Internet of Things Approach for Automation of the Complex Industrial Systems

Yuriy P. Kondratenko[1,2], Oleksiy V. Kozlov[2], Oleksiy V. Korobko[2], Andriy M. Topalov[2]

[1] Petro Mohyla Black Sea National University, 10, 68th Desantnykiv Str., Mykolaiv, 54003, Ukraine
y_kondrat2002@yahoo.com, yuriy.kondratenko@chmnu.edu.ua
[2] Admiral Makarov National University of Shipbuilding, 9 Heroes of Ukraine Av., Mykolaiv, 54025, Ukraine
oleksiy.kozlov@nuos.edu.ua, oleksii.korobko@nuos.edu.ua, topalov_ua@ukr.net

Abstract. This paper presents the analysis of the Internet of Things (IoT) approach and its application for the development of embedded monitoring and automatic control systems (EMACS) for technological objects and processes that are included in complex industrial systems. The functional structure and main components of EMACS based on IoT approach are given. The examples of IoT applications in design of specialized EMACS for such complex technical objects as gas turbine engines and floating docks are presented. Considerable attention is given to particular qualities of the functional structures, software and hardware implementation as well as multi-level human-machine interfaces of the EMACS for main process parameters. The developed EMACS provide: (a) high precision control of real-time operating processes of gas turbine engines and floating docks, (b) monitoring and automatic control of current technological parameters with high quality indicators, that leads to significant increasing of energy and economic efficiency of both industrial objects.

Keywords: Complex industrial systems, automation, SCADA, Internet of Things, embedded monitoring and automatic control systems.
Key Terms: InformationCommunicationTechnology, ComputerScience, Object, Process, Industry.

1 Introduction

The development of computer aids and modern computer networks has led to the creation of new types of automated control systems of technological processes (ACSTP) [1]. Modern information-measuring technical equipment and data transmission technologies solve many problems associated with collection, conversion, transmission and storage of various information for technological processes control [2].

New ACSTP characterized by the transition to the creating of complex systems in which information processing is decentralized, and some parts of the ACSTP are often remote from each other. There is a trend towards increasing use of sensor networks and appropriate hardware and software means of conjugation at all levels of the hierarchy [1].

In the process of ACSTP creating and using for complex industrial systems, that include objects of oil and gas, energy, machinery and other types of industry the following problems are solving: creation of systems for monitoring and control of both manufactured goods and for certain technological processes, taking into account local and systemic approaches [3, 4]. Providing of an operational monitoring of all parameters with high accuracy and a timely control of actuators of various kinds of technological processes is a complex technical task that requires limiting attentiveness of staff for a long time. Any "human" errors or outdated equipment can lead to an increase of production time per unit, respectively to the decrease of an economic efficiency of equipment using, and possibly to emergencies at the facility.

The rapid development of computer and information technology contributes to the creation of effective supervisory control and data acquisition (SCADA) systems in production sphere [2, 5, 6]. Use of SCADA-systems enables the operator to automate the control parameters of various kinds of industrial systems and processes, enable or disable mechanisms and devices, open or close valves on pipelines, monitor any parameters from a specially equipped console with a centralized or supervisory control. SCADA systems have a number of components [5, 6] that facilitate the development of computerized data acquisition and analysis tools, such as communication protocols for external devices connection, built in signals filtering, supporting of structured query language (SQL) data exchange etc. This and many other features make the SCADA software a perfect tool for implementation of control, data analysis and information processing algorithms in industry, household and science research [5-10].

More actively with modern SCADA-systems the wireless data transmission technology is implemented [11]. The combination of SCADA-systems with wireless technologies and the Internet allows creating the WebSCADA-systems [12]. The term WebSCADA, usually refers to the implementation of human-machine interfaces (HMI) of SCADA-systems based on web-technologies. This allows implementing monitoring and control of SCADA-systems through a standard browser, acting in this case as a thin client. The architecture of these systems includes WebSCADA server and client terminals - personal computers, personal digital assistants or mobile phones with a Web browser [11-13]. Connecting of customers to the WebSCADA servers via Internet/Intranet allows them to interact with applied automation tasks as with simple Web or WAP pages.

Even more novel and promising approach for automation of complex industrial systems as well as for ACSTP creation is the Internet of Things approach [14-16].

Internet of Things is the concept of the computer network of physical objects ("things"), equipped with built-in technologies for communication with each other and with the environment [16]. The organization of such networks is recently considered as a phenomenon that can rebuild the economic and social processes as well as exclude the need for human intervention from the part of actions and operations [14]. This concept formulated in 1999 as a comprehension of prospects of wide application of radio frequency identification (RFID) means for interaction of physical objects between themselves and with the external environment [17]. Filling the IoT concept with multiform technological content and introduction of practical solutions for it implementation considered to be a stable trend in information technology primarily due to the widespread dissemination of wireless networks, appearance of cloud computing, development of machine to machine technology, beginning of active transition to the new Internet protocols and development of software-configurable networks [18-23].

Examples of IoT concept implementing are systems of “Smart house” [24], “Smart farm” [19, 25], “Smart city” [18], “Smart environment” [19, 25], “Smart enterprise” [26], “Smart transport” [16], “Smart wearable” [22, 23] and others.

The main purpose of this work is analysis of the IoT approach and its application for the development of embedded monitoring and automatic control systems for technological objects and processes that are included in complex industrial systems.

Basic features, involved technologies, and main applications of the IoT approach are given in the paragraph 2. The functional structures, software and hardware implementation as well as multi-level HMIs of the developed EMACS for complex technological objects, such as gas turbine engines and floating docks, based on IoT are presented in the paragraph 3. Paragraph 4, in turn, has conclusions, discussion of the results and further research on the IoT approach application for the complex industrial systems, technological objects and processes automation.

