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CYBERPHYSICAL MODEL AND IOT TECHNOLOGIES FOR INTELLIGENT INFORMATION SUPPORT SYSTEM OF AGRO-INDUSTRIAL PRODUCTION

An advanced cyberphysical model of intelligent information system for support of small - scale agricultural production on the basis of decomposition of separate levels of standard conceptual model of cyberphysical systems in the form of multilayer architecture is offered. The tasks characteristic of the Internet of Things technology within the framework of the proposed model are defined, as well as software tools for their solution: Google Cloud Platform, Google Cloud Messaging, Google Firebase. Examples of the model of multi-loop translation of data and instructions between individual layers of the model are given and described. Practical approbation of the offered decisions is realized for typical processes of control of humidity of soil and air, level of illumination of a production zone in a hotbed, monitoring of daily temperature, etc. The hardware is based on the Raspberry Pi 3B + module and sets of typical intelligent sensors and servos. It is shown that the proposed model and systems approach can be used as a conceptual framework for creating smart ecosystems CPS and IoT for agricultural production.

Keywords: internet of things, crops, information system, cyberphysical system, information model, smart system, plants.

МИКОЛА ТРАФЕНЧУК, ГЕОРГІЙ ВОРОБЕЦЬ
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КІБЕРФІЗИЧНА МОДЕЛЬ ТА ТЕХНОЛОГІЇ IOT ДЛЯ ІНТЕЛЕКТУАЛЬНОЇ СИСТЕМИ ІНФОРМАЦІЙНОГО ЗАБЕЗПЕЧЕННЯ АГРОПРОМИСЛОВОГО ВИРОБНИЦТВА

Запропоновано удосконалену кіберфізичну модель інтелектуальної інформаційної система для підтримки дрібнотоварного сільськогосподарського виробництва. Обґрунтовано підхід, який передбачає застосування як узагальненої стандартної концептуальної моделі кіберфізичних систем, так і декомпозицію окремих рівнів у вигляді багатошарової архітектури. Визначено задачі характерні для технології Інтернету речей в рамках запропонованої моделі, а також програмні засоби для їх вирішення: хмарне середовище на основі Google Cloud Platform, надсилання інформаційних повідомлень з допомогою Google Cloud Messaging, зберігання станів фізичних процесів і правил управління з використання ресурсів Google Firebase..

Наведено та описано приклади моделі багатоконтурної трансляції даних та інформаційних інструкцій і повідомлень між окремими рівнями і шарами моделі. Практична апробація запропонованих рішень реалізована для типових процесів контролю вологості ґрунту і повітря, рівня освітлення виробничої зони у парнику, моніторинг добової температури, тощо. Для апаратної частини використано рішення на основі модуля Raspberry Pi 3B+ та наборів типових інтелектуалізованих сенсорів та сервоприводів.

Показано, що модельне представлення інформаційних потоків та узагальненої архітектури інтелектуальної інформаційної системи на рівні багато параметричних функціоналів дозволяє оптимізувати апаратно-програмні ресурси та підвищити економічну ефективність та основні виробничі показники досліджуваної системи. Для отримання покращених результатів експерименту необхідно враховувати більше природних та антропогенних факторів і використовувати складні моделі CPS для агропромислових комплексів.

Запропонована модель і системний підхід можуть бути використані як концептуальні засади для створення смарт екосистем CPS та IoT для сільськогосподарського виробництва.

Ключові слова: Інтернет речей, агрокультури, рослини, інформаційна система, кіберфізична система, інформаційна модель, розумна система.

Introduction

One of the industries where information technology and systems (ITS) have been widely implemented in recent years is agriculture in all its varieties [1-4]. Motivating factors for this are already the results of statistical and economic analysis of production indicators of the industry due to the introduction of simple means of automation of production processes, and forecasting the demographic situation in the world. In particular, according to the Food and Agriculture Organization (FAO) of the United Nations (UN), tens and hundreds of millions of people are currently suffering from malnutrition, and in a pandemic the situation is exacerbated [5, 6]. According to a study forecast [7], by 2050 the population of the Earth will reach 9.6 billion.

