FROM WIRELESS SENSOR NETWORK TO WIRELESS SMART SYSTEM: AGRICULTURE

Volodymyr Romanov, Igor Galelyuka

Abstract: *The technology of Internet of Things (IoT) and smart systems are being widely implemented in various spheres of human activity and everyday life. Agriculture is not an exception. Usually, wireless sensors or wireless sensor networks (WSNs) acquire data in such systems. The authors of the article had developed and brought to serial production standalone devices and WSNs for usage in agriculture. As world experience shows, developing a smart system for any application is quite a difficult task, as each such system is unique in terms of used technologies, protocols, hardware and software. The article presents the experience of the authors in developing the principles of creation and architecture of a smart system for agriculture based on a WSN created by the authors. The analysis of existing architectures of smart systems and solutions based on the IoT made it possible to choose a typical system architecture what was further adapted to the applied task of agriculture. Two main components of the proposed smart system are defined, namely, a data server and a device at the edge. These components will further define a stack of protocols and standards for communication and data transferring, as well as a set of basic hardware and software. The structure of each of the main components is described and their functional blocks are clearly defined. Finally, the challenges and problems faced by developers at the initial stages of developing of the smart system for agriculture are given. Most of the mentioned challenges are currently not completely solved by the world community and during development of each systems, they need an individual approach and different tools for solving.*

Keywords: *wireless sensor network, smart system, Internet of Things, agriculture*

ITHEA Keywords: *J.3 Life and Medical Sciences.*

DOI: *https://doi.org/10.54521/ijita32-03-p02*

Introduction

Until recently, large number of data acquisition and monitoring systems were used in industry and various spheres of human activity. Such systems included wired or wireless sensors, connected to local intermediate data unit. This data unit collected measurements from all sensors according to a pre-defined program or operator command and transferred those data to the central unit of the system. The central unit processed the data and on their base prepared the visualisation of object state. In addition, these data were the base for preparing and making a managerial decision in automatic mode or directly by the operator. Although often the automatically generated managerial decision had to be approved by the operator. Technological progress led to an increase of the size and complexity of technological objects, what caused an expansion of the list of parameters for measurement and a significant increase of the amount of data that the sensor network had to measure and transmit to the central node of the system. The intensive increase of amount of acquired data negatively affected the efficiency of data processing and the speed and accuracy of making managerial decisions. For real- or quasi-real time systems, this situation became a negative factor and required developing and applying new scientific and technical solutions.

The development of information and microprocessor technologies made it possible to transfer some calculations to intermediate units of systems, and sometimes closer to monitored objects. The integration of microprocessors into intermediate data acquisition units or measuring nodes enabled to pre-process the information at the place of data acquisition and make certain managerial decisions there. The development of information and communication technologies made it possible to replace networks of wired or wireless sensors with WSNs. Wireless sensor nodes in these networks are able to organize data transferring channels by themselves, form topologies of wireless networks and select protocols and mechanisms for data transferring to guarantee high quality and reliability of data delivery.

All mentioned led to the emergence of such technologies as WSNs, mesh networks, the IoT, cloud and fog technologies, Intellect at edge etc. The implementation of these technologies into different applied usage makes it possible to create data acquisition and processing systems to cover enough large and complex objects. In addition, such system can store and process large amount of data, prepare and make managerial decisions at different levels of the system, inform users about the occurrence of one or another emergency event, detect the influence of negative stress factors. If it`s necessary, such system can impact on the monitored object via special actuators to eliminate of the influence of negative stress factor or avoid emergency. Currently, such systems are implemented at complex technological objects, agricultural lands, greenhouses and medical organizations etc. In this way, it is appeared such new smart technologies, as smart factories, smart houses, smart fields, smart greenhouses and even smart cities.

Currently, there are many research projects and ready solutions, focused on the application of wireless technologies, smart systems and IoT in agriculture, environmental monitoring and protection. In [Simo et al, 2022] it is described an example of development of wireless sensors, based on the technology of IoT, for real time measuring of environmental and soil parameters, power consumption in greenhouses to help the farmer in making optimal decisions. The overview of applied solutions for different implementations of smart systems and wireless technologies in agriculture is made in [Kim et al, 2020]. The authors of paper clearly divided systems by application areas, such as, monitoring various parameters in greenhouses and on open fields, monitoring of diseases and pathogens, controlling of pesticide, herbicide and fertilize application, monitoring of soil parameters, application of systems in animal production etc. The paper [Bua et al, 2024] presents the smart wireless system, intended for application in hydroponic greenhouses. Described system not only measures the climatic parameters in the greenhouse, but also accordingly to pre-set algorithms executes the feedback impact via lighting or ventilation to optimize the parameters of plant growth. An overview of applications of machine learning methods in different smart systems for agriculture is given in [Mohyuddin et al, 2024]. It is described more than 12 applied tasks in smart and digital agriculture, which are already being solved by means of machine learning algorithms.

Work Objectives

Work objectives are developing the architecture of the smart system, based on existing WSNs, for application in agriculture.

