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«Intellectual security system for industrial enterprises (ISS)»

Application project

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Introduction

The economy around the world is changing rapidly, with new ways of industrial production being introduced all the time. This is due to the Fourth Industrial Revolution. The main objectives of Industry 4.0 [5] are digitalization and full automation of production processes, which increase productivity and worker safety.

Engineering problem:

Problem: low response rate to industrial accidents due to lack of control over workers and environmental indicators.

Relevance: Occupational injuries are common throughout the world. According to the International Labour Organization [13] (ILO), approximately 340 million accidents occur at work every year, approximately 2.3 million of which are fatal. In addition, 160 million people suffer from occupational diseases every year, and in a third of cases they result in incapacity for work lasting four or more days. If a person is seriously injured at a business due to poor supervision or a slow response to an incident, the enterprise may face various legal consequences and fines. For example, in Russia fines can reach 400 thousand rubles or more (Order of the Ministry of Labor of Russia dated 19.08.2016 N 438n "On Approval of the Model Regulation on the Labor Protection Management System), because the enterprise is obliged to ensure the safety of workers in accordance with the Federal Law of 21.07.1997 N 116-FZ "On Industrial Safety of Hazardous Industrial Facilities". Total economic losses caused by the state of working conditions and occupational safety in the Russian Federation in 2019 amounted to approximately 1.73 trillion rubles, or 1.6% of GDP, according to the Federal State Budgetary Institution "All-Russian Research Institute of Labor" of the Ministry of Labor of Russia [1].

Project plan:

Purpose of the work: development of a comprehensive safety system that monitors the health of workers and environmental indicators.

Objectives:

1. To develop a concept for a system that will reduce response time to accidents;
2. To create a prototype of the system consisting of a helmet module and a chest module;
3. To test the system at an industrial enterprise.

Project stages:

- Development of the theoretical part of the project:
 - Analysis of the causes of injuries;
 - Analysis of existing solutions;
 - Development of the device operation concept.
- Prototyping:
 - Selecting the components;
 - Writing software code for the devices;
 - Manufacturing cases;
 - Assembling the modules;
 - Writing software code to display data from devices.
- Testing the prototype in laboratory conditions and its improvement:
 - Checking the accuracy of data from sensors;
 - Calibration of sensors based on accuracy check;
 - Testing the operating time of devices.
- Manufacturing the industrial design:
 - Selecting of components suitable for industrial enterprises;
 - Modeling the case that meets the required IP protection level;
 - Assembly of devices;
 - Obtaining a certificate of suitability for use of devices at the enterprise.
 - Testing the system at the enterprise:
 - Selection of device testing methods;
 - Selection of methods for processing results;
 - Conducting tests and evaluating their results;
 - Analysis of test results and further planning based on it.

Theoretical part

Causes of injuries at industrial enterprises:

From the diagram (Fig. 1) it is clear that the main cause of injuries and various accidents is **poor organization of labor**. This concept implies a system of measures that ensures the rational use of labor resources. To achieve high labor efficiency, it is necessary that each employee understands his tasks and knows in which areas of the enterprise he is allowed to work. In addition, an important factor is various violations of labor regulations by employees, which result in emergency situations. In such cases, employees need to send an SOS signal.

