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DEVELOPMENT OF AN IOT DEVICE BASED ON A GEIGER COUNTER

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Abstract. *The threat of radiation exposure is always present in modern world. In recent years, this threat has become even more pronounced due to Russian aggression on Ukrainian territory. Therefore, the need for remote data collection and analysis of radiation background information has become even more important, and research in the field of creating small, low-cost devices that can monitor radiation levels of a certain area in real-time and provide information to local government agencies responsible for the safety of populated areas can be considered relevant. Radiation background level monitoring is essential to ensuring that people are informed of any potential threats to their health. It is proposed to develop a dense network of monitoring stations that can collect and transmit data about background radiation in real time. Measurement results will be processed and stored on a resource that is available to both local authorities and public. The Message Queue Telemetry Transport (MQTT) protocol is used to transmit information, as it is durable, lightweight, and efficient. A hardware and software system for collecting and transmitting radioactivity values has been developed. The system is based on a module with Geiger counter tube, which is used to measure the level of radiation in the area. The module is connected to a microcontroller, which processes the data and transmits it to a central server. To summarize and process the measurement results, the Majordomo broker is used. It is installed on a remotely accessible network storage. In conclusion, the proposed system can ensure the safety of the public, allowing authorities, experts and trained personnel to quickly and efficiently respond to any potential radiation threats, protecting people from radiation exposure.*

Анотація. *У сучасному світі завжди існує загроза радіаційного опромінення. Останніми роками ця загроза стала ще більш відчутною через російську агресію на території України. Тому потреба у дистанційному зборі даних та аналізі радіаційної фонової інформації стала ще більш актуальною, а дослідження в галузі створення невеликих недорогих пристроїв, які можуть контролювати рівні радіації певної території в режимі реального часу та надавати інформацію актуальними можна вважати органи місцевого самоврядування, відповідальні за безпеку населених пунктів. Моніторинг рівня радіаційного фону має важливе значення для того, щоб люди були поінформовані про будь-які потенційні загрози їх здоров'ю. Пропонується розробити щільну мережу станцій моніторингу, які зможуть збирати та передавати дані про радіаційний фон у режимі реального часу. Результати вимірювань будуть оброблені та збережені на ресурсі, доступному як для місцевої влади, так і для громадськості. Для передачі інформації використовується протокол Message Queue Telemetry Transport (MQTT), оскільки він надійний, легкий і ефективний. Розроблено апаратно-програмний комплекс для збору та передачі значень радіоактивності. В основі системи лежить модуль з лічильником Гейгера, який використовується для вимірювання рівня радіації в місцевості. Модуль підключається до мікроконтролера, який обробляє дані та передає їх на центральний сервер. Для узагальнення та обробки результатів вимірювань використовується брокер Majordomo. Він встановлений на віддалено доступне мережеве сховище. На завершення, запропонована система може забезпечити безпеку населення, дозволяючи органам влади, експертам і навченому персоналу швидко та ефективно реагувати на будь-які потенційні радіаційні загрози, захищаючи людей від радіаційного опромінення.*

Keywords: radioactive background, Geiger counter, network storage, remote access, MQTT protocol.
Ключові слова: радіоактивний фон, лічильник Гейгера, мережеве сховище, віддалений доступ, протокол MQTT.

1. Introduction

Currently, people are exposed to many radioactivity threats related to russian aggression in Ukraine. This includes the possibility of missile attacks on nuclear power plants, irresponsible actions at the occupied Zaporizhzhia nuclear power plant, and threats of tactical nuclear weapon usage [1]. Hence, the need for remote monitoring and analysis of radiation background information has become very important.

A proposed solution is to create a network of monitoring stations that will provide real-time information on the background radiation. The MQTT (Message Queue Telemetry Transport) protocol is used for information transfer [2]. It is a simplified network protocol that works on TCP/IP and allows for the creation of devices that transmit information from sensors based on cheap and easy to use microcontroller components.

2. Literature analysis

Typically, radiation measurement with a dosimeter is performed once (on demand) and is not regular. Thanks to wireless communication, readings from such devices can be viewed from several meters away [3]. At the same time, the radiation background can change while performing specific activities, for example, after maintenance work (laying gravel coverage, decoration with granite, e. g. installing granite panels/countertops, etc.), observation on a spiral computer tomography, after inhalation of radioactive aerosol, etc. After trips through areas with significant radiation contamination (e.g. the Chornobyl exclusion zone), air filters in car engines and cabins can retain radioactive dust and carry it over long distances.