2 Internet of Things Approach

Basically the IoT is a network consisting of interrelated physical objects (“things”) or devices that have built-in sensors and software that allows you to transfer and exchange data between the physical world and computer systems by using standard communications protocols [14]. In addition to sensors the network can have actuators embedded in physical objects and linked together with wired or wireless networks. These interrelated objects (“things”) have the ability of data reading and actuating according to the control signals, the functions of programming and identification, as well as allow excluding the need for human participation by using the intelligent interfaces [15].

The basis of IoT approach is a possibility of connection all kinds of objects (“things”) that people can use in everyday life, such as refrigerator, car, bicycle, washing machine, etc. [14]. All of these objects (“things”) should be equipped with built-in sensors that are able to process information coming from the environment, share it and perform different actions depending on the received information. The ideology of the IoT is aimed at increasing of economic efficiency by processes automation in various fields of activity and exclusion from them human impact [14-17].

For the implementation of the IoT approach, the following technologies are used.

2.1 IoT Technologies

Identification tools. The special equipment for information recording and processing as well as for actuators controlling is involved in any IoT system. Obviously, for the effective functioning of the IoT system it is necessary to ensure a high level of network service and consequently the unique identification of software and hardware elements of the system. The identification problems for connected devices depend on the number of concurrent connections to the Internet, which the given system can support, and on the quality of service, which can be guaranteed [14]. Now the majority of Internet-connected devices use IPv4 protocol from the family of TCP/IP protocols, which is based on 32-bit addressing scheme and is limited to 2^{32} (4 294 967 296) unique addresses [22]. Considering that predicted for the IoT possible number of connected units is 50-100 billion for optimal scalability it is required to move to IPv6 protocol from the family of TCP/IP protocol, which uses 128-bit addressing system capable of supporting up to 2^{128} addresses ($3{,}4\cdot10^{38}$ units) [17, 21, 22]. Currently several initiatives are implementing to influence the development of IPv6 protocol to support the IoT. One of them is the project IoT6, dedicated to research, design and development of service-oriented architecture with high level of scalability based on IPv6.4.

Also, identification of network elements of the IoT can be achieved with the help of RFID chips that can transmit information to reading devices without their own power source [17]. Each chip has a unique number. As an alternative to this technology for the identification of objects the QR-Codes can be used. Furthermore, to determine the exact location of IoT objects the GPS technology can be used, which effectively operates today in smartphones and navigators.

Measuring instruments. By measurement means of the object measuring transducers are generally understood, that are designed to generate measurement data in a form, suitable for transmission, further transformation, processing and storage [7-10]. The IoT technology uses a wide class of measurement tools, from the elementary sensors (temperature, rotation angle, etc.), consumption metering devices (smart meters) to complex integrated measurement systems [9, 19, 23]. Also, all measuring devices are combined, as a rule, in the wired/wireless sensor networks, due to what is possible to build M2M interaction systems. In recent years, the wireless sensor networks are used due to miniature components, low power consumption, embedded transceivers, sufficient processing power and relatively low cost [10-13].

Measuring sensors can be fixed permanently, and also have a relative mobility, that is to move freely relative to each other in a certain space, without breaking the logical network connectivity. In the latter case, the sensor network has no permanent fixed topology and its structure changes dynamically over time [10, 13].

Data processing means. For the processing and storage of data, given from the sensors, it is advisable to use embedded software and hardware means in the form of small-sized computers (for example, Raspberry Pi, Intel Edison) with access to the Internet [7-10, 20]. Moreover, the final processing of the data and making an informed decision on the cloud service is performed with the use of Big Data technologies [19]. For the processing of measurement data today are available for free in the test mode such cloud services as: Azure, Freeboard, Grovestreams, Developer.ibm, Thingspeak, Thingworx and other [9, 19].

Data transmission means. The range of possible data transmission technologies covers all possible means of wireless and wired networks. For wireless transmission of data between the software and hardware elements of the IoT networks a particularly important role play such qualities as efficiency in conditions of low speeds, resilience, adaptability, the ability to self-organization [9, 15, 16, 18]. Therefore, the class of wireless personal area networks (WPAN) is actively used. Currently WPAN can be with a short range (up to 10 m) and with increased range (up to 100 m), which allows them to be located on the functional capabilities at the junction with the wireless local area networks (WLAN). WPAN can be created based on different technologies of the IEEE 802.15.4 standard: ZigBee, WirelessHart, MiWi, etc. [14-16].

Among wired technologies of software and hardware components interaction the long-established industry network standards are used in the IoT, such as Profibus, Canbus, LON, Modbus, etc. [8-10]. It should be also noted, that for the software and hardware elements connection to the Internet the standard family of protocols TCP/IP is basically used in the IoT. Moreover, today for the networks service development in the IoT according to the standard IEEE 802.15.4 it is especially important to use the open 6LoWPAN protocol, standardized by IETF, that allows combining the intellectual sensors in the Internet with a low data rate [22].

Using the given above technologies the IoT approach can be applied in various fields. The main of them are listed below.

2.2 IoT Applications

The possibility of networking of the different types of sensors, actuators, embedded devices with CPU, memory and power resources indicates that IoT approach finds applications in almost all spheres [15]. The systems based on IoT may be involved in collecting information and controlling of objects in different settings, buildings, factories cities, natural ecosystems, etc. [16]. The main areas in which the IoT approach is increasingly applied are as follows.

Home automation. In this field the “Smart house” systems are used, that are the residential extension of building automation and realize the control and automation of lighting, air conditioning, ventilation, heating and security [24]. Such systems include different switches and sensors, washers, dryers, ovens, refrigerators and other home devices, that are connected to a central hub for remote monitoring and control. The user interface can be interacted with a wall-mounted terminal, tablet, laptop, mobile phone software or a web interface via internet cloud services [24]. The most popular communications protocols for such systems are: X10, Ethernet, RS-485, 6LoWPAN, Bluetooth LE (BLE), ZigBee, Z-Wave and others [8-10, 22].