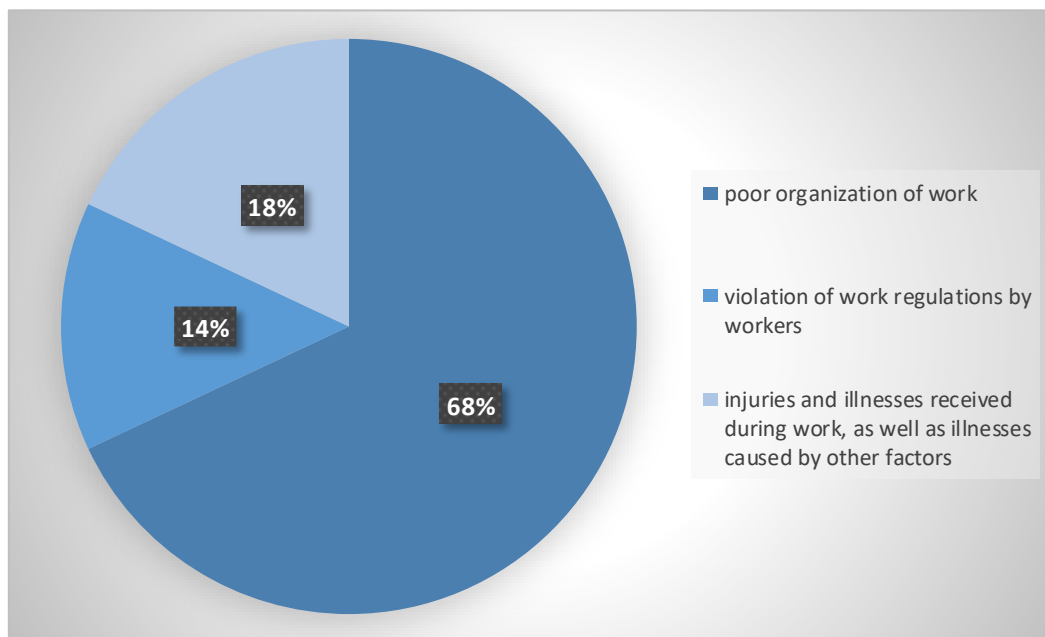


Fig. 1. Causes of industrial injuries [10].

Also, **injuries and illnesses** can often be caused by various factors related to the specifics of the enterprise's work, as well as those related to the action of gravity in various situations. At the moment, according to the current GOST (All-Union State Standard) 12.0.003–2015 SSBT, the following causes of injuries are classified:

1. The action of gravity in cases where it can cause a person standing on a supporting surface to fall onto the same supporting surface;
2. The action of gravity in cases where it can cause a person to fall from a height;
3. Hazardous and harmful production factors caused by excessive air pollution;
4. Dangerous and harmful production factors associated with abnormal microclimatic

parameters of air in the location of a person: temperature and relative air humidity;

5. Worker being in blind spots - incidents involving bunching, etc;
6. Negligence in the use of personal protective equipment.

In addition to monitoring environmental indicators, in order to provide timely assistance to the worker when indicators deviate from the norm or to eliminate the causes of malfunctions, it is necessary to monitor the worker's physical indicators such as pulse and position in space.

The key factor influencing the severity of the consequences of injuries is the time of detection of the incident, since the sooner a problem is detected, the sooner it can be responded to, i.e., the damage can be minimized. Therefore, the solution to this problem is a quick response to emergencies. In addition, a quick response simplifies the investigation of accidents: according to information from the resource “Occupational Safety: Simple and Clear” [9], when an employee immediately reports an injury to management, there are no problems in investigating and registering the accident.

Target audience:

- petrochemical plants;
- oil and gas producing enterprises.

Competitor analysis:

Three main analogues were identified:

- RealTrac "Plant" is a security system for solving problems of meeting industrial safety requirements.
- SOFTLINE "Smart Helmets" - an intelligent system for monitoring industrial safety and labor protection.
- MIRAXST– security system with a wide range of equipment for chemical plants.

After a detailed analysis of competitors, it was revealed that there are currently many projects in Russia aimed at creating similar systems. Each system is effectively used to solve its problems. For example, RealTrac [11] does a great job of eliminating bunching incidents, but the general trend is that most of these solutions are designed for specific enterprises. However, this approach leads to a delay in the implementation process due to the need to study the specifics of each enterprise. This in turn increases costs, since a long system design is required.

Table 1. Competitor analysis

	Worker tracking	SOS signal	Tracked physical and external indicators	Modular approach
SOFTLINE «Smart Helmets»	Signal strength monitoring LoRaWAN	-	Serious impacts to helmet, temperature	-
MIRAX ST	GPS, BLE beacons, LoRaWAN	+	Temperature, humidity, pollution level, pulse	-
RealTrac	Wi-Fi; LoRa; BLE (depends on customer request)	-	Only location is tracked	-

After developing such a solution for one enterprise, developers try to offer their system to other enterprises. However, due to the unique characteristics of each company, such solutions are not always suitable for use in other businesses.

Thus, the main competitive advantage of the project may be a modular approach to creating the system. This will allow the customer to specify the required set of sensors and other equipment. If it is necessary to supplement the system with a new sensor, it is not necessary to produce new modules, but only to integrate the sensor into the existing module. Thus, the enterprise will spend less time on individual development and updating of the system.