At the same time, it has been experimentally proven that the application of soil moisture control shows an increase in yield up to 30% [8]. The use of well-known agricultural producers SCR from Allflex and Cowlar Internet of Things (IoT) technology, in particular the so-called labels for collars, allows to obtain data on the condition of animals - temperature, health, activity, nutrition information for each individual animal, and some values generalized collective information about the herd [9]. A similar technology is proposed in [10]. Experimental tests show that the use of the proposed reasonable control over the behavior of animals increases their livestock by about 15-20% [11].

Therefore, the problem of improving existing and creating modern intelligent ITS on the basis of IoT technologies is an urgent task for commodity agricultural production, which allows to increase its efficiency.

Related works

The most complete overview of the current state of application of Internet of Things technologies in different countries, in particular in the USA, Canada, Germany, India, China is given in [2]. It analyzes the practical developments and the economic effect obtained from the development of mechanization, automation, digitization and implementation of the Internet of Things in agriculture, as well as considers the main trends, tendencies and forecasts of these technologies.

One of the typical solutions of ITS [8] are meteorological stations, which with the help of a network system of intelligent sensors and measuring transducers allow to automate the control of maintaining the optimal amount of moisture in the soil in the greenhouse. Well-known branded IoT products are Farmapp, Growlink, GreenIQ solutions. They use intelligent IoT sensors and a controller of so-called sprinklers, which allows using conventional computer tools, such as a smartphone, to remotely control irrigation and lighting systems in greenhouses [8, 9].

For precision farming, one of the largest manufacturers of agricultural equipment, John Deere, began producing tractors with GPS trackers and connected to the Internet [12]. Various geopositioning and remote sensing systems are used for the same purpose [13]. In addition to various modifications of IoT technologies [14], other ITS are considered in agro-industrial production. In particular, Matthew Grassy and Paul Schrimpf, editors of PrecisionAg magazine (USA), ranked the most promising, in their opinion, the latest computer technology in agriculture [15]. These include: machine learning tools and artificial intelligence; use of smart sensors for accurate planting; New Leader NL5000 G5 technology for precise fertilizer application; modeling of plant fertilization processes with nitrogen fertilizers; use of robots, drones, both guided and unmanned.

Thus, IoT technological systems in agricultural production are becoming more branched and multicomponent. Accordingly, the requirements for preventing the loss of information in such systems are increasing.

However, most of the publications cited above [3, 4, 13-15], as well as publications on general approaches and models of agricultural enterprise management [16, 17], consider mainly the structural solutions of ITS and there are no examples of models of systems, which complicates their design. Therefore, the purpose of this study was to create an information cyberphysical model of an intelligent information system to control and support the life of crops on the example of greenhouses.

Intelligent information system to support of agro-industrial production

We describe the information system to support the life of crops as a generalized cyberphysical system (CPS) [18] based on a systems approach [19]. Information system modeling aims to provide synergistic interaction between elements of physical and cyberspace CPS by synthesizing generalized functional algorithms. The latter are synthesized on the basis of structural solutions and models, that take into account specific features, the purpose of CPS and the IoT technologies used in them. The creation of information models involves the decomposition of the problem of analysis and synthesis of the system into individual nodes and modules. They are then considered as basic structural units related to specific physical processes. In the developed system, they provide the implementation of two types of functions: information processing and management of physical components of the system. Therefore, the description of the information model is relevant individually for a specific example of the implementation of CPS and IoT technology.

In the general case, it is advisable to analyze the structuring of the system and identify the classes of problems and models that may be needed for information modeling. The proposed model (Fig. 1) describes in detail the structural components at the levels of physical space, cyberspace and the interaction between them at the level of information flows. The data circulating in the information flows are generated by the sensor system and "absorbed" by the elements of the control system and servos. In cyberspace (CS) it is advisable to distinguish the following structural parts: 1) built-in computer tools for local data processing and computing; 2) cloud data storage resources for complex information processing, complex calculations and modeling of physical space (PS) processes; 3) end-user computer tools that have access to the system. IoT technologies allow to implement recirculation of information flows and data exchange in CPS at the levels of local and advanced global cycles of CS and PS interaction. The end-user level describes the functionality and interaction of system components with end users. The latter can monitor the system, receive notifications about events, the state of objects and the results of monitoring their parameters. Communication between end customers and the level of the cloud environment is provided using a system of customer authentication and authorization. This approach provides all the necessary information to access the physical space. Each time the end customer requests data, the cloud storage interacts with the authentication system to provide the required data.