City infrastructure automation. In this field the “Smart city” systems are used, that implement monitoring and controlling operations of urban and rural infrastructures like bridges, railway tracks, on- and offshore- wind-farms etc. [18]. The IoT infrastructure can be used for monitoring and control of any parameters of urban objects that can increase safety and compromise risk. For example, the IoT system for city automation can calculate and predict the energy balance point of the city for a certain period of time, automatically sending the control data to generators, power grids and smart household devices in order to maintain the required energy balance [18]. Municipal companies can save large sums of money, while continuing to maintain the reliability and integrity of the power supply instead of buying new equipment.

Transport automation. The IoT can assist in monitoring, control, and information processing across various transportation systems [16]. IoT systems can help to configure dynamically switching of traffic lights and adjustable exits from highways, thereby reducing congestion and improving traffic flow in real-time, rather than in predictive models. Application of the IoT extends to all aspects of transportation systems: smart parking, smart traffic control, vehicle control, fleet management and logistic, electronic toll collection systems, road assistance, etc. [14-16].

Environmental monitoring automation. IoT applications for environmental monitoring use different sensors to aid in the field of environmental protection [19, 25]. These IoT systems can implement monitoring of air and water quality [19] as well as soil and atmospheric conditions [25]. For example, a young Dutch company "Sparked" implants sensors in the ears of cows, that allows farmers to monitor the health and movement of cattle. This technology can increase the amount and quality of produced meat. Also, the IoT applications for tsunami and earthquake early-warning systems can be used by emergency services to provide more effective aid. IoT devices in this application should be enough mobile because they cover a large geographic area [25].

Industrial automation. The application of the IoT in the manufacturing industry is called the Industrial Internet of Things (IIoT) [26]. The IIoT will revolutionize manufacturing by enabling the acquisition and accessibility of far greater amounts of data, at far greater speeds, and far more efficiently than before. A number of innovative companies have started to implement the IIoT [16, 26]. The company "Inductive automation" developed the only IIoT platform “Ignition” with effective MQTT data transfer protocol and full-featured SCADA functionalities built right in. “Ignition’s” cross-platform compatibility and flexible modular configurability make it the world’s first truly universal industrial application platform. “Ignition” empowers you to connect IIoT data across your entire enterprise, launch clients to any device equipped with a web browser, rapidly develop automated systems without any limits [26].

The IIoT can greatly improve the efficiency of the industrial renewable resources installations, for example, windmills and solar panels. Business leaders can use IIoT data to get a full and accurate view of how their enterprises are doing, which will help them make better decisions [16, 26].

The IIoT networks, by definition, cannot be limited by the perimeter of this or that enterprise. Very important is the interaction with the manufactured product (“thing”) during its operation, as well as access to cloud services that can be implemented in data centers, scattered throughout the world [13, 26]. Thus, geographically distributed infrastructure is a key feature of the IIoT.

The main complexity of the IoT approach application in the industry is that “things” in the industrial systems are complex technical objects, such as internal combustion engines, industrial robots, steam turbines, chemical reactors, cargo cranes, lathes, etc., that are involved in the performance of complex technological processes. For the productive carrying out of these technological processes it is necessary to implement monitoring and automatic control of their technical objects main process parameters via the internet with high quality indicators in the real time mode [7-10]. Any technical malfunctions or errors, caused by the incorrect control, slowing down of the performance, loss of the Internet for some time, etc., can lead to a reduction of an economic efficiency or serious industrial accidents sometimes even with human victims.

Thus, the IIoT systems should include highly efficient software and hardware means for the implementation of specialized algorithms of monitoring and automatic control. Also, such systems should have an increased level of reliability, performance and information security.

Analyzing all the above requirements, we can conclude that at the current stage of development of the IoT technologies it is advisable to develop and implement the specialized EMACS for complex industrial technological objects and processes automation on the basis of the IoT approach. Such systems should have a modular structure with reliable and highly efficient software and hardware means as well as industrial communication interfaces, located in close proximity to the technical objects, for monitoring and automatic control implementation in safe and uninterrupted mode at the local level. Also, these systems should be easily integrated into existing large-scaled IIoT systems through a wired or wireless Internet connections which cover one or a group of industrial enterprises for monitoring and automatic control at the remote level.

Let us consider the developed by the authors EMACS for complex technological objects and processes based on IoT approach.

3 Embedded Monitoring and Automatic Control Systems for Complex Technological Objects and Processes Based on IoT

The basic diagram of the generalized EMACS for complex technological objects and processes based on IoT approach is presented in Fig. 1, where the following notations are accepted: PC – personal computer; PLC – programmable logic controller; FPGA – field-programmable gate array; SBC – single-board computer; SDAM – sensors data acquisition module; AOM – analog output module; S – sensor; AM – actuating mechanism; u_1, u_2, $u_{n\text{-}1}$, u_n – control signals of actuating mechanisms; y_1, y_2, $y_{n\text{-}1}$, y_n – output variables values of actuating mechanisms; x_1, x_2, $x_{n\text{-}1}$, x_n – technical object process parameters; u_{S1}, u_{S2}, $u_{Sn\text{-}1}$, u_{Sn} – sensors output signals.

The proposed generalized EMACS for complex technological objects and processes based on IoT approach has two levels of monitoring and automatic control: local level and remote level. Local level, in turn, is divided into three hierarchical levels of monitoring and control:

1) lower level – the level of the sensors and actuating mechanisms of the technical object, that is involved in the performance of a certain technological process;

2) average level – the level of the peripheral monitoring and control devices (includes modules for data acquisition and analog output as well as PLC/FPGA/SBC);

3) upper level – the level of HMI (includes industrial PC).

