This paper describes the architecture and components of the distributed information and management system for collecting, processing, storing, and distributing data on a radiometric and dosimetric experiment using the principle of the Internet of Things. Data exchange between elements in the system, as well as the analysis of the received information, involves active application of the ThingSpeak cloud service. Two-way communication with the cloud with a 15-second loop has been implemented. Data are processed in the MATLAB (America) environment, integrated into the cloud. The developed hardware and software solutions demonstrate an increased accuracy of measurements due to the use of promising cadmium telluride (CdZnTe) detectors, modern microcontroller and micro communication technology, and a new algorithm for correcting the dependence of detector sensitivity on radiation energy. Measurement with correction by the method of average charge pulse amplitude is carried out in the energy range from 60 keV to 3 MeV. The resolution of the spectrometric channel is 6.5 % at the peak of 662 keV of full absorption from the reference source, Cesium (Cs – 137).

The module for a laboratory sensor network, designed to measure the dose of ionizing radiation, has a built-in spectrometric analog-digital converter, microcontroller control, and a communication unit. Constructing the diagrams demonstrates the operation of the interrupt handler in the form of a series of events occurring when requests arrive from a Web server. The peculiarity of the system is the absence of intermediate devices that make it possible to establish a connection with the Internet.

The developed system, equipment, algorithms, and programs are used for experimental studies of radiation and nuclear-physical processes. Elements of the system were useful for remote laboratory work by students

Keywords: information management system, UML diagrams, Internet of Things, CdZnTe radiation detector

UDC 004.35:004.7

DOI: 10.15587/1729-4061.2021.243153

DESIGN AND IMPLEMENTATION OF THE DISTRIBUTED DOSIMETRIC SYSTEM BASED ON THE PRINCIPLES OF IOT

Vitalii Terokhin
Corresponding author
Postgraduate Student*
E-mail: kbs-com@karazin.ua
Oleg Ridozub*
Mykola Stervoyedov
PhD, Associate Professor, Head of Department*
*Department of Electronics and Control Systems
V. N. Karazin Kharkiv National University
Svobody sq., 4, Kharkiv, Ukraine, 61022

Received date 25.08.2021
Accepted date 22.10.2021
Published date 29.10.2021

***How to Cite**: Terokhin, V., Ridozub, O., Stervoyedov, M. (2021). Design and implementation of the distributed dosimetric system based on the principles of IoT. Eastern-European Journal of Enterprise Technologies, 5 (9 (113)), 91-100. doi: https://doi.org/10.15587/1729-4061.2021.243153*

1. Introduction

One of the leading trends in the development of information management systems (IMSs) now is the wide application of the principles of the Internet of Things (IoT). This approach is successful in various fields of science, education, medicine, and industry. It could create favorable conditions for remote work with radiation data due to the use of modern hardware base and new software solutions. The harmfulness of working conditions and territorial distance from educational institutions would cease to be factors that complicate the process of training new specialists and the development of the radiation industry. It is advisable to connect radiometric and dosimetric devices of individual laboratories to the general network using IOT tools, improving the total result of the system parts and providing prompt and reliable access to experiments on-line. Despite the significant number of scientific works related to building IMSs on the principles of IOT, each practical field still faces problems and tasks solving which is a relevant issue.

The limited use of certain information and physical resources during the pandemic has increased dramatically. Therefore, establishing remote access to the working space is extremely important to support the work of various spheres of human activity. These activities include tasks of monitoring radiation conditions of the environment, radiometric and dosimetric studies. The work of specialists and training of specialists is also complicated by the relative limited access to closed laboratories engaged in radioactivity research. That is why it is a relevant task to disseminate dosimetric experiment data in real time by constructing an extensive spectro-dosimetric system with remote access.

2. Literature review and problem statement

Paper describes the potential of radiological institutions, which can be significantly increased by distributing experimental data on the principles of the Internet of Things, a promising concept of combining physical devices into a single system in order to obtain useful effects as a result of sharing data [1] coming from separate, geographically branched, system elements [2]. However, the issues of combining radiation equipment and laboratories into a system based on the Internet of Things remained unresolved. Owing to this, we shall be able to produce a unique synergistic effect when the integrated indicator would exceed the sum of the research results of individual scientific institutions. This will sure happen due to an increase in researchers [3] who will be able to access experimental information, excluding duplicate measurements, or vice versa, by accelerating the control confirmation of the data obtained [4]. A particularly significant result could be obtained for remote training of specialists in the radiation industry [5].

The architecture, the principle of operation, and the general structure of the spectro-dosimetric system are described in paper. The interaction of subsystem components and variants of their interaction with each other are clearly shown. The sequence of interactions between parts of the system and Android application users [6] is shown. An important step was the use of data processing in the cloud service using MATLAB packages. The disadvantages of these subsystems are the power supply of modules in remote locations where there is no network. Work describes the functionality of applications using UML diagrams, such as diagrams of Android application precedents and a dosimetric module, where actors are a client and an engineer who have the ability to configure modules and applications of all subsystems. The UML dosimetric module precedent diagram has a series of disadvantages in the absence of part of the detector and cloud service, because there is a challenge of active actors, on a timer. The UML module states diagram reveals the behavior of the module from the moment of power supply to a regular or emergency shutdown, and reveals the requests for detection and sending that the module performs. The main issue was to build a class diagram of the software for the data exchange module and the client Android application. Combining the implementation of the work of the microcontroller and software has made it possible to construct a distributed dosimetry system based on semiconductor detectors. The structure scheme of the dosimetric module of the system considers analysis of the main parameters of the detection systems of charged particles, such as sensitivity, the range of measured energies of ionizing radiation, the signal/noise ratio [7]. Thus, the calculation of the exposure dose and exposure dose capacity of radiation involves a modified algorithm, which is used in development.

Overcoming the corresponding difficulties can be the system architecture and a hardware and software complex that could implement the joint work of its elements based on semiconductor dosimetry with CdTe detectors of nuclear radiation.

3. The aim and objectives of the study

The purpose of this authentic research is to develop an architecture and structural scheme of a distributed dosimetry system based on semiconductor detectors, and to conduct a study into the features of its components. The would-be hardware and software solutions could make it possible to demonstrate a full cycle of work with the data from a dosimetric experiment, including remote access to experimental equipment and building fundamentally new schemes for the wireless network of radiation monitoring of the environment.

To accomplish the aim, the following tasks have been set:

– to devise a general representation of the architecture based on determining the operational principles of the dosimetric system;

– to design components of the dosimetric system and options for their interaction;

– to construct a sequence of executing the processes and sequence of operations of interaction of elements in the system;

– to build UML diagrams of the dosimetric system;

– to prepare a structure scheme of the dosimetric module.

4. The study materials and methods

The object of research is a distributed information management system for collecting, processing, and distributing dosimetric experimental data based on the principle of the Internet of Things.