Selecting a wireless communication protocol:

To develop a system, it is important to decide on the method of transmitting information. The main selection criteria are:

- Range of action over 80 meters (this distance is determined by the size of the premises of chemical plants);
- High noise resistance when using multiple devices
- High noise resistance to electromagnetic waves of enterprise equipment
- High noise immunity for the use of multiple devices

Thus, Bluetooth was chosen because it meets the specified criteria.

The range of this communication protocol for class 1 devices is 100 meters. Also, Bluetooth is noise-resistant even to microwave ovens, according to the article “Bluetooth Modules in Industrial Applications and Data Collection Systems” [8].

Location tracking technology and transmission of data to the control center:

Many modern Russian enterprises have a data transmission line from equipment to the control center via Ethernet. In this case, data from worker modules can be transmitted to stations interacting with the Ethernet cable line. Information comes to the stations from the employee modules via Bluetooth. If there is no cable line at the enterprise, there are two options for organizing data transmission:

1. Installation of own cable line. This option can be used for small enterprises, since cable wiring will be cheaper than that for large enterprises. This approach provides better data transmission quality.

2. Organization of a completely wireless network. This approach is cheaper than the previous one, because it requires only additional stations. But at the same time, the probability of error is higher in this approach.

The method is determined based on the characteristics of the enterprises, as well as the customer's request and budget.

There are many approaches in the field of local positioning, among which three main ones stand out with their advantages and disadvantages:

1. *Triangulation method* based on signal detection. It is convenient due to simple algorithms for determining the location and a large radius of action, but it requires complex antennas (rotating or with a phased array) and is not very accurate.

2. *Trilateration method*, based on measuring the signal travel time from the device to the base station. It is characterized by low power consumption, high accuracy of location determination and a large range. The only drawback is the need to synchronize the time on all devices.

3. *Signal strength method* allows determining the distance from the base station to the sender by converting power to distance or according to coverage maps. This method is inexpensive and cost-effective, but it is very sensitive to interference and may fail.

Thus, the trilateration method was chosen, because it does not require complex antennas and has a high accuracy of determining the location even at large distances. Let's analyze the algorithm for determining the coordinates of the worker (Fig. 2). Let's choose a reference system associated with the enterprise, and take the top view of the enterprise as the plane. A Bluetooth

station is installed on the production equipment, and the coordinates of the equipment are determined. Let point P be a worker, the point has coordinates that need to be found. When a signal is sent to the worker's module, the time it takes for the signal to reach the recipient is measured, and then the distance is calculated ($S=t*c$, where t is time, c is the speed of light).

Thanks to the value of S , we can find the worker's coordinates using the Euclidean distance formula, since we know the initial coordinates, and the sought-after values are the coordinates of point P . This algorithm is also applicable to three-dimensional space, only the z -axis indicators are added to the formulas.

