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Alexandr Neftissov
PhD, Associate Professor, Research and innovation center "Industry 4.0"
Alexandr.neftissov@astanait.edu.kz, orcid.org/0000-0003-4079-2025
Astana IT University, Kazakhstan

Andrii Biloshchytskyi
Doctor of Technical Sciences, Professor, Vice-Rector for Science and Innovation
a.b@astanait.edu.kz, orcid.org/0000-0001-9548-1959
Astana IT University, Kazakhstan
Professor Department of Information Technologies,
Kyiv National University of Construction and Architecture, Ukraine

Sapar Toxanov
PhD candidate
sapar6@mail.ru, orcid.org/0000-0002-2915-9619
D. Serikbayev East Kazakhstan Technical University, Kazakhstan

Saken Ordabayev
PhD candidate, junior researcher, Research and innovation center "Industry 4.0"
ordasabe@outlook.com
ilyaskazambayevgmail.com, orcid.org/0009-0001-3404-9078
Astana IT University, Kazakhstan

Olexandr Kuchansky
Doctor of Technical Sciences, Head of the Department
of Information Systems and Technologies
kuczanski@gmail.com, orcid.org/0000-0003-1277-8031
Taras Shevchenko National University of Kyiv, Ukraine

Yurii Andrashko
PhD, Associate Professor, Department of System Analysis and Optimization Theory
yurii.andrashko@uzhnu.edu.ua, orcid.org/0000-0003-2306-8377
Uzhhorod National University, Ukraine

Vladimir Vatskel
Researcher, CEO of IT-LYNX LLC
v.vatskel@it-lynx.com, orcid.org/0000-0001-5662-4523
IT-LYNX LLC Kyiv, Ukraine

MATHEMATICAL, SOFTWARE AND HARDWARE SUPPORT OF THE CONCEPTUAL MODEL OF THE INFORMATION SYSTEM OF PRECISION AGRICULTURE

Abstract: This study analyzes the current situation of application of precision farming technologies and solutions by agricultural enterprises of the Republic of Kazakhstan. The main players and used solutions have been identified. The statistics of application, as well as the potential of use is examined. Within the framework of the analysis of the applied solutions the advantages and disadvantages of competitors in the market were determined. It was defined that the applied systems provide the possibility of remote management, but EGISTIC is more focused on the management of all processes of the farm, including the warehouse, while John Deere is focused on the management and analytics of agricultural machinery. EGISTIC offers features for warehousing and inventory planning, something not found in the base version of

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John Deere Operations Center. John Deere focuses on data sharing which can be important for large farms or groups of farmers. EGISTIC makes extensive use of satellite imagery to analyze field conditions which can be a great asset for identifying problem areas and planning interventions. Depending on the specific needs and priorities of an agribusiness, one system may be preferable to another. If machinery management is the main focus, John Deere might be the best choice. If in-depth analysis of field conditions and inventory control is important, EGISTIC may be more appropriate. By analyzing, the directions for research are highlighted. A conceptual model of information system for precision farming is developed. Hardware for realization of the conceptual model is possible on the basis of universal programmable logic controller of modular architecture being developed. Within the limits of the given research the conceptual model of the universal programmable logic controller of modular architecture and the structural model of the software of the universal programmable logic controller of modular architecture have been developed. The interaction with the conceptual adaptive model of information and communication system is also considered. This paper analyzes the key principles and functions of both the universal programmable logic controller and the information and communication system, as well as their possible integration within a single concept.

Keywords: precision farming; universal programmable controller; mathematical support; hardware; software; meteorological control; forecasting; yield**.**

Introduction

Precision farming is an integrated approach to agricultural production management based on global positioning systems (GPS), geographic information systems (GIS), remote sensing of the earth (RS) and other methods and tools.

As of 31 December 2022, the number of enterprises in the field of "Agriculture, forestry and fisheries" on the territory of the Republic of Kazakhstan uses:

1. RFID technologies – 1,468 enterprises [1].
2. ICT tools – 4,377 enterprises [1].

GPS is used for real-time monitoring of machinery and fuel utilization. It provides the real number of hours worked for each machine, its location at a given time, the history of movements on the ground for any period of time, real fuel consumption, the exact area of cultivated fields and other data important for the cultivation of fields and crops.

Geographic information systems (GIS) are modern computer technologies for mapping and analyzing real-world objects, as well as events occurring on our planet, in our lives and activities. This technology, without the use of formal definitions, integrates traditional database operations, such as queries and statistical analysis, with the benefits of full visualization and geographic (spatial) analysis provided by a map. These capabilities distinguish GIS from other information systems and open up unique prospects for its application in various tasks related to the analysis and forecasting of phenomena and events in the world around us.

The process of obtaining information about the surface and interior of the Earth from outer space is called "remote sensing". It becomes possible with the use of such approaches as: observation and measurement of the own and reflected radiation of the elements of land, ocean and atmosphere.

Remote sensing spacecraft is used for monitoring the Earth's natural resources, solving meteorological problems, and also in agriculture, geodesy, cartography, land and ocean surface monitoring.