An analytical approach has been applied using MathWorks (USA) ThingSpeak platform, which is well adapted for IoT projects [8]. The ThingSpeak platform enables to create private or public channels, use the RESTful and MQTT APIs, set the execution time of commands, and send warnings. The service has rich libraries for working with different programming languages and supports Arduino, Particle Photon and Electron, ESP8266, Raspberry Pi, mobile and web applications, Twitter, Twilio, and much more. An important factor is that MathWorks owns the popular MATLAB mathematical package, which is integrated into the ThingSpeak platform. In the study of the information and management system, the mathematical packages MATLAB were used. The use of unified modeling languages (UML) has made it possible to build and investigate the components of the dosimetric system and their interaction variants, which are designed to measure the dose of ionizing radiation.

All other components and indicators of interaction of elements in the system to build a model were calculated and are demonstrated below.

5. Results of studying the work of a distributed spectrodosimetric system with remote access

5. 1. General representation of architecture based on determining the principles of dosimetric system operation

Fig. 1 depicts the proposed general architecture of the distributed dosimetric system, which is a series of the same type of research (DL) and educational (TL) cells (subsystems). All research centers have sets of hardware and software elements for controlled measurement of radiation parameters of objects or the environment. Data exchange between elements in the subsystem and between subsystems and the analysis of the received information are carried out with the active use of cloud services. An important option of the system is the possibility of remote interference in the measurement process on-line. As shown in Fig. 1, it allows an on-line transmission of initial and processed experimental data to classrooms.

Fig. 2 shows the components of the subsystem and their interaction options. The first component of the system (1) is a dosimeter based on the semiconductor CdZnTe detector, microcontrollers STM32F407VGT and ESP 8266 with a Wi-Fi interface. Its structure is similar to that described in [9]. Traditionally, a dosimeter registers the presence of radioactivity, for example, gamma radiation, and transmits digital signals, proportional to the dose rate of ionizing radiation, to the second component – module (2) for the interpretation, preliminary analysis, and data transmission. The proposed solution is preferable because the module scheme is based on the Wemos D1 R2 (China) board whose core is also a 32-bit microcontroller ESP 8266 (China). The third component is a smartphone, in this case, operated by Android OS (3). It has the developed application installed. With the help of this application, a smartphone user can configure the module via the Wi-Fi interface. Having established a connection with the Internet via a Wi-Fi router (5), a smartphone (3) can also receive indicators of the parameters of the channel of the cloud service ThingSpeak (6). To select the desired communication channel, there is a configuration page for the plugin.

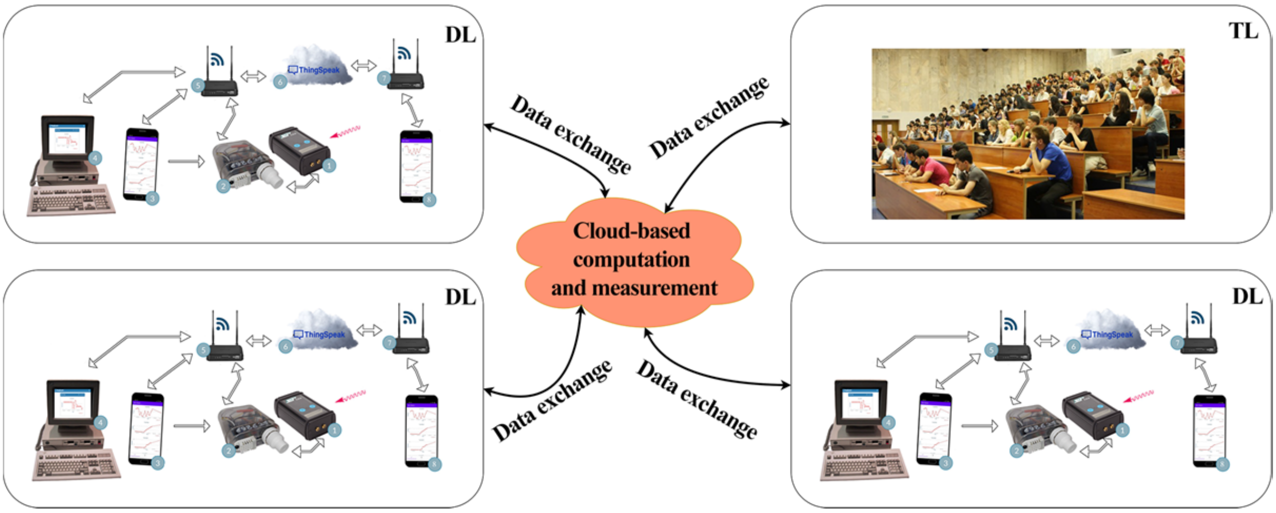

Fig. 1. Distributed dosimetric system architecture

Fig. 2. Components of the dosimetric system and options for their interaction

The fourth component (4) is a desktop computer (PC) connected to the Internet via a wired connection to a Wi-Fi router (5). With the help of a web browser, a PC user can go to the page of the selected channel ThingSpeak (6), view the charts, and operate the data using the built-in MATLAB package [10]. This distinction between the functions of the system is considered optimal. Although, if necessary, mobile device users are also capable of such manipulations. Wi-Fi routers (5) and (7) and cloud service ThingSpeak (6) are ready-made solutions and perform standard communication and computing operations. The functions of remote monitoring and process management give us the best measurements of radiation state parameters carried out using the application installed on the remote user's smartphone or tablet (8).

Fig. 3 shows the sequence of interaction operations of parts of the system, which includes the process of deploying and starting the system in a new environment. The process begins with the configuration of the dosimeter and the module of interpretation, analysis, and data transmission using the Android application – step 1. After initialization in the second step, the module connects to the Wi-Fi router to exchange data with the ThingSpeak cloud service. Next – step 3, a dosimeter transmits data on the radiation parameters of the module, which, at step 4, broadcasts pre-processed and compressed data to the cloud. The information processed in the cloud service using MATLAB can be viewed by local and remote users.

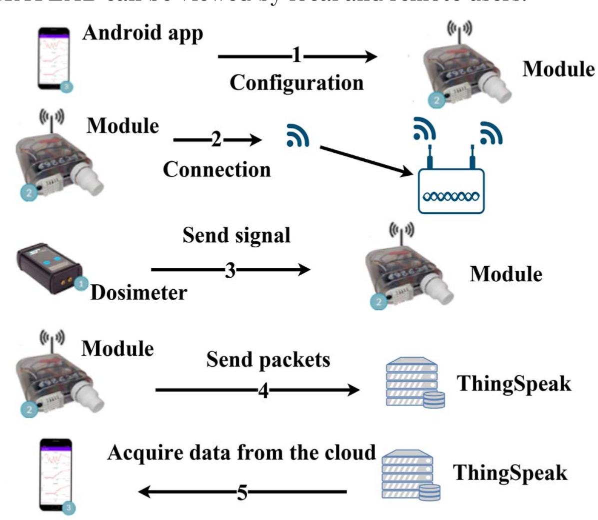

Fig. 3. The order of execution of processes and the sequence of operations of interaction of elements in the system

In addition, through cloud services, data are exchanged between research teams and, if necessary, broadcasting the measurement process to experts, students, and other interested parties.