An effective solution would be deploying networked radiation detectors to measure radiation characteristics in real-time. For example, the European MPX ATLAS network has been operating for 20 years [4]. However, this equipment is solely for scientific research and doesn't monitor background radiation for population protection.

In Ukraine, the issue of creating an automated radiation control system as the main component of radiation safety for the population has been discussed for over 10 years [5]. However, the resolution of organizational issues regarding this problem has stalled, and currently such a system does not function. Only well-known automated systems for monitoring radiation are operating in Ukraine and are located around nuclear power plants. At the same time, similar systems are already functioning in some countries of the world.

For example, in Finland, the radiation control system consists of 290 stations that are evenly distributed throughout the country. The measurement results are stored in the National Data Bank. This information is available to the government in real-time. The automated system also receives information from other Scandinavian countries [6].

The UK National Radiological Monitoring and Emergency Response Network (RIMNET) was established in 1988 to track the impact of foreign nuclear incidents on the country [7]. RIMNET consists of 94 posts throughout the country and the data received is stored in the UK National Nuclear Database. Similar computerized systems for automatic determination of radiation situation are also available in Bulgaria, Belgium, Japan, and other countries.

Thus, research in the field of creating small, low-cost devices that can monitor radiation levels of a certain area in real-time and provide information to local government agencies responsible for the safety of populated areas is considered relevant.

3. Object, subject, and methods of the research

The object of the research is the process of remote monitoring and data processing for radiation background.

The subject of the study is a network of remote radiation monitoring stations based on electronic sensor modules.

Tasks that were set for the research are:

– Automated environmental radiation monitoring in an unlimited number of stationary or mobile points;
– Data transfer from the monitoring point to the server via the Internet network;
– Warning and emergency notifications for when the results of radiation background measurement exceed specified threshold levels;
– Viewing of dosimetric information through the Internet from a computer or smartphone.
– Research methods: The ionization method of radiometry and radiation control using gas-discharge devices (Geiger counter).

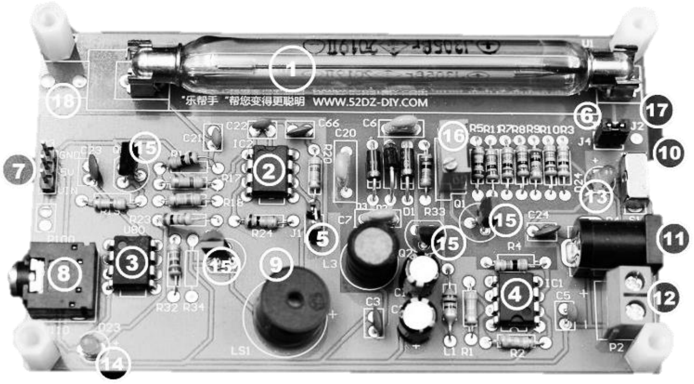
Practical significance: As a result of the studies, it will be possible to generalize and process the results of remote radiation background measurement in a distributed network of monitoring stations for timely notification of the agencies responsible for ensuring people from the consequences of radioactive contamination.

4. Device development

4.1. Hardware components

Now, let's examine the components that comprise the system for collecting information about the background radiation levels of the surrounding area.

Geiger counter sensor module (Fig. 1) is the main component responsible for radiation levels measurement [8].



1 – J305 tube, 2,4 – 555 timer ICs, 3 – LM358P, 5 – J1 jumper, 6 – J4 jumper, 7 – microcontroller connection terminal, 8 – 3.5mm TRRS terminal, 9 – buzzer, 10 – power switch, 11 – 5V DC jack input, 12 – power input screw terminal, 13, 14 – LED indicators, 15 – S8050 transistor, 16 – calibration potentiometer, 17 – J2 calibration mode jumper, 18 – SBM-20 tube connector

Fig. 1 – Geiger counter sensor module

Description of components:

1) J305 tube (alternative to M4011), capable of capturing gamma- and beta-radiation;
2, 4) 555 timer ICs, which are responsible for initiating data capture;
3) LM358P, dual channel op-amp;
5) J1 jumper, responsible for enabling or disabling buzzer sound;
6) J4 jumper, used during the calibration process;
7) Microcontroller connection terminal – responsible for supplying power to the board via GND and 5V pins. INT pin is responsible for transferring data to the MCU. External interrupts configuration on the MCU is required for setting up data collection based on received impulses;
8) 3.5 mm TRRS (audio jack) terminal, which enables data collection on smartphones. Special mobile application can be installed in order to collect and process the data, which is then displayed on the screen;
9) Buzzer, that emits a clicking sound every time an impulse is registered;
10) Sliding switch for turning the sensor on and off;
11) Auxiliary 5V power supply socket (5.5 mm × 2.5 mm);
12) Auxiliary screw terminal block for supplying 5V power;
13) LED power indication;
14) LED indicating impulse registration;
15) NPN-transistors S8050;
16) Calibration potentiometer;
17) J2 calibration jumper;
18) Additional contact plates for switching the J305 tube to SBM-20.

