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The main areas of application of IoT technologies in agriculture

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Abstract. The relevance of the research topic is determined by the significant pace of implementation of IoT technologies in agriculture and the poor theoretical development of their application. The purpose of the study is to identify the main areas of application of IoT technologies in agriculture. The scientific novelty is the theoretical provisions on the directions of the use of IoT technologies in the industry. The analysis of scientific publications in this area of research has been carried out and the main areas of application of IoT technologies in the industry have been clarified, and their characteristics have been given. The main applications of IoT technologies in agriculture include smart (smart farm, smart field) and intelligent (real-time data collection) environments, predictive analysis of crop yields and animal productivity, various measurements, predictive maintenance, resource consumption control and remote management of machines and equipment. The results of the study allow deepening knowledge about IoT technologies used in agriculture, contributing to their systematization, expanding the range of IoT types used by agricultural organizations.

1 Introduction

The term "Internet of Things" (IoT) was coined by Kevin Ashton [1] in 1999 to attract P&G senior management's attention to a new method of supply chain optimization by using radio frequency identification (RFID). IoT technologies can be described as a "patchwork quilt" made up of devices of different levels. At the first level, IoT technologies are represented by devices and sensors, which continuously collect data from the environment and send them to the next level. The next level hosts IoT gateways that control data flows between different networks and protocols; they also bridge the communication gap between the connected devices and sensors. The obtained data are sent to the cloud (the IoT cloud), which is a complex high-performance network of servers for real-time collecting, processing, managing and storing large amounts of data. At the last level, analog data received from multiple smart devices and sensors are converted into useful information that can be interpreted and used for detailed analysis.

By the end of 2022, agriculture accounted for around 7% of all IoT projects

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implemented worldwide. IoT technologies are used by 0.05–5 % of agricultural producers in Russia [2] as compared to 60 % in USA and 80 % in EU. Precision farming solutions, to a greater or lesser extent, are used by around 10 % of Russian agricultural businesses, holding companies and farms. The minimum economic impact of IoT adoption in Russian agriculture can reach 469 billion rubles by 2025 [3].

It should be noted that application of IoT technologies in agriculture needs further study. Further research is needed in farmers' motivation and expectations for these technologies; there are very few guidelines for IoT adoption. Russia has no consistent training of employees capable of using IoT technologies in agriculture. All the above provides the rationale for the study.

2 Materials and Methods

Currently, there is a huge hype regarding the prospects for the development of IoT technologies. Various experts and reports vying with each other predict a rapid growth in the number of connected devices, including in agriculture. At the same time, the theoretical aspects of the application of IoT technologies in agriculture have not been sufficiently studied.

The purpose of the study is to identify the main directions of scientific research on the application of IoT technologies in agriculture.

The main objectives of the study were as follows.

1. Identify scientific publications on the application of IoT technologies in agriculture
2. Determine the scope of IoT technologies in agriculture.
3. Perform a SWOT analysis of the use of IoT at the level of agricultural organizations, outline ways to overcome them

The preparatory stage included the analysis of publications on IoT technologies. The review of literature was based on the content analysis of the Web of Science bibliographic database with articles published within the last 10 years. The review was focused on the articles with such key words as Internet of Things and agriculture; it also identified the frequency of occurrence of certain research areas in the world scientific literature according to the Web of Science database. The review helped identify primary research themes addressing IoT application in agriculture; the themes were further arranged into groups. The other articles were found irrelevant and having nothing to do with the problem under study, as they dealt with IoT technologies in agriculture only indirectly and, therefore, were excluded from the further analysis.

The final stage incorporated SWOT analysis tools used to assess the IoT status and prospects for IoT application by Middle Ural farmers. The analysis made it possible to identify weaknesses and strengths, to outline opportunities and threats that may arise from IoT application in agriculture of the region. Most of the surveyed farmers are engaged in the production of milk and dairy products (52%). A significant part is engaged in the production of cattle meat (31%) and pig meat (9%), the rest are specialized in the production of grain crops (8%).