Lower level of the developed EMACS consists of the automatic control subsystems (ACSS), which perform automatic regulation of the given values of the technical object major controlled data according to a control program in terms of various disturbances operation [8-10].

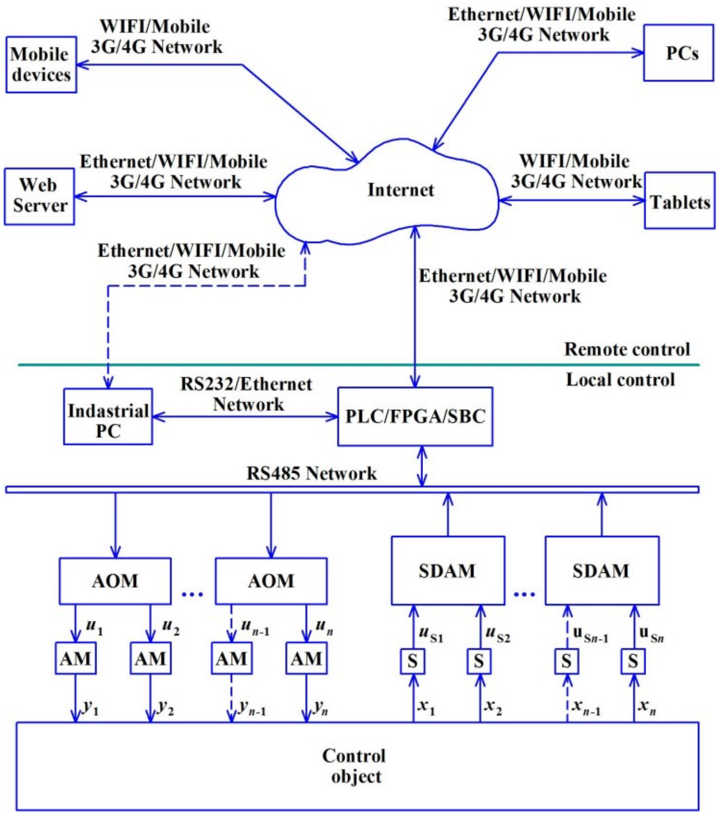

Fig. 1. Basic diagram of the generalized EMACS for complex technological objects and processes based on IoT approach.

Industrial PC of the upper level serves as the operator station. It contains a specialized HMI in the form of a control panel of the technological process with the image of the technical object main components and their technical parameters that are measured by various sensors [9]. Also, the set values of the control parameters, that are inputs of the technical object's ACSS, are established on the industrial PC according to a control program. PLC/FPGA/SBC of the average level processes the information received from the sensors and sends it to the industrial PC. Also, it gets the set values of the technological process control parameters and performs the functions of it automatic control. Data acquisition modules receive signals from sensors and transmit it to the PLC/FPGA/SBC in a convenient form for further processing [8]. Analog output modules receive digital control signals from the PLC/FPGA/SBC and produce corresponding analog control signals that go directly to the technical object's actuators.

The monitoring and automatic control operations in the remote level are implemented by means of powerful web servers, remote computers, tablets and different types of mobile devices [10]. In this case PLC/FPGA/SBC or industrial PC with the help of wired (Ethernet) or wireless (WiFi, mobile network 3G, 4G and others) connection technologies and family of protocols TCP/IP exchange data via the Internet with specialized web server that is placed on a powerful computer. Specialized web server, in turn, receives data process parameters and provides Web access to other users (remote computers, tablets, mobile devices). Moreover using the web server the access to the technological process data can be given from any PC of the enterprise IIoT system, that is running under any operating system (Windows, Linux, Mac OS, etc.), and if desired, from any PC in the world connected to the Internet.

In turn, the specialized HMI in the form of a control panel of the technological process is installed on the server and on the all computers of the enterprise IIoT system, where it is necessary, with all available functions of monitoring and control. Also, the specialized server can implement the function of automatic data sending to all the necessary users of the enterprise IIoT system in case of emergency and include the online expert system for data analysis and forming the further control goals.

As a concrete examples of the given above approach implementation let us consider the developed by the authors highly effective EMACS for such complex technical objects as gas turbine engines and floating docks.

3.1 Embedded Monitoring and Automatic Control System for Gas Turbine Engines

A new high-performance EMACS for a gas turbine engine is implemented with the modular structure that includes monitoring and automatic control of main parameters technological parameters in the local and remote levels using powerful data storage and analysis tools. This system provides execution of the following functional tasks: monitoring, automatic control and visualization of a gas turbine engine main process parameters in real time mode at the local level and at the remote level via the internet; visual display of information about the state of the engine with clear indication of current states and emergencies; the ability of integration into existing large-scaled IIoT systems of machine-building plants, enterprises or factories; automatic data sending in case of emergency to the all users of the enterprise IIoT system. Also, the developed EMACS for the gas turbine engines has modern and highly integrated programming environment, that is enough flexible and easy to extend, flexible network designs and ability of connection to online expert system for more detailed data analysis.

The functional structure of the proposed by the authors highly effective EMACS for a gas turbine engines is shown in Fig. 2.

As the software facilities of the developed EMACS for a gas turbine engines the TRACE MODE 6 is used, which belongs to the class of integrated systems that provide maximum comfort to designers and users. Basing on the system tasks with the help of TRACE MODE 6 the authors developed the specialized HMI, main screen of which is shown in Fig. 3.