MCU module ESP32-CAM was used for data collection and transferring (Fig. 2). It is Wi-Fi and Bluetooth-enabled and equipped with OV2640 camera module [9]. An additional programming shield can be connected, which allows flashing the board and communicating via USB.

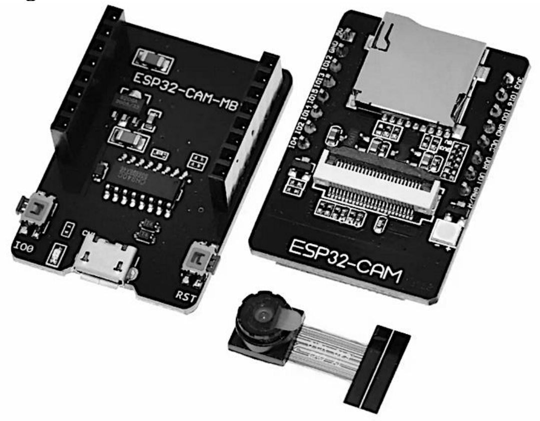


Fig. 2 – **ESP32-CAM module with its programming shield**

For this task, any module based on ESP32 or ESP8266 with built-in Wi-Fi subsystem is suitable. The mentioned module was used for the prototype because it was available.

The power supply unit with a voltage of 5V is used, both for powering the Geiger counter board and the ESP32 module.

A logic signal level converter is also used. The Geiger counter board operates with a logic level of 5V, while the ESP32 module operates with a logic level of 3.3V. A simple converter circuit is used to synchronize these levels (Fig. 3).

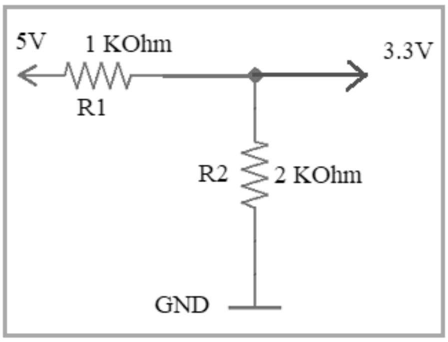


Fig. 3 – **Logic level converter circuit**

Sample of radioactive material for system testing. A so-called "Energy Pendant" was used (Fig. 4), which, according to the description, "improves the energy state of the organism". This pendant has weak radioactivity.

Fig. 4 – **Radioactive material sample**

When handling radioactive materials, it is important to remember that you cannot see radiation. Hence, it is crucial to know and understand their behavior. Compounds that emit even weak radiation should be stored in a refrigerator (freezer) or behind a concrete wall, etc. [10].

4.2. Software structure

For data collection and processing, the MQTT (Message Queue Telemetry Transport) protocol is used. It is a simplified network protocol that operates over TCP/IP [11].

This protocol uses the "publisher-subscriber" principle for data exchange (Fig. 5).

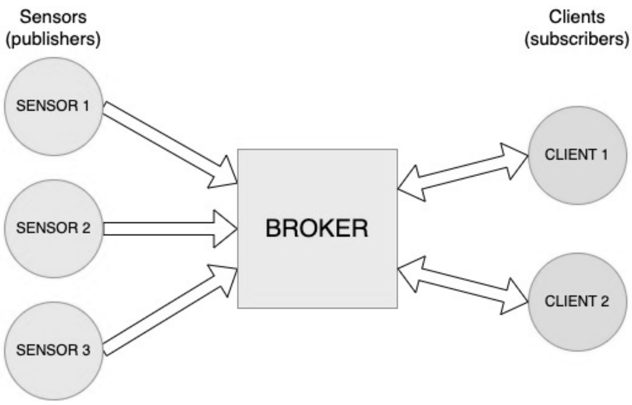


Fig. 5 – **The working principle of the MQTT protocol**

The protocol involves the presence of the following main components:

– "Publisher" – devices responsible for data collection;
– "Subscriber" – data consuming devices;
– "Broker" – devices responsible for the interaction and operation of the protocol.