Preconditions for Creating of Smart Systems

At the Glushkov Institute of Cybernetics two decades ago there were developed, created and launched to mass production autonomous devices of "Floratest" family, intended for measuring the state of live plants in express mode without damaging the plants [Romanov et al, 2012] (Fig. 1, a). Until now, these devices are used by agronomists, scientists and other specialists in laboratories, greenhouses or on agricultural fields to estimate the state of plants, optimize the artificial irrigation and herbicides or fertilizers application, determine the content of heavy metals and harmful substances in plants and soil, etc. The emergence and rapid implementation of technologies of precision and digital agriculture into wide practice set a challenge to the specialists of the Glushkov Institute of Cybernetics, consisted in the integration of developed autonomous devices into new agricultural technologies. For this purpose, the autonomous device was upgraded into a wireless measuring node [Romanov et al, 2021] (Fig. 1, b). A certain number of such wireless measuring nodes are able to organize a WSN to cover large areas of agricultural land, green spaces or greenhouses with measurements. Further, the measured data are transferred from wireless sensors to the network coordinator, which pre-processes and stores data, displays data in a convenient form at user's request, aggregates data and prepares them for sending to the higher-level system. At this approach all measuring data are stored and processed on a central node of system. These data are used to make a managerial decision, either directly by the user himself based on his own experience, or in automatic mode with the help of algorithms specially entered by the user. The automatically made decision must be approved by the user, what introduces a possible error of human factor into final decisions.

a)

b)

Figure 1. Tools for measuring the state of plants (a – portable device of "Floratest" family, b – the cluster of wireless sensor network)

Modern agriculture requires that data acquisition systems not only measure and process data about the state of plants and environment, but also determine the impact of negative stress factors, prepare and make some managerial decisions, that are reasonable to implement via recommendations to the user regarding further actions to care for plants or via feedback mechanisms to eliminate the influence of negative factors or improve the state of plants through watering, fertilizers application, etc. This approach requires the integration of methods of artificial intelligence and machine learning, including the technology of Intellect at the edge, into measuring nodes and systems in whole. The integration of these technologies with WSNs leads to the emergence of smart systems in agriculture, including those that are able to operate without the participation of a specialist or only under his supervision while performing most agrotechnical operations. Smart systems in agriculture should operate autonomously or without maintenance for most of time.

The Architecture of Typical Smart System

When developing smart systems for using in different areas of human activity or industries, first of all, it is necessary to highlight and generalize the features or, in other words, functional levels inherent in a typical smart system [Tokody et al, 2019, Giese et al, 2015]. With this approach, it`s necessary to emphasize, that cloud, wireless, information and communication technologies, and also technologies of distributed systems, are the basis of typical smart system. This causes the appearance of the main challenges, which consist in the organization of the correct operation and interaction of all components at all functional levels of the smart system, as well as in the organization of stable, valid and secure channels for data transferring. All above mentioned has to be solved by scientists and engineers during modelling, developing and implementing of smart systems in any application [Arsan, 2016].

The architecture of the system serves as the start point of the development process. Exactly the future architecture defines the methodology by which a smart system will be designed and built. Currently, the scientists distinguish several main groups of architectures peculiar to smart systems based on WSNs or IoT, namely, layered, service-oriented and hybrid. The last one derivatives from the two first architectures. Such a variety of architectures is caused by a large number of applied usages.

In layered architectures, there are several layers, mostly four or five, depending on the applications for which they were developed [Vashi et al, 2017, Guerrero-Ulloa et al, 2019]. For example, some 5-layers architectures may contain the following layers: layer of sensors, network layer, interfaces layer, application layer, and business process layer. Another example of a 5-layers architecture is given in Fig. 2. At the same time, the division into specific layers is just conventional, because in reality the edges between the layers are very blurred. For example, the implementation of the new technology "Intellect at the edge" requires combining the layer of sensors and layer of local computing. The new united layer should easily allow replacing one sensor or device to another without interfering in the intelligent component. However, there is also a reverse approach, when replacing methods of smart data processing should not require significant adaptation or upgrading of existing measuring tools.

