

FEATURES OF THE IMPLEMENTATION
OF SMART TECHNOLOGIES IN THE MINEMaksym Butov¹, Tetyana Pavych², Yaroslav Paramud¹¹ Lviv Polytechnic National University, 12, S. Bandery Str., Lviv, 79013, Ukraine.² MedBridge Inc, 1633 Westlake Ave, Seattle, WA, 98109, USA

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Abstract: The basic methods and principles of mine safety systems have been considered in the paper. The algorithm of one possible smart device (smart helmet) is depicted. This algorithm describes the basic principles of this device. The device allows to find danger in the environment where the miner works, as well as monitors the condition of the miner. It can also quickly analyze this information and report the danger when it is detected. The system has been developed and programmed including basic modules for implementing this algorithm. The results of the comparative analysis of the new system showed an increase in the level of safety by 45 % compared to other systems.

Index Terms: Computer system, Warning systems, sensors, smart technology.

I. INTRODUCTION

Much attention has been paid to portable (electric) devices since Google Inc. released its Google Glass. Handheld devices have been able to gain a significant place in the consumer electronics market in a short period of time and they are considered a new tool to meet the needs of many industries. For example, the construction industry has introduced the use of portable devices in the workplace to monitor health and safety by detecting approaching hazards and physiological monitoring of construction workers. The logistics industry has begun using glove scanners to scan barcodes to simplify non-hands-on work, and some insurance companies have already promoted the use of portable devices to encourage healthier eating. In addition, devices such as fitness trackers are being used by medical professionals to obtain physiological, behavioral and contextual data for diagnosis and treatment. While much research is still ongoing to determine how these devices can be better adapted to different industries, the use of portable device technology is expected to expand significantly in the near future.

In mines, unfortunately, most of the time old stationary sensors and warning systems are still used, which does not provide a guarantee that a gas leak will not occur outside the sensor range and the miner will be informed about it [1]. Also, none of the existing systems

process the information immediately, but pass it outside to the control room, thus precious time is wasted [2]. Therefore, a new system is needed, which should include not only a ground monitoring system, but also an autonomous handheld module that will process the data and inform the miner of the danger both inside the mine and about the health of the miner [3].

The introduction of new smart technologies should be based on modern microcontrollers [4], a gas sensor [5], temperature sensor [6], heart rate sensor [7], light sensor [8], distance sensor, sound alert device, light warning devices, vibrating alert device, LCD display, flashlight, data transmission device, overhead monitoring complex.

The systems that now provide occupational safety monitoring in the mine are divided into two types. The first most common ones do not meet modern safety standards and have a number of drawbacks. An example of such systems is "Radius-2" [9]. The others are too large-scale and expensive. An example of such systems – "SBGPS" [10].

A review of literary sources indicates the relevance and feasibility of conducting research on the implementation of modern smart technologies in the mine.

II. COMPARATIVE ANALYSIS OF EXISTING
SYSTEMS FOR MONITORING LABOR SAFETY IN
THE MINES

The main disadvantages of a considerable part of the existing systems, ensuring work safety in a mine, are stationary location of sensors and lack of monitoring of miners' condition from outside. Examples of such systems are Radius -2, SUBR-1P, SBGPS. The first two systems are the most widespread and used, the last one requires sufficient investment and time for its implementation.

A. RADIUS-2 AND SUBR-1P

Radius-2 and SUBR-1P are the most common systems that ensure work safety in the mine. They are based on the technology of signal transmission through the rock strata. These systems are the most reliable,

because they are not afraid of cable breaks, as the transmission is carried out by low-frequency electromagnetic waves using a frequency grid from the lower range of 25 Hz to 2500 Hz in increments of 50 Hz. The coverage area of the "Radius-2" complex is up to 2000 m deep through the mountain massif and up to 15 km along the mine field. The transmitting antenna of the complex, which is a grounded dipole or frame covering the mine field, can be suspended on the poles of power lines, laid on the ground surface in the ground or underground mine workings, safe with respect to gas and dust. The antenna is connected to the power amplifier PDD, which, depending on the geometric dimensions of the mine field, the geoelectric properties of rocks selected from a range of 1.25, 2.5, 5.0, 10, 15 kW [9].