The remote sensing space system of the Republic of Kazakhstan is intended to provide information received by means of space satellites and systems for analysis, improvement of activities and problem-solving in various spheres and sectors: agriculture, defense and security, prevention of emergencies, ecology and nature management, land use, geodesy, cartography, and other areas of life activity, not only for individual cities and regions but also for sectoral ecosystems.

During the operation of the space system, Kazakhstan's remote sensing satellites have imaged 1,134,246,997 square kilometers of the Earth's territory as of 15 January 2020 [2].

In 2019, more than 11,000 space images covering 22 million square kilometers of the country's territory were processed and provided for the country's state bodies, including space monitoring [2].

During the operation period of the space system of remote sensing of the Earth of the Republic of Kazakhstan (KazEOSat-1 and KazEOSat-2) from 2015-2020, the sale of space images in the domestic market brought 15 million tenge, as for the sales in the foreign market, the revenues amounted to 316 million tenge [2].

For 2020, high-resolution remote sensing space images for 2,876,400 km2 and medium-resolution remote sensing space images for 3,006,003 km2 were provided to government agencies [2].

The use of precision farming technologies in the agro-industrial complex of the Republic of Kazakhstan is of strategic importance for increasing yields, reducing production costs and ensuring food security of the country. The statistical data is considered, and the situation is analyzed.

Statistics on the use of precision farming technologies in the Republic of Kazakhstan:

1. GPS-enabled cultivation area: According to the latest data, more than 20% of agricultural land in Kazakhstan is cultivated using GPS technology for precise plant placement and resource optimization.

2. Drone use: Drones have become widely used monitoring and management tools in agriculture in Kazakhstan. They are used to analyze soil, determine moisture levels, and detect diseases and pests. More than 30% of agricultural enterprises in the country use drones.

3. Use of smart agro-technologies: Introduction of sensors, automation and monitoring systems, as well as crop management systems (Precision Agriculture) allow to improve yields and product quality. About 40 per cent of large agricultural producers in the Republic of Kazakhstan are actively using smart agro-technologies.

4. Use of geospatial data: Geospatial data and geographic information systems (GIS) play a key role in optimizing farming. They help agricultural enterprises make more informed decisions about crops, fertilizers and harvesting.

Literature review

Digitalization of agriculture in Kazakhstan and the region, in particular, is limited by the financial and technical capabilities of medium and small land users who are unable to "digitize" arable land without government support due to the high cost of processing space images and lack of specialists. At present, elements of precision agriculture for all categories of users are implemented in the region on 48% of arable land, which is the maximum in the country. Along with increasing the yield of cultivated crops, reducing energy and resource production costs, the introduction of precision farming systems allows, through "digital reclamation", to reduce in-field geomorphological and agrochemical heterogeneity of working areas. This aspect is extremely important in the conditions of Northern Kazakhstan, a region with an extremely complex structure of soil cover, where the share of solons in soils increases from 10 to 70 per cent when moving from north to south. In addition to reducing energy and resource inputs and increasing yields, precision farming allows for contact detection - programming of the full cycle of agronomic operations on the contours of the working field, which is especially important in the conditions of adaptive-landscape farming in forest-steppe small contour agrolandscapes with maximum bioecological potential [3].

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Agricultural research has made significant strides in recent years, particularly in the realm of data aggregation and transformation. One study [4] introduced a model enabling the collection and utilization of data from various agricultural machines in real-time. This innovation ensures the seamless integration of different datasets, making them suitable for smart farm management applications.

Furthermore, the potential of Information and Communication Technology (ICT) applications in precision farming was explored in another paper [5]. This research highlighted the benefits of incorporating modern technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) into agriculture. By bridging the crop production gap, reducing food waste, and optimizing resource utilization, these technologies hold the key to enhancing global food security.

Sustainable agriculture stands as a linchpin for economic growth, especially considering the challenge of feeding a burgeoning global population. The agricultural sector remains fundamental to many countries' economies, emphasizing the crucial need for sustainable practices [6]. Understanding the spatial distribution of soil nutrients and implementing precise fertilizer management strategies are pivotal components of this sustainable approach [7].

Moreover, supporting smallholder farms through well-devised policies is imperative for ensuring food security and fostering the shift towards more sustainable and equitable food systems [8]. The implementation of autonomous farming systems not only reduces labour costs but also ensures timely feeding and automatic watering. Additionally, integration with the Internet of Things empowers farmers by enabling remote monitoring of their farms even physically distant [9].

The basics of precision agriculture in Kazakhstan are mapping of fields, use of mechanisms for forecasting yields, and recognition of crop pests. In practice, this is implemented through the use of GPS-systems to determine, for example, uncultivated areas, tracking the movement of machinery and vehicles, means of field cultivation, drawing up parallel driving routes to increase the efficiency of using tillage tools, sprayers or for yield mapping. In such a farm it is necessary to create its own portal, where all maps, all geodata are stored, they are available all the time, 24 hours a day, 7 days a week: field condition maps, weather station data, maps from drone flights, fertilizer application maps, yield maps, soil analysis maps. This allows employees to quickly use these maps and access the necessary information at convenient time [10].