In the cloud environment there are 3 main components. The module for archiving and storing system states contains data on physical processes that are implemented by embedded computing tools during monitoring. The control module is designed to send information to the embedded computing facilities about the rules and control states used by the system, which should be applied in the process of system management. The end customer can set these rules using the control unit. That's why we have a two-way connection between the end-client management module and the cloud storage rule and module modules. The cloud notification management module should provide end customers with current notifications about events in the system that relate to certain actions, processes, control states of PS and CS.

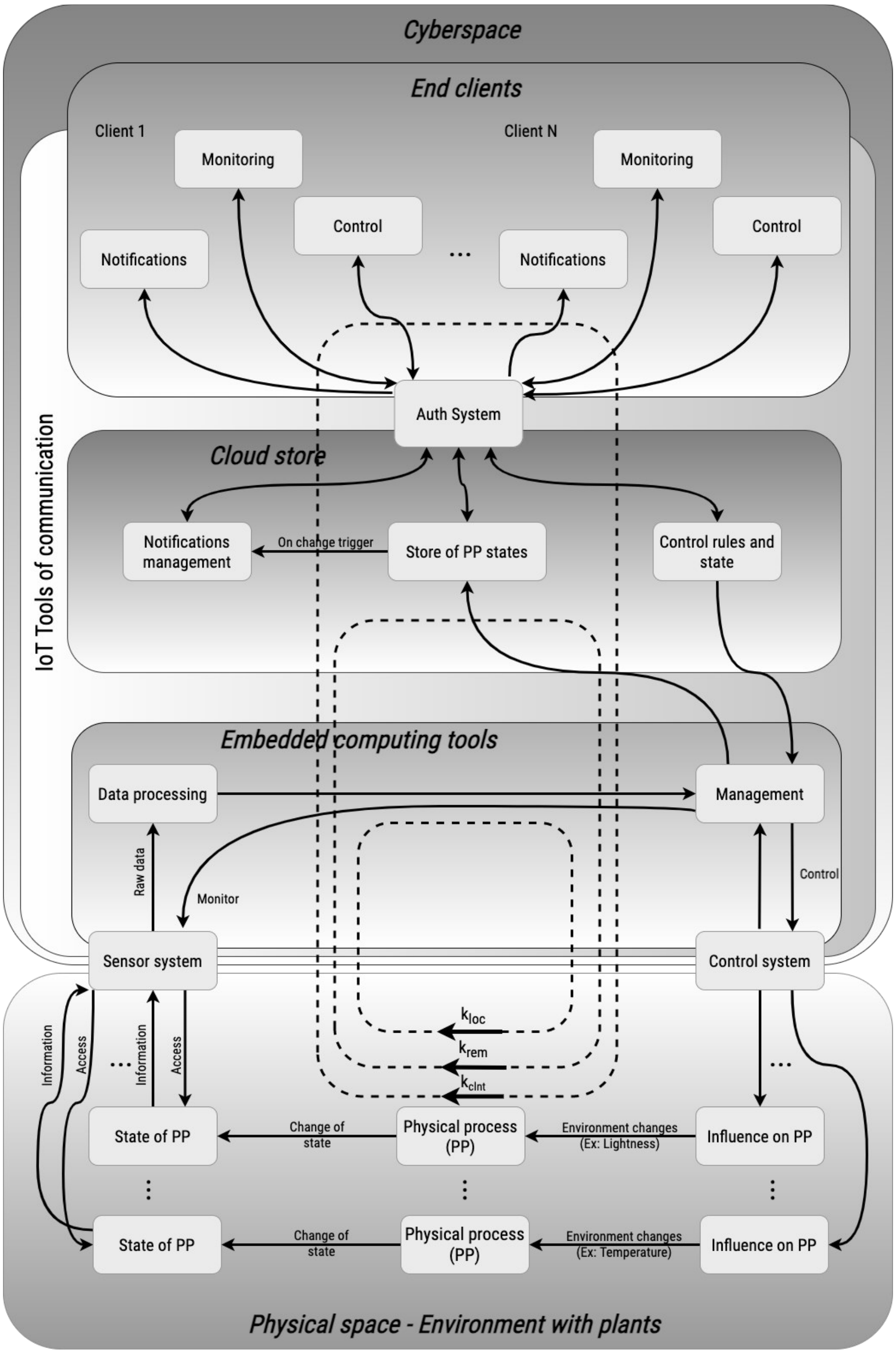


Fig.1. Information cyberphysical model for the system of life support of agricultural crops