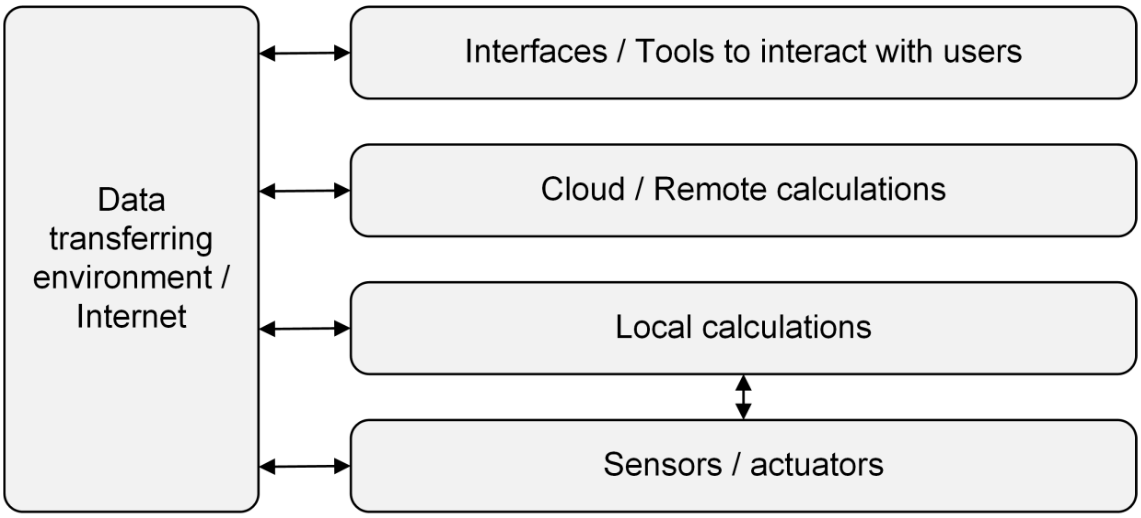

Figure 2. Architecture of 5-layers smart system

Implemented smart systems often has 3-layers architectures [Mora et al, 2017, Gianni et al, 2019]. The lower layer in such architectures is mainly responsible for control and interaction with sensors, measuring devices and actuators. The upper layer is responsible for the operation of applied software and interaction with users. At the same time, the type of implementation of the middle layer depends on the applied task and used technologies, but its main functions are to guarantee data processing, reliable communication and maintaining the environment of data transferring between the lower and upper layers. In some systems, such communication is realized via cloud or fog technologies, and in other systems by means of own servers or third-party infrastructure.

That`s why the main feature of layer architecture should be the ability quickly and easily to combine and separate existing layers without significant impacts on the characteristics of whole system. Mentioned above should be determined at the stage of system planning and development of the preliminary requirements specification.

In service-oriented architectures [Kijas and Zalewski, 2020], the main components are software services for the implementation of predefined functions or groups of functions, which further are supplemented by auxiliary software and, if necessary, appropriate hardware. The peculiarity of this approach is that software services are often heterogeneous, which necessitates the creation of special interface modules to combine them into a single system.

Often service-oriented architectures are also divided into layers. For example, a typical service-oriented architecture can consist of four layers:

1) The hardware layer, which contains all the hardware tools for maintaining the system's operation.

2) The network layer, which provides wired or wireless communication within the whole system.

3) The service layer, which is designed to create the necessary services to maintain the system operation.

4) The layer of applied software, which ensures the interaction of users with services.

In service-oriented architectures focused on the implementation of clearly software systems, there may be only three layers, which, as a rule, correspond to a server-oriented structure. Such layers may have different titles, but usually the top layer is called as the server part, the bottom one is the user part, and the middle one is called as the layer of applied interfaces.

Hybrid architectures, as a rule, do not contain real layers or services, and the division is performed according to an abstract sense. In this case, abstract layers contain components or services grouped according to a specific task or a specific conditional entity, model or knowledge base. Other hybrid architectures can be oriented on combining around certain components or resources. In the first case, the integration of hardware or software is performed in accordance with the used technology. In such an architecture, it is possible to have a layer of IoT, a layer of cloud computing, etc. In the second case, the integration is made around a certain resource, for example, computing resources, memory, power or similar.

Each of the architectures has its own features and applied usage, what should be taken into account at the beginning of the development of a smart system. The correct selection of architecture and its layers significantly simplifies and decreases the cost of system upgrading and maintenance in the future.

Development of Smart System Architecture for Agriculture

When designing and creating smart systems based on WSNs or IoT, it should be applied the mentioned above rules to develop the architecture. The feature of such systems is that each of them is unique and determined by stack of applied protocols, tools and interfaces, as well as hardware available at the time of development. However, during the creation of systems based on WSNs or IoT, it can be clearly distinguished the three main layers, which are typical in the architecture of almost every existing smart system. The first layer is the layer of sensors. This layer typically is hardware and contains measuring tools, actuators, "smart" devices and means, whose primary aim is to interact with the environment. The second one is the network layer to ensure the reliable communication and data transferring between system elements. This layer, in addition to hardware and software tools called as the data-transferring infrastructure contains a mandatory stack of protocols and applied interfaces to combine individual components, often heterogeneous, into a single system. The third layer is the layer of applied software, which provides special software services to work with data.

These three layers, mentioned above, make it possible to build different types of architectures, in particular with using of cloud or fog technologies, artificial intelligence, distributed computing, edge computing, etc. For example, architectures based on cloud technologies provide the possibility to create and apply services to ensure the availability of all data to any user from any remote access point. The application of "computing at the edge" makes it possible to move data processing and storage, as well as control functions closer to the monitored objects. This results in a fast feedback impact of system on the monitored object, what is often very important for industrial objects or other real-time applied tasks. The application of each of these approaches has its advantages if technologies are applied correctly and appropriately according to the requirements specification. Fig. 3 shows an example of the architecture of a typical smart system based on IoT with applied cloud technologies and "computing at the edge".