The scientific novelty is the theoretical aspects of the use of IoT technologies in agriculture. In particular, based on the analysis of publications in this area, the main areas of application of IoT technologies in the industry are specified and their characteristics are given. This allows making knowledge about IoT technologies in agriculture more profound, contributing to their systematization, expanding the range of IoT types used by farmers. In addition, some socio-economic aspects are summarized, in particular, the expectations and level of awareness of farmers about the use of IoT in agriculture. Also there is a quantitative assessment of farmers' expectations regarding the increase in production profitability after introduction of these technologies. This allows identifying barriers and limitations of IoT use by farmers, and outlining ways to overcome them.

The study results can contribute to government policies aimed at evaluation of expediency of further development of IoT technologies and improvement of their efficiency in agriculture by using possibilities offered by the technological breakthrough and digital solutions. The study will also help detect potential problems that may arise from application of IoT technologies in agriculture and can help the government and economic entities develop adequate measures for their solution. The results of the study can be used by executive authorities in preparing programs for development of digital economy and industry-specific programs for digitalization of agriculture.

3 Results

In our opinion, there is a significant gap in the scientific literature on studies on application of IoT technologies in agriculture. The analysis of the selected articles showed that 77.5% are related to «Computer Science», a significant share of publications (62.1%) are related to «Engineering», and 39.9% of the articles are related to «Telecommunications» (Fig. 1).

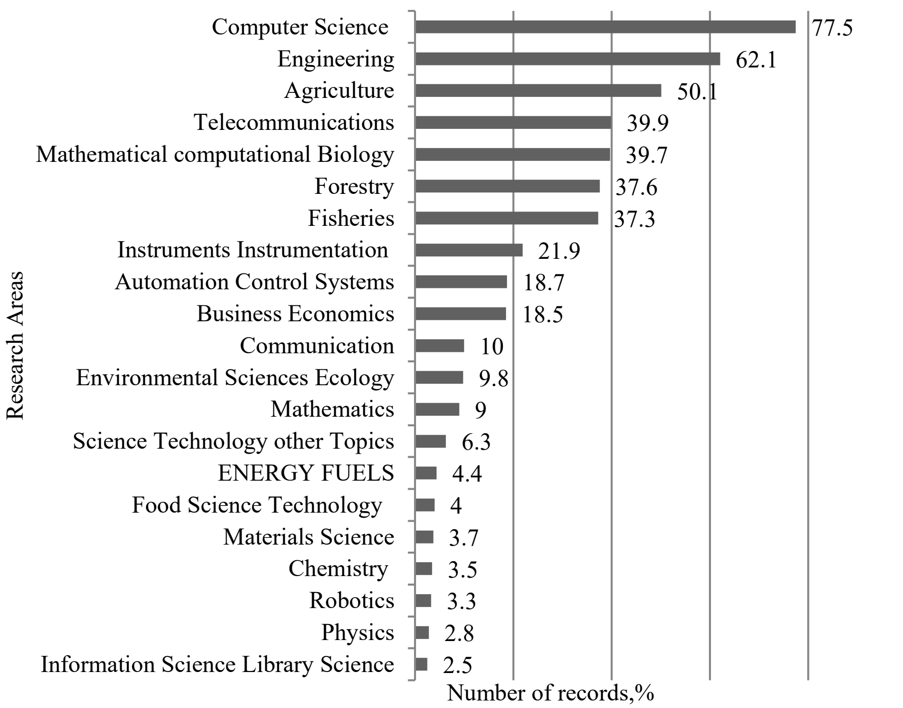

Fig. 1. Areas of research on the application of IoT technologies in agriculture
Source: authors data

However, little attention is paid to the economic, cultural and social aspects of the application of IoT technologies in agriculture. Thus, Business Economics is associated with only 18.5% of publications. Some fundamental aspects such as, for example, motivational aspects of application of IoT technologies in such a traditional industry as agriculture are not considered. One hypothesis is that farmers lack motivation to apply these technologies because they are afraid that information about their activities may be used by third parties.

