Development of a system for operational monitoring of the soil agrochemical indicators

S Komkova, E Kosolapova*, V Kosolapov, A Chesnokov and S Stankovski

Department of Information Systems and Technologies, Nizhny Novgorod State Engineering and Economic University, 22 a Oktyabrskaya Street, 606340, Knyaginino, Russian Federation

*E-mail: Kosolapova@ngieu.ru

Abstract. Today digitalization is being introduced into all spheres of human activity, including rural areas. One of the tasks of agricultural organizations is to control the state of soils and monitor crops at all stages of the production cycle. For this, chemical or instrumental methods are used, which have low mobility and high labor intensity of taking soil samples, analyzing them and processing the results. The paper presents a description of the system, which includes three modules. The first module is peripheral equipment, combined into a sensor unit that measures soil indicators and collects data from the measuring elements. The second module represents the communication channels that include the infrastructure of the Internet of Things, giving the possibility to the sensor nodes to be organized into a sensor network providing data collection and wireless transmission. The third module is an information system that provides reception, recording and analysis of data transmitted from sensors. According to these approaches, control over the application of mineral and organic fertilizers, pesticides and herbicides is increased. They are applied only in areas where it is required and in precisely calculated doses, excluding oversaturation with harmful substances and a decrease in anthropogenic impact on the environment.

1. Introduction

Modern agriculture involves using various tools of digitalization in order to reduce the labor intensity, processes energy intensity, production costs and increase profitability.

An important task, within the framework of this project, is to study the state of the soil cover of sown areas and restore its fertility on the basis of the development of new progressive approaches that also allow to reduce the anthropogenic influence of man on nature. One of the promising solutions to this problem includes systems for monitoring the state of the soil during the plant vegetative period and modeling the results of crop cultivation in terms of technical and economic indicators.

Today, precision farming technologies are actively introduced and developed. It is an integrated process of managing the development and growth of plants in accordance with their needs.

The quality of agricultural land, the reproduction of its fertility, especially of the arable land is of great importance. Since the full development of cultivated crops depends on its condition and the content of trace elements in it in sufficient quantities, monitoring the state of the soil and the possibility of timely adjustment of the technological process as well as the point changes in the volume and composition of mineral fertilizers applied to the soil allows control the yield and the final profitability of production.
At the same time, the use of traditional methods for the continuous application of mineral or organic fertilizers, pesticides and herbicides can lead to serious environmental consequences due to high concentrations of drugs and reagents, if they are not rationally distributed over the field [1-3].

Scientific and technological progress in the development of microelectronics, information and telecommunications technologies, the creation of global positioning systems [4,5] and geoinformation systems [6,7] laid the foundations for the development and implementation of differentiated agricultural technologies in space and time.

Nowadays, most manufacturers of agricultural machinery strive to integrate various advanced technologies into it – global positioning systems (GPS); geographic information systems (GIS); yield monitor technologies [8], variable rate technologies, remote sensing of the soil [9], which are based on a set of special sensors, video surveillance and photo fixation. Among the foreign manufacturers are John Deere (USA), CLAAS (Germany), CNH Industrial (Netherlands), New Holland (Italy). Among the Russian manufacturers it is worth noting − Rostselmash, Krasnoyarsk Combine Plant, Agrotechnmash, Kirov Plant, Bryanskelsmash. In addition, various software is used, which is aimed at linking data on agricultural production processes with information about working processes at the level of the agricultural organization.

All this is aimed at obtaining the maximum volume of high-quality and cheapest agricultural products, taking into account environmental safety standards.

Thus, it is possible to control the productivity of crops, based on the use of a complex of satellite and computer technologies [10]. Thanks to them, agricultural producers can calculate the amount of seeds, fertilizers and other resources for each section of the field with an accuracy of up to a meter. It is no longer necessary to plow, sow, and water “by sight”, as it has been done traditionally for many years.

A review of information sources [11-13] showed that various digitization tools are currently being developed and implemented based on the use of various types of sensors to ensure operation in online and off-line mode for measuring the properties of soil and plants by electrical and electromagnetic, optical, optoelectric and radiometric, mechanical, laser, acoustic, pneumatic and thermal parameters.

