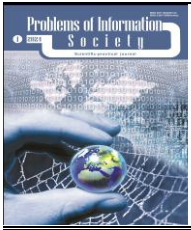

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Application of IoT wireless technology in precision agriculture by the example of creating a smart greenhouse

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ABSTRACT

Intelligent agricultural applications are gaining momentum, promising 24-hour monitoring of soil and crops, equipment productivity, storage conditions, plant and animal behaviour, energy consumption levels, etc. Combining different sensors, connected devices and agricultural facilities, IoT platform optimizes the development of intelligent agricultural systems and provides maximum flexibility, for example, for individual architectural design. This is a huge advantage for companies or farmers that plan to steadily expand their ecosystem of the IoT devices and over time introduce new intelligent agricultural solutions. Managing several solutions and upgrading them on a single IoT platform ensures rational operation and predictable results. One of such intellectual solutions is offered in this article on the example of the project "Smart greenhouse" using wireless IoT technologies.

1. Introduction

Steady growth in labor productivity is a key factor in achieving success and profit. In this sense, the experience of the United States is indicative, where during the 20th century the growth rate of labor productivity averaged 2.5% per year, of which 0.4% came from the financial sector, 0.5% was the contribution of marketing policy, and the remaining 1.6% came from production and operational management. As can be seen from this scenario, the role of production management and, in particular, making operational decisions is more than significant in increasing income and in acquiring a competitive advantage for the firm, the company and the state as a whole.

The path to achieving maximum profit and, consequently, to commercial success lies through reducing production and operating costs, creating new revenue streams and increasing the level of consumer utility. Formally, it looks as shown in Fig. 1.

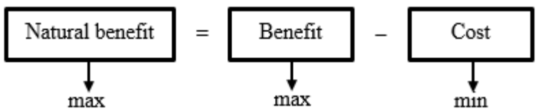

Fig. 1. Maximizing the net profit

If maximizing profits, which is carried out by promoting new product flows and increasing the level of consumer utility, is the responsibility of marketers and partly financiers, then minimizing production and operating costs lies entirely within the scope of production and operational management. In the context of optimizing the the net profit, every company needs to carefully analyze its own business and customer consumer behavior, identify and use hidden data to improve operations, decision-making and efficiency.

Modern agriculture operates on the same principles as any business – a permanent desire to reduce the cost of a unit of production and increase productivity per unit of resources expended (Katalin, 2012; Chandrakant et al., 2019). The tools used in agriculture today are still relevant, but their potential has almost reached the limit possible with the current level of technology (Addicott, 2019; Belov et al, 2021). At the same time, previously unavailable new tools such as satellite and computer technologies emerged, which defined the methodology of precision agriculture.

Precision agriculture is a crop productivity management system based on the use of a complex of satellite and computer technologies (Simon et al., 2021). Instead of plowing, sowing, and fertilizing "by eye", as was done throughout previous agricultural history, today farmers can accurately calculate the amount of seeds, fertilizers and other resources for each section of the field with an accuracy of up to a meter (Robert et al., 2019).

Today, the so-called "Smart Agriculture" is already relevant, offering a high-tech complex of solutions that allows for maximum automation of agricultural sectors, as a result of which KPI[1] increases, the quality improves and the quantity of products increases, and production becomes economically profitable (Niccolò et al., 2020). IoT (Internet of Things) technology based intelligent farming will enable farmers to reduce waste and increase productivity, from the amount of fertilizer used to the number of trips made by farm machines (Sankar et al., 2020; Karim et al., 2020).

In particular, a huge layer of hidden and useful information is concentrated in the form of data that, through IoT technology, can be obtained from operating greenhouse devices. Crops, soil, irrigation devices, greenhouse equipment, and climate control devices including temperature and humidity can accumulate, send, and process data, creating invisible images that are ready to be used to make operational decisions (Camilo et al., 2021; Kussul1 et al., 2023).