Embedded Computing Tools (ECT) are designed to provide direct interaction between PS and CS. ECT provides processing of data from physical space and control of its states, respectively through a system of sensors and measuring transducers as sources of information, and drivers and servos as final recipients of data and control signals.

Depending on the structure and complexity of the agro-industrial complex in PS, several physical processes can be implemented simultaneously: control of soil moisture - irrigation / irrigation of the soil; humidity control - ventilation / air drying; control of the level of lighting of the production zone in the greenhouse - control of lighting of this zone; daily temperature monitoring in the production room - control of heaters / fans; control of soil mineral composition - application of mineral fertilizers; etc. Accordingly, several information flows will circulate between PS and CS.

In general, ECT in the CPS model can be considered in two aspects: 1) as elements of the PS, which are located directly on the physical object and provide automated data collection and primary information processing in automatic mode, as well as management of PS objects; then these are the means of automation, which relate to physical space; 2) as elements of edge computing in CS, which provide primary data preparation for optimizing the traffic of digital streams in CS and data exchange between CPS modules. In the latter case, ECTs are elements of the cyber component in the CPS.

According to the functional purpose in the ECT allocate blocks of data processing and management. The data processing unit is used for the primary conversion and formatting of data. The original data format must be acceptable for use in a cloud environment and in a control unit. The control unit must synchronize the steps of receiving data from the PS sensor network and sending control commands to the PS objects. Execution of certain actions with an object or process takes place only in the case of execution of the rules defined in the algorithm, or the occurrence of relevant events. The intelligent data processing module can be hosted in a cloud environment, on a system server, or as part of a CPS cyber component. It depends on what mathematical models are used in CPS, for what type of crops the current modeling will be implemented, and for what processes: diffusion of substances in the environment, calculation of convection fluxes, thermal processes, etc. On the other hand, the results of process modeling based on sensor data are also parameters of the model of recirculation of information flows between PS and CS for the correction of control modes of objects and processes PS.

The generalized model of information processes and data flows at the basic level of the structural organization of the CPS of the analyzed information system (Figs. 1, 2) can be described as a multiparameter functional, similarly as proposed in [20]:

$$M_F = \{[(S(p), K_e(S)), (M(p), K_e(M))], C, [(A(u), K_h(A)),$$
$$(K_h(M), K_h(S))], (K_u(A), K_u(S), K_u(M))\} \times P, P = \{p\}, u \in \{u_1, \dots, u_i\} \quad (1)$$

where $S(p)$ – is a sensory subsystem; $M(p)$ – control subsystem; K_e – embedded computing tools: $K_e(S)$ – for data processing and $K_e(M)$ – for control and management; C – IoT communication tools; K_h – cloud environment (resources): $K_h(S)$ – to store the states of physical processes and $K_h(M)$ – to determine the control states of processes and objects in the system and control rules, and $K_h(A)$ – to manage notifications; $A(u)$ – authorization system; K_u – end customer (user, client): $K_u(A)$ – notification signals, $K_u(S)$ – system monitoring signals, $K_u(M)$ – system control signals; $P = \{p\}$ – set of physical processes, $\{u_1, \dots, u_i\}$ – set of unique users.