Initially, the application of IoT technologies in agriculture was limited to connecting farming equipment to the Internet. Only machines and equipment exchanged data flows. The most important data relating to livestock and crops were collected manually. Thus, the collected data could be very limited and could contain significant errors. In 2000, there were 520 million farms worldwide; however, none of them used IoT technology [3]. The development of IoT technologies made it possible to connect different objects, including plants and animals, to the Internet.

Dairy farming is one of the sectors using IoT technologies. For example, the IoT system for dairy cow monitoring is used for real-time transmission of data collected from wearable smart collars to the cloud for their further analysis. Furthermore, the dairy cow data control platform can use the data collected from each cow for comprehensive monitoring of the health of the livestock. If the electronic ear tag of a dairy cow detects any disease, it sends an alarm signal and automatically separates the sick cow from the herd. In the long run, IoT technologies will find their full-featured application in the livestock industry and fodder production, significantly contributing to their improved efficiency. The application of these technologies for monitoring animals' health and physiological cycles as well as for their location tracking will facilitate future using of smart feed, fodder management and other advanced technologies.

It is advisable to identify the main areas of research addressing IoT application in agriculture. The analysis of the publications from the Web of Science database within the last 10 years shows that IoT technologies were most frequently mentioned in the context of smart environments, which include such concepts as a smart farm or a smart field. Other main areas of research on IoT agricultural applications were smart environments that could combine efficiently agricultural objects in rural locations [4, 5, 6]. Intelligent ecosystems [7, 8] for real-time data collection represent a physical infrastructure (sensors, actuators and networks) capable of receiving and using information about the surrounding reality (Table 1).

Table 1. IoT agricultural applications based on the analysis of publications in the Web of Science database

Group of IoT technologies	Content	Publications
Smart environments (a smart farm, a smart field)	Efficient information exchange between production objects in rural areas	Ahmed et al., 2018; Jayaraman et al., 2016; Kaloxylos et al., 2012
Intelligent ecosystems	Real-time data collection represents a physical infrastructure (sensors, actuators and networks) capable of receiving and using information about the surrounding reality	Rao et al., 2012; Li et al., 2011; Edwards-Murphy et al., 2016; Mazon-Olivo et al., 2018; Saad A., et al., 2017
Crop yield prediction analysis, livestock productivity	Creating relationships between different sets of data collected from sensors	Jayaraman et al., 2016; Goldstein et al., 2018; Severino et al., 2018; Neethirajan et al., 2017; Shahzad et al., 2016
Taking measurements	Measuring different environmental parameters including temperature, humidity, pressure	Alahi et al., 2017 Narayut et al., 2016
Monitoring of conditions at the farm	Monitoring and maintaining ambient parameters in livestock buildings	Ariawan E., 2018; Chin, YS, 2017
Maintenance	Preventive maintenance	Sepehri et al., 2018; Thirunavukkarasu et al., 2018
Resource monitoring	Estimating consumption of seeds, fertilizers, fuel, water and electric	Srinivasan et al., 2017 Zhang et al., 2017 Harun et al., 2015

	power	Li et al., 2017; Lee et al., 2013
Remote control of machines and equipment	Operating machines and equipment remotely in natural and artificial environments	Colantoni, et al., 2018; Yingyi, et al., 2017

Source: authors data

IoT technologies are used for collecting data selected by a number of parameters to monitor operation environments at different agricultural production sites, from beehives [9] and greenhouses to livestock buildings [10, 11]. Remote control of machines and equipment is needed both in natural [12] and artificial environments such as aquaculture [13]. Crop yields can be predicted very precisely with the help of interrelated sets of data collected from sensors [14, 15, 16]. Livestock productivity is predicted through quantitative assessment of physiological, immunological and behavioral responses of productive livestock [17, 18]. Monitoring of conditions at the farm helps monitor and maintain vital parameters both in standard and special livestock buildings characterized by controlled turbidity, continuous supply of oxygen, nitrogen and CO^2 [19], including vertical farming systems [20]. Preventive maintenance implies early fault detection and diagnosis [21]. In agriculture, measuring of different environmental parameters such as temperature [22], humidity [23], pressure [24] is of great importance. IoT technologies open vast opportunities for more economical consumption of seeds [25], fertilizers [26], fuel, water [27] and electric power [28, 29].