Problem definition

The influence of external factors, such as frost or cold night, negatively affects crop yields and worries greenhouse farmers. To grow any agricultural crop, for example, in a greenhouse in winter, it is required a reliable system for monitoring and regulating microclimate parameters. On many farms, temperature measurements, air quality and soil conditions are collected manually, which means environmental data may not be available regularly or may contain human errors. Thus, all processes of watering, ventilation and heating are based on inaccurate (or fuzzy) information, which leads to significant crop losses. With the current level of development of computer technology, the use of wireless IoT technologies is becoming an effective means of combining data from several sources to extract useful information and decision-making support (Rzaev, 2016) within the automated greenhouse management from a remote command monitor. In this regard, it is necessary to develop a high-tech set of solutions that will allow maximum automation of greenhouse farming to improve the quality and increase the yield of agricultural products.

2. Connecting data to decision-making using wireless IoT technology

In the historiography of the development of modern technologies, the emergence of the concept of the "Internet of Things" is usually associated with the name of Kevin Ashton, who first used this phrase in 1999 in a presentation of a project related to the optimization of supply chains by Procter & Gamble through the use of sensors. However, in a substantive sense, the idea itself appeared back in the 1970s, when network devices began to be used under the guise of "full computerization". Today, the concept of the "Internet of Things" refers to a data transmission network between devices. More specifically, IoT is a system that connects devices into a computer network and allows them to collect, analyze, process and transmit data to other objects using software, web applications or technical devices (Selim et al., 2021).

If we assume that the company's equipment is connected to the Internet in one way or another, then corporate business systems can receive data from devices in real time and, accordingly, analyze them to obtain additional information about the company's business process and clients (Gabriele et al., 2020; Rzayev, 2012). An Internet-connected device, through a sensor, provides the user with data that, if read correctly, can generate new contextual knowledge that is not available through any other means. With proper organization of the business process, a company can convert the knowledge acquired in this way into its competitive advantages and, thereby, strengthen its position in the market. In some advanced companies, the compilation of such

[1] KPI (Key Performance Indicator) is an indicator that helps determine the productivity of a company.

knowledge is already carried out using artificial intelligence tools, in particular, machine learning for processing data from devices connected to the Internet, generating information that cannot be identified in conventional ways (Agricultural Internet of Things, 2020).

There are various scenarios for applying the enormous potential of IoT technology in many business sectors. The most common of these is remote monitoring, which can be applied to many business situations. Sensors built into the equipment continuously collect data on current production conditions, productivity and other problems, and regularly transmit it at set intervals to the primary processing point (Eduardo et al., 2019). In addition, the feedback allows to remotely monitor the operation of devices, which significantly reduces the cost of their maintenance and ongoing repairs (Khalid et al., 2020).

IoT-based remote monitoring allows to consolidate data from multiple web devices to identify information useful for decision making. At the same time, the remote monitoring system includes four main components: device sensors, connectivity tools, data processing tools and a user interface (Nicolas et al., 2019). Controlled web devices collect data and send these data to the cloud, where software processes it in close collaboration with accumulated databases and knowledge.

Sensors of connected devices continuously collect relevant data in a dedicated environment to solve planned tasks and send them to the cloud at set intervals, using, for example, wireless technologies such as Wi-Fi, Bluetooth, Zigbee, LoRa, Cellular networks (Nb-IoT, LTE, etc.), creating energy-efficient long-range networks or when connecting directly to the Internet via Ethernet. The choice of connection means depends on the application of a particular device within the IoT-based remote monitoring system (Carlos et al., 2020).

From the moment it enters the cloud (or any information platform), data from web devices undergoes primary software processing to make decisions about performing certain actions, for example, turning on a warning signal or automatically setting up sensors from the device without direct human participation. However, in some cases the user may need to enter additional data, which requires a user interface. The interface is necessary not only for entering user data, but also for permanently checking the functionality of the remote monitoring system (Giorgia et al., 2020).