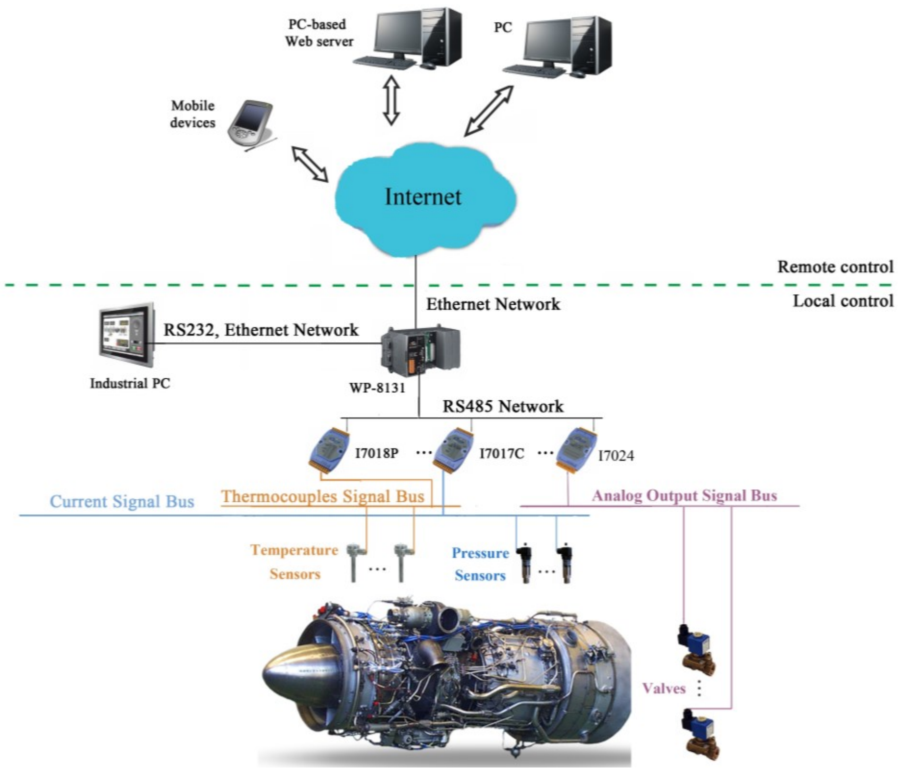

Fig. 2. Functional structure of EMACS for a gas turbine engine.

The given HMI is intended to indicate the values of the basic parameters and the position of elements of fuel, oil and air systems, launch systems, and others. Also, the set values of the control parameters, that are inputs of the ACSSs of the gas turbine engine EMACS, are established with the help of HMI on the industrial PC. PLC, in turn, processes the information received from the sensors and sends it to the industrial PC. Also, it gets the set values of the gas turbine engine control parameters and performs the functions of it automatic control. Data acquisition modules receive signals from sensors and transmit it to the PLC in a convenient form for further processing. Analog output modules receive signals from the PLC and produce corresponding control signals that go directly to the gas turbine engine actuators.

The hardware facilities for the EMACS for gas turbine engines implementation are data acquisition modules, analog output modules and PLC. As a PLC the WP-8131 of the ICP DAS company is used. To receive signals from sensors of different types in this EMACS 2 types of the ICP DAS company data acquisition modules are used: I-7018P modules with 8 inputs – for data acquisition from thermocouples; I-7017C modules with 8 inputs – for data acquisition from sensors with current output (0...20 mA). To implement the conversion of digital signals from the PLC to analog ones that directly go to the actuators of the complex parameters ACSS the I-7024 modules with 4 outputs of the ICP DAS company are used.

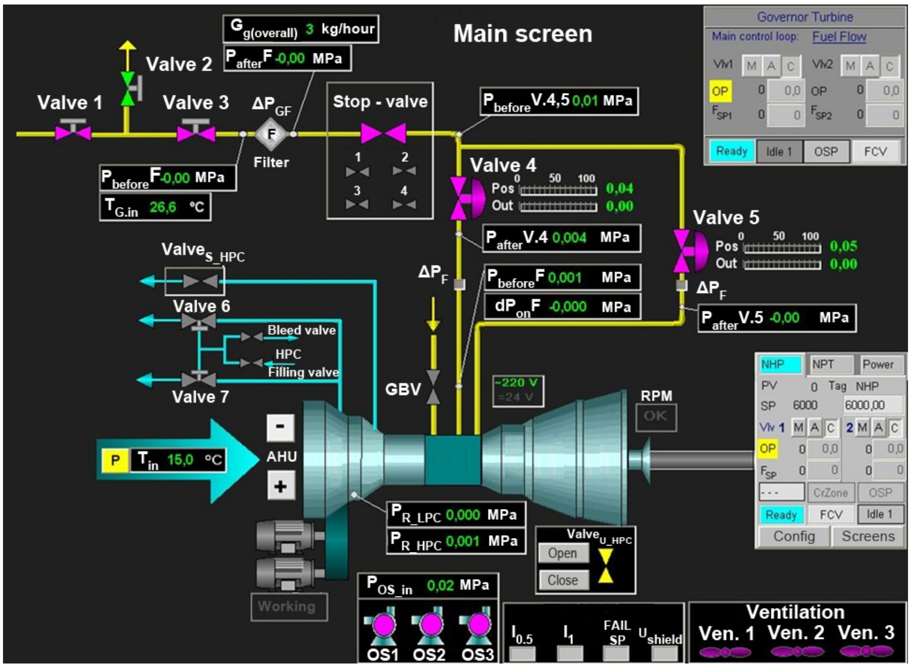

Fig. 3. Human-machine interface of the EMACS for a gas turbine engine.

In this EMACS the monitoring and automatic control operations in the remote level are implemented by means of specialized web server, remote computers, tablets and different types of mobile devices. In this case, PLC with the help of Ethernet connection and family of protocols TCP/IP exchange data via the Internet with the enterprise main web server that is placed on a powerful computer. The main server, in turn, receives the gas turbine engines data process parameters and provides Web access to other users (remote computers, tablets, mobile devices).

