Shield, 3 program codes were written:

- - port check code and response of AT commands;
- - code for checking the possibility of making a call;
- - SMS verification code.

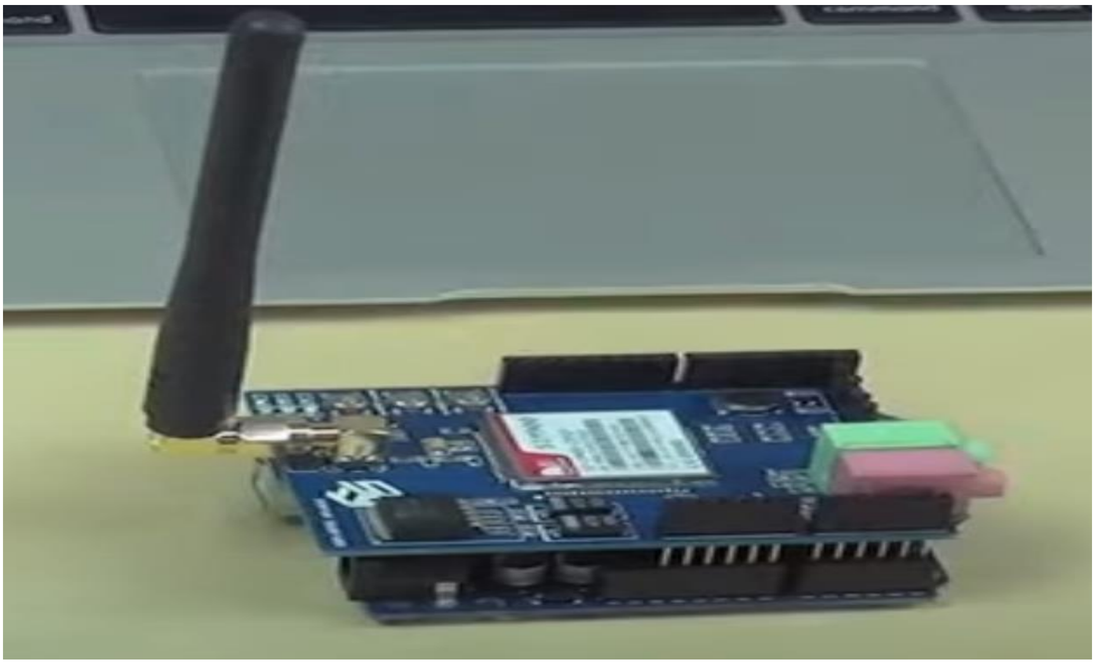

Fig. 6. Connecting Arduino Uno and GSM/GPRS Shield.

During the implementation of the project the methods of probability theory, mathematical statistics, processing of experimental results, simulation and circuit modeling, applying of software packages for industrial controllers were widely used.

In practice proven methods and technologies for creating industrial electronics devices, software and hardware automation tools based on industrial controllers, intelligent sensors, SCADA systems and wireless information transmission devices have been applied.

There is a wide application of experimental methods, including the creation of specialized stands for testing automated systems, as well as the development of technical solutions on mock-ups, followed by the manufacture of samples of control devices and tests in the laboratory. During the implementation of the project, bench tests were carried out in modes corresponding to operating conditions. All studies were carried out according to a single methodology, which makes it possible to judge the reliability of the results obtained.

4. Conclusion

The developed complex passed the laboratory tests under conditions close to real for 6 months (from September to February 2021). It was found that in the process of aerobic respiration of grain in the agricultural molten bubbles the composition of air in the intergranular space is constantly changing, while the content of carbon dioxide increases and oxygen decreases. Thus, an atmosphere favorable for grain storage is created. Sensor data is transmitted in real time to a computer in the control room. In case of intentional damage to the integrity of the agricultural sleeve, a sharp increase in the level of oxygen was noted which triggered an alarm.

When using the automated system for remote monitoring of the microclimate in polymer agricultural molten bubbles developed by the authors during grain storage, the following results were obtained:

1. The system remained operational for at least 12 months after filling the polymer agricultural molten bubbles with grain;
2. When testing the system by introducing special metallic inclusions in the system, an alarm was activated about existing violations of the integrity of the sleeve;
3. The flow of incoming data did not stop and the integrity of the polymer sleeve was continuously monitored throughout the entire testing period;
4. Continuous monitoring of the microclimate was carried out (temperature, humidity, assessment of the dynamics of oxygen content and carbon dioxide content during grain storage);
5. With a molten bubble length of up to 70 meters, control was provided at least at three points.
6. The transmission of technological information was as follows: once a week - at a temperature of 10 degrees of heat and higher; once every two weeks - at a temperature below 10 degrees of heat; once a month at a temperature of 0 degrees and below; In emergency situations (a gap of polymer sleeve, a sharp change in microclimate, predicted approximation to critical values of

microclimate parameters), information should be transmitted once per hour until the system is turned off or normalized control parameters.

7. On the side of the dispatching point, all incoming information is constantly stored before the end of the storage period of the current portion of grain, and after the end of this period, the possibility of its archiving should be provided.
8. Information from the automated system is transmitted in a wireless way, but data transfer equipment should not require certification or receipt of special permits. The transmission of technological information is carried out by the system of mobile communications of the GSM 3 and/or 4 generation standard.
9. It was found that the optimal moisture of grain for effective storage in the sleeves is 10 -14%., The optimum grain temperature for effective storage in the sleeves is +10 ... +12°C with the temperature measurement error (not more than ±1°C).

Testing of the system is currently planned on a farm that uses polymeric agricultural sleeves to store seed grain. In the future, the developed automated system will be manufactured and sold for the needs of farms. In cooperation with Altyn Arna Holding LLP, which is a manufacturer of polymeric agricultural sleeves, a commercialization strategy has been developed based on the conclusion of licensing agreements with industrial enterprises for the production of a hardware and software complex of automated systems. A program of concessional lending is being developed for the purchase of agricultural sleeves equipped with automated systems for remote monitoring and diagnostics of the microclimate during grain storage with the participation of development institutions of the Republic of Kazakhstan.

The socio-economic effect of the project is to create a domestic industrial automated system which will improve the quality of grain and reduce the cost of storing it in polymeric agricultural sleeves.

5. Acknowledgements

Automated system of remote monitoring of microclimate in polymer agricultural molten bubbles during grain storage was created as part of grant financing of projects by the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan IRN Project No. AP08052553.

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