5. 2. The UML diagrams of Android application precedents and dosimetric module

To determine the functionality of the application by means of UML, a diagram of precedents was built, which is shown in Fig. 4. Depicted are the actors working with the system, the services it offers, as well as the types of relations between the system's precedents and its users.

The main actors in the system are a client and an engineer. The secondary actors are parts of the Internet of Things system to which the system connects either directly (module) or with the help of intermediate devices (ThingSpeak). These actors do not initiate the functions of the application.

Actors who initiate the functions of the application are a client and an engineer who inherits all the rights of the client, and has the right to configure the module. The client, in turn, can configure the parameters of the application (channel number, number of points depicted, number of data fields), and view the data on the experiment in the form of tables, graphs, what not. When configuring the module, parameters such as Wi-Fi access point authentication parameters (SSID, password), time detection parameters (exposure time, time between measurements, time between data packets) are set. In addition, the parameters of the ThingSpeak channel used (channel number, API, write and read keys). Changing the mode of operation of the module after accepting the data packet, and deleting previous entries from the module memory, is not mandatory. Changing each of these categories is optional.

However, to confirm the request to send data, one must enter a value of at least one of the parameters. Sending is impossible if there are errors in the format of the entered values, as well as the absence of an SSID value with the specified Access Point Wi-Fi password. In addition to the module settings, the settings of the application [12] are also checked. If there are errors in the configuration of the application or module, the user of the application must be notified that the input cannot be confirmed, the type and place of the error.

The diagram of precedents in the dosimetric module for detecting and transmitting data, shown in Fig. 5, demonstrates options for interaction of three actors with the functions of the module.

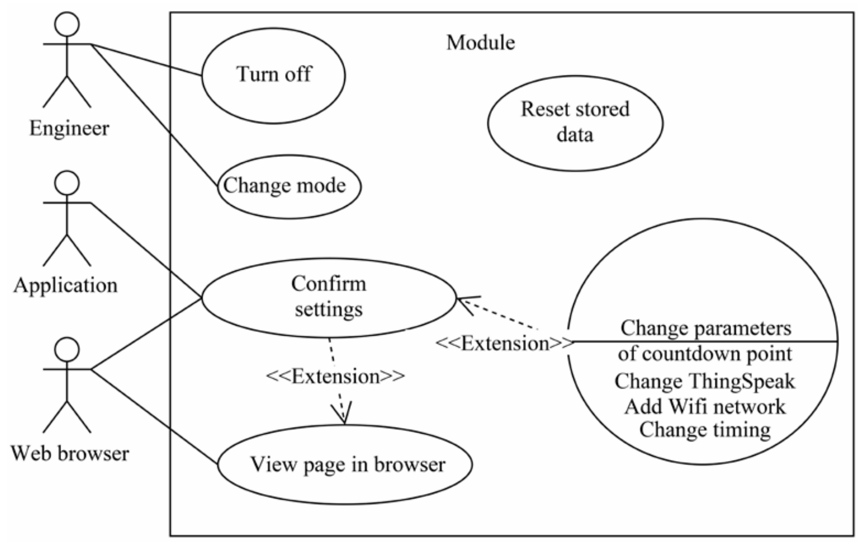

Fig. 5. UML diagram of dosimetric module precedents

Since some precedents can be called in by hardware using control buttons, in addition to actors-programs, there is a human actor (engineer) on the diagram.

The web browser configures the module, has the ability to view the web page of the configuration, which the module sends in response to the Protocol (HTTPS) Get request containing the URL specified by the module. Since sending this request is possible not only by clicking the corresponding button on the web page but also manually, using the address bar of the web browser, the precedent of sending settings has a direct association with this actor.

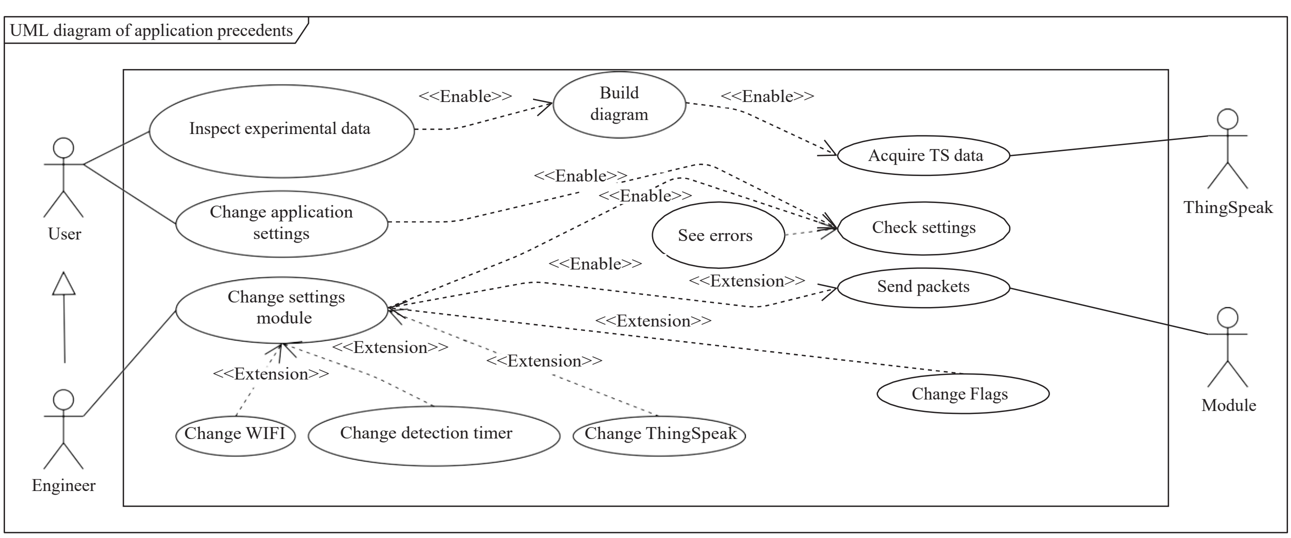

Fig. 4. UML diagram of application precedents

The dosimetric module precedent diagram lacks part of the detector and cloud service. This decision was made due to the lack of a generally accepted designation of precedents, carried out without calling active actors, on a timer. In the unified modeling language (UML), possible solutions to this problem are the inclusion of an active or passive actor of the "system" type, or a complete absence of associations with such a precedent. However, the introduction of additional actors is not correct due to the lack of intent in the actions of the timer, and its belonging to the system. As for the absence of associations with the main actors, this approach is not possible, since for the precedent of "working with data", cloud service and detector act as actors, which can cause misunderstandings when examining the architecture of the system.