During the process of development, a "Publisher" device was created. This device will interact with other components through the MQTT protocol. Data processing and publication will be performed using standard MQTT protocol tools.

The advantage of ESP32 boards is the ability to create programs for them in the Arduino environment, using standard libraries written for this platform.

The program consists of two main parts, which are described in the following sections.

4.2.1. Processing of the data received from the Geiger counter

The Geiger counter module outputs impulses which are used to interrupt the MCU program. The number of invoked interrupts per minute is calculated and then transformed into background radiation data.

Calculations are performed using the following code.

Data preparation:

```
#define LOG_PERIOD 20000 //output period in milliseconds
#define MAX_PERIOD 60000 //max monitoring period

unsigned long counts; //count of impulses per minute
unsigned long cpm; //counts per minute
unsigned int multiplier; //multiplier for CPM calculation
unsigned long previousMillis; //time storing variable

float mkzvHours = 0.0; // µSv per hour

void tube_impulse(){//external interrupt handler,
```

```
  counts++; //counts impulse number per LOG_PERIOD
}

void setup(){ //Initial program setup
counts = 0; //clear the impulse counter
cpm = 0; //clear the stored CPM value
multiplier = MAX_PERIOD / LOG_PERIOD; //calc the CPM multiplier
pinMode(2, INPUT); //setup pin 2 as input
attachInterrupt(0, tube_impulse, FALLING); //setup the interrupt
} //on falling edge on pin 2 (signal changes from 1 to 0)
```

Main program loop:

```
unsigned long currentMillis = millis();
if(currentMillis - previousMillis > LOG_PERIOD)
{ //if the difference is greater than LOG_PERIOD, output the current CPM
previousMillis = currentMillis;
cpm = counts * multiplier; //Calc the CPM value
mkzvHours = cpm / 151.0; //convert to µSv/hour
counts = 0; //Reset the counter
}
```

In this program fragment, the number 151.0 is the pulse number conversion coefficient, which depends on the type of Geiger tube. This value is set for the M4011 tube, but it will differ for another variants of tubes. For example, it must be set to 0.057 for the SBM-20 tube.

4.2.2. Publishing the data via MQTT protocol

In the beginning, used libraries must be imported, and network configurations must be set:

```
#include <WiFi.h>
#include <PubSubClient.h>
const char* ssid = "yourNetworkName"; //Wi-Fi network SSID
const char* password =  "yourNetworkPassword"; /Wi-Fi network password
const char* mqttServer = "m11.cloudmqtt.com"; //MQTT server
const int mqttPort = 12948;
const char* mqttUser = "yourMQTTuser"; //MQTT server login
const char* mqttPassword = "yourMQTTpassword"; //password
WiFiClient espClient;
PubSubClient client(espClient);
void setup() {
Serial.begin(115200); // Serial port opened for debug messages
WiFi.begin(ssid, password);
while (WiFi.status() != WL_CONNECTED) {
delay(500);
Serial.println("Connecting to WiFi..");
}
Serial.println("Connected to the WiFi network");
client.setServer(mqttServer, mqttPort);
while (!client.connected()) {
Serial.println("Connecting to MQTT...");
if (client.connect("ESP32Client", mqttUser, mqttPassword )) {
Serial.println("connected");
} else {
Serial.print("failed with state ");
Serial.print(client.state());
delay(2000);
}
}
```

In the main program loop, a message to “esp/CPM” topic is sent every time the value is calculated:

```
client.publish("esp/CMP", CPM); //CPM value output to esp/CPM topic
```

In this part, we establish a connection to the MQTT broker and transmit the readings from the Geiger counter.

4.3. Architecture of the monitoring stations network

The broker Majordomo was utilized to receive the results. It was installed on remotely accessible NAS Synology DS-220+ shown in Fig. 6 [12].

Fig. 6 – **NAS Synology DS-220+**

General system architecture is represented on Fig. 7.