3.2 Embedded Monitoring and Automatic Control System for Floating Docks

The new efficient EMACS for floating docks is designed for implementation of the main docking operations, monitoring and control of current values of the draft, list and trim angles, hogging and sagging, input and output valves states, as well as liquid level, temperature and volume in ballast tanks of floating docks [10]. EMACS modular structure ensures flexibility and scalability of the system, and therefore can be easily embedded into large-scaled IIoT systems of shipbuilding plants, enterprises and shipyards. Also, it provides automatic data sending in case of the floating docks emergency situations to the all users of the ship's enterprise IIoT system.

The functional structure of the proposed by the authors highly efficient EMACS for floating docks docking operations is shown in Fig. 4 [10].

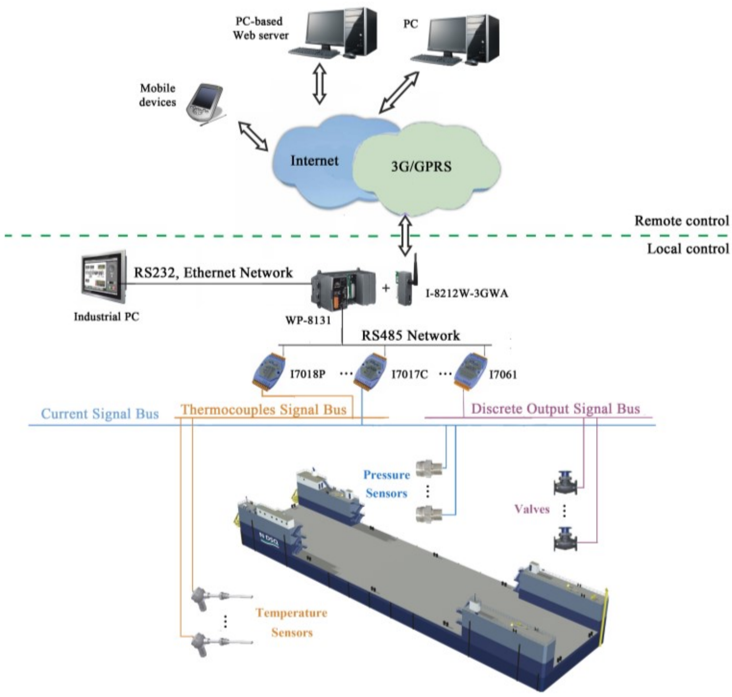

Fig. 4. Functional structure of EMACS for floating docks docking operations.

EMACS for floating docks is divided into local and remote control options of floating dock. Local control of parameters is made directly on the floating dock, operator has the ability to monitor all the parameters and control of the dock actuators. Distance control of parameters required for use from shipbuilding plant, enterprise or shipyard land office [10]. It is implemented via the wireless Internet connection.

As the software means of the developed EMACS for floating docks docking operations also the TRACE MODE 6 is used, with the help of which the specialized HMI (Fig. 5) is developed by the authors [10]. The proposed HMI allows displaying the basic parameters recorded by the control system of dock operations for floating docks.

As a PLC the WP-8131 of the ICP DAS company is used. For the successful launch of the given EMACS the industrial PC and all the computers of the ship's enterprise IIoT system must be equipped with a real-time monitor Trace Mode 6. To receive signals from the floating dock sensors of different types in this EMACS the ICP DAS company I-7018P and I-7017C data acquisition modules are used.

To implement the conversion of digital signals from the PLC to analog ones that directly go to the floating dock parameters ACSS the I-7061 modules for output are used. PLC is also connected with industrial and dual-band 3G WCDMA with 4 ranges GSM/GPRS module I-8212W-3GWA, which enables the creation of wireless communication to the Internet for remote monitoring and control options of floating dock.

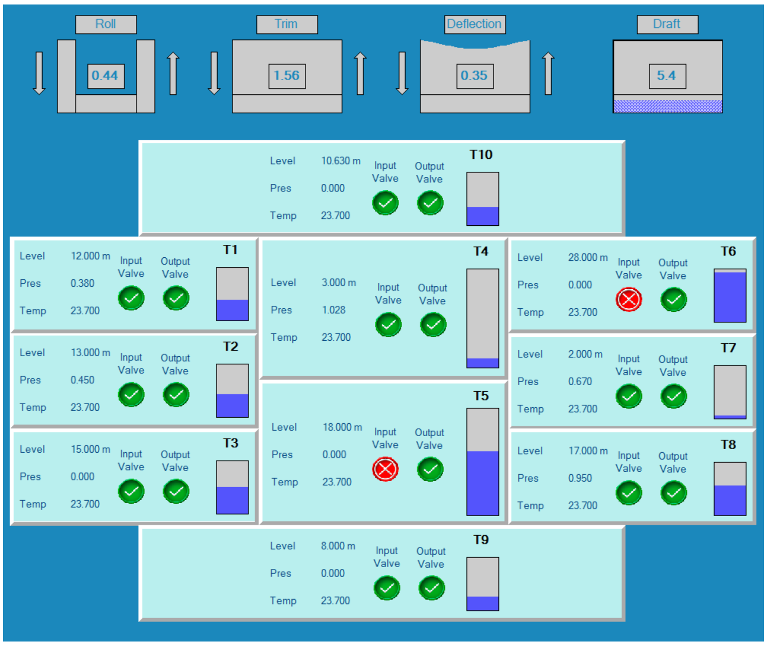

Fig. 5. Human-machine interface of the EMACS for floating docks

In the developed EMACS the monitoring and automatic control operations in the remote level are implemented by means of the web servers, remote computers, tablets and different types of mobile devices [10]. In this case, PLC with the help of wireless mobile network 3G or 4G connection and family of protocols TCP/IP exchange data via the Internet with specialized web server that is placed on a ship's enterprise land office. The main web server, in turn, receives the floating dock data process parameters and provides Web access to the other users (remote computers, tablets, mobile devices).