The lower layer of proposed architecture is the layer of sensors, which is often not static by its structure. This layer can be repeatedly modernized during the life cycle of the system to connect new sensors, actuators and smart devices or tools, especially new means of IoT. It`s reasonable to expand this layer to connect not only new separate devices and tools, but also external measuring systems. This is especially important for the technology of industrial IoT [Chalapathi et al, 2021], when data for main system can be acquired, processed and aggregated by another system or subsystem, for example, a "smart" enterprise, a smart "office" or even a "smart" home. At this case, separate measuring devices or WSNs can acquire and pre-process measuring data.

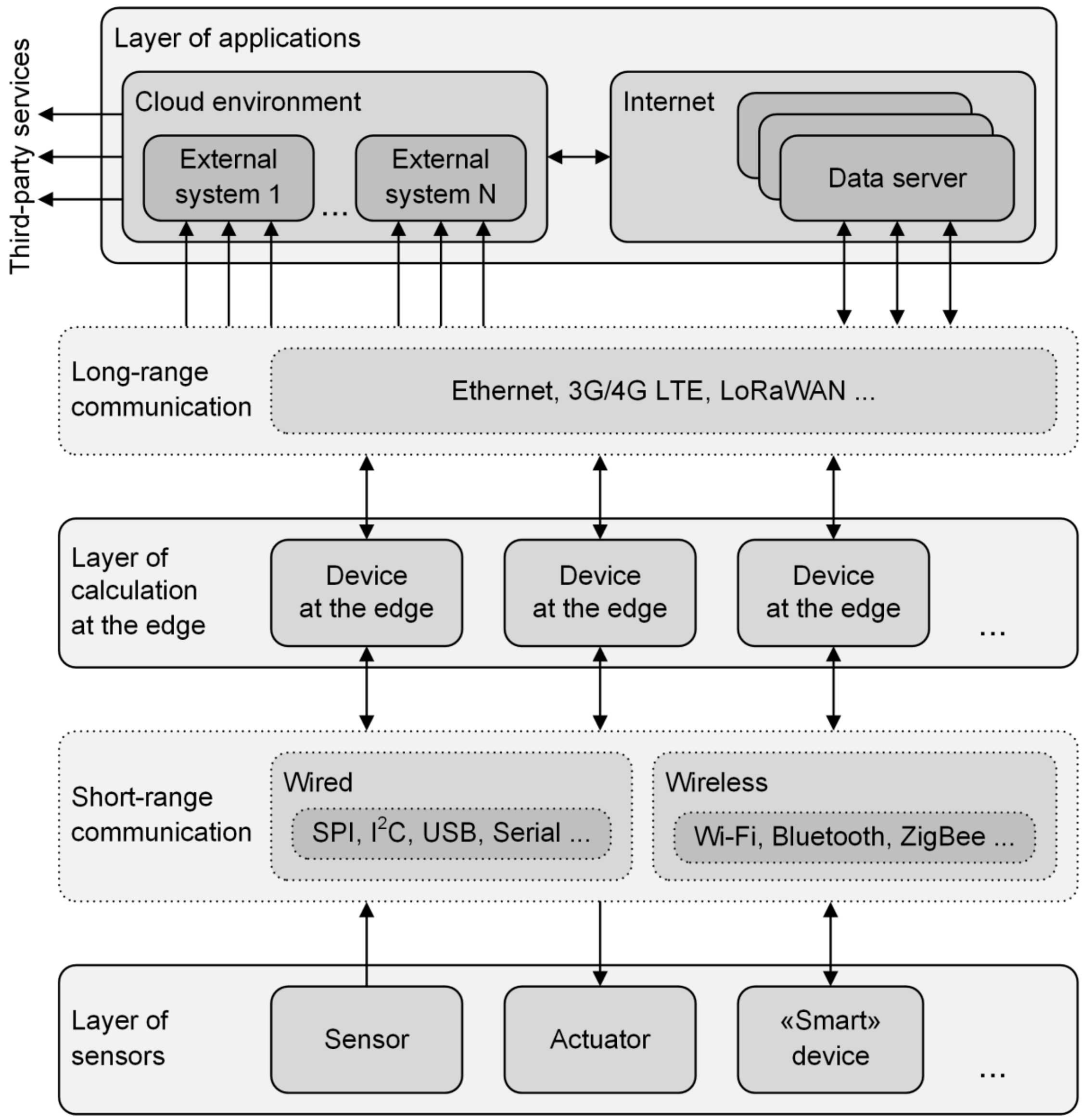

Figure 3. The architecture of smart system for agriculture

Data transferring between the layer of sensors and the layer of devices at the edge is performed by means of short-range communication, for which both wired and wireless channels can be used. Wired channels includes most wired standards and protocols of data transferring, such as, USB, SPI, I^2C, serial port etc. In addition, microprocessor general-purpose input/output pins (GPIOs) serve as short-range wired data transferring channels. Short-range wireless protocols include most common wireless protocols, such as, Wi-Fi, Bluetooth, etc., or protocol for industrial application, such as, ZigBee. Usually, these protocols are not only used in data transferring in "from device to device" mode, but are often used to create WSNs of various types and topologies to acquire data from a large number of objects and transfer them to higher levels of the system.