At the current stage of execution and analysis we can say that about 74% of farmers are familiar with digital technologies and even use some solutions in their own property. A rather large group of respondents (26%) indicated that they do not use digital technologies in their work. It should be noted that indeed the majority (over 70%) of farmers from rural areas indicated they have only the mobile Internet on their territory which is not enough modern technologies. 5% indicated that they have no internet at all. The most demanded, judging by the surveys, were technologies of control and tracking based on GPS navigation, first of all for the movement of agricultural machinery in real time mode of fulfilment of works in time (57.7% of respondents from among those using digital technologies indicated it). Sensors for accounting and control of fuel and lubricant consumption are also popular among farmers; 30% of respondents and farmers using digital technologies use them. According to the surveys, farmers are working on implementing elements and systems of precision farming. For example, systems of differentiated application of fertilizers and protection products sprayers with GPS navigation are used by more than 22% of "advanced" farms. This digital technology as a solution often goes together with the digitization of fields (21.1% of digital technologies, indicated that their fields are digitized) [11].

Another part of this number of farmers installs auto steering (parallel driving) systems on their machinery – 9% of those using digital solutions. Some farmers (5.5%) said that they use complex solutions for analyzing field conditions, including those from different manufacturers of technological solutions. Units only as auxiliary – weather stations, weather apps, and soil moisture sensors [11].

In the context of the topic Introduction of elements of "precision farming" in a number of farms, including the use of meteorological stations, the following indicators were achieved: in a number of farms as pilot projects, elements of "precision farming", including the use of meteorological stations, were introduced. 9 farms were identified in North Kazakhstan region, Akmola, Karaganda and Kostanay regions: 3 farms each in dairy, meat and crop production.

The introduction of digital technologies on dairy farms allowed to increase milk yield per cow by 25% [12].

At the moment in Kazakhstan, the subjects of agro-industrial complex have the opportunity to apply several popular systems of precision agriculture.

The main solutions of precision farming are represented by the following systems:

1. EGISTIC
2. Universal accounting system USU.kz – does not work
3. Borlas AgroSystem – does not work
4. AgroMon – does not work
5. John Deere Operations Centre

However, 2, 3 and 4 are not functioning at the moment for various reasons. In further research and analysis 1 and 5 solution will be considered.

The EGISTIC system was developed in 2018 and currently has a market solution in the form of a consolidated system of IT solutions for the subjects of the agro-industrial complex of Kazakhstan. In 2018, the copyright No. 409 dated 05 November 2018 for the computer program "Software for automation of processing, analysis and visualization of raster image from Sentinel 2A, Landsat8 spacecraft" was obtained [13].

EGISTIC has the following main elements/modules to provide the functionality of precision farming:

- The "Farming" module has functionality to analyze the condition of fields by vegetation indices (NDVI), nitrogen, moisture and chlorophyll using space images.
- The "Telematics" module determines and tracks the movements of transport and technical mobile vehicles using GPS sensors, residue and fuel consumption of agricultural machinery.
- The "Crop Rotation" module allows storing data on agricultural fields of AIC subjects and specifying the type of planted crop. The module has the functionality to enter data on harvested yields of crops planted.
- The module "Vegetation index" determines problem areas of fields, highlighting areas with nutrient deficiency and low humidity, determines areas with increased weed density, by NDVI index determines the level of crop maturity, determines differences in growth and development of plants in the field - by multispectral images the user can see information about vegetation (NDVI index), vegetation (contrast), nitrogen, chlorophyll and humidity for each field.
- The "Market" module is a marketplace for crop protection products, fertilizers, and seeds. The module integrates a system for concluding electronic contracts, as well as a system for analyzing operational purchases of agribusiness entities for economic activities.
- The "Lease" module allows leasing agricultural machinery of neighboring agribusiness entities with a system for creating reporting data on output and shifts for automatic calculation of agricultural machinery lease.
- The John Deer Operations Centre system is a solution for John Deer agricultural machinery, which, in particular, is distributed in Kazakhstan. John Deer solution allows the user to use precision farming technologies in the following modes:

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- “Land manager” module. Allows you to see a detailed map of agricultural fields with the ability to draw your own information on the field. Creates boundaries based on previous operations or by clicking a satellite image of a known field location.
- “Product manager” module. Logbook for keeping records of harvest and filling of storage tanks for crops and other agricultural products.
- “Data manager” module. The module is required for communication and data transfer between the system monitors and the John Deer Operation Centre software itself. The solution allows drawing maps of the fields on which John Deer equipment operates. Once the fields and their status are mapped, the system can generate agronomic reports. Layers can be connected for agronomic analyses, field trends and machine performance information. The layers available for viewing depend on the functionality of the machine.

Comparison:

- Both systems offer remote management capabilities, but EGISTIC is more focused on managing all farming processes, including the warehouse, while John Deere concentrates on farm machinery management and analytics.
- EGISTIC offers features for warehousing and inventory planning that are not available in the basic version of John Deere Operations Centre.
- John Deere focuses on data sharing which can be important for large farms or groups of farmers.
- EGISTIC makes extensive use of satellite imagery to analyze field conditions, which can be a great asset for identifying problem areas and planning interventions.