One of the most important particularities of the developed by the authors new highly efficient EMACSs is that they can implement intelligent principles and technologies of automatic control based on the theory of artificial neural networks and fuzzy logic [27-30]. This allows achieving higher quality indicators and accuracy at automatic control of main process parameters of the complex technical objects with essentially nonlinear and non-stationary characteristics. The monitoring and automatic control systems, developed on the basis of artificial neural networks and fuzzy logic, currently successfully applied in such areas as: technological processes and transport control, financial management, medical and technical diagnostics, pattern recognition, stock forecast, etc. [31-35].

At the further development and improvement of the IoT technologies it is reasonable to improve the developed by the authors EMACS in the following way. The main functions and algorithms of monitoring and automatic control of the technical objects main process parameters should be transferred from the software and hardware means of the local level, located in close proximity to the technical objects, to the high performance servers of the remote level that will be located in the server clusters, data processing centers or clouds. The main benefit of the new structure is that the total number of the monitoring and automatic control systems will be significantly reduced, that simplify the monitoring and control process itself. Moreover, computing resources using effectiveness will increase and will need less means.

This transition can be possible only at a significant quality improving of the network infrastructure, specifically at essential increasing of data transfer performance and connection reliability as well as eliminating of unexpected delays between local level devices and their serving servers. These issues are highly relevant and are still the subject of research for leading scientific and technical teams in different countries.

4 Conclusions

The analysis of the IoT approach and its application for the development of embedded monitoring and automatic control systems for technological objects and processes, that are included in complex industrial systems, are presented in this paper.

The IoT information technologies provide unique abilities to the developers of complex data processing, monitoring and control systems. Range of functions that they provide eases the creation of distributed computerized systems.

The examples of IoT applications in design of new effective specialized EMACSs for such complex technical objects as gas turbine engines and floating docks are presented. The functional structures, software and hardware implementation as well as multi-level HMIs of the developed embedded systems for monitoring and automatic control of main process parameters are given. These systems have the modular structures with reliable and highly efficient software and hardware means as well as industrial communication interfaces, located in close proximity to the given technical objects, for monitoring and automatic control implementation in safe and uninterrupted mode at the local level. Also, the given systems implement monitoring and automatic control of the given objects main parameters from the remote servers and clients via the wired and wireless Internet connections and can be easily integrated into existing large-scaled IIoT systems of industrial enterprises.

As a result the developed new efficient EMACS based on IoT approach provide: high precision control of operating processes of gas turbine engines and floating docks in the real time mode, monitoring and automatic control of their current technological parameters with high quality indicators, that leads to significant increasing of energy and economic efficiency of both given complex technical objects.

Further research should be conducted towards the development of the IoT based systems, which main software and hardware means of monitoring and automatic control functions and algorithms will be transferred from the local level to the high performance servers of the remote level, located in the server clusters, data processing centers and clouds. This transition should be followed by improving of the network infrastructure through increasing of data transfer performance and connection reliability as well as eliminating of unexpected delays between local level devices and their serving servers.

References

1. Merz, H., Hansemann, T., Hübner, C.: Building Automation: Communication systems with EIB/KNX, LON and BACnet. Berlin, Heidelberg: Springer-Verlag (2009)
2. Mehta, B.R., Reddy, Y.J.: Chapter 7 - SCADA systems. Industrial Process Automation Systems, 237-300 (2015)
3. Dulău, I.L., Abrudean, M., Bică, D.: SCADA Simulation of a Distributed Generation System with Storage Technologies. Procedia Technology, 19, 665-672 (2015)
4. Tanyi, E., Noulamo, T., Nkenlifack, M., Tsochounie, J.: A Multi-agent Design and Implementation of an Internet Based Platform for the Remote Monitoring and Control of the Cameroon Power Network. Engineering Letters, 13(2), 195-203 (2006)
5. The use of an integrated platform for creating TRACE MODE SCADA and Production Management: Theory and Practice, 5th int. conf., the conference materials (2005)
6. Erez, N., Wool, A.: Control variable classification, modeling and anomaly detection in Modbus/TCP SCADA systems. International Journal of Critical Infrastructure Protection 10, 59-70 (2015)
7. Kondratenko, Y.P., Korobko, O.V., Kozlov, O.V.: Frequency Tuning Algorithm for Loudspeaker Driven Thermoacoustic Refrigerator Optimization. Lecture Notes in Business Information Processing: Modeling and Simulation in Engineering, Economics and Management. – K. J. Engemann, A. M. Gil-Lafuente, J. M. Merigo (Eds.). – Berlin, Heidelberg: Springer-Verlag, 115, 270-279 (2012), DOI: 10.1007/978-3-642-30433-0_27
8. Kondratenko, Y., Korobko, O., Kozlov, O., Gerasin O., Topalov A.: PLC Based System for Remote Liquids Level Control with Radar Sensor. The crossing point of Intelligent Data Acquisition & Advanced Computing Systems and East & West Scientists, in Proceedings of the 2015 IEEE 8th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), Warsaw, Poland. 47–52 (2015), DOI: 10.1109/IDAACS.2015.7340699
9. Kondratenko, Y.P., Korobko, O.V., Kozlov, O.V.: PLC-Based Systems for Data Acquisition and Supervisory Control of Environment-Friendly Energy-Saving Technologies. In book: Green IT Engineering: Concepts, Models, Complex Systems Architectures. Series: Studies in Systems, Decision and Control, V. Kharchenko, Y. Kondratenko, J. Kacprzyk (Eds.), Vol. 74. Berlin, Heidelberg: Springer International Publishing, 247-267 (2016)
10. Topalov, A., Kozlov, O., Kondratenko, Y.: Control Processes of Floating Docks Based on SCADA Systems with Wireless Data Transmission. Perspective Technologies and Methods in MEMS Design: Proceedings of the International Conference MEMSTECH 2016, Lviv-Poljana, Ukraine, 57-61 (2016), DOI: 10.1109/MEMSTECH.2016.7507520
11. Kim, H.J.: Security and Vulnerability of SCADA Systems over IP-Based Wireless Sensor Networks. Hindawi Publishing Corporation International Journal of Distributed Sensor Networks (2012)
12. Aydogmus, Z., Aydogmus, O.: A Web-Based Remote Access Laboratory Using SCADA. IEEE Transactions on education, 52(1), 126-132 (2009)
13. Sulthana, S., Thatiparthi, G., Gunturi, R.S.: Cloud and Intelligent Based SCADA Technology. International Journal of Advanced Research in Computer Science and Electronics Engineering (IJARCSEE), 2(3) (2013)
14. Weber, R. H., Weber, R.: Internet of Things. Berlin, Heidelberg: Springer-Verlag (2010)
15. Giusto, D., Lera, A., Morabito, G., Atzori, L.: The Internet of Things. Berlin, Heidelberg: Springer-Verlag (2010)
16. Uckelmann, D., Harrison, M., Michahelles, F.: Architecting the Internet of Things. Berlin, Heidelberg: Springer-Verlag (2011)