The various types and systems of sensors installed on the equipment perform mainly the operations of applying liquid and solid mineral fertilizers, growth activators, fungicides and plant protection products (SideKick by Raven Industries (USA), AGROCOM VRA by CLAAS, CROP-METR by Müller Electronik (Germany), P3 Sensor ALS by Agricon (Germany), TREK by “Aerosouz-Altay” (Russia), as well as plant observations – detection of weeds, pests, plant diseases, leaf damage (WeedSeeker® by Trimble, Inc.) yield assessment (vegetation cover scanners CropSpec™ by Topcon Corporation (Japan), ISARIA by Fritzmeier (Germany).

To determine the required amount of fertilizers, samples are taken at each site. To do this, various methods and tools are used. As part of the transition to digital format, automated devices – soil collectors are actively introduced (Amity A2450 by Amity Technology (USA), Easy-Sampler by Nielfeld (Germany), Wintex 1000 by the Danish company Wintex Agro). They take soil samples in the field for further analysis in the laboratory. Today, advanced precision farming technologies are based on wireless sensor networks due to their capabilities, which are advantageous over traditional data collection schemes.

Thus, the transformation of the processes of monitoring the soil agrochemical indicators (moisture, acidity, soil type) into a digital form has already begun. However, the processes related to the study of the soil qualitative characteristics within the cultivated areas in Russia remain poorly covered and require special attention.

The purpose is to develop a system for operational monitoring of the soil agrochemical indicators in order to adjust the technological process of agricultural crops cultivation, depending on the stages of their development.
2. Methods and materials
For the organization of operational monitoring of soil agrochemical indicators, we propose a system that is three interconnected modules—peripheral equipment, communication channels and an information system.

The first module is a collection of sensor nodes of the same type. Each of them combines a set of sensors to measure various parameters. Each of them combines a set of sensors for measuring various parameters—these can be sensors for measuring the content of phosphorus, nitrogen, moisture, acidity, temperature, humus and other indicators in soil. The laboratory sample includes sensors for humidity, acidity, temperature and nitrogen.

Within the framework of the project, a virtual simulation of the sensor node was carried out in the TinkerCad environment (Autodesk, USA) based on the Arduino microcontroller (figure 1). The wiring diagram of all the elements was modeled to check the operability and their interaction based on the sketch written in the C++ programming language in the Arduino IDE.

![Figure 1. Simulated wiring diagram of the elements of the sensor node on the Arduino platform.](image1)

The working virtual model was used as the basis for the physical model of the node. It includes: the ESP8266 moisture sensor (Diymore, China), the M8 PT100 temperature sensor (TAXNELE, China), the KC868-Soil-npk acidity (Hebei, China), phosphorus and nitrogen sensor, the Arduino Pro mini board (Q-BAIHE, China), the zs-042 real-time clock (Diymore, China), the CP 210x USB programmer (SINFORCON, China), the autonomous power supply module, which is a set of accumulator batteries with a nominal value of 1.5 V and a capacity of 1000 mAh (figure 2).

![Figure 2. Physical model of a sensor node without the body.](image2)
Pre-processing of all sensors included in the first main module is performed on the microcontroller of the board, which is Arduino Pro mini, which has a small size and a sufficient number of analog and digital leads.

Each element is responsible for performing certain functions, which are related either to measuring the value of a parameter that characterizes the soil cover state, or to ensuring the operability of the device itself. The presented sensors are a temporary solution, their totality may vary depending on the customer’s needs.

The second module is the sensor network, which collects data from sensor nodes and transmits it to the information system for registration and further processing. Data transmission is based on the ZigBee open wireless communication standard for data acquisition and management systems. It allows creating self-organizing and self-healing wireless networks with automated message relay, with support for battery and mobile nodes. It is aimed at applications that require long battery life and high data transfer security at low data transfer rates. To create a sensor network, each sensor node includes a LoRaWAN Model V6.2 wireless communication module (CDSENET, China) (figure 3).