5. 3. The UML diagrams of module status

Since the module software is an ultimate automaton, an image of its operation is appropriate using the state diagram shown in Fig. 6.

The module state diagram shows the behavior of the module from the moment of power supply to a regular or emergency shutdown. Its behavior is expressed in the change of system states in response to external and internal events. The general state of the system between the beginning and stopping of its operation is indicated by rectangle "Running". Because the dosimetric system layout does not work with critical information, maintaining data integrity is not a priority. However, to eliminate the possibility of memory damage, it is necessary to devise a regular method of disabling the module. Unlike the Terminate state, the transition to which can occur at any time in the system, the Shutdown state involves the completion of the remaining processes. The logic of module operation is built around the cyclic verification of the system mode variable, which can change both when the button is pressed, and as a result of selecting the appropriate option through configuration programs. The status of "client" is the main working state of the module. Its work has been demonstrated by waiting, detecting, and sending. After passing the timeout of one detection and the availability of time before sending the packet, the module enters a state of detection. At the same time, it receives, interprets, and writes data to memory. After that, the counter of one detection is reset, a new cycle of measuring and sending data takes place. After the time before sending, the previously saved data are entered into the packet, the packet is sent to the cloud, the sending counter is reset, and the automaton re-enters the mode check state.

A state diagram includes a Web server state that contains a specific number of logical operations, making the program composite. A web server is the part that is responsible for handling signals coming from connected devices. After the first change in the mode of operation to "server", the loop starts the Web server, the logic of which is triggered by external interrupts. The interrupt occurs when a new encrypted HTTPS request arrives. For a more detailed image of the interrupt handler, a diagram of the activity of the corresponding state of the system has been constructed: Fig. 7.

The activity diagram shows the work of the interrupt handler in the form of a series of events occurring in the event of a request. The entry point is to call the interrupt handler. Significant is the presence of three main query options that correspond to the necessary pages of the elementary website. The main page with configuration forms, a page of successful sending of a message, and a page by default with a message that the entered page is missing on the web server. The central sequence of actions demonstrates the simplified logic of the module configuration process, controlled by the data transmitted in the request. It is worth noting that the removal of previous settings in the activity "Clear saved" should take place before saving new settings, in order to save the current record in the first available cell of the area of energy-independent storage of data [13]. In addition, in this process, it is possible to change the mode of operation of the module when the established mode change attribute is detected. After performing the signal processing, the program enters the main cycle of the program, shown in Fig. 6. The next stage of work is the formalization of the process described in Fig. 3 as a diagram of the sequence of interaction of system components.

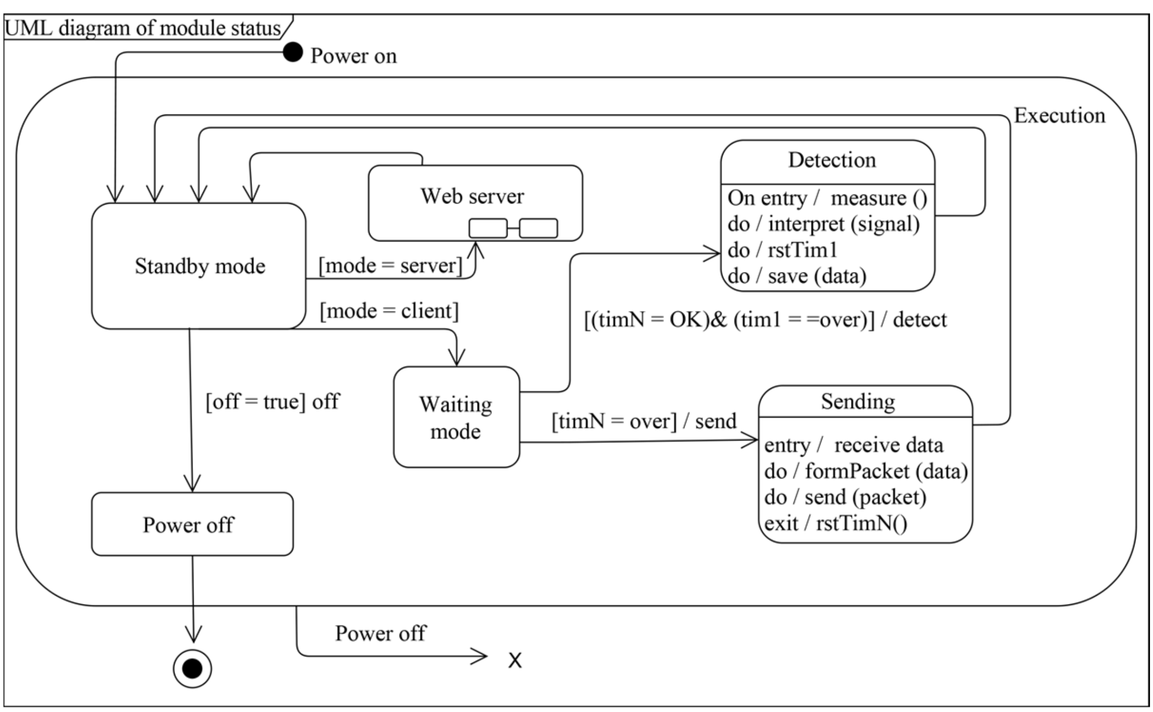

Fig. 6. UML diagram of module status

The diagram of the sequence, shown in Fig. 8, depicts the joint work of four components of the dosimetric system and two actors: a client of the system (researcher, student) and an engineer with access to laboratory equipment.