The middle layer is the layer of "devices at the edge", the appearance of which is, first of all, caused by a large number of primary measurements. The necessity to transfer such large amount of data to the server for processing generates rather large load both on separate data transferring channels and on whole data transferring infrastructure. This peculiarity caused the necessity to move a part of data processing and analysis functions from the server closer to the measured objects, namely, to the devices at the edge.

Communication between the layer of "devices at the edge" and the upper layer of the system is performed mainly via long-range wireless communication protocols, for example, 3G/4G LTE, LoRaWAN and others. Often for such communication it can be used wired channels by means of Ethernet protocol, both within local and global networks.

The upper layer, namely the layer of applications, is usually implemented with using of cloud technologies or individual servers. This layer should performs those data processing and analysis functions, which can not be fulfilled at the layer of "devices at the edge". As a rule, these calculations are "heavy", require additional computing and other resources, and consider the peculiarities of many data streams from different monitored objects. Cloud technologies at this layer are usually used to organize the processing and storing of data transferred to third-party systems or services. Individual servers are mainly used to manage the operation of the whole system, authorize users and ensure data security.

The mentioned above architecture of system sets certain requirements to the functionality of its components, in particular to devices at the edge and data servers. Last ones determine the rules of system behaviour and functioning of data flows within the system, the rules of data processing and storing. In general, the structures of the device at the edge and the data server are similar in terms of the sets of functional elements they have to contain. Each of them should have several mandatory units, namely: 1) subsystem of input signals; 2) data processing subsystem; 3) subsystem of output signals; 4) control subsystem. Such structures are not limited only to the list of specified subsystems, but depending on the application task and device type may contain other elements to implement the necessary functionality. Each subsystem contains a set of units. Every unit is intended to perform one or several similar functions to achieve one of the subsystem goals.

The subsystem of input signals of the device at the edge is responsible for establishing communication with the layer of sensors, receiving measuring data and transferring service messages. As a rule, this subsystem contains a set of standard models of input data, the main aim of which is to define standard data formats to exchange with other devices. During creating new smart devices and tools, including means of IoT, in most cases developers introduce standard data formats to exchange measuring data with other devices or systems without prior agreement of data formats. This approach significantly reduces the time for connecting new devices to the system and expands the list of possible compatible devices. If the measuring data has a non-standard format, the subsystem of input signals has a data transformation unit, which based on configuration files or special service messages can convert the received non-standard measuring data into the format specified by the models of input data. The transformed data becomes more convenient for further transferring, storage and processing.

The subsystem of input signals of the data server has a slightly different functionality, as there are some peculiarities in its operation. The first peculiarity is that already formatted and aggregated measuring data arrives to the data server. So, the subsystem of input data only unpacks correctly formatted measuring data. The second peculiarity is that input data arrives to data server via many input streams from many sources. It makes necessary for subsystem of input data to have a unit of input data flow control, which separates data according to their sources.

The data processing subsystem of the device at the edge is intended to process the received measuring data according to specified data processing rules. Such data processing close to monitored objects is necessary to optimize and analyse a large amount of measuring data. A set of data processing rules is necessary to help in making urgent decisions in real time. This set contains an array of criteria and features of data, which are the base to form and transfer a service message or signal about an emergency to the user, or service command to proper actuator. It should remember that devices at the edge have limited computing resources, so it is necessary to create a reasonable number of data processing rules and try to avoid "heavy" calculations.

The data processing subsystem of the data server is intended to process the received data according to specified data processing rules. The input stream processing unit is designed to process continuous input data individually from each of data sources. Mainly such continuous data is packed by the data source with appropriate time stamps. The last unit monitors the observance of a clear time sequence in the stream of continuous data, which arrives in separate packets from certain data source and is unpacked on the data server. The data analysis unit is used to analyse measuring data according to the specified rules in order to find patterns in data or make a managerial decision. The data synchronization unit is intended to synchronize the received data with the databases, in which they are stored, to avoid duplication of measuring data. The data interface unit provides interfaces for connecting external modules to process data if it is necessary to use mathematical or other data processing methods that are not available on the server. Such external modules, which are services or libraries connected directly to the data interface unit, process data using defined methods and store obtained results on the server.

The main purpose of subsystem of output signals of the device at the edge is transferring prepared measuring data and service data, such as commands to actuators or emergency messages, to other layers of system or out to the other system. The data-transferring unit is responsible for transferring of all data, including measuring data. The data aggregation unit aggregates measuring data and packages them for further transferring. The data visualization unit provides simple tools for the user to review available data and service information. Such data visualization can be performed, for example, via simple web interface or hardware display. The unit of emergency and service messages is intended to generate special urgent messages and transfer them to the user via e-mail, messengers, or SMS service of cellular operators. The unit of feedback impact is used to generate and transfer service commands to actuators in accordance with managerial decisions. The unit of applied interfaces contains a functional tool, which enables to access data by third-party systems, tools or services via special requests. This approach is implemented in order to easily integrate the different tools and devices of third-party manufacturers into proposed system.