B. SBGPS

The SBGPS system is one of the most modern and technologically advanced on the market. The underground part is a network of base stations (BS) and individual notification devices. The distance between each base station is 200-500m, for full radio coverage of the entire area of the excavation.

The system uses a hybrid connection method because it uses Mesh-Net technology.

The individual notification device is an ordinary miner's flashlight, attached to the helmet. In addition, it also consists of a WiFi module, through which communication with the infrastructure is continuously ensured, a voice processor, as well as a methane sensor, which allows for a more complete aero gas control in workings, supplementing the stationary sensors. The operating time of this light is 44 hours [10].

The above-ground part consists of a control panel, located at the dispatcher, and a server that continuously receives and processes data from the sensors.

This system continuously receives and processes signals from both stationary sensors and from sensors on the miner's head. If it is detected that the concentration of methane exceeds the permissible norm, this information about the danger is immediately transmitted to the dispatcher. And he transmits a safety signal to the BS, which in turn transmits it to the miner.

In fact, such types of radio communication can effectively cope with the task of emergency notification of underground personnel only in small mines. If you try to implement it in a mine with a very long excavation, the number of BS will be extremely large and this implementation will turn out to be too expensive. Another disadvantage is that the information is processed outside, not inside, and there is no monitoring of the state of the miner himself.

III. FORMULATION OF THE PROBLEMS

Today, the mining industry is one of the most dangerous and underdeveloped in the use of portable smart devices. Although miner safety is one of the most important issues in this field, the systems that provide it

are in one case too outdated, or not up to code, and in another case, they are so expensive and extensive that the benefit from their use is minimal. At present in the countries with developed mining industry, such as Japan, Poland, Australia, USA, Great Britain, etc., they use different types of systems ensuring safety of miners in a mine on the basis of modern information technologies.

The general structure of such systems consists of two main parts:

1) Ground complex of devices:

- Central monitoring department (production and dispatching department). The monitoring system operates from a continuous power supply, in case of failure of voltage supply, the system begins to be powered from the standby power grid or generator. All characteristics of the system are in the central monitoring department.

- The production department can use the information, but cannot interfere with the system; the maintenance personnel can understand the condition of the environment in the mine via the local network.

2) Underground complex of devices:

- Devices in the mine – gas sensors installed to monitor the condition of the air in the workings.

- Signal conversion and transmission devices.

- Air velocity sensors, which are usually installed in the same workings, as well as in the ventilation shafts of the head ventilation fan.

- Automatic switches that ensure the power is turned off when the concentration of hazardous gas exceeds a predetermined threshold.

All of these sensors are stationary, although in mine development these sensors are placed in places where there is an increased risk of gas that will threaten the lives of miners, this does not guarantee that the dangerous gas will appear in this particular place and not elsewhere. And since the warning systems are located in specific places, if the miner is far enough away from that location, or is working near a loud device, he simply won't hear it [1].

Another big disadvantage of such systems is that almost all have information transmitted to the outside, then processed, and only then, in case of danger, is it transmitted back to the mine and only then the warning systems are activated. As a consequence, in the case of a breakdown, the signal may simply not reach the miner at the right moment. Also, none of these systems tell the miner exactly what happened [2].

The general structure of the labor safety monitoring system in the mine is shown in Fig. 1.

From this, we can conclude that the problem of ensuring the safety of the miner in the mine is quite relevant and important to create a new system, using smart technology. This system will include an above-ground monitoring system for the condition of the mine, as well as the health of the miners themselves, and an autonomous portable module that will independently

notify the miners of the danger and send the information about the condition of the miner and the mine workings, to the outside [3].