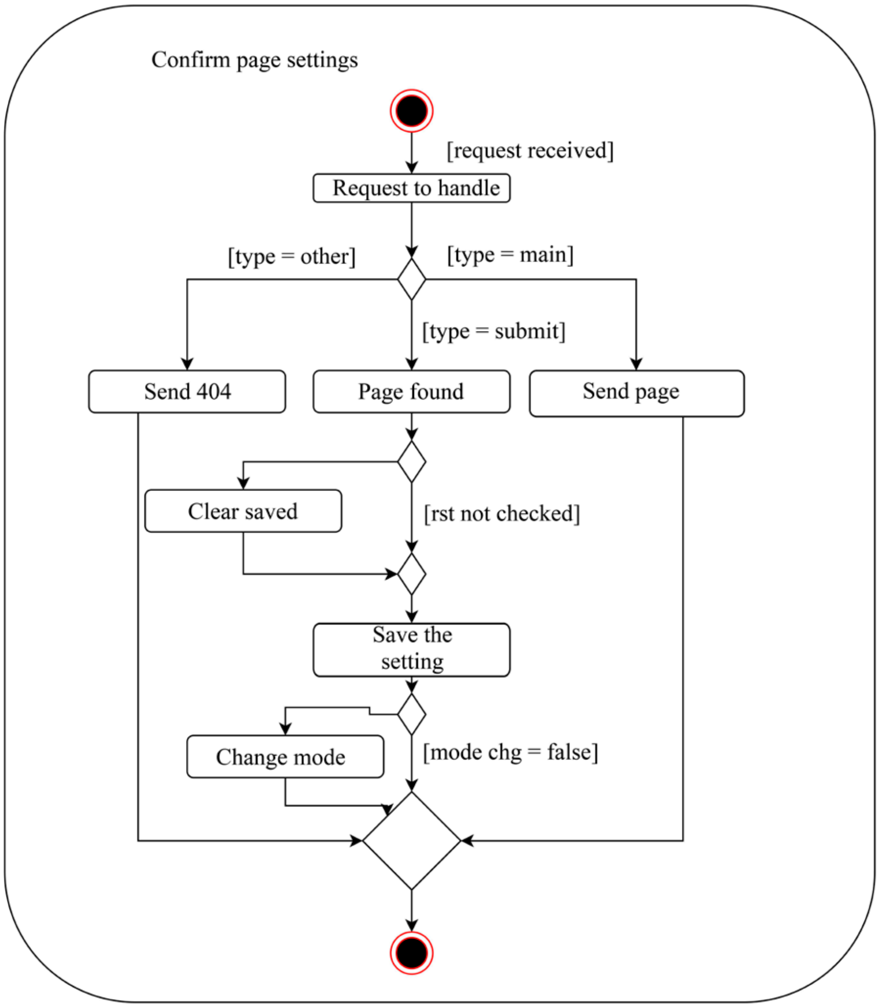

Fig. 7. UML diagram of HTTPS request handler (module)

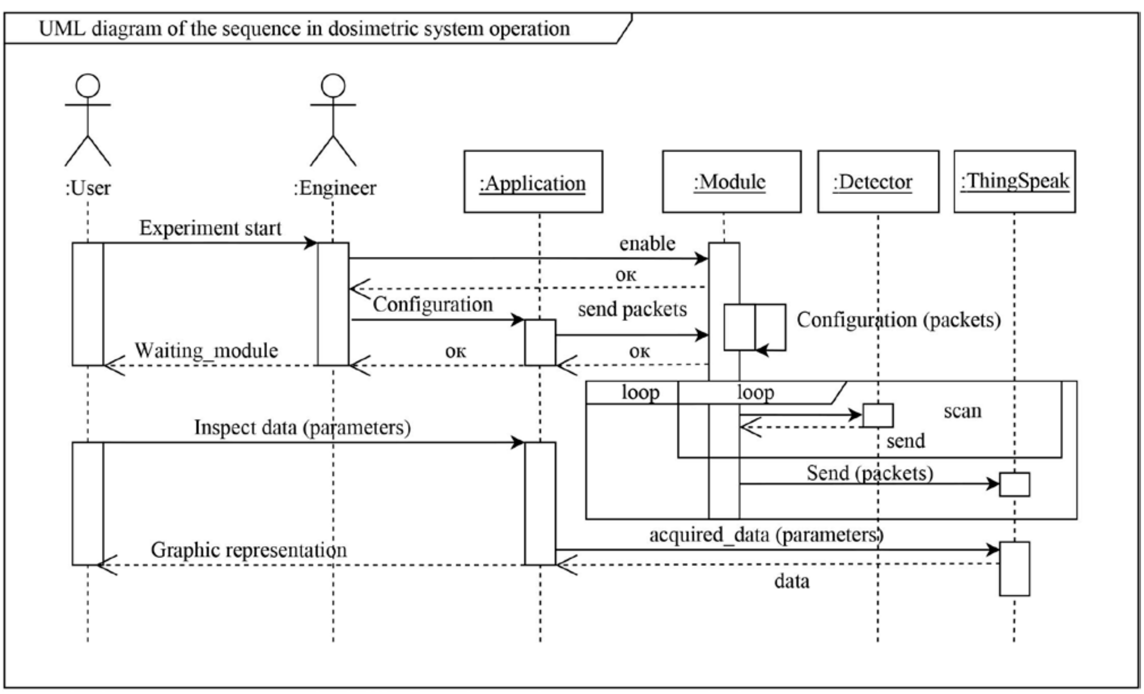

Fig. 8. Diagram of dosimetric system sequence

As part of this work, the client himself can act as an engineer. Separating actors' powers requires authentication capabilities, which involves having a specific infrastructure – a server with authentication data, a unique layout access key, etc. [13].

In addition to the actors, the sequence diagram differs from the described structure of the system by the absence of intermediate devices that make it possible to establish connections with the Internet. Of course, establishing a connection with ThingSpeak without using Wi-Fi access points is not possible for the rest of the system devices – the diagram somewhat simplifies the physical representation of the system structure.

It is worth paying attention to the types of messages exchanged between parts of the system and the focus zone when executing certain commands. One can see that some messages are marked with a filled arrow and will keep the process active until a response from the addressees arrives. Other messages that are asynchronous make it possible to use the system component as soon as one sends the command. In addition, the diagram shows two areas of the cycle. They are responsible for the cyclic detections counting the time between individual detection attempts, and the time between sending the data packet to ThingSpeak.

5. 4. The diagram of software classes of data exchange module and client Android application

The description of the dynamics of the dosimetric system layout is enough for the development and program implementation of its algorithms. To complete the development of the system architecture, it is necessary to create diagrams of software classes of the data exchange module and the client Android application that would determine the structural elements, their attributes, and behavior. Fig. 9 shows the UML diagram of the software classes of the data exchange module.

Data exchange module software does not require the creation of a large number of classes. The processes that take place in this part of the system are generally implemented without the use of object-oriented programming. Fig. 9 shows that the classes that the work needs to implement are working classes. The EEPROMWorker class encapsulates all the work with the energy-independent microcontroller memory. It must write SSID pairs and passwords transmitted in HTTPS requests to EEPROM. In addition, it is necessary to store the number of these pairs and the position of the last memory cell. In addition, one needs to be able to clear the memory with a return to the original format and load the stored values into the class responsible for connecting to known Wi-Fi access points. This class, like the rest of the classes absent in this diagram, is part of the finished library. Because of this, their representations in the class diagram are not necessary because they are a "black box" for the system.

More relevant is to construct a class diagram for the client Android application, which is shown in Fig. 10.

The application class module software diagram shows only classes that need to be developed. To build a graphical user interface, one needs to use a significant number of finished components from different Android libraries. Some links are set at the library level and secret implementation parts. The main class of the application is the MainActivity class. With its initialization, the program begins. The analysis of the implementation of systems, including the elements necessary for this project, made it possible to distinguish a certain number of service classes to ensure the proper operation of the application. To provide the context of the program, a single access point was created in the form of the AppContextProvider class. It makes it possible to transfer the context of the program to other activities besides the main one. The DataViewerSVM class provides the ability to asynchronously access multiple fragments to common variables, namely: a data demonstration fragment and an application configuration snippet.