![LoRaWAN Model V6.2 wireless communication module.](image)

On its basis it is possible to create a network of wake-up sensors with the ability to low-energy and error-free data transmission over long distances up to 8 km. The efficiency of the operation consists in a channel width of 125 kHz and a transfer rate of 5 Kb/s. The RF data transmission module operates using an external antenna with a gain of 2.5 dBi, which makes possible to achieve high and stable data transmission quality, under normal weather conditions.

The general connection diagram of the peripheral equipment is shown in figure. 4.

![The general connection diagram of the peripheral equipment.](image)
Almost all components of the system are located in a sealed case, filled with silicone compound for reliability, except the output for additional configuration and modification of the board, as well as dip sensors (temperature, humidity and soil acidity, and others). For additional synchronization of the device, the scheme comprises a real-time clock for keeping the time and date. The entire structure of the dip part is planned to be placed in a special drift, with a special extractable mechanical screw for sampling the soil. The number of sensor nodes depends on the physical size of the field and the signal transmission distance.

Based on the information about the coverage area, the selected data transmission technology, and the analysis of the terrain of agricultural land, the graph of the sensor network was modeled (figure 5). Its vertices 0, 1, 2... n are the sensor nodes, and the arcs are the communication channel with the minimum and maximum values of the distance between the nodes in meters.

This model contains 21 vertices; the 22nd node is a data collection point (DCP), which transmits information to the computer of the system user.

The blue color indicates the route for transmitting information packets from the 2 sensor node to the data collection point. This route is optimal because it runs in arcs with the lowest weights. And the red marks the devices involved in the transmission of this information.

Each of the vertices does not have a rigid binding to the terrain and can move inside the graph, the main criterion for placement is compliance with the requirement: the maximum distance to the neighboring vertex should not exceed 5 km, and to the vertex diagonally 7 km. In this way, it is possible to go around complex terrain areas, such as plantings, separately growing trees and water reservoirs.

The pre-processed data received from the sensors is formed into a file by the control element, which is transmitted to the base station and then to the network server. It is then passed to the information system for further processing. Each of the devices contains its own unique identifier, which allows uniquely interpreting the received data.

The third module is an information system designed to receive data from sensor nodes and process them. The information system is developed in the Microsoft Visual Studio environment in the C# language. It is able to automatically record data on soil moisture, as well as on the content of various trace elements necessary for the crops cultivation with reference to a specific sensor node at the operator’s request (figure 6).

The data is registered in the system automatically, coming from the base station via the MAC protocol. The recorded values are compared with the nominal values in the library. After that, depending on the cultivated crop and its life cycle, the application provides recommendations for watering and applying fertilizers available in the database.
Figure 6. Window of the information system for operational monitoring of the soil agrochemical indicators.

The database of the information system is executed in the SQL language in the Microsoft SQL Server program.

In this case, the system is aimed at processing a large data stream with minimal manual labor. Thus, this property characterizes it as a modern digitalization tool for processing big data.

2.1. How the system works
The operation of the system for monitoring agrochemical indicators assumes a clear relationship of all three modules described above.

The principle of operation of the system involves the transmission of the first message (request) by the data receiver, which acts as an information system (figure 7). The signal is received by the sensor nodes and data collection begins from this moment. After receiving the command to initiate taking readings from the ground via the Arduino Pro mini control element, the access point sends a message to each sensor requesting data. Next, the indicators are measured by each measuring element.

The recorded values of the soil indicators are transmitted to the Arduino Pro mini control element, where a code file is generated. It is then transmitted to the nearest sensor node thanks to the LoRaWAN Model V6.2 wireless communication module based on the MAC addressing protocol. The operation is repeated from node to node to the data collection point. After that, all the information is entered into the information system by identifying the elements of each sensor node. At the end of the transfer, it receives a message about the successful transfer. The information system analyzes the received data and makes recommendations for adjusting the technological process.

Figure 7. The principle of operation of the system for monitoring soil agrochemical indicators.

3. Results and discussion
Studies were conducted using 131 sensor nodes and one base station. The sensor nodes are located on the experimental field of the organization according to the calculations and the diagram presented in figure 8.
Figure 8. Layout of sensor nodes (●) and base station (□).