17. Sarma, Sanjay E., Stephen, A. Weis, Daniel W. Engels: RFID systems and security and privacy implications. In Cryptographic Hardware and Embedded Systems-CHES 2002, Berlin, Heidelberg: Springer-Verlag, 454-469 (2003)
18. Ovidiu, V., Friess, P., Guillemin, P. et al.: Internet of things strategic research roadmap. Internet of Things-Global Technological and Societal Trends, 9-52 (2011)
19. Vermesan, O., Friess, P.: Internet of Things: Global Technological and Societal Trends from Smart Environments and Spaces to Green ICT. River Publishers (2011)
20. Payam, B., Wang, W., Henson, C., Taylor, K.: Semantics for the Internet of Things: early progress and back to the future. International Journal on Semantic Web and Information Systems (IJSWIS) 8 (1), 1-21 (2012)
21. Rellermeyer, Jan S., Duller, M., Gilmer, K. et al.: The software fabric for the internet of things. In The Internet of Things, Springer Berlin Heidelberg, 87-104 (2008)
22. Zach, Sh., Bormann, C.: 6LoWPAN: The wireless embedded Internet. John Wiley & Sons, 43 (2011)
23. Parikshit, M., Babar, S., Prasad, N. R., Prasad, R.: Identity Management Framework Towards Internet of Things (IoT): Roadmap and Key Challenges. Recent Trends in Network Security and Applications, Berlin, Heidelberg: Springer-Verlag, 430-439 (2010)
24. Li, R. Y. M., Li, H. Ch. Y., Mak, Ch. K., Tang, T. B.: Sustainable Smart Home and Home Automation: Big Data Analytics Approach. International Journal of Smart Home, 10 (8), 177–198 (2016)
25. Li, Sh., Wang, H., Xu, T., Zhou, G.: Application Study on Internet of Things in Environment Protection Field. Lecture Notes in Electrical Engineering Volume. Lecture Notes in Electrical Engineering, 133, 99-106 (2011)
26. Lee, J., Bagheri, B., Kao, H.: A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manufacturing Letters, 3, 18-23 (2015)
27. Zadeh, L. A.: The role of fuzzy logic in modeling, identification and control, Modeling Identification and Control, 15 (3), 191–203 (1994)
28. Takagi, T., Sugeno, M.: Fuzzy identification of systems and its applications to modeling and control, IEEE transactions on systems, Man, and Cybernetics, 15 (1) (1985)
29. Piegat, A.: Fuzzy Modeling and Control, Physica-Verlag, Heidelberg, New York (2001)
30. Jang, J.-S. R., Sun, C.-T., Mizutani, E.: Neuro-Fuzzy and Soft Computing: A Computational Approach to Learning and Machine Intelligence," Prentice Hall (1996)
31. Hayajneh, M. T., Radaideh, S. M., Smadi, I. A.: Fuzzy logic controller for overhead cranes, Engineering Computations, 23 (1), 84-98 (2006)
32. Wang, L., Kazmierski, T. J.: VHDL-AMS Based Genetic Optimization of Fuzzy Logic Controllers, International Journal for Computation and Mathematics in Electrical and Electronic Engineering, 26 (2), 447-460 (2007)
33. Kondratenko, Y.P., Kozlov, O.V., Klymenko, L.P., Kondratenko, G.V.: Synthesis and Research of Neuro-Fuzzy Model of Ecopyrogenesis Multi-circuit Circulatory System. In: M. Jamshidi, V. Kreinovich, J. Kazprzyk (Eds) Advance Trends in Soft Computing, vol. 312, Springer, Series: Studies in Fuzziness and Soft Computing, 1-14 (2014)
34. Kondratenko, Y.P., Kozlov, O.V.: Mathematical Model of Ecopyrogenesis Reactor with Fuzzy Parametrical Identification. Recent Developments and New Direction in Soft-Computing Foundations and Applications. Studies in Fuzziness and Soft Computing 342. Lotfi A. Zadeh et al. (Eds.). Berlin, Heidelberg: Springer-Verlag, 439-451 (2016)
35. Kondratenko, Y.P., Korobko, O.V., Kozlov, O.V.: Synthesis and Optimization of Fuzzy Controller for Thermoacoustic Plant. Recent Developments and New Direction in Soft-Computing Foundations and Applications. Studies in Fuzziness and Soft Computing 342. Lotfi A. Zadeh et al. (Eds.). Berlin, Heidelberg: Springer-Verlag, 453-467 (2016)