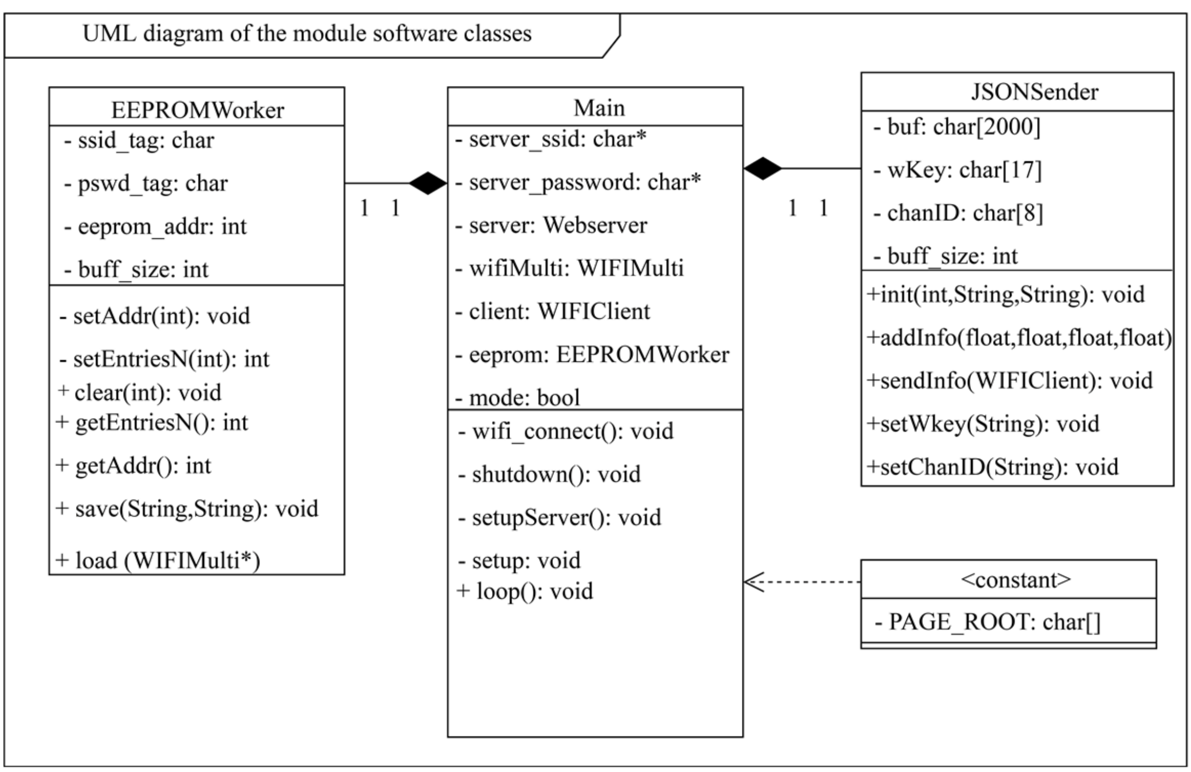

Fig. 9. UML diagram of the module software classes

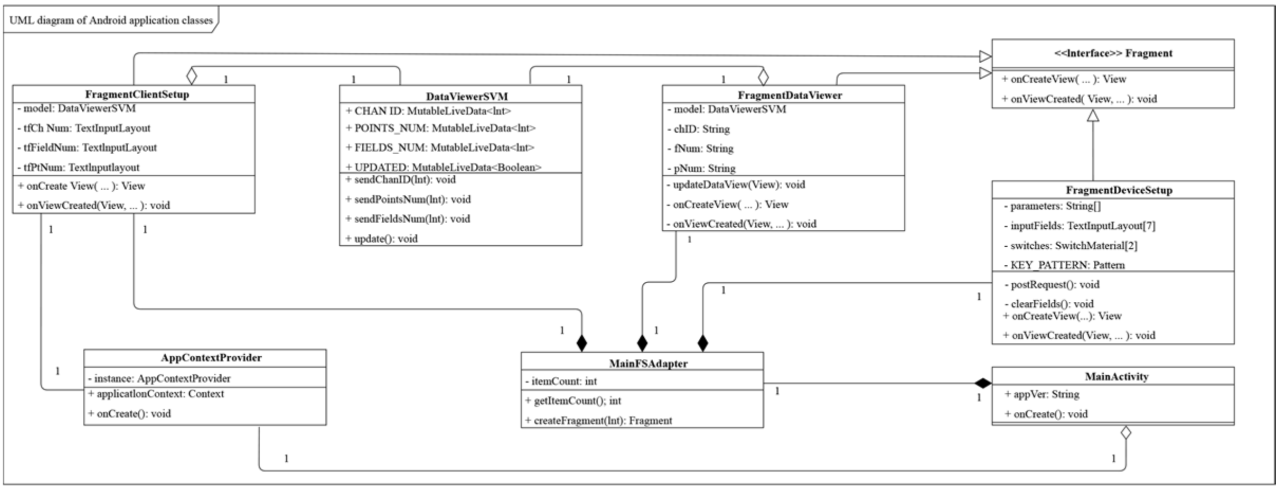

Fig. 10. UML diagram of Android application classes

The general data here are the data that will act as parameters of the request to the cloud service. Creating such a class is the only option for exchanging data between fragments of the Android application. In addition to these fragments, the system includes a module configuration fragment. Structurally, this fragment is similar to the configuration fragment of the client but its peculiarity is the ability to form configuration packets and transfer them to the module. All three fragments follow the Fragment class. The snippet change is controlled using the Fragment State Control Adapter (MainFSAdapter).

5. 5. Building the structure scheme of the dosimetric module of the system

One of the defining elements of the designed system is a sensor module for measuring the dose of ionizing radiation. Analysis of basic parameters of charged particle detection systems, such as sensitivity, range of measured energies of ionizing radiation, signal/noise ratio, etc. The dosimetric module scheme was built on the basis of a semiconductor CdZnTe detector. Modern microcontrollers STM32F407VGT and ESP 32 are used to control the module, preprocess data, and organize the wireless Wi-Fi interface according to the protocol IEEE 802.11AH [12].

The structural diagram of the dosimetric module is shown in Fig. 11.

RS ionizing radiation is recorded by a semiconductor CdZnTe detector D. A signal from the detector, which is proportional to particle energy, is sent to the analog processing unit (ASPU). The analog signal processing unit consists of a preliminary amplifier (RA), fast (RA) and spectrometric (SMA) amplifiers. Pulses from the rapid amplifier are used to count the events of acts of radiation registration. The exposure dose is a complex function of the number of these pulses. The spectrometric channel is used to determine the spectral components of radiation energy and for hardware and software correction of exposure dose measurement results.