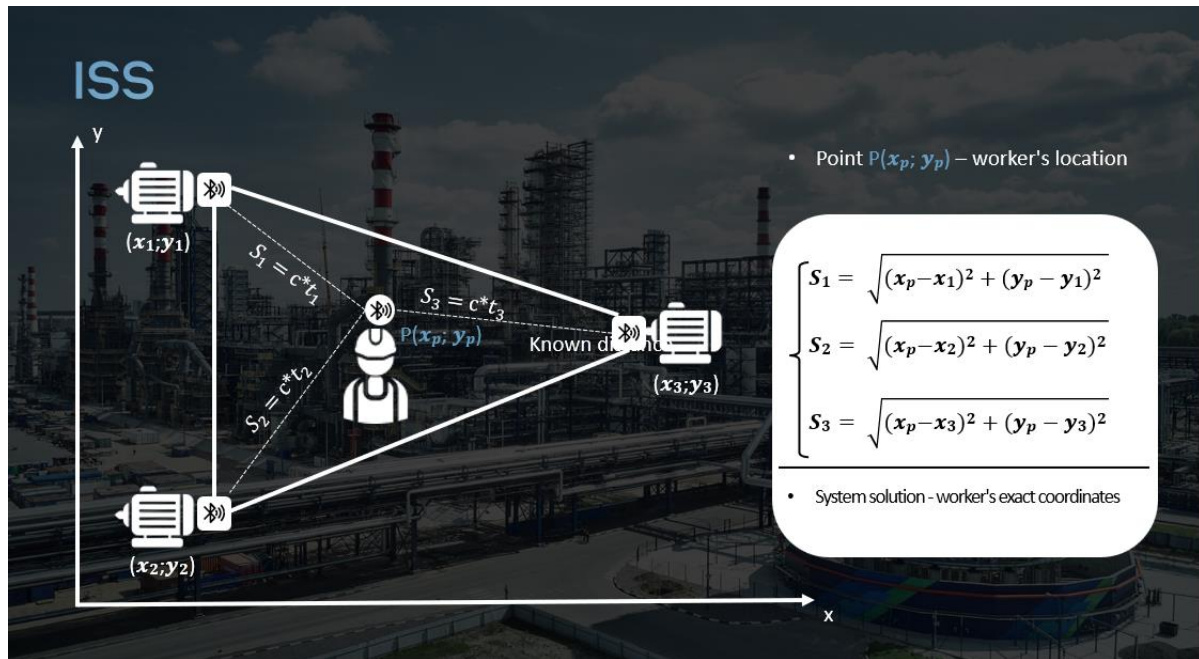


Fig. 2. Determining the coordinates of the worker.

Methods:

As a result of the analysis of information about existing solutions, a concept for the system's operation was developed that allows for a faster response to incidents and the prevention of some of them. The system is a hardware and software complex consisting of various modules worn by employees. The modules have the following functions:

1. Monitoring temperature and humidity;
2. Monitoring the concentration of methane and liquefied petroleum gas;
3. Control of wearing PPE;
4. Location tracking;
5. Strong blows to the helmet, as well as falls of the worker;

6. Possibility of sending an SOS signal, as well as the possibility of sending messages from the control center.

The specific factors that will be monitored depend on the specifics of the enterprise. Since the modules are sectional, the number of monitored indicators can be increased in the future. In addition, to eliminate traumatic cases caused by a worker being in a blind spot, it is proposed to implement additional functions related to the automatic sending of notifications about the worker's close proximity. The basic set of modules includes:

1. Helmet module equipped with a flammable gas sensor, an accelerometer for tracking falls and movement, and an RGB LED for hazard signaling. If the worker does not move for more than 5 minutes, a message will be sent to him asking if he is okay. If the worker does not respond to this message, then a notification will be sent to the control center for further response to the incident;

2. A watch-shaped module or a chest module (depending on the customer), equipped with a display, which is necessary for displaying notifications, a climate sensor, an SOS button and a button for reading messages.

3. Module for other personal protective equipment. In addition to helmets and special clothing, it is often necessary to track the wearing of gloves, masks, etc. Therefore, it is proposed to use a special module that will have an accelerometer to monitor PPE wearing. At the beginning of the working day, the device will record a specific PPE.

- Base stations for tracking the location of an employee. These can be special equipment that sends signals to employees' wearable modules, or equipment units at the enterprise. The choice of station depends on the specifics of the enterprise, be it open space or closed premises. If there is wired data transmission (Ethernet) at the enterprise, it is possible to use this signal as the main one for communication with the control center. This reduces the number of pieces of equipment for wireless data transmission and increases the accuracy of positioning, because the position of a person will be determined wirelessly in a specific area and then transmitted to the control center via Ethernet. In other cases, when the enterprise does not have a data transmission cable line, an additional number of transmitter-receiver beacons is required.

The modules worn by the employees send a signal, then, having determined their location using trilateration, transmit data from the sensors to base stations, and the information is then sent to the control center for further processing.

- Software installed in the control center, which processes data coming from the modules, as well as data on the location of employees.

Practical part

First system prototyping:

In order to test the proposed technologies, it was decided to create a prototype of the system, which includes a chest module, a helmet module and a data processing program. Thus, the following components were selected for the prototype:

- Arduino-Nano board. 2 pcs.
- jdy-31 Bluetooth module. 2 pcs.
- SHT21 digital humidity and temperature sensor.1 pce.
- MQ-5 combustible gas sensor.1 pce.
- Troyka-module accelerometer.1 pce.
- OLED-display module 1, 54дюйма.1 pce.
- Button.1 pce.
- RGB LED.1 pce.
- Switch.1 pce.