Almost all components of the M_F model are also multiparameter functionals, and their parameters describe the structural elements of the lower hierarchical level in the designed system. In addition, these components can be grouped by higher-level functionalities of the hierarchy. From the above set (1) we can distinguish three functional clusters of components: 1) components that provide the functionality of the internal local circuit k_{loc} data translation in CPS (Fig. 2) – $[(S(p), K_e(S)), (M(p), K_e(M))]$; their set may be sufficient for the implementation of simple stand-alone CPS, which work using co-processor reconfiguration models using standard libraries [18, 19]; 2) components of the external contour of k_{rem} interactions in the CPS with the involvement of network access to the cloud environment (resources) including IoT technologies – $[(A(u), K_h(A)), (K_h(M), K_h(S))]$; which require the use of specific mathematical models for predicting the phase trajectories of the system [18, 19]; 3) components of the contour of the k_{clnt} client interaction with separate CPS layers – $(K_u(A), K_u(S), K_u(M))$.

Applying the CPS functional layer model is quite convenient. This approach allows you to optimize the number and justify the technical requirements of hardware and software resources for the implementation of CPS [19]. Functional clusters are essentially a reflection of information flows in the contours of the interaction between the individual layers, on the set of resources of the technical solution CPS. It is clear that in addition to the contours of the interaction of layers of cyberspace with physical space, the contours of interaction between the individual layers of CS are possible. The defined four-layer functional structure of this information system is only an example of the proposed approach. Here the first functional layer is the environment of physical objects and processes, the second – technical means and a stack of standard and non-standardized protocols of interaction of the built-in component with PS, the third – computing and communication resources of the cloud environment, and the last – means, protocols and The conceptual model for the interaction contours, based on the functional-layered CPS architecture, can be represented by the following functional:

$$M_k = \{(P \times K(p)), (U \times K(u)), K(c)\} \times \{R(g), R(q), R(e)\} \quad (2)$$

where $P = \{p\}$ – the set of physical processes, $U = \{u\}$ – the set of users, $R(g)$ – the set of computing units, $R(q)$ – set of communication resources, including IoT technologies, $R(e)$ – set of energy resources, $K(p)$ – contour of interaction of CS components with PS, $K(u)$ – contour of interaction of CS components with users, $K(c)$ – contour of internal interaction of components CPS.

In general, the proposed cyberphysical model improves the conceptual model of CPS by detailing individual levels and allocating layers of functional interaction, as well as the inclusion of IoT technologies in the interaction loops [21, 22] complements the previously described system approach [18, 19] and allows to structure and optimize hardware and software solutions for CPS of arbitrary configuration [21, 22].

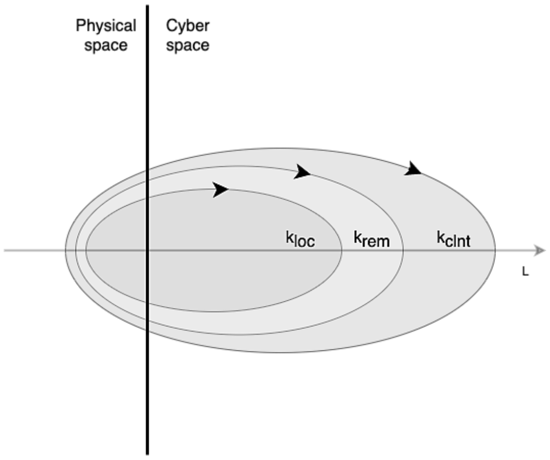
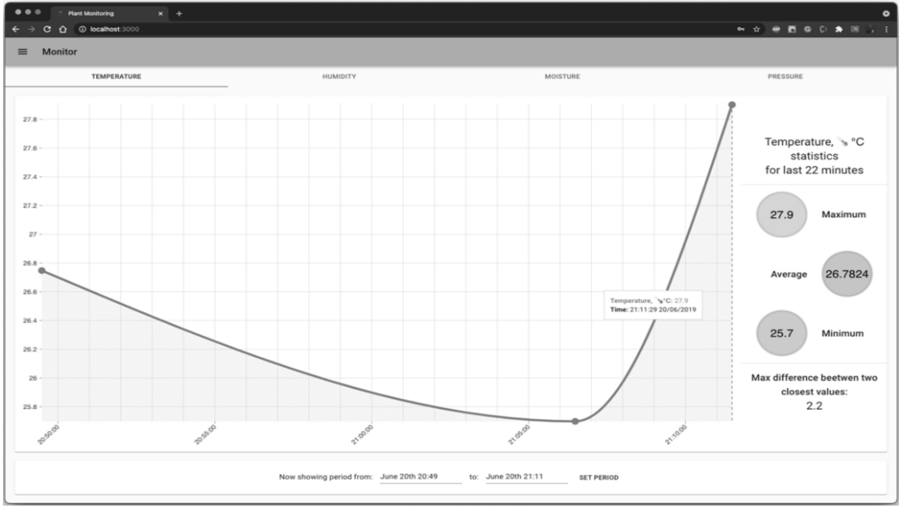