3. Application of IoT technology using the example of remote monitoring of temperature and humidity in a greenhouse

At the current level of development of precision agriculture technologies, an urgent problem for producers of greenhouse crops is that employees still have to manually and permanently measure indicators inside greenhouses, which does not allow them to quickly respond to critical changes in instrument readings (Takoi et al., 2019). Due to the delay in the time allotted for the manual measurement and subsequent review of the statistics, taking into account the entering of the current readings, the harvest could suffer significantly (Zecha et al., 2013). Based on this premise, the importance and relevance of creating a system for remote monitoring of the microclimate in a greenhouse using IoT technology becomes obvious. The creation of this system involves the phased implementation of the following activities:

- remote monitoring of indicators within the network coverage area;
- restoration of the history of web device readings for the entire observation period in the form of time series to identify possible anomalies;
- prompt notification of critical parameters;
- creating conditions for the subsequent development of the system;
- forecasting and harvest planning based on historical data obtained.

To implement the above tasks, a monitoring system “SINAM IoT-Greenhouse” based on the use of a SaaS platform[2] is proposed as an IT solution.

The following sensors are planned to be used:

- soil humidity sensor;
- soil temperature sensor;
- soil PH-sensor[3];
- NPK-sensor[4] for the content of microelements in the soil;
- plant moisture sensor;
- air-temperature sensor;
- air humidity sensor;

[2] The sensing-as-a-service platform allows users to share resources across borders and understand phenomenon, which are not available in their own countries.

[3] It detects the pH value of the soil by inserting two stainless steel probes vertically into the soil.

[4] Soil NPK sensor is a device that is used to measure the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in soil.

- elumination sensor;
- air quality sensor,

The following actuators are planned to be used for:

- irrigation control;
- controling the activation of air heating elements;
- controling the activation and distribution of air ventilation;
- elumination control;
- controling the supply of fertilizers and microelements.

To exchange information within the framework of the proposed "SINAM IoT-Greenhouse" concept, along with a wired Ethernet network, it is planned to use NB-IoT (Narrowband Internet of Things), which, as a wireless network standard, is designed to connect web devices with low power consumption and low data transfer rates. The combined use of Ethernet and NB-IoT networks predetermined the architectural solution of the intelligent monitoring system "Sinam IoT Greenhouse". Fig. 2 shows the software and hardware architecture of this solution, taking into account the necessary functional modules. Such approach allows to significantly reduce the severity of restrictions on the network and hardware architecture and ensure compliance with the requirements for information security of network interaction.

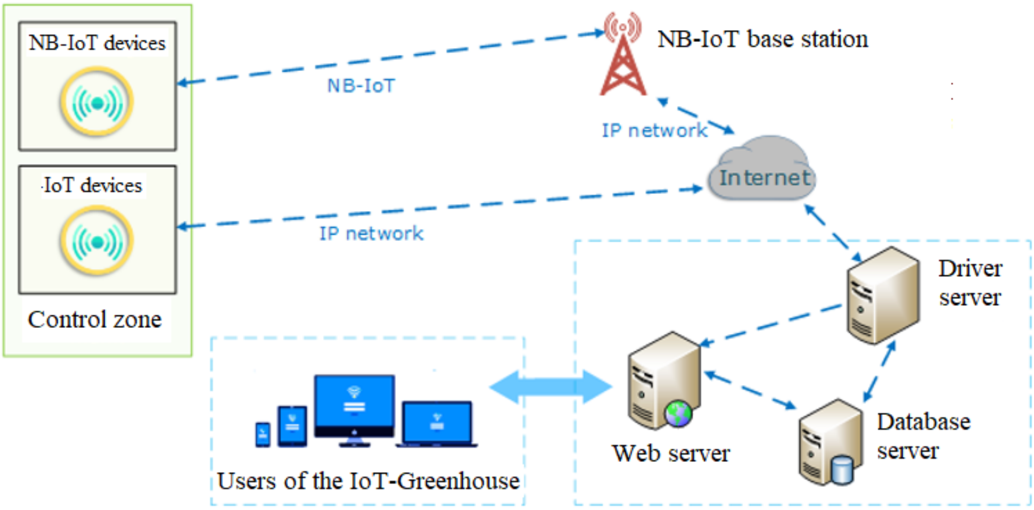

Fig. 2. Architecture of the intelligent monitoring system "SINAM IoT Greenhouse"