The main purpose of subsystem of output signals of the data server is interaction with users and external services. The data visualization unit provides advanced tools for the user to review and analyse available data and service information. Such data visualization usually is implemented by means of special web interface or standalone software, which can connect to remote or distributed system databases. The unit of emergency and service messages, like to one in the device at the edge, is intended to generate special urgent messages and transfer them directly to the user via e-mail, messengers, or SMS service of cellular operators. The unit of applied interfaces contains a set of functional tools of developer, which enables to organize the data access by third-party systems, tools or services via development of user-applied interfaces. This approach is necessary for simple integration of different tools and devices of third-party manufacturers into different layers of the proposed system. The unit of user applications contains a set of software tools embedded into the system that help the user to interact with the system, process and analyse data, obtain results in convenient form, and generate service commands to control the system, its elements or connected devices. The database of IoT devices contains configuration files, adjustment data and other information about connected to system or standard IoT devices. These data help quickly to connect new devices to the system, configure them and process measuring data, acquired from them. If the new connected IoT device is absent in the database of IoT devices, the system contains the unit for interaction with IoT devices. This unit on the base of embedded templates and algorithms generates the configuration files and other adjustment data needed for correct connection and interaction with the new device. In addition, the last unit simplifies the interaction of system with already connected devices in the case, if there are some problems in the device operation and an update of applied software is required. If the database of IoT devices contains working firmware, the unit for interaction can update the software of IoT device with new firmware without disconnecting the device from the system.

The main function of the control subsystem is the general control of the device at the edge and its components to ensure its long-term correct and reliable operation. The scheduling unit is intended to schedule operations, which require significant computing resources or power consumption, such as transferring large amounts of data, "heavy" or long-term calculations, etc. The data security unit contains mechanisms to ensure data privacy and secure. The unit of local data storage is implemented for the case, when the device at the edge can`t transfer data and needs to store them safety on the device until the time when the other components of the system is reconnected. In addition, the local data storage may contain databases needed for device operation, for example, databases with sets of certain rules or templates. The unit of remote adjustment is intended for remote loading of new configuration files, checking these files and making changes to the configuration of the device at the edge. This approach makes it possible quickly to change the settings and configuration of the device at the edge without removing it from the system. In this way, it is possible to preserve the efficient operation of whole system.

The control subsystem of the data server operates in similar way to the control unit of the device at the edge, only with the exception that it controls not only the data server itself, but also the whole system.

Challenges in Developing of Smart System for Agriculture

During developing and creating a new smart system for agriculture based on WSNs or IoT, we, like other developers, met some challenge issues, that nowadays can`t be solved or only partially solved by means of available tools and technologies. Such challenges include compatibility, scalability, delays in data transferring, big data, power consumption, and quality of service.

Compatibility in smart systems based on WSNs and IoT means the ability of devices to exchange data within the whole system without difficulty. This data exchange does not depend so much on the used hardware and software, but on the heterogeneity of different solutions and technologies used during the creation of the system. In the initial stages of system development when the wireless sensors and WSNs, developed by us, were used, the problem of compatibility didn`t appear. Such situation was because for data exchange we used our own data formats, transferring and processing of which required predetermined and known computing and power resources. With further integration of other sensors and devices into the system and setting interaction with other systems, the problem of compatibility arises for us, since our data formats of plant state from wireless sensors are not standardized and are often incompatible with data formats and protocols used in other devices and systems. It should be taken into account, since such incompatibility has a certain impact on the hardware and software of developing system.

The problem of compatibility can be divided into compatibility within devices, networks or platforms. The problem of compatibility on level of devices occurs because wireless devices with different functionality will be used within the system. The simplest devices are ones that have extremely limited power and computing resources, small memory and communication capabilities. Such devices are used in our network as simple measuring nodes that perform measurements at certain intervals. The most complicated type of devices in the network are devices with a powerful microprocessor and a standalone data transferring module. Such devices can run real-time operating system and perform complex calculation using machine-learning methods. As a rule, such devices operate continuously, have large or almost unlimited power resources, and can use a large number of peripheral devices. It is assumed, that the smart system will be expanded by means of integration of devices and systems of third-party manufacturers, which will have their own embedded communication protocols, computing and power resources. So, all devices may use different communication and data transferring protocols, have different requirements to power and computing resources, what lead to the problem on level of devices.

The problem of compatibility at the network level is caused by the fact that wireless networks operate in environments with heterogeneous obstacles. As a rule, most network nodes work with different short-range protocols, which should ensure the stability of the data-transferring channel and the reliability of message delivery. However, in the conditions of incoordination of the protocols and the presence of obstacles, it is quite difficult to achieve guaranteed quality of service. Although these problems are tried to be solved by means of development and application of reliable routing protocols, optimization of network resources and organization of node mobility, but due to the heterogeneity of communication protocols and the data-transferring environment itself, the issue of compatibility at the network level has not been finally solved yet.