Data processing is carried out in a digital processing unit (DSPU). The DSPU hardware includes spectrometric analog-digital converter (SADC), a pulse counter, and a microcontroller (MC).

Calculation of the exposure dose D_e and exposure dose power X_e of gamma radiation is performed according to the modified algorithm used in somebody's report. The calculation of these parameters is carried out taking into consideration the peculiarities of the dependence of the detector sensitivity on the energy of the recorded quantum. For a CdZnTe detector, the method of correcting this dependence is proposed in paper [12].

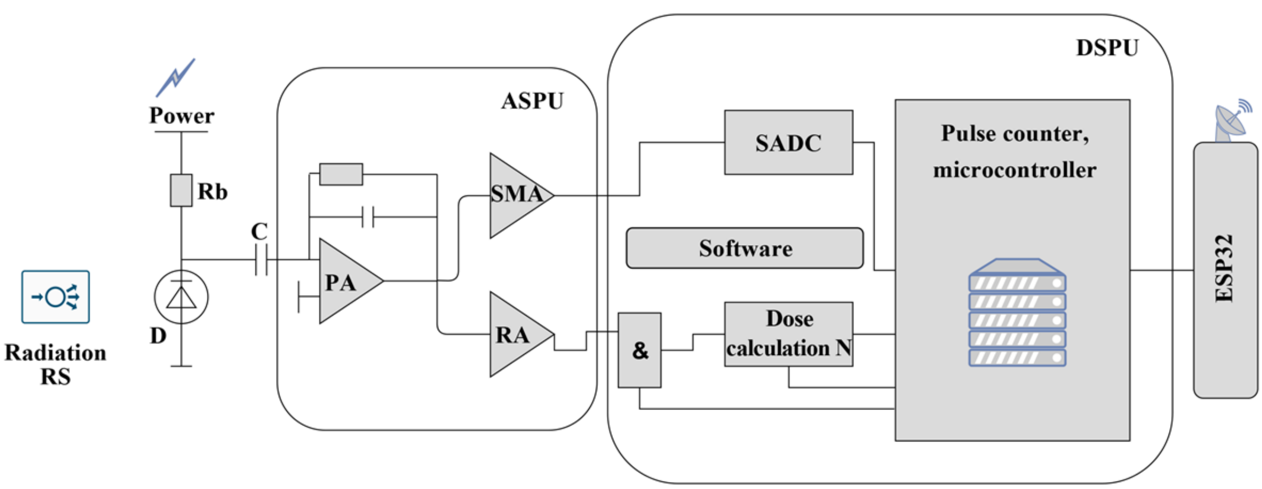

Fig. 11. Structural diagram of dosimetric module

To this end, after recording the spectrum and the number of N_{total} pulses during exposure, the microcontroller program calculates the real exposure dose De in micro roentgens [μR] from the following formula (1):

$$D_e = \left(A < E_{pulse} > +B\right) * N_{total}, \quad (1)$$

where the average pulse amplitude $<E_{pulse}>$ is calculated by formula (2):

$$E_{pulse} = \sum i\left(i * n_i / N_{total}\right), \quad (2)$$

where i – pulses, as the total sum of pulses in the spectrum $N_{total} = \sum i n_i$ is (3):

$$D_e = A\sum_i i * n_i + B * \sum_i n_i. \quad (3)$$

The values of coefficients A, B are determined during the calibration process and are given in a table for a specific detector. Exposure dose rate of gamma radiation X_e in [μR/s] is defined as (4):

$$X_e = D_e / t, \quad (4)$$

where t is the measurement time in seconds [s].

The energy sensitivity correction method of the CdZnTe detector, termed the medium charge pulse amplitude method, operates in the energy range from 60 keV to 3 MeV. The advantage of this method in comparison with the traditional method of compensating filters is the absence of a decrease in the sensitivity of measurements over the entire energy range.

The designed dosimetric module can also be used as the base unit of the gamma-radiation spectrometer. Fig. 12 shows the control energy spectrum from a reference Cs–137 source of gamma radiation. The spectrum was acquired using the designed module. The resolution of the spectrometric channel with the detector was 6.5 % at a peak of 662 keV of full absorption.

We developed software for the dosimetric module in the Keil μVision 5 programming environment using the graphic tool for configuring the STM32CubeMX microcontroller.

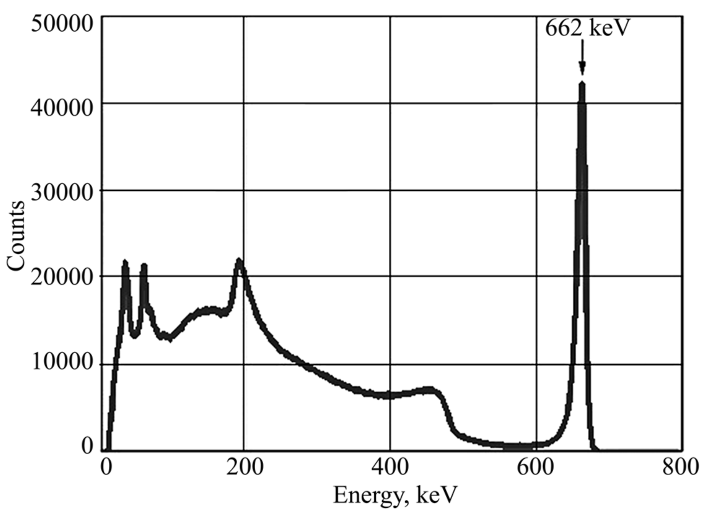

Fig. 12. Gamma radiation spectrum from the reference Cs-137 source

6. Discussion of results of studying the IOT-based distributed dosimetric system

Our study of the model of a distributed dosimetric system based on the IoT principles has made it possible to build a unique architecture and combine a number of the same type of researchers and educational centers (subsystems) using cloud services.

To analyze the advantages of the proposed results, it is advisable to compare them with a study reported in [13]. The authors carry out radiation measurements based on CdZnTe semiconductor detectors at room temperature. Unlike their studies, the designed module can work at a temperature from −30 to +40 °C without error.

Unlike study [13], in which analog-digital converters and data processing units of outdated types were used to improve the accuracy of measurements, it becomes possible to build a dosimetric module on fundamentally new components. The use of a dosimeter based on the semiconductor CdZnTe detector, microcontroller STM32F407VGT, and ESP 8266 with a Wi-Fi interface has made it possible to construct a powerful module that has a large number of advantages over that in [13].