4 Discussion

Mass adoption of IoT technologies will turn data into "the new oil" that will bring a new "black gold rush". Each connection capable of perception will become an "oil well" pumping out data. Data will be the main resource in the "smart" world. Collection and using of data will be a crucial factor in competitiveness of a company.

Possibilities offered by IoT adoption are expanding due to emerging digital technologies and decreasing prices for hardware and software. Permanent connection with the Internet is becoming faster and more reliable; developers create integrated devices, applications and platforms for agriculture. Yet, remote rural communities still have difficulties with cell phone coverage. Analysis of the literature on this topic and the results of the survey allow us to draw some conclusions about the prospects for the use of IoT technologies in agriculture (Table 2).

Table 2. Prospects for the application of IoT technologies in agriculture

Strengths:	Weaknesses:
Reduction in maintenance and repair costs	Lack of readily available funds for IoT adoption
Improvement of energy efficiency of buildings and facilities; increased efficiency of production processes	Concerns about third-party users' access to the company's sensitive information when using IoT technologies
Reduction in consumption of physical resources	Insufficient government support in IoT adoption
Availability of IoT suppliers	Shortage of skilled employees capable of introducing and using IoT technologies in agriculture; using outdated programs for training students in agricultural educational institutions
Opportunities:	Threats:
Increasing Internet coverage of rural areas	Insufficient legislative and regulatory support for IoT application

Decreasing prices for meters, sensors and other IoT devices	Lack of information or incomplete information about existing and emerging IoT technologies; poor awareness of potential benefits of IoT technologies
Existing program of the industry digitalization; interested top leaders	Possible increase in the level of unemployment in rural areas of certain regions
Availability of objects of information transmission and storage	Slow penetration of digital technologies into rural areas and agricultural production

Source: authors data

Top leaders are becoming increasingly interested in development of digital technologies. For example, the RF Ministry of Agriculture is planning to subsidize the development of infrastructure for data transmission from connected devices. At the same time, the ministry intends to use transmitted data for their own analysis and accumulation of information about agricultural production.

The threats standing in the way of IoT agricultural application, first of all, include insufficient regulatory and legal support of coordination and inter-departmental teamwork in implementation of digital technologies and collection of information for needs of agriculture. We can also point out a lack and incompleteness of information about existing and emerging digital technologies as well as poor awareness of potential benefits resulting from using IoT technologies. In its turn, slow penetration of digital technologies into rural communities and agricultural production (less than 10 % of the companies), as compared to economically developed countries, has an adverse impact on the competitiveness of Russian agriculture. It is believed that the use of IoT technologies can lead to a reduction in employment in many industries. At the same time, the impact of the use of Internet of Things technologies in agriculture on a possible increase in unemployment requires further research.

The weaknesses include provision of human resources for this sector. The Russian Federation has around 112.9 thousand IT-specialists in agriculture or 2.4 % of the total number engaged in the agricultural industry [2]. To reach the levels of world's leading countries (USA, Germany, Great Britain) the Russian agriculture needs another 90 thousand IT engineers. Today, in Russia, there is only one IT engineer for 1,000 people employed in agriculture. Financial challenges encountered by most of the agricultural businesses impede adoption of innovative technologies. The above problems can be solved through improved subsidy assistance in purchasing and adoption of IoT technologies, including equipment from foreign manufacturers.

5 Conclusion

With the massive adoption of IoT technologies, data will become the "new oil" that will spark a new "black gold fever". Each connection that has the ability to perceive will become an "oil well" pumping out data. Data will become the main resource in the "smart" world. The determining factor in the competitiveness of the enterprise will be the collection and application of data. The interest of the top leadership of Russia in the development of digital technologies is growing. Thus, the Ministry of Agriculture of the Russian Federation intends to subsidize the construction of infrastructure for data transmission from connected devices. At the same time, the agency intends to use the data transmitted by agribusinessmen for its own analytics and accumulation of information on agricultural production.

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