Depending on the specific needs and priorities of an agribusiness, one system may be preferable to another. If machinery management is the main focus, John Deere might be the best choice. If in-depth field condition analysis and stock record keeping are important, EGISTIC may be more appropriate.

To critically analyze both systems, we will look at their possible advantages and disadvantages based on the information provided in Table 1.

Table 1. Advantages and disadvantages of systems of precision agriculture.

	EGISTIC	**John Deere Operations Centre**
	Advantages	
1	Versatility: the system offers a comprehensive approach to agribusiness management, including warehouse accounting, planning and analyzing agro-activities.	Specialization: the system is specialized in fleet monitoring and management, making it optimal for this purpose.
2	Use of satellite imagery: this can provide in-depth analyses of field conditions, which is useful for identifying problem areas and making decisions.	Data sharing: the functionality allows for easier communication and co-operation between different stakeholders.
3	Telematics: real-time tracking of machinery improves resource control and management.	Centralization: bringing all data together in one place makes management easier and more systematic.
	Disadvantages	
1	Complexity: given the many functions, the system may take time to master and may be redundant for small farms.	Limited functionality: compared to EGISTIC, the system may offer fewer functions for integrated agribusiness management.
2	Dependence on satellite imagery: although valuable, satellite imagery may not always be up to date or available due to weather conditions.	Equipment dependency: specific machines and sensors from John Deere may be required to fully utilize the system.
3		The system is designed for use as a mobile application only and cannot be installed on other types of computers or mobile equipment.

Conceptual model of precision farming information system.

To create a conceptual model of precision farming information system, all the advantages of the known ones were taken, and an attempt was made to solve their disadvantages. In turn, the proposed conceptual model of precision farming information system is designed for effective management of agricultural activities, structured at three levels: user interface, data processing level and database level.

Thus, the proposed solution should fully solve the shortcomings of existing/operating solutions in the region of precision agriculture applied at agribusinesses in Kazakhstan.

Figure 1. Conceptual model of a precision agriculture information system

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The conceptual model of the information system of precision farming, designed for effective management of agricultural activities, is structured at three levels: user interface, data processing level and database level. In this system, two microservices are distinguished at the level of user interface - microservice of agro-enterprise subjects and microservice of administrator:

Agribusiness entities microservice: this microservice provides agribusiness entities (e.g. farmers) access to the system functionality. It includes a user interface that allows users to view data about their fields, plants, farm machinery, and receive recommendations and forecasts to optimize farming operations.

Admin microservice: this microservice is designed for system administrators. It provides the ability to manage users, databases, system settings and monitor system performance.

The data processing layer includes five key modules:

Meteorological data prediction module: this module receives real meteorological data from the weather station and data collection sensors. It then uses a prediction model, possibly based on artificial neural networks, to predict the impact of weather data on crop performance. The results are then stored in the Crop Performance database.

Agricultural machinery movement control module: this module interacts with the GPS monitoring system, monitors fuel consumption and controls attachments. It collects data on the location and condition of agricultural machinery and transmits this information to the Farm Machinery database.

Irrigation automation module: this module automatically manages irrigation systems, taking into account soil and weather data. If necessary, it can interface with the Crops database to determine the irrigation requirements of plants.

Data Analysis Module: This module analyses data from various sources such as the Farm Machinery, Plant, Plant Disease, Fertiliser, Meteorological and Yield databases. It provides recommendations and solutions affecting agri yield and efficiency, which are then displayed to users through the user interface.

Dashboard: This module is a graphical interface that displays all relevant agribusiness performance indicators. It is integrated with databases for data visualization.

The database (figure 2) layer contains six independent databases: "Agricultural Machinery", "Agricultural Plants", "Plant Diseases", "Fertilisers", "Meteodata" and "Yield".