The key components and features of the intelligent monitoring system "SINAM IoT-Greenhouse" are:

- NB-IoT sensor/Ethernet sensor, as a physical device connected to the NB-IoT/Ethernet-IoT module, collects the necessary data and transmits it over the NB-IoT/Ethernet network.
- Executive devices connected to web devices via the network interface are controlled by commands received through the control server. Actuators play an important role in converting data and signals from web devices into actual physical actions.
- NB-IoT module/Ethernet-IoT module, which provides interconnection of the sensor with the NB-IoT/Ethernet network. The module processes data from the sensor and establishes a connection to the network for data transfer.
- NB-IoT/Ethernet-IoT network providing the infrastructure for data transfer from the NB-IoT/Ethernet module. Data is transmitted through the network to the target server.
- Target server, including driver server, database server and web server. The target server receives data transmitted over the network. It performs the functions of storing, analyzing and processing data. This component can be configured to automatically process data or provide a user interface to access data.
- A user interface that provides the user with the opportunity to interact with the results of processing data collected from web devices. This can be a web interface, mobile application or other user interface that allows to view, analyze and manage data received from sensors.

The movement of data within the proposed architecture of the "SINAM IoT-Greenhouse" monitoring system in general looks like as following. Sensors installed on the corresponding web devices transmit current data on air temperature and soil moisture to the target server through NB-IoT and Ethernet-IoT modules that establish connections to the network. In the target server (or in the cloud service), the received data is processed and together with the data history forms an information picture about the current state of the greenhouse farming. Users can access this information via the web interface.

Web devices, as the main components of the "SINAM IoT-Greenhouse" system, have two built-in functional components: a receiving one, where the sensor operating according to the given protocol is used as the signal receiver, and an executive one, which controls a certain space.

The receiver type web device consists of the following three elements (see Fig. 3):

1. The sensor that records data in the form of environmental observations.
2. The control module that includes a microcontroller that performs calculations and controls the operation of the web device, and built-in flash memory containing software, data set and configuration information.
3. The communications module or network interface required to connect the web device to the Internet. For the wired connection, the Ethernet network is used, and for the wireless connection, the NB-IoT or Wi-Fi network is used.

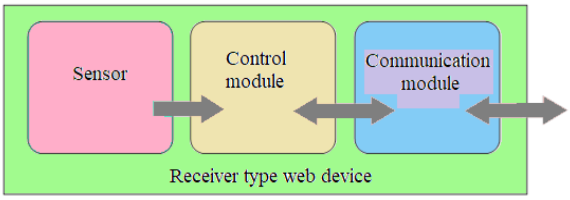

Fig. 3. Receiver type web device

The executive-type web device is used to monitor and regulate the state of the controlled space zone. The executive component of the device includes communication and control modules for a number of functional devices, symbolically indicated in Fig. 4.

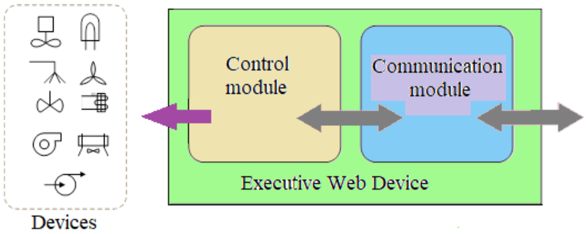

Fig. 4. Executive web device

4. Control structure, sensors and step-by-step implementation procedure

Fig. 5 shows the structure of centralized greenhouse management within the "SINAM IoT-Greenhouse" project.