Fig.2. Outlines of interaction in the CPS used in the information system

Experiments

To test the proposed approach and the improved layered architecture of the 5C model, a prototype of an information system for a small greenhouse was built. The hardware for the implementation of the circuit of local interaction with the components $S(p)$, $M(p)$, $K_e(M)$, $K_e(S)$, is based on a single paid solution Raspberry Pi 3B +. The functional elements of this circuit are built-in computing resources of microcontrollers of intelligent digital sensors, as well as sets of other sensors and actuators. Modeling of the information system functionality was performed for physical processes of monitoring the temperature of the environment and soil, air and soil humidity, as well as the level of illumination of individual areas of the greenhouse. The use of controlled servos allowed to control the water pump for controlled regulation of soil moisture, air fans and ventilation system, and power switches with digital control – to control the lighting level of technological areas of cultivation of individual crops. The cloud environment was implemented using the Google Cloud Platform. Google Cloud Messaging was used to send informational messages to users. The function of storing the states of physical processes and control rules was performed using Google Firebase resources. This decision is based on the fact that the API is available for both the end of the client and for the Raspberry Pi in the form of a Python library. The final client part is presented in the form of a WEB program SPA. React works for interface management, and the niv.rocks library works for data visualization. Material UI is selected as the interface library. This stack showed excellent consistency in the process of processing and displaying data in the implemented information system (Fig. 3).

Thus, a cyberphysical model with the use of Internet of Things technologies in the form of a hardware-software platform of an information system for small-scale agricultural production was developed, implemented and experimentally tested. Previous experimental studies of the created system have shown sufficient efficiency of the proposed approach and implemented solution. In particular, due to the use of proven algorithms for controlling the temperature, lighting and humidity of the experimental object, there is an increase in vegetable yields by 5-8%, reducing energy consumption by 15-17% compared to the non-computerized version of the greenhouse. The cost of implementing the system compared to analogues [8, 9] is lower by 25-28%. Of course, in order to obtain the best indicators and ensure the stability of the experimental results, it is necessary to apply mathematical models of the recommended agronomic cycles for specific types of crops. Then it is also appropriate to model the real processes of supporting the growth and development of such crops using powerful computing tools of the cloud environment.



Temperature, °C: 27.9
Time: 21:11:29 20/06/2019

Temperature, °C statistics for last 22 minutes

27.9 Maximum

Average 26.7824

25.7 Minimum

Max difference beetwen two closest values: 2.2

Now showing period from: June 20th 20:49 to: June 20th 21:11

Fig.3. Developed system monitoring interface

Conclusions

Conclusions As a result of the conducted researches the improved cyberphysical model of the intelligent information system for support of small-scale agricultural production is offered. The proposed approach involves the application of a multilayer architecture for individual levels of the standard conceptual model of cyberphysical systems, Internet of Things technology, as well as a model of multi-loop data transmission and information instructions and messages between individual levels and layers of the model.

The model representation of information flows and the generalized architecture of the system are described at the level of many parametric functionalities. This allowed to minimize hardware and software resources and increase system efficiency. The method used to describe the system can be easily adapted to the physical objects and processes of more complex technological systems.

However, to obtain the expected results, the generalized mathematical model requires a more detailed substantiation of the objective function of CPS synthesis [19], and taking into account the features of physical and information processes of a particular system [18]. The obtained values of improving the efficiency of the system for a particular experiment are estimated and may depend on many natural and anthropogenic factors. Therefore, further in-depth research is needed to implement specific CPS that can be used in agro-industrial complexes. The proposed model and systems approach can be used as a conceptual framework for creating smart ecosystems CPS and IoT for agricultural production.

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