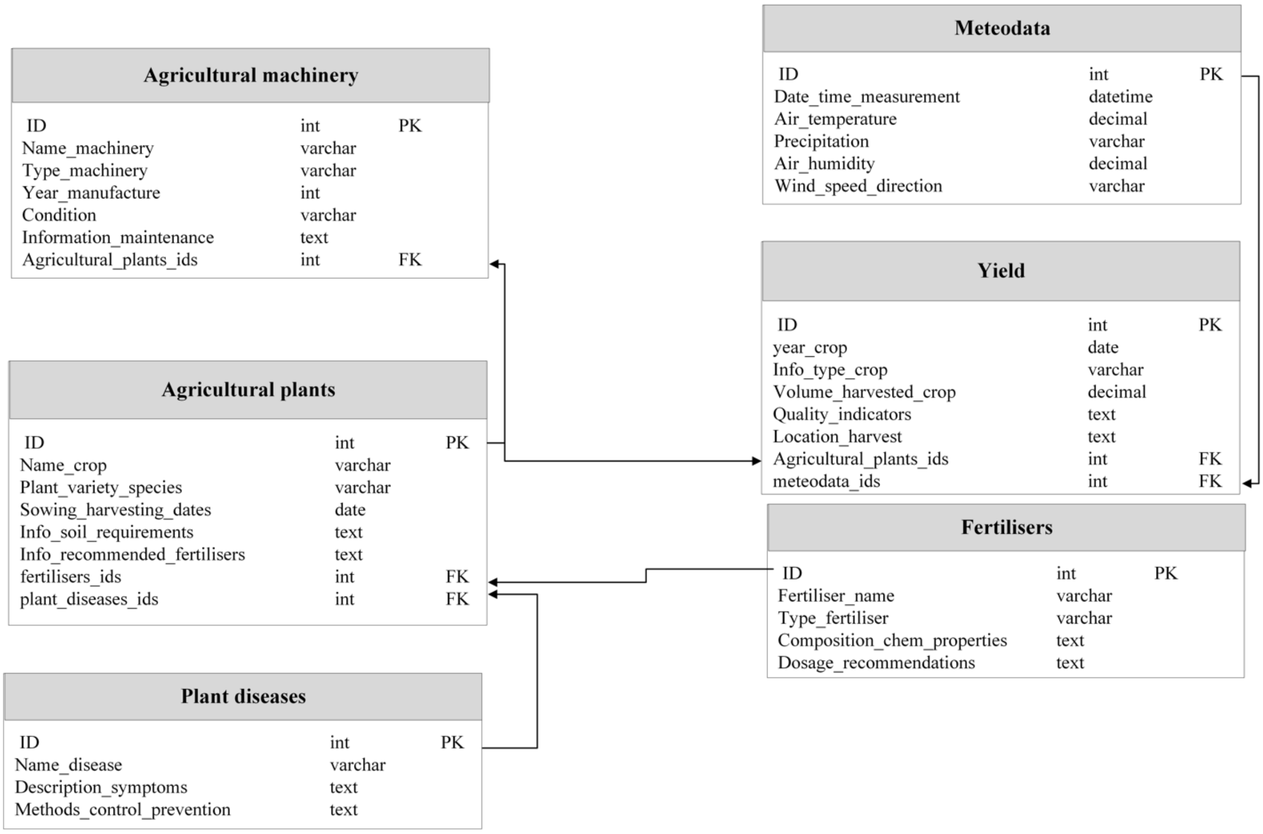

Figure 2. ER diagrams of the developed database.

These databases are linked by keys such as unit ID, crop ID, measurement date, and others to enable data integration and better management of agricultural activities using the precision farming system.

All levels of the system interact with each other to collect, process, analyze and provide the information needed to make informed decisions and optimize agricultural activities. A precision farming information system will enable agricultural enterprises to effectively manage all aspects of their operations, from monitoring the condition of farm machinery and plant diseases, to forecasting weather conditions and analyzing yields. By linking and integrating data from various databases, the system will provide complete information required for decision making and optimization of production processes.

When implementing the developed conceptual model of the precision farming information system, it is necessary to consider and develop the necessary mathematical, software and hardware support.

Results

The implementation of a yield forecasting module is possible, but first it is necessary to develop a mathematical description for its operation.

For yield forecasting, many indicators need to be monitored [1], in particular:

- Taking into account agronomic indicators such factors as plant variety, soil, fertilizer applied. Let us denote them by $A1, A2,..., A\ p$
- Meteorological indicators that take into account air temperature and humidity, soil temperature and humidity, precipitation, etc. Let's denote them by $W\_1, W\_2,...,W\_k$
- Phenological indicators, which are determined by satellite and aerial surveys in different spectrum ranges.

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Many studies show the possibility of assessing the condition of crops due to the calculation of the normalised differential vegetation index (NDVI) using the formula [2]:

$$N = \frac{I-R}{I+R} \tag{1}$$

where N is a quantitative indicator of photosynthetic active biomass used to quantify vegetation cover, R is the intensity of light reflected from the field in the visible red region of the spectrum (wavelengths at 660±30 nm); I is the intensity of light reflected from the field in the infrared region of the spectrum (wavelengths at 830±70 nm).

Yield model. Let a certain monocrop is grown on a certain plot F. Let us introduce a yield function v , which is equal to the ratio of yield U to the area of the plot. Given that yield depends on agronomic parameters, meteorological parameters, time, and yield also depends on area, then the yield of the monocrop on plot F for the time interval t∈[t_0,t_n] can be determined by the formula:

$$U = \int_{t_0}^{t_n} \iint_{(x,y)\in F}^{0} v\big(\mathrm{A}_1, \mathrm{A}_2, \dots, \mathrm{A}_p, W_1, W_2, \dots, W_k\,, N, \mathrm{x}, \mathrm{y}, \mathrm{t}\big) dxdy\ dt \tag{2}$$

If the field F is irregularly shaped, to simplify the calculations, we can restrict the field to a rectangle with dimensions r×q and introduce a function – indicator of points belonging to the field γ (x,y).

$$\gamma(x,y) = \begin{cases} 0, \text{if } (x,y) \notin F \\ 1, \text{if } (x,y) \in F \end{cases}$$

Then the yield formula will be written as:

$$U = \int_{t_0}^{t_n} \int_0^r \int_0^q \gamma(x,y) \times v\big(\mathrm{A}_1, \mathrm{A}_2, \dots, \mathrm{A}_p, W_1, W_2, \dots, W_k\,, N, \mathrm{x}, \mathrm{y}, \mathrm{t}\big) dx\, dy\, dt \tag{3}$$

The above-described yield model is continuous, but discrete yield models are often considered in research [14].