IV. THE AIM OF THE WORK

The aim of the work is to increase the level of safety in one of the least developed industries – the mining industry by introducing modern intelligent technologies, as well as to reduce the number of incidents related to material and human losses. Among others: to improve one of the most problematic characteristics of older systems, namely the coverage of the mine, and to provide autonomy of parts of system.

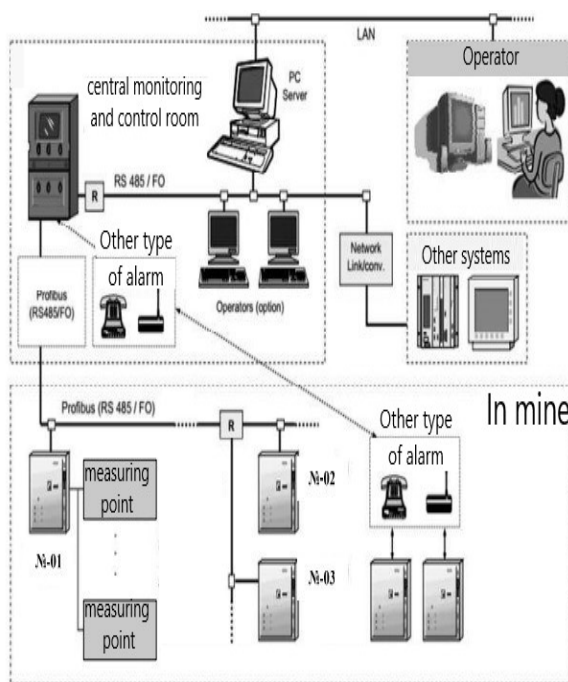


Fig. 1. The general structure of the labor safety monitoring system in the mine

V. THEORETICAL FOUNDATIONS OF SMART MINE

A smart mine must consist of an above-ground and underground set of devices that can interact with each other or work autonomously of each other. Structural diagram of a smart mine is shown in Fig. 2. Therefore, the smart mine system must include an autonomous portable module, the first part of which will be attached to the miner's helmet, and the second part – to his arm. The helmet will contain sensors, a microcontroller, warning and data transmission devices.

Owing to this module, a number of problems will be solved, namely:

- Since the sensors are now portable, the entire working area of the mine will be covered, not just where the sensors are installed.
- Owing to the microcontroller, the system will be able to process the information immediately and

report the danger, instead of waiting for a response from the above-ground part.

- The warning devices will always be close to the miner, so he will always be notified of the danger.

Owing to the transmission devices the above-ground monitoring complex will always have information not only about the mine workings but it will also be able to see information about the state of health of each worker, namely his condition and where he is. Also, in the event of an accident, the dispatcher at the top will be able to inform the closest miners, who can quickly rectify the situation.

- Since this module is self-contained, it can continue to work and ensure the safety of the miner even in the event of a break in communication or if it is used without an above-ground part.