The problem of compatibility at the platform level means that the proposed smart system will use ready-made wireless nodes that have their own set of peripherals, communication modules and their own vertical infrastructure. Such nodes have embedded operating system, applied software and communication protocols. Currently many nodes with their own infrastructure have been developed, but at the same time, the issue of interaction of nodes with different infrastructure with each other or with other devices has not been finally solved yet. One of the solutions, used now, is the development of cross-platform interfaces, both only software and hardware-software. However, this approach complicates and increases the cost of our application.

By scalability, we understand the ability of the proposed smart system to operate correctly, when the load increases or decreases due to a change in the number of nodes and devices connected to the system or network. As a rule, such a change consists in sharp increase of connected new sensors and nodes, what causes the issue of scalability.

The issue of scalability appears in our applied task then, when to solve certain problems it is necessary to increase the computing, power, or communication capabilities of some nodes. The integration of additional computing units, memory or other modules into the node may cause worsening of other operating characteristics of the modernized wireless node, what can lead to problems in operation of whole network. The other way to solve the issue of scalability is placing additional node in parallel with the main node, which must take a part of work functions of the main node. Such modernization significantly increases the number of nodes in the network and the load on certain network cluster, what does not improve the operation of the network in general. It should be noted that the distribution of work functions between several nodes could increase the fault tolerance of a single node due to the decreasing of the load on it.

The optimal solution of the scalability issue is the introducing the principles of functional scalability. In this case, we increase the functionality of a separate node not via hardware changes, but through the upgrading the software resources, for example, by using parallel computing, optimization of existing computing algorithms or addition of new algorithms, etc. As a rule, changes in the functionality of a node lead to positive changes in the operating characteristics of both a separate node and the network or system in common. However, this is possible only if the node has free computing, power or other resources.

The problem of delay in signal transferring appears for us due to the sufficiently large territorial distribution of the system, the heterogeneity of the wireless nodes and protocols themselves, and primarily due to the presence of a large number of obstacles caused by our applied task. That is why we have the situation, when the system can`t achieve the guaranteed delay time. Although methods for optimal distribution of network resources are currently being developed and implemented, it is not always possible to ensure the necessary signal delay time in the conditions of applied tasks in agriculture.

Nowadays WSNs and smart systems contain hundreds and sometimes thousands of sensors, which generate rather large amount of measuring data. Such a large amount of acquired data now can be called as "big data". This amount of data creates certain issues not only for local storage and computing units of wireless nodes, but also causes a heavy load on data transferring channels, which leads to unstable operation of the whole network or system. One of the solutions of problem of big data, what have been used recently, is moving some calculation closer to the monitored object. Such solution is implemented via integration of "computing at the edge" technology into new or existing systems. In this case, at the output of layer of sensors we placed special "devices at the edge", which pre-process measuring data and make some managerial decisions without necessity to transfer data to the higher level of system. This approach makes it possible to significantly reduce the load on data transferring channels, but it cannot completely solve the problem of big data by itself.

It should be noted another issue that appeared during the developing of a smart system, namely the problem of power consumption. This problem is caused the fact, that almost all wireless networks and smart systems are based on autonomous sensors, devices and actuators that have embedded batteries and are considered to be able to work without recharging and maintenance for a long time. However, as practice shows, the mechanisms of controlling and optimization of power consumption do not solve this problem without a negative impact on the functionality of wireless nodes and devices.

The mechanisms of guaranteeing the quality of service ensure the correct usage of resources of individual nodes and the whole system in such way, that the functions with a higher priority have access to needed resources first. The issue of guaranteeing the quality of service is that these mechanisms cannot optimally control the distribution of resources at all layers of the system. If the usage of computing resources can be planned in time according to priority tasks, communication resources often cannot be clearly planned due to the impossibility of accurately predicting their loading because of existing obstacles and failures in the transferring of messages. Any delays in the data transferring from sensors or other nodes can cause a significant worsening in the quality of service.

Conclusion

The article presents the practical experience of the authors in developing the principles of creation a smart system for agriculture based on an existing WSN. The common architectures of smart systems and systems based on IoT are analyzed. A typical architecture of a smart system was selected, which further was adapted to the applied task of agriculture using the technology of "calculation at the edge". All layers of the proposed system are described and the principles of data transferring within the system are given. Two main components of a smart system are defined, namely, a data server and a device at the edge, and their structures and functional blocks are described. Finally, the challenges and problems faced by authors at the initial stages of development of the smart system for agriculture are given.

Bibliography

[Simo et al, 2022] Simo A., Dzitac S., Badea G.E., Meian D. Smart Agriculture: IoT-based Greenhouse Monitoring System. International Journal of Computers Communications & Control. 2022. 17(6), 5039. P. 1–17. https://doi.org/10.15837/ijccc.2022.6.5039.

[Kim et al, 2020] Kim W.S., Lee W.S., Kim Y.J. A Review of the Applications of the Internet of Things (IoT) for Agricultural Automation. J. Biosyst. Eng. 2020. 45. P 385–400 (2020). https://doi.org/10.1007/s42853-020-00078-3.