The width of the field is 0.9 km, the length is 1.9 km, the perimeter of the field is 5.84 km, the area is 1.71 km². The intensity of data collection is once a day. The average distance between sensor nodes is 100±10 m. Received parameters: temperature, humidity, pH. The depth of measurements is 15 cm. The period of taking the parameters is 30 days. The start of reading the indicators is May 10.

The data obtained can be interpreted in a way convenient for the end user. In the study, gradient maps were generated, combined with the original image of the field (figure 9), as well as graphs of temperature changes during a selected period of time for each of the nodes or several of them (figure 10).

Figure 9. Temperature gradient over the area of the investigated field.

In the same way, graphs and gradients of soil moisture and acidity can be obtained. It is important that on the basis of the data obtained, it is planned to determine indirect indicators, such as the content of nitrogen or potassium.

Figure 10. Graphs of soil temperature changes for three nodes 120 (―), 34 (—) and 72 (—–).
There are publications [14,15,16], reflecting information about similar projects, which have their own distinctive features.

For example, Lofar Agro [14] is a project aimed at combating late blight in a potato field. Its development is highly dependent on the climatic conditions of the field - relative strength, brightness, atmospheric pressure, precipitation and wind direction, as well as the height of the water table. Tracking these indicators in the project is organized using a sensor network. The data is transferred to a PC for registration via a Wi-Fi connection. This data transmission technology is very energy intensive. The use in the proposed project of a low-power data transmission technology based on LoRaWan ensures a long service life of the system without the need for additional recharging of the battery. Also [15] there is information about a project for the cultivation of potatoes in Egypt. Researchers link sensor nodes, sensors for temperature, environment, soil pH and soil are placed at a distance of more than 10 m. The application layer is not disclosed, it is indicated that the application receives network data and processes it accordingly, that is, read values at a certain speed and requests from lower levels to send them also at a certain speed or at special events. In [16], a project is presented to develop a sensor network for monitoring paddy rice crops in Malaysia. Standard sensors - temperature and ambient, pH and ambient are integrated into all nodes. Data transmission is carried out through a server to a web page on the Internet, as well as to a notification system via SMS via a GSM modem in real time to the responsible person on a mobile phone. In the proposed system, the third module is an expert information system. Its algorithm involves comparing the values received from the sensors of the sensor node with the reference values of the needs of the cultivated crop contained in the application library. Based on the results obtained, the system issues recommendations for the dosage of fertilizers and watering.

4. Conclusion
According to the widespread use of all kinds of sensors, energy efficient data transmission systems and the development of digital technologies, it has become possible to implement operational monitoring of the soil and adjust the technological process of cultivation of agricultural crops, regardless of the location of the territories.

The suggested approaches are supposed increase the profitability of crop production through regular and timely monitoring of the technological parameters of the cultivated environment and their adjustment. In addition, providing wireless data transmission according to the principles of the Internet of Things, they may reduce transport, energy and labor costs. Operational monitoring of agrochemical soil parameters using the proposed system allows avoiding resource overruns where they are used in excess, and increasing the productivity of those fields that previously did not receive the required amount of necessary microelements and irrigation. In addition to the economic positive effect, the proposed approaches help to reduce the anthropogenic impact on the environment as a result of agricultural activities. This is due not only to the rational distribution of the applied fertilizers, irrigation, but also to the fact that this system involves many seasonal use with recharging the batteries to ensure the system’s operability.

In the further development of the project and research, a portable prototype of the system is presented, capable of collecting data with a table at least in terms of parameters (temperature, humidity, pH, hydrolytic acidity, illumination, nitrate nitrogen content, ammonium nitrogen content, mobile phosphorus and potassium). The system will provide data during the vegetative period of plant growth and will not depend on the region or country in which it will be applied. Replacing components with industrial electronics allows you to expand the range of influence of abiotic factors (humidity, temperature, oxidation resistance). The proposed technology does not replace the methods of analysis using spacecraft and agricultural machines, it allows to provide quality indicators of the cultivated areas, which will have a positive effect on the ecology and the environment.

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