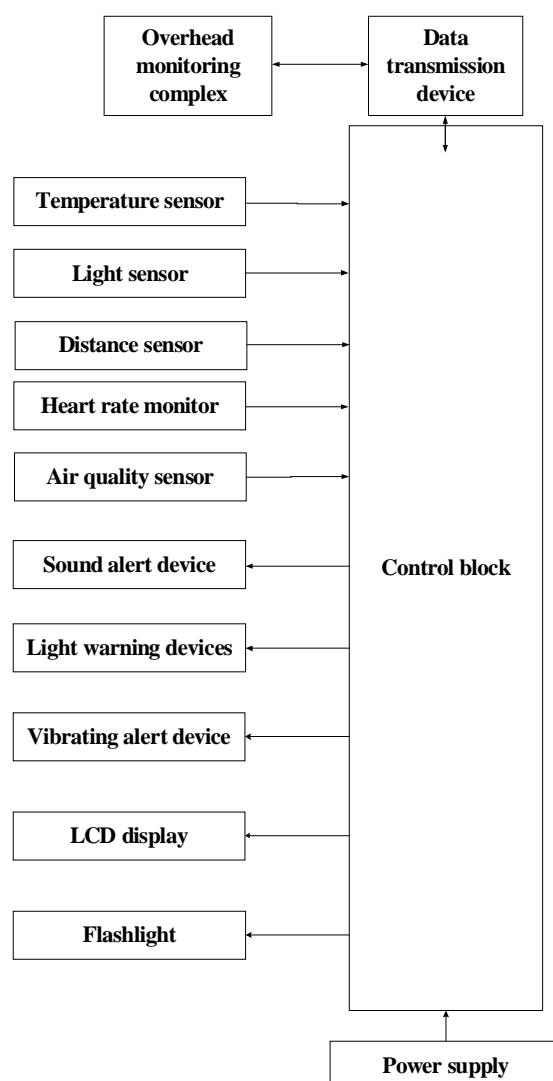


Fig. 2. Structural scheme of a computer system for monitoring labor safety in a mine

A screen (like a watch) will be placed on the miner's arm, which will help the miner understand what kind of accident has occurred, as well as monitor the

battery charge, because if the battery charge is low, the sensitivity of the sensors may be reduced or their operation will be suspended altogether.

To ensure reliability in the system, each base station will be additionally connected to several other system components. As a consequence, as a result of a break in the main line, the signal will communicate wirelessly with the nearest base station

This connection technology is called Mesh-Net, which ensures that if there are problems along the way, the signal will move from one node to another, looking for a path to the destination.

The system will also be open to new functionality that will further improve mine safety monitoring.

VI. BASIC PRINCIPLES OF OPERATION OF THE NEW SYSTEM

Generalized algorithm of the autonomous system device is shown in Fig. 3.

The first step initializes all necessary foams of the system and switches on all subsystems: gas sensor, temperature sensor, light and pulsometer as well as light, vibration and sound alarms. The required default data for the sensors is also set.

The next step is the process of obtaining the data required for analysis from the gas sensor.

After that, the received value is analyzed for exceeding the permissible gas concentration, and if it is exceeded, a signal is sent to the alarm device. In turn, the frequency of operation of these devices depends on how much the concentration limit is exceeded.

The next step is to obtain the temperature sensor data required for analysis.

After that, the received value is analyzed for exceeding the allowable temperature, and if it is exceeded, a signal is sent to the alarm device. In turn, as in the case of the gas sensor, the frequency of operation of these devices depends on the allowable temperature is exceeded.

The next step involves obtaining the necessary data from the light sensor.

After that, it is checked whether the received value of the illuminance value is lower than the nominal value. If this is the case, a signal is sent to the lantern and it is switched on. Also, if the lantern has already been on and the value of the illuminance value is above or equal to the rated value, a signal is given to turn it off and the lantern is turned off to save power.

Then, the next step, the data from the heart rate monitor is received.

The value received is then analyzed. If it is lower or higher than the norm, a signal is sent to one of the warning lights, and the frequency of its operation will depend on whether the norm has been lowered or exceeded.

Also, all data of the miner's condition monitoring is always displayed on the screen as well as data of his working environment.

This algorithm is in fact an endless cycle, as all measurements are cyclic. The exit from this cycle is to turn off the device.