[Bua et al, 2024] Bua C., Adami D., Giordano S. GymHydro: An Innovative Modular Small-Scale Smart Agriculture System for Hydroponic Greenhouses. Journal Electronics. 2024; vol. 13(7): 1366. https://doi.org/10.3390/electronics13071366.

[Mohyuddin et al, 2024] Mohyuddin G., Khan M.A., Haseeb A., Mahpara S., Waseem M. and Saleh A.M. Evaluation of Machine Learning Approaches for Precision Farming in Smart Agriculture System: A Comprehensive Review, in

IEEE Access, vol. 12, pp. 60155-60184, 2024, doi: 10.1109/ACCESS.2024.3390581.

[Romanov et al, 2012] Romanov V., Artemenko D., Brayko Yu., Galelyuka I., Imamutdinova R., Kytayev O., Palagin O., Sarakhan Ye., Starodub M., Fedak V. Portable Biosensor: from Idea to Market. International Journal Information Theories & Applications. Vol. 19, Number 2. Sofia, Bulgaria. 2012. – P. 126–131.

[Romanov et al, 2021] Romanov V., Galelyuka I., Voronenko O. Wireless sensor networks for smart agriculture. International Journal of Reasoning-based Intelligent Systems (IJRIS), Vol. 13, No. 3, 2021. P. 147–154. https://doi.org/10.1504/IJRIS.2021.117079.

[Tokody et al, 2019] Tokody D., Papp J., Iantovics L.B., Flammini F. Complex, Resilient and Smart Systems. In: Resilience of Cyber-Physical Systems. Advanced Sciences and Technologies for Security Applications. Ed. by F. Flammini. Springer, Cham, 2019. P. 3–24. https://doi.org/10.1007/978-3-319-95597-1_1.

[Giese et al, 2015] Giese H., Vogel T., Wätzoldt S. Towards Smart Systems of Systems. In: Fundamentals of Software Engineering. FSEN 2015. Lecture Notes in Computer Science, vol 9392. Ed. by M. Dastani, M. Sirjani. Springer, Cham, 2015. P. 1–29. https://doi.org/10.1007/978-3-319-24644-4_1

[Arsan, 2016] Arsan T. Smart Systems: From design to implementation of embedded Smart Systems. In: Smart Communities: Improving quality of life using ICT, IoT and AI (HONET-ICT). Haspolat, Nicosia, Northern Cyprus, October 13-14, 2016. P. 59-64. https://doi.org/10.1109/HONET.2016.7753420.

[Vashi et al, 2017] Vashi S., Ram J., Modi J., Verma S., Prakash C. Internet of Things (IoT): A Vision, Architectural Elements, and Security Issues. In: Proceedings of the International Conference on IoT in Social, Mobile, Analytics and Cloud, I-SMAC 2017, Nadu, India, 10–11 February 2017. IEEE: Palladam, India, 2017. pp. 492–496.

[Guerrero-Ulloa et al, 2019] Guerrero-Ulloa G., Rodríguez-Domínguez C., Hornos M.J. IoT-Based System to Help Care for Dependent Elderly. In: Commun. Comput. Inf. Sci. 2019, 895, 41–55.

[Mora et al, 2017] Mora S., Gianni F., Divitini M. RapIoT Toolkit: Rapid Prototyping of Collaborative Internet of Things Applications. In: Proceedings of the International Conference on Collaboration Technologies and Systems, CTS 2016, Orlando, FL, USA, 31 October–4 November 2016; IEEE: Orlando, FL, USA, 2017; pp. 438–445.

[Gianni et al, 2019] Gianni F., Mora S., Divitini M. RapIoT Toolkit: Rapid Prototyping of Collaborative Internet of Things Applications. In: Future Gener. Comput. Syst. 2019, 95, 867–879.

[Kijas and Zalewski, 2020] Kijas S., Zalewski A. Capturing the Evolution of Service-oriented Systems with Architectural Decisions. In: Communication Papers of the 2020 Federated Conference on Computer Science and Information Systems, M. Ganzha, L. Maciaszek, M. Paprzycki (eds). ACSIS, 2020, Vol. 23, pages 67–76.

[Chalapathi et al, 2021] Chalapathi G.S.S., Chamola V., Vaish A., Buyya R. Industrial Internet of Things (IIoT) Applications of Edge and Fog Computing: A Review and Future Directions. In: Fog/Edge Computing For Security, Privacy, and Applications. Springer: Cham, Switzerland, 2021; pp. 293–325. https://doi.org/10.1007/978-3-030-57328-7_12.

Authors' Information

Volodymyr Romanov *– Head of department of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine, Doctor of engineering sciences, professor; Prospect Akademika Glushkova 40, Kyiv, 03187, Ukraine;*

e-mail: VRomanov@i.ua;

website: http://www.dasd.com.ua

Igor Galelyuka *– Leading research fellow of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine; Candidate of engineering sciences; Prospect Akademika Glushkova 40, Kyiv, 03187, Ukraine;*

e-mail: galelyuka@gmail.com;

website: http://www.dasd.com.ua