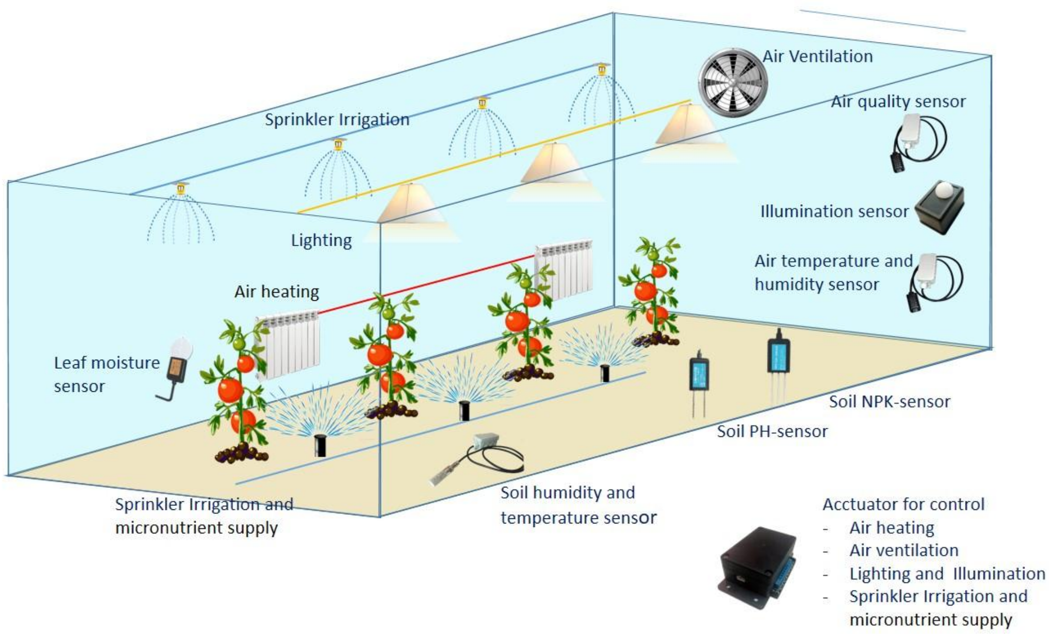

Fig. 5. The structure of centralized greenhouse management within the "SINAM IoT-Greenhouse" project

As part of the implementation of the "SINAM IoT-Greenhouse" project the following key components are used on the example of the NB-IoT segment:

- temperature and humidity sensors DHT22;
- control module based on Arduino Pro mini;
- NB-IoT radio module based on the Sim7020e chipset.

In particular, to organize remote monitoring of temperature and air humidity in the greenhouse using an NB-IoT sensor, the following step-by-step procedure for Arduino-based control and information transfer is implemented.

1. Connecting the temperature and humidity DHT22 sensor to the Arduino-based control module.
2. Encoding and reading data. Based on the use of existing libraries of temperature and humidity sensors, data is read from the sensor used.
3. Connection to the NB-IoT network. For data transmission, the Sim7020e chipset-based NB-IoT wireless communication is used, which is connected to the Arduino control module.
4. Formation and transmission of data. Based on the read temperature and humidity data, the data packet is generated for subsequent transmission. The data is encoded into a structured format.
5. Connection of call and transferring data. Based on the use of the Sim7020e-based NB-IoT radio module, the connection is established with the server that receives data from web devices. In this case, the generated data packet is transmitted via the NB-IoT connection.
6. Data processing on the server. To receive, process and store data from web-devices, the server is pre-configured.
7. Data visualization. The server provides the possibility to visualize and analyze the processed data from the web-devices on the working panel, as well as to interpret them at the request of the customer.
8. Connecting devices. Certain devices are connected to the relay ports of the actuator, allowing to control the parameters of the workspace.
9. Control of instruments and devices. Using information received from web devices, scenarios for managing workspace parameters are generated and configured. For example, by receiving data from the temperature NB-IoT sensor and connecting the heating and/or cooling device, automatic regulation is provided to maintain the required temperature in the workspace. The same applies to the humidity control process.