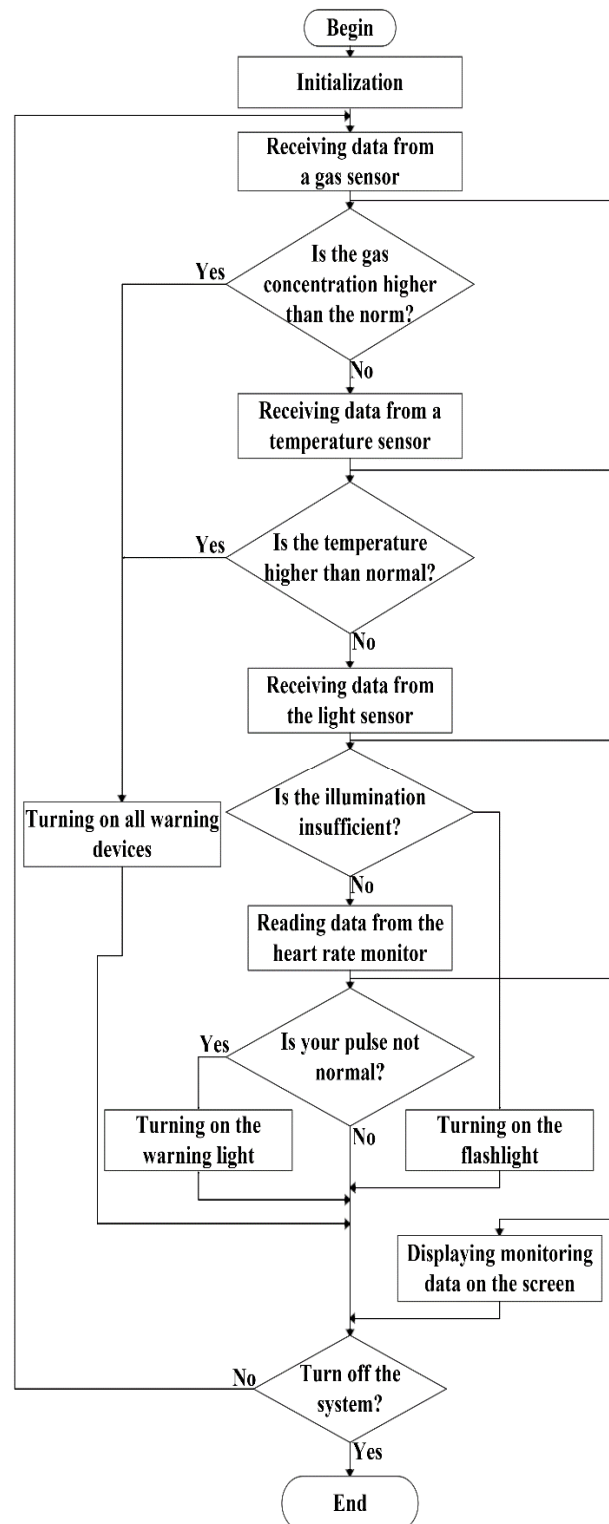


Fig. 3. Generalized algorithm of the autonomous system device

VII. FUNCTIONAL PRINCIPLES OF SOFTWARE AND HARDWARE IMPLEMENTATION OF THE MAIN COMPONENTS OF THE AUTONOMOUS PART OF THE SYSTEM AND TESTING OF THE OPERATION ALGORITHM

The functioning of all nodes of the microcontroller is provided by the clock pulses generated by the clock generator. The microcontroller ATmega328 includes a built-in oscillator for these clock pulses. But in Arduino UNO the clock of this microcontroller is controlled by an external clock with a 12 Mhz crystal oscillator. It is connected to the microcontroller through the outputs XTAL1 and XTAL2 [4]. The wiring diagram is shown in Fig. 4. The gas sensor MQ-2, which measures the concentration of gases harmful to the miner, is connected via output A0 on the module to the analog output A5 on the Arduino. The VCC and GND outputs on the module are connected directly to the 5 V and GND outputs respectively. No additional elements need to be connected [5].