Let the field be covered by a uniform grid with a step, i.e. x_i=x_0+i×Δx, where r is the number of partition points on the abscissa axis, depends on the field width F and y_j=y_0+-j×Δu where q is the number of partition points on the ordinate axis, depends on the field length F . Let yields be recorded at some discrete moments of time t_l=t_0+l×Δt, for example, once a day or weekly, where n is the number of observation periods. Then the discrete yield model can be written as follows

$$U = \sum_{l=0}^{n} \sum_{i=0}^{r} \sum_{j=0}^{q} \gamma(\mathrm{x}_i, \mathrm{y}_j) \times v\big(\mathrm{A}_1, \mathrm{A}_2, \dots, \mathrm{A}_p, W_1, W_2, \dots, W_k\,, N, \mathrm{x}_i, \mathrm{y}_j, t_l\big) \tag{4}$$

Taking into account the constructed yield model, the yield forecasting problem can be formalised as follows: let the yield values at the moments of time be known. $t_l = t_0 + l \times \Delta t$ for $l = 1, n$ then the sequence forms a discrete time series, $\{U_0, U_1, U_2, \dots, U_n\}_{\ 1}$, then discrete time series forecasting methods can be applied for forecasting. The task of discrete series forecasting is to determine the future values of yield $U_{n+1}, U_{n+2}, \dots$ based on the analysis of past data.

Discrete series forecasting methods can be classified according to different features:

1. Statistical methods, in particular autoregression, use the dependence of the future value on previous values of the time series. [15]
2. Spectral analysis methods, which take into account not only ternary but also periodic component in forecasting. [16]
3. Machine learning methods are used to model complex dependencies [17]

4. Mixed methods use a combination of methods of different types to improve the prediction accuracy.

Hardware for the implementation of the conceptual model is possible on the basis of the *universal programmable logic controller of modular architecture* being developed. The conceptual model of the universal programmable logic controller of modular architecture and the structural model of the software of the universal programmable logic controller of modular architecture have been developed within the framework of this research. The interaction with the conceptual adaptive model of the information and communication system is also considered.

Special attention should be paid to the development and implementation of universal programmable logic controllers (UPLC) of modular architecture, which represent a highly effective means of automation, allowing flexible control and management of various processes. In parallel, adaptive information and communication systems are being actively developed and implemented, which provide a fast and reliable exchange of information between the various participants in the production process.

The task of the study was to develop a conceptual model of the UPLC and a conceptual adaptive model of the information and communication system, which could serve as a basis for the creation of integrated solutions in the region of agricultural management.

Conceptual model of *universal programmable logic controller of modular architecture*. Universal programmable logic controller of modular architecture occupies an important place in modern automation and control systems, performing a wide range of tasks in the region of control, monitoring and data processing. Thanks to its modular architecture, the UPLC offers the possibility of rapid adaptation to specific project requirements, making it particularly relevant for rapidly changing production environments.

The UPLC hardware is based on a modular architecture. This concept implies division of the equipment into a basic module, which includes the basic components necessary for the controller operation, and additional modules designed to extend the functionality of the basic module. The basic module is equipped with a constant and backup power supply unit, a central processor, a real-time clock, a non-volatile memory, an I/O unit and an interface unit. These components interact with each other as follows:

- *The power supply* provides power to all the components of the UPLC, and the backup power is automatically switched on when the main power supply fails.
- *The CPU* manages all controller operations and coordinates the interaction between the various components.
- *A real-time clock* synchronizes all controller operations and provides the correct time and date for data logging.
- *The I/O block* provides an interface between the UPLC and external devices or sensors, transferring data between them.
- *The interface* block allows the UPLC to connect to a variety of networks and devices, providing flexibility in interfacing.

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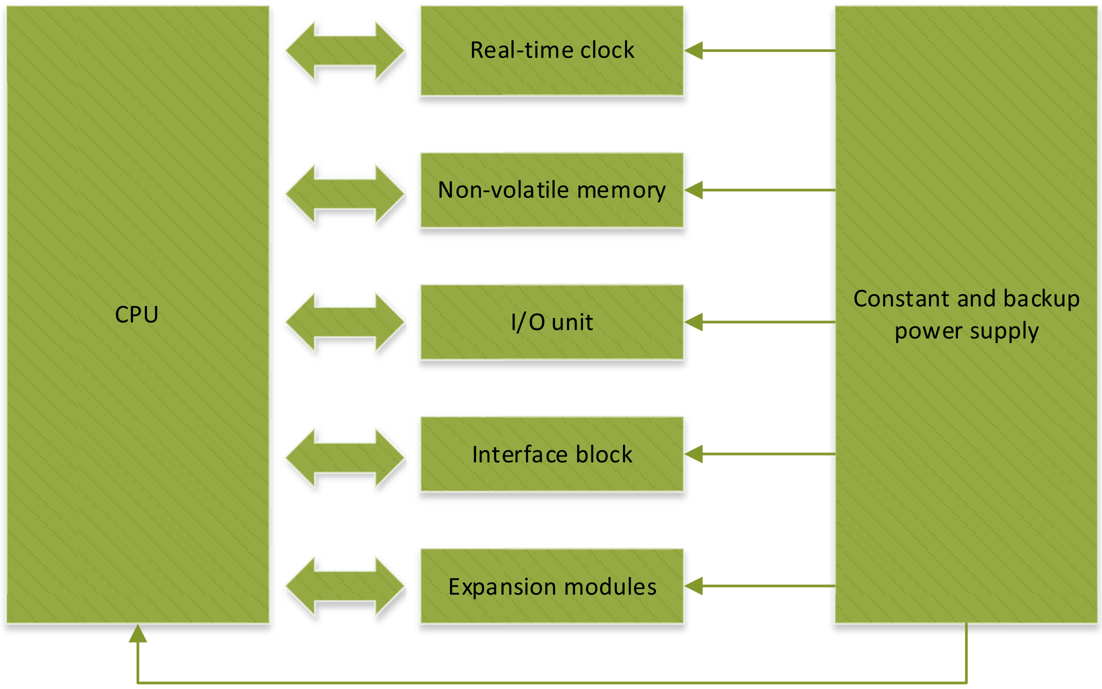