Our hardware and software solutions make it possible to demonstrate the full cycle of the dosimetric experiment. The essence of the functioning of the dosimetric subsystem sequence is in the construction of a certain database of rules for the interaction of the user and intermediate devices of connection with the Internet. The construction of module state diagrams has made it possible to clearly demonstrate the behavior of the module from the moment of power supply and a regular or emergency power outage; but the task is to preserve the integrity of the data and build a regular shutdown of the module. The modular principle of organization of the dosimetric system can significantly reduce the number of devices necessary to perform the entire range of tasks due to this approach. The use of cloud services has made it possible to use downloaded data for analysis and visualization. A feature is the architecture of the dosimetric system, which includes two different cells, such as experimental and educational. When solving the main functions, the dynamics of the system, which was presented in the UML diagrams, the change in the mode of operation of the module after the adoption of the data packet and the deletion of previous entries from the module memory, have been described.

The disadvantages of the system are the dependence on the presence of a poor signal from the wireless Internet and the inability to request a web server from some countries. The modularity of such a system makes it possible to place mobile points in places where it is needed. Compared to the existing principles of dosimetric systems, it was not possible to adjust the settings on-line. Developing the Android application allowed us to measure the parameters of the radiation state of the environment from around the world in the presence of the wireless Internet and a smartphone or tablet. The processes taking place in this part of the system are generally implemented without the use of object-oriented programming, which made it possible to develop software using existing libraries and applications. This study could be advanced through the implementation of the developed system in radiation and nuclear-physical processes around the world, using it in the training of new specialists in this field, as well as improving the application and creating new functions.

7. Conclusions

1. The general representation of architecture has been proposed on the basis of determining the operational principles of a dosimetric system. The system is a series of the same type of research and training subsystems. The subsystems consist of sets of hardware and software modules for remotely controlled measurement of radiation state of objects or environment.

2. The components of the system have clearly demonstrated options for their interaction with each other. With the help of a web browser, a PC user can visit the page of the selected ThingSpeak channel, inspect graphs, and operate data using the built-in MATLAB package. Remote monitoring and control functions of the process of measuring radiation state parameters are carried out using the application installed on the remote user's smartphone or tablet.

3. The smartly devised order of execution of processes and the sequence of operations of interaction of elements in the system make it possible to cover the whole experiment on the principle of the Internet of Things. Thus, the joint work of elements based on semiconductor dosimetry with CdTe detectors of nuclear radiation is organized. Building a sequence of interactions between system parts involves the process of deploying and starting the system in a new environment for the interaction of elements in the system. This interaction begins with the configuration of the dosimeter and the module of interpretation, analysis, and data transmission using the Android application.

4. The construction of UML diagrams of the dosimetric system makes it possible to fully understand the system and components, as well as methods for acquiring reliable data. Data exchange between elements in the subsystem and between subsystems and analysis of the received information is carried out with the active use of the structural scheme of the dosimetric module. Two-way communication with the cloud with a 15-second loop has been implemented. On a commercial basis, the cycle can be reduced to one second. This is enough for most dosimetric and radiometric studies.

5. The structural scheme of the dosimetric module, which is designed to measure the dose of ionizing radiation, has been constructed. It has a built-in spectrometric analog-digital converter, microcontroller control, and a communication unit. This makes it possible to accurately measure and calculate the exposure dose and exposure dose rate of gamma radiation due to the new algorithm for correcting the dependence of the detector sensitivity on radiation energy. The communication unit provides wireless connection with laboratory equipment and reliable communication with cloud services.

Measurement by medium charge pulse amplitude is carried out in the energy range from 60 keV to 3 MeV. The advantage of this method in comparison with the traditional method of compensating filters is the absence of a decrease in the sensitivity of measurements in the entire range of the specified energies of the radiation gamma. Due to the hardware-software correction of measurement results, the resolution of the spectrometric channel of 6.5 % was reached at the peak of 662 keV full absorption from the reference source Cs–137.

In the future, our architecture, algorithms, and programs could be used for experimental studies of radiation and nuclear-physical processes. In addition, the system elements were useful for remote laboratory work by students during quarantine.

References

1. Batura, T. V., Murzin, F. A., Semich, D. F. (2014). Cloud technologies: basic models, applications, concepts and development tendencies. Programmnye produkty i sistemy, 3 (107), 64–72. doi: http://doi.org/10.15827/0236-235x.107.064-072
2. Gubbi, J., Buyya, R., Marusic, S., Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29 (7), 1645–1660. doi: http://doi.org/10.1016/j.future.2013.01.010
3. Ridozub, O., Terokhin, V., Stervoyedov, N., Fomin, S. (2019). Sensor node for wireless radiation monitoring network. Bulletin of V.N. Karazin Kharkiv National University, Series «Mathematical Modeling. Information Technology. Automated Control Systems», 44, 88–93. doi: http://doi.org/10.26565/2304-6201-2019-44-09
4. Finance, G. (2012). What actor should I use for scheduled use cases? Available at: http://www.umlchannel.com/en/uml/item/24-use-case-actor-system-timer/24-use-case-actor-system-timer Last accessed: 10.10.2020
5. Kutnii, V. E., Rybka, A. V., Davydov, L. N. et. al. (2021). Detektory ioniziruiuschikh izluchenii na osnove tellurida kadmiia – tsinka. Kharkiv: Tipografiia Madrid, 352.
6. Terokhin, V., Styervoyeodov, M., Ridozub, O., Fomin, S. (2020). Intelektualniy vuzol of sensory framing of radio monitoring. Materials of the conference CMNT – 2020. Kharkiv, 49–51.
7. Adame, T., Bel, A., Bellalta, B., Barcelo, J., Oliver, M. (2014). IEEE 802.11AH: the WiFi approach for M2M communications. IEEE Wireless Communications, 21 (6), 144–152. doi: http://doi.org/10.1109/mwc.2014.7000982
8. Somov, A. S. (2019). Sbor i vizualizatsiia dannykh s pomoschiu platformy interneta veschei Libelium Waspmote. Moscow: Skolkovskii institut nauki i tekhnologii, 30.
9. Kumar, S., Tiwari, P., Zymbler, M. (2019). Internet of Things is a revolutionary approach for future technology enhancement: a review. Journal of Big Data, 6 (1). doi: http://doi.org/10.1186/s40537-019-0268-2
10. MATLAB – MathWorks – MATLAB & Simulink. Available at: https://www.mathworks.com/products/matlab.html
11. Hryhorieva, L. I., Tomili, Yu. A., Rozhkov, I. M. (2008). Ionizuiuche vyprominiuvannia ta yoho vplyv na liudynu. Mykolaiv: MDHU im. Petra Mohyly, 208.
12. Owens, A. (2019). Semiconductor Radiation Detectors. CRC Press, 494. doi: http://doi.org/10.1201/b22251
13. Zakharchenko, A. A., Nakonechnii, D. V., Shliakhov, I. N., Rybka, A. V., Kutnii, V. E., Khazhmuradov, M. A. (2019). Simulation of energy dependence of CdTe (CdZnTe) gamma-radiation detectors sensitivity. Tekhnologiia i Innovatsii, 44, 245–247.