To create modules, you will need cases that will be printed on a 3D printer from ABS plastic. In addition, you will need a soldering iron to connect the components, as well as the following consumables:

1. Flux rosin
2. Solder
3. Insulation for wires

The power supply will require charging modules and 5V batteries.

Helmet module designing:

The module that tracks a person's position in space, sudden falls of a person, lack of movement, and the level of gas concentration must be equipped with an RGB LED that acts as a status indicator (green - good, yellow - problems, red - danger). The location of such a module is especially important, since it is necessary that the indicator be in the worker's field of vision. Two options for the module's location were proposed: in place of the headphones using a special mount and in place of the flashlight (front part of the helmet).

The components are connected according to the diagram shown in Figure 3.

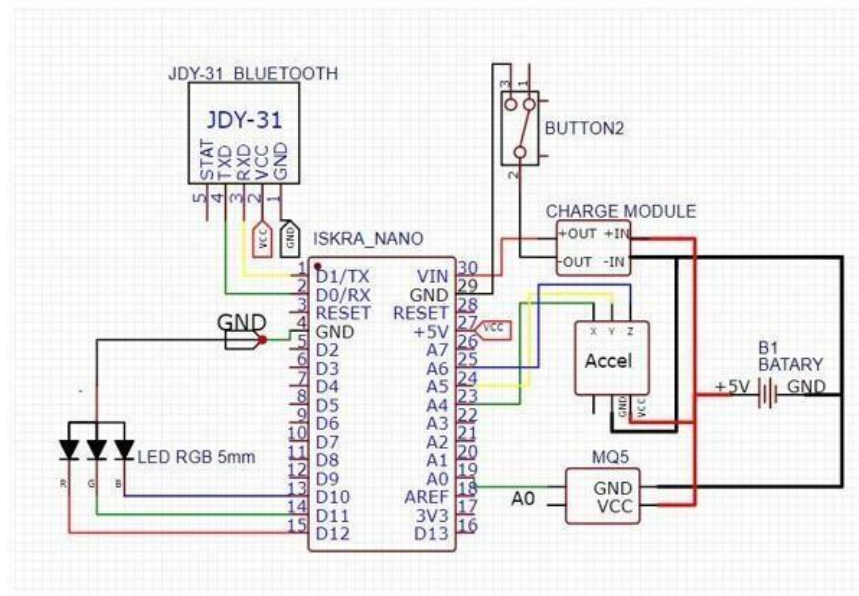


Fig. 3. Helmet module diagram.

The color of the LED is determined based on the state of the worker and the environment. In addition, the message sent to the control center depends on the fall type. In case of a fall from a great height, the message "BIG FALL" is displayed. The concentration value of natural gas and methane is also displayed. The fall is determined by processing the accelerometer readings. The initial and final acceleration values are compared along the three axes.

If the difference is greater than a specific threshold value, a corresponding message is displayed.

```
int x = round(accel.readAX());
int x1 = round(accel.readAX());
if (abs(x - x1) > 5 or abs(x1 - x) > 5)
{
  Serial.print("2");
  Serial.print(',');
  Serial.println("BIG FALL!");
  g = 0;
  r = 1;
  b = 0;
}
```

Fig. 4. Fall detection.

To transfer these values from the module to the computer via Bluetooth, the values are output to the board's COM-PORT, because the JDY-31 module communicates with the board via the UART interface. For the interface to work correctly, it is necessary to correctly form a data

packet.

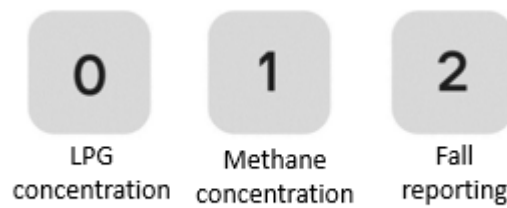


Fig. 5. Data sending package (helmet module).