Figure 3. Conceptual hardware model of a universal programmable logic controller of modular architecture

Optional expansion modules allow the UPLC to adapt to different tasks and requirements by providing additional interfaces, I/O functions or specialized capabilities for specific applications.

At the heart of the controller software is a kernel that serves as a bridge between the physical controller hardware and the execution of software commands. This kernel provides an intuitive interface to interact with hardware components, simplifying development and configuration and making it as secure as possible.

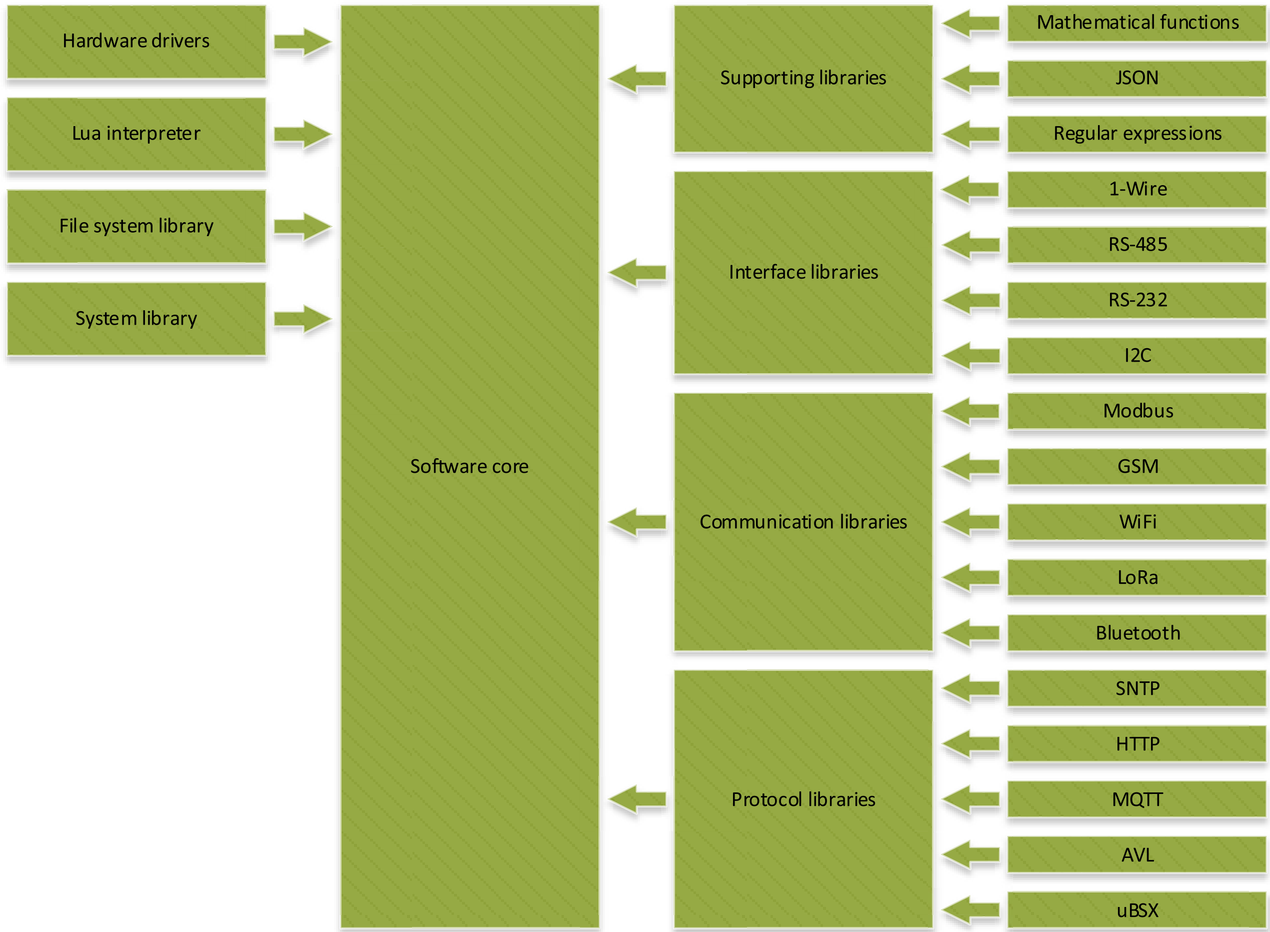

Figure 4. Structural model of the software of a universal programmable logic controller of modular architecture