Thus, using the air temperature and humidity sensor DHT22 together with heating/cooling and air humidification devices, for example, the enclosed space for growing crops, the automated system of temperature and humidity control in the greenhouse is developed.

5. Conclusion

Thus, within the framework of the "SINAM IoT-Greenhouse" project, the task of monitoring and controlling indicators inside the greenhouse while maintaining data history was fully completed. Data on current greenhouse microclimate conditions and soil moisture are available online. The operator directly carrying out on-site inspection sees all the information in real time on the digital panel.

All information from the sensors is sent via radio to the corresponding gateway, recognized and transmitted to the application server. This data becomes available to farmers through a web application from a computer or smartphone. When equipment breaks down, a pipe breaks or a short circuit occurs, the application sends notifications to the messenger by bots.

The IoT network allows to permanently analyze conditions in the greenhouse, soil moisture to turn on automatic watering at the right time in the right place without the presence of employees, and remotely change conditions depending on the situation. Automatic collection of analytics relative to the volumes of water and electricity used makes it possible to more accurately plan the budget, regulate resource consumption and the impact on the environment.

Thus, the near future of precision agriculture lies in IoT platforms, with the help of which farmers can make the right decisions on the further development of their farming.

6. Acknowledgments

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References

Abbas, Y., B., Zolfaghari, A., Azmoodeh, A., Dehghantanha, H., Karimipour, E., Fraser, A.G., Green, C., Russell, E., Duncan (2021). A review on security of smart farming and precision agriculture: security aspects, attacks, threats and countermeasures. Applied Sciences. http://dx.doi.org/10.3390/app11167518.

Addicott, J. E. (2019). The Precision Farming Revolution: Global Drivers of Local Agricultural Methods. Palgrave Macmillan, 2019.

Agricultural Internet of Things and Decision Support for Precision Smart Farming. Elsevier, 2020. http://dx.doi.org/10.1016/c2018-0-00051-1.

Beloev, I., D., Kinaneva, G., Georgiev, G., Hristov, P., Zahariev (2021). Artificial intelligence-driven autonomous robot for precision agriculture. Acta Technological Agriculture 24(1), 48–54. doi: 10.2478/ata-2021-0008.

Camilo, L., A., Favela-Contreras, A., Aguilar-Gonzalez, L. C., Félix-Herrán, L., Orona (2021). Energy-efficient wireless communication strategy for precision agriculture irrigation control. Sensors 21(16). http://dx.doi.org/10.3390/s21165541.

Carlos, P. E., S. Fuentes (2020). Editorial: Special Issue "Emerging sensor technology in agriculture". Sensors 20(14): 3827. doi: 10.3390/s20143827.

Chandrakant, Sh., P. (2019). Testing and monitoring agricultural soil using precision farming. International Journal for Research in Applied Science and Engineering Technology 7(7). http://dx.doi.org/10.22214/ijraset.2019.7063.

Eduardo, P. J., S. Bimonte, Gil De Sousa, J. C., Corrales (2019). Data-centric UML Profile for wireless sensors. International Journal of Agricultural and Environmental Information Systems 10(2), 21–48. doi: 10.4018/ijaeis.2019040102.

Gabriele, B., R., Khosla, A., Mouazen, O., Naud, A., Castrignano (2020). Agricultural Internet of Things and Decision Support for Precision Smart Farming. Elsevier Science & Technology Books, 2020.

Gang, F. L., Z. B., Liu, H. L., Li, C. D., Gu, M. L., Dai (2021). Application of wireless sensor network for M2M in precision fruits. Advanced Materials Research 267, 482–87. doi: 10.4028/www.scientific.net/amr.267.482.