The data is generated using the key-value method, Figure 5 shows the correspondence of a specific key to a value, and Figure 6 shows a fragment of the code responsible for reading data from the gas sensor and sending it to the COM-PORT.

```
l = float(mq5.readLPG());  
m = float(mq5.readMethane());  
  
Serial.print("0");  
Serial.print(',');  
Serial.println(l);  
Serial.print("1");  
Serial.print(',');  
Serial.println(m);
```

Fig. 6. Sending data from MQ5

[Link to the full program code for the helmet module](#)

Chest module designing:

As mentioned earlier, this module can also be made in the form of a watch, but a rectangular shape was chosen for the prototype due to the large dimensions of such a device.

It is planned that the module will be located in the breast pocket of special clothing. This device may have various functions, but it was decided that the prototype will perform the following functions:

- reading temperature values;
- reading humidity values;
- sending an SOS signal;
- displaying messages from the control center.

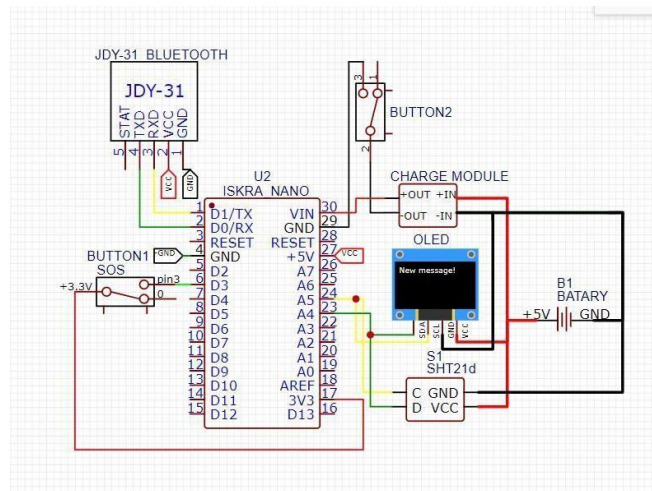


Fig. 7. Chest module prototype diagram.

The SOS button is a slicer to prevent accidental pressing of the regular button. Similar to the helmet module, data is output to the COM-PORT, and messages from the control center are read and displayed on the display.

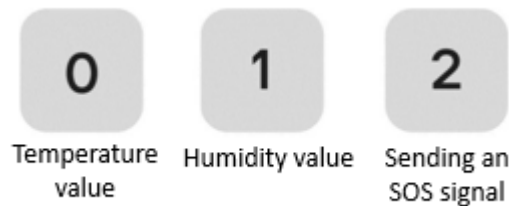


Fig. 8. Data sending package (chest module).

The data is also formed using the key-value method; Figure 8 shows the correspondence of a specific key to a value, and Figure 12 (in the appendix) shows a fragment of the code responsible for sending the information.

The data sent from the control center also has its own specific format: a text message consisting of no more than 50 characters and necessarily ending with a semicolon. The code in Figure 13 (in the appendix) shows the code that cuts the value down to the “;” sign and writes it to the data array so that it would be possible to add the ability to send more messages at once. After this, a text appears on the display indicating that a new message has been received.

[Link to the full program code for the chest module](#)

Designing the cases for devices:

For a laboratory sample of both devices, it is enough to create a case that does not meet

dust and moisture protection standards. It is undeniable that for further versions of the prototype, it is necessary to develop a case that meets the IP65 standard. Figure 14 (in the appendix) shows the final versions of the 3D models of the devices. During the design, all necessary holes for sensors, etc. were taken into account. The final models of the devices were printed from white PTG plastic.

Development of GUI application:

To develop an application displaying data from modules, the Processing programming language was chosen, which is designed to create multimedia applications. The processing.serial libraries are also used to read data from COM-PORT and controlP for various visual elements.

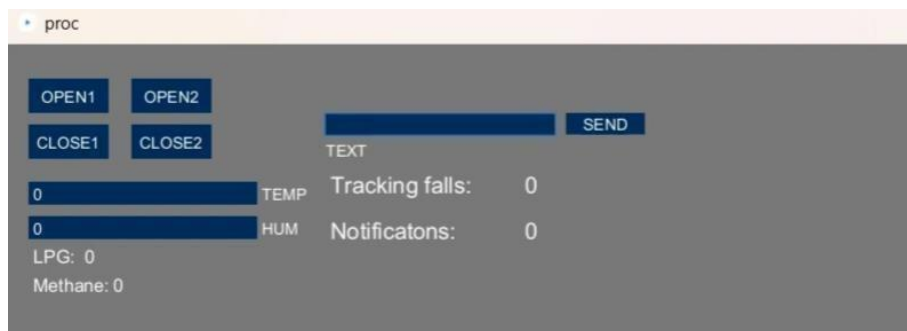


Fig. 9. GUI application.