The Lua script programming language is used to write the monitoring, control and monitoring logic. This choice is due to the flexibility of the language, which allows describing the controller's operating algorithms quickly and without unnecessary complications. Thus, engineers and developers can easily adapt the controller to different tasks without getting into the nuances of low-level programming.

Interaction of UPLC and adaptive information and communication system. In today's conditions of rapid technological development and complexity of agricultural processes, the right combination of UPLC and information and communication systems become a key element for effective and efficient management. Of particular importance here are the benefits and possibilities of such an integrated approach in the context of precision farming.

In modern farming systems, UPLC acts as a central control and management element, providing guaranteed data collection, real-time implementation of automated processes and equipment control. This approach provides instant response to changing conditions and rapid on-site decision-making.

Adaptive information and communication systems based on microservice architecture provide fast and reliable information exchange between different participants in the production process. These systems are highly flexible, allowing them to easily adapt to changing requirements and operating conditions.

It is the combination of the capabilities of UPLC and adaptive information and communication systems that enables a high degree of automation and control. The UPLC sends data to

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the system in real time, where it is analyzed and converted into control commands, which are then sent back to the equipment.

The client applications of the ICT system provide end users with intuitive dashboards and analysis tools, allowing them to instantly assess the current status of the production process, identify potential problems and respond quickly.

In conclusion, the successful combination of the FPGA and the adaptive information and communication system creates a holistic and integrated approach to agricultural management, ensuring high efficiency and reliability of all processes.

Discussion

Within the framework of discussion of the conducted research on the development of the conceptual model of the information system of precision agriculture and analysis of known and applied solutions in the market of precision agriculture in Kazakhstan, the following comparison can be made according to the following criteria:

1. Complexity of the solution:

- The proposed model is an integrated approach to agricultural business with multiple modules including weather forecasting, machinery management, irrigation and data analysis.
- John Deere Operations Centre: it is a cloud-based platform exclusively for Android, IOS mobile devices that allows farmers to manage their equipment, data and ag operations in one place. It provides tools to plan, execute and analyze work in the fields.
- EGISTIC: focuses on supply chain management, transport flow optimization and vehicle monitoring, only partially affecting the condition of the fields and the development of plant crops on them.

2. Personalization:

- The proposed model offers a personalized experience for agribusiness actors with clear delineation of information by subject databases, a separate administration module for the processes of transferring and retrieving the data set.
- John Deere Operations Centre: also provides a personalized interface, allowing users to customize workflow and view data related to their operations.
- EGISTIC: focuses on logistics tasks and can provide personalized data on the movement of goods and vehicles.

3. Data Automation and Analysis:

- The proposed model provides in-depth data analysis and automation for a number of agro-operations.
- John Deere Operations Center: also provides tools for task automation and data analysis, especially in the context of equipment operation and yields, but the process of process automation can be implemented only with the use of specialized John Deere agricultural machinery, which significantly reduces the applicability of this solution in agribusinesses in Kazakhstan.
- EGISTIC: provides tools to automate logistics processes but may not have the same depth of agricultural data analysis as Our system or John Deere Operations Centre.

4. Machinery monitoring and management:

- The proposed model offers a module to monitor the movement of agricultural machinery, as well as separate thematic databases to further analyze the agricultural machinery usage of a particular agribusiness.
- John Deere Operations Centre: has a strong focus on monitoring and management of John Deere machinery, providing detailed data on machine performance.
- EGISTIC: although it provides monitoring of agricultural transport vehicles, the main focus is on logistical tasks rather than agricultural operations.

Conclusion

The proposed conceptual model for a precision farming information system contains modules and elements that will create a comprehensive solution, and will integrate many aspects of agribusiness.

In turn, it is worth noting that John Deere Operations Centre is primarily focused on the management and monitoring of John Deere agricultural machinery, while EGISTIC is probably best suited for logistical tasks. The proposed conceptual model for a precision farming information system will provide a solution that will satisfy those looking for a single solution to manage all aspects of their agribusiness.

The right combination of UPLC and information and communication systems are becoming not just a current trend, but also an indispensable condition for effective management and operational decision making.

The use of modular architecture of UPLC provides a high degree of automation and real-time process control, while adaptive information and communication systems provide powerful tools for analyzing data, enabling effective interaction between different levels of management.

Combining these two technologies creates a harmonious and highly adaptive system that can respond quickly to the changing conditions and needs of modern agribusiness. This integration ensures increased productivity, risk reduction, cost optimization and, as a result, sustainable development of agricultural production.

In the future, this integrated approach will further stimulate innovation and research in precision farming, deepening technological partnerships and co-operation between the various industry players.

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