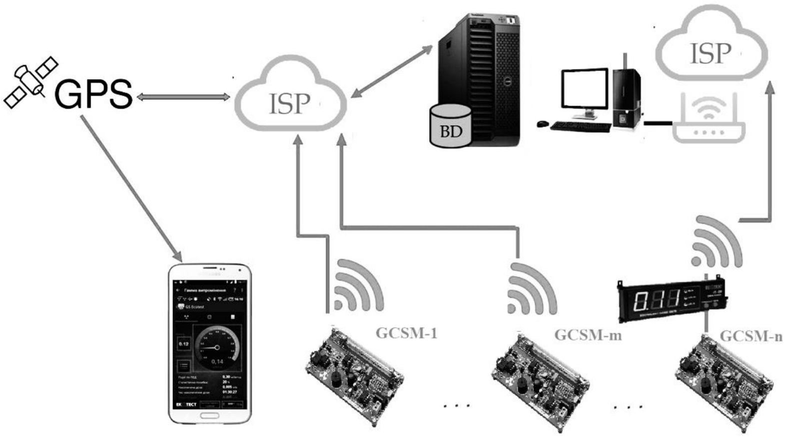


Fig. 7 – **Net diagram of the monitoring stations network**

Information from numerous Geiger counter sensor modules (GCSMs) in real-time arrives through Wi-Fi modules and Internet Service Providers (ISP) to the decision-making center's database (DB). The mentioned DB is located on the network storage (Fig. 6) which is also remotely accessible. Processed data is available to users who have installed an application for monitoring local radiation background. The location chosen in the app or the smartphone's geolocation (if enabled) is used to access the data.

4.4. Results Analysis

An external subscriber program was used to generate a CSV file, which stored data of the measurements with a 1-minute interval. The results of the measurements are displayed in a graph, where time is plotted on the X-axis in minutes and the radioactivity value on the Y-axis in µSv/h (Fig. 8).

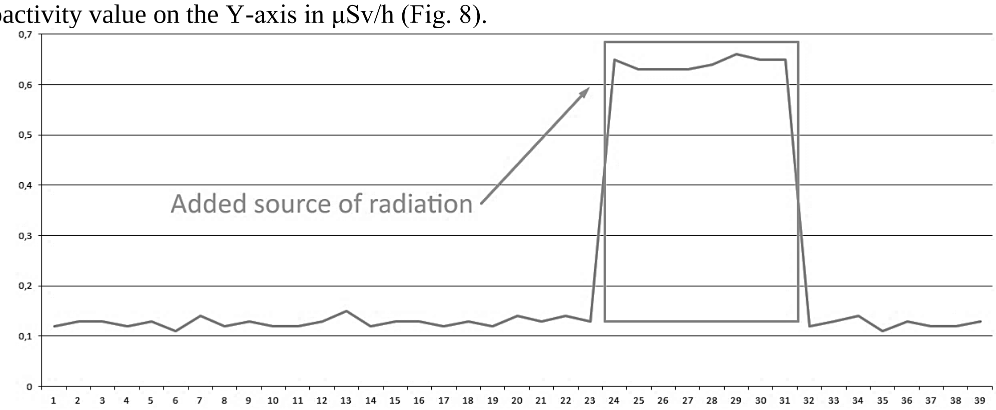


Fig. 8 – **Measurement results**

As seen on the graph, upon bringing the radioactive substance to the Geiger tube, the readings of radioactivity increase to values of 0.61–0.65 µSv/h from the background natural values of 0.11–0.14 µSv/h.

The obtained spike value of 0.65 µSv/h in Fig. 7 exceeds the population's sanitary standard (which is 0.30 µSv/h) almost twice, thus special measures are required from the relevant authorities.

This indicates that all components of the chain "publisher" – "broker" – "subscriber" are functioning properly.

5. Conclusions

It should be noted that weather service messages regarding radiation levels correspond to reality only for a certain limited area. And it would not be accurate to say that its level is consistent throughout the city. The radiation background that is measured using the developed hardware-software complex is a combination of natural and technogenic radiation background (caused by human activity or an emergency) on a dispersed territory.

The territory is expected to be covered by a dense network of developed monitoring stations, from which real-time actual information about the radiation background will be received at the decision-making center. The developed hardware and software system for collecting and transmitting radioactivity values using the MQTT protocol allows both the accumulation and processing of large amounts of data on remote network resources in real time. Real-time notifications about increased radiation background will ensure that the public is well informed about potential dangers, and trained personnel is prepared to protect people from any potential threats.

The use of information technology and automation tools in this study will allow for prompt identification of ionizing radiation levels that pose a threat to human health and for taking necessary evacuation measures.

In the future, an interactive map with dosimeter data can be developed with the ability to view it through a web browser.

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АНАЛІЗ ПРОБЛЕМИ РОЗРОБКИ СИСТЕМ КЕРУВАННЯ ГАЗОФРАКЦІЙНИМИ УСТАНОВКАМИ

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Анотація. *Стаття присвячена проблемі керування газофракційними установками у цілому й окремими ректифікаційними колонами цих установок, таких як деетанізатори, депропанізатори, дебутанізатори тощо.*