The most important part of the program code is parsing the data received from the Bluetooth module. The code splits the string into keys and values. An example of a string received from the module: "0, 28; 1, 68;". After splitting the string, a switch&case construct is used to write the value to the allocated variable, which is then used for display in the interface (Fig. 15). The code also contains a function for sending data to the chest module. Сначала считывается значение с определенного текстового поля в интерфейсе. First, the value is read from a specific text field in the interface. Then, this value is typed to the COM-PORT of the chest module. Example of a data packet: 0,dowork;

```
void send()
{
  val = cp5.get(Textfield.class, "text").getText();
  println(val);
  serial1.write("0,"+val+");");
}
```

Fig.10. Sending a message to the chest module.

[Link to the program code of the GUI application](#)

Results

During the work on the project:

1. The causes of injuries at enterprises were studied;
2. The concept of the system operation was developed;
3. An interface for monitoring the conditions of workers in real time was developed;
4. The first prototype of the system is designed;
5. Two consultations were held with an expert from the company OOO Gazprom Dobycha Shelf Yuzhno-Sakhalinsk. During the consultations, it was possible to learn about the causes of injuries, as well as receive recommendations for the project.



Fig.11. Prototype.

The helmet module performs the following functions:

1. Reading and outputting methane and liquefied petroleum gas concentration data;
2. Tracking falls and strong impacts to the helmet;
3. LED color change when detecting strong impacts to the helmet or human falls;
4. Transferring data via wireless communication protocol.

The chest module performs the following functions:

1. Reading temperature and humidity data;
2. Sending SOS messages using a switch;
3. Displaying messages from the control center on the device display;

4. Transferring data via wireless communication protocol.

GUI application works successfully. Data is correctly output from both modules without delay.

Interpretation of results

Link to demonstration of the helmet module

Link to demonstration of the chest module



Fig. 12. QR code for demonstration of the helmet module operation.



Fig. 13. QR code for demonstration of the chest module operation.

Conclusion:

By collecting and analyzing data on the condition of employees and the environment, the developed system for monitoring the condition of workers in real time allows for the timely identification of potentially dangerous situations and prompt response to them. This contributes to a significant reduction in the level of industrial injuries and improvement of working conditions, increasing overall safety at the enterprise. In addition, the system provides valuable

information for analyzing the causes of incidents and developing measures to prevent similar situations in the future, which leads to optimization of production processes and reduction of economic losses caused by accidents.

In addition, the system was compared with analogues.

Table 2. Comparison of the system with analogues.

	Employee tracking	Signal SOS	Monitored physical and external data	Modular approach
ISS	<u>Bluetooth+Ethernet</u> ; Bluetooth	+	Pulse, movement, major falls, temperature, humidity, pollution levels, etc.	+
SOFTLINE «Smart Helmets»	Tracking signal strength <u>LoRaWAN</u>	-	Serious blows to the helmet, temperature	-
MIRAX ST	GPS, маяки BLE, <u>LoRaWan</u>	+	Temperature, humidity, pollution level, pulse	-
<u>RealTrac</u>	Wi-Fi; <u>LoRa</u> ; BLE	-	Employee tracking only	-

Thus, the ISS system will be able to become a competitive product on the Russian market with the help of a modular approach to devices, and as a result, become more efficient for many enterprises.

Further development:

It is planned to receive official documents from industrial partners confirming the relevance of the work in the near future. Thus, it is planned to conduct tests of the system at a petrochemical enterprise. After testing the system, it is necessary to analyze the behavior of the devices in the field and refine them.