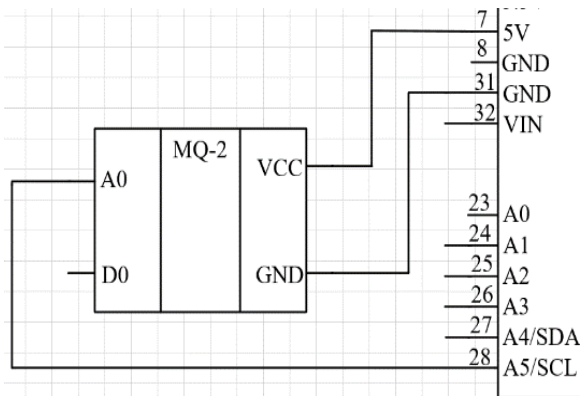


Fig. 4. Wiring diagram of the MQ-2 gas sensor

The DS18B20 temperature sensor, which measures high and low temperatures for miner operation, is connected via the DQ output on the module to the digital input D11 on the Arduino. The VDD and GND outputs on the module are connected directly to the 5 V and GND outputs respectively. It is also mandatory to connect an additional 4.7 kOhm resistor from the signal wire to the power wire. This is done due to the fact that the signal transmitted through the signal wire is quite small, so it is pulled up by the additional power from the 5 V [6]. The wiring diagram is shown in Fig. 5.

The pulsometer XD-58C, measuring the miner's heart rate too high or too low, is connected via output S0 on the module to the analog input A4 on the Arduino. The VCC and GND outputs on the module are connected directly to the 5 V and GND outputs respectively. No additional elements need to be connected [7]. The wiring diagram is shown in Fig. 6.

The light sensor (photoresistor), which checks enough light in the mine working for comfortable work of the miner, is realized as a voltage divider. The connection diagram is shown in Fig. 7. One output it is connected to GND and the other to the analog output A0

and the voltage source. To the voltage source it is connected through a 10 kOhm resistor. As a result, in this connection scheme the maximum voltage value will correspond to absolute darkness and the minimum value to good light. Also, the connected resistor performs an additional function, namely to limit the amount of current in the branch, so that when the resistance of the fully illuminated resistor disappears the connection foams do not burn out [8].

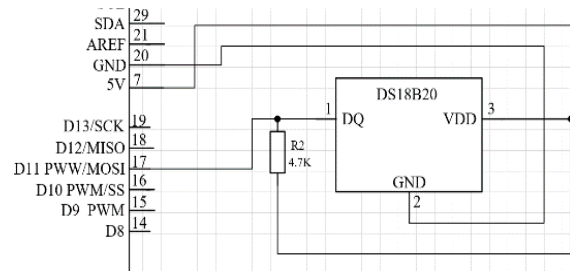


Fig. 5. Wiring diagram of the DS18B20 temperature sensor

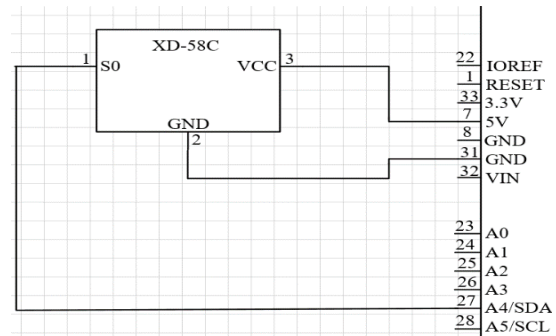


Fig. 6. Wiring diagram of the XD-58C heart rate sensor

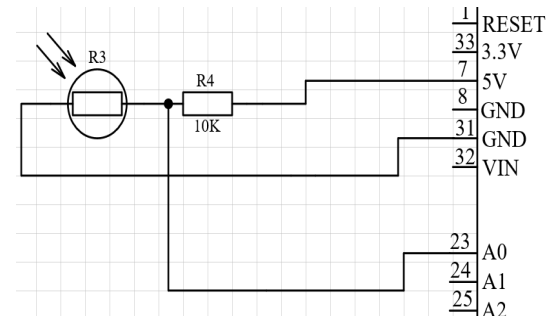


Fig. 7. Wiring diagram of the GL5516 light sensor

The software implementation of this algorithm assumes the presence of such architectural modules of the program:

- Module for receiving input data – designed to receive input data from sensors and write them into variables for subsequent analysis.
- Module for data processing – analyzes data from the gas sensor, temperature sensor, pulsometer, and light sensor. Each gas concentration, temperature or pulse value has its own code block with its own parameters for alarm systems. In the case of the light sensor, it analyzes whether the