Giorgia, B. D., Bentivoglio, M., Belletti, A., Finco (2020). Measuring a farm's profitability after adopting precision agriculture technologies: a case study from Italy. ACTA IMEKO 9(3). http://dx.doi.org/10.21014/acta_imeko.v9i3.799.

Irfan, A., N., Bafdal, E., Suryadi, A., Bono (2020). Greenhouse monitoring and automation using Arduino: a review on precision farming and Internet of Things (IoT). International Journal on Advanced Science, Engineering and Information Technology 10(2). http://dx.doi.org/10.18517/ijaseit.10.2.10249.

Karim, F., M., Abid, N., Ben Hadj-Alouane (2020). Enhancing energy saving in smart farming through aggregation and partition aware IoT routing protocol. Sensors 20(10). http://dx.doi.org/10.3390/s20102760.

Katalin, T. G. (2012). Economic aspects of an agricultural innovation – precision crop production. Applied Studies in Agribusiness and Commerce 6(1-2), 51–57.

Khalid, H., I. U., Din, A., Almogren, N., Islam (2020). An energy efficient and secure IoT-based WSN framework: an application to smart agriculture. Sensors 20(7), 2081. doi: 10.3390/s20072081.

Niccolò, L., A., Affinito, G., Bonanomi (2020). Introducing Evja – "Rugged" intelligent support system for precision farming. ACTA IMEKO 9(2). http://dx.doi.org/10.21014/acta_imeko.v9i2.795.

Nicolas, D. R., N., Dercas, N. V., Spyropoulos, E., Psomiadis (2019). Remotely sensed methodologies for crop water availability and requirements in precision farming of vulnerable agriculture. Water Resources Management 33(4), 499–519. doi: 10.1007/s11269-018-2161-8.

Robert, F., S. M., Swinton, El Benni N., Walter A. (2019). Precision farming at the nexus of agricultural production and the environment. Annual Review of Resource Economics 11(1). http://dx.doi.org/10.1146/annurev-resource-100518-093929.

Sankar, R. C., S., Ravimaran, R. S., Krishnan, E. G., Julie, Y. H., Robinson, R., Kumar, L. H., Son, Ph. H., Thong, N. Q., Thanh, M., Ismail (2020). Internet of Green Things with autonomous wireless wheel robots against green houses and farms. International Journal of Distributed Sensor Networks 16(6). http://dx.doi.org/10.1177/1550147720923477.

Selim, H. Md., M. H., Rahman, M. S., Rahman, A. S. M., Sanwar Hosen, C., Seo, G. H. Cho (2021). Intellectual property theft protection in IoT based precision agriculture using SDN. Electronics 10(16), 1987. doi: 10.3390/electronics10161987.

Simon, S., D, Culibrk, M., Bandecchi, W., Gross, W., Middelmann (2021). Soil monitoring for precision farming using hyperspectral remote sensing and soil sensors. Automatisierungstechnik 69(4), 325–35. doi:10.1515/auto-2020-0042.

Takoi, T.K., J. S., Durrence, G., Vellidis (2009). Precision farming practices. IEEE Industry Applications Magazine 15(2), 34–42. doi: 10.1109/mias.2009.931816.

Zecha, C. W., J., Link, W., Claupein (2013). Mobile sensor platforms: categorization and research applications in precision farming. Journal of Sensors and Sensor Systems 2(1), 51–72. doi:10.5194/jsss-2-51-2013.

Rzaev, R. R. (2016). Analytical Decision Support in Organizational Systems. Saarbruchen (Germany), Palmerium Academic Publishing (in Russian)

Rzayev, R. R. (2012). Neuro-fuzzy Modeling of Economic Behavior. Moscow, Lambert Academic Publishing (in Russian)

Kussul, E., Baydyk, T., Curtidor, A., Herrera, G. V. (2023). Modeling a system with solar concentrators and thermal energy storage. Problems of Information Society 14(2), 15–23.