Appendix

```
Serial.print("0");  
Serial.print(",");  
Serial.println(temp);  
Serial.print("1");  
Serial.print(",");  
Serial.println(hum);  
Serial.print("2");  
Serial.print(",");  
Serial.println(str1);
```

Fig. 14. Sending data from the chest module.

```
if (Serial.available())  
{  
  buttl.tick();  
  char buf1[50];  
  int i = Serial.readBytesUntil(';', buf1, 50);  
  buf1[i] = NULL;  
  GParser data(buf1, ',');  
  int ints[10];  
  data.parseInts(ints);  
  switch (ints[0])  
  {  
    case 0:  
      buttl.tick();  
      data.split();  
      oled.clear();  
      oled.home();  
      oled.print("New message!");  
      delay(3000);  
      oled.clear();  
      oled.home();  
      oled.print(data[1]);  
    }  
  }  
}
```

Fig.15. Processing messages from COM-PORT and displaying them on the display.

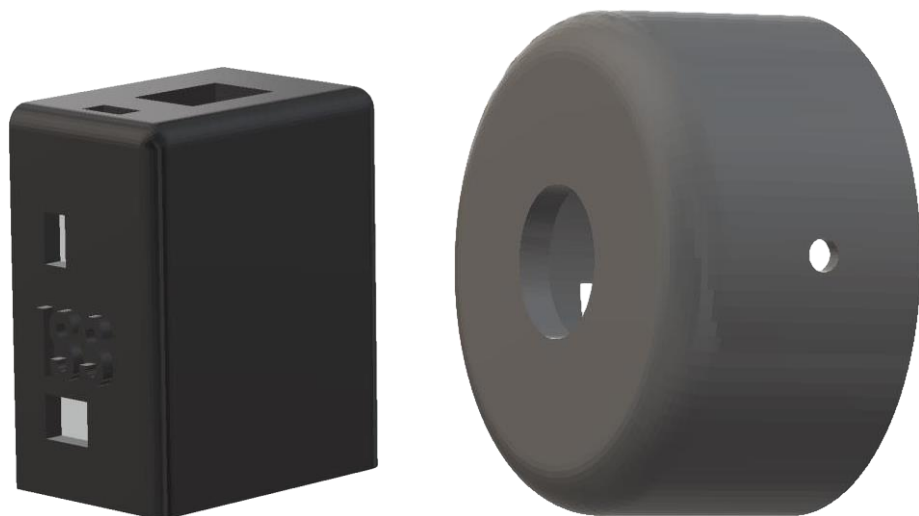


Fig. 16. 3D models of devices.

```

if (serial2 !=null)
{
    if (serial2.available()>0)
    {
        String str = serial2.readStringUntil('\n');
        str = str.trim();
        String data2[]=str.split(",");
        int key = int(data2[0]);
        switch(key)
        {
            case 0:
                lpgVal = str(int(data2[1]));
                break;
            case 1:
                metVal = str(int(data2[1]));
                break;
            case 2:
                moveVal = data2[1];
                break;
        }
    }
}

if (serial1 !=null)
{
    if (serial1.available()>0)
    {
        String str = serial1.readStringUntil('\n');
        str = str.trim();
        String data1[]=str.split(",");
        int key = int(data1[0]);
        switch(key)
        {
            case 0:
                temp = int(data1[1]);
                break;
            case 1:
                hum = int(data1[1]);
                break;
            case 2:
                notVal = data1[1];
                break;
        }
    }
}

```

Fig.17. Splitting the data packet into final values.

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【評語】 100046

1. The research topic matches the global human needs for a better working environment.
2. In addition to describing the engineering process of this research work, it would be good (also required) to present the innovation of this work. A comparison of the proposed system with existing state-of-the-art methods should be provided in the introduction so the advances, contributions, and novelty of the approach can be identified.
3. The report only covers the design part, including prototype making and experimental validation would be good.
4. Bluetooth, initially designed for short-range, low-bandwidth communication, was controlled as a serial port in computers. However, the limited number of serial ports on computers restricts the number of concurrent users. Additionally, when users move in a large space or encounter obstacles, the communication range may be shortened, requiring communication with a set of nearby fixed stations. In such scenarios, authors should consider how to track these devices.

5. Since there would already be ethernet communications, authors are advised to consider Wi-Fi over Bluetooth. For large enterprises, integrating with existing (mesh) Wi-Fi coverage may be more convenient.
6. For enhanced precision in positioning, ultra-wide band technology may prove advantageous.
7. What is the tracking (localization) accuracy?
8. Do you consider the false negative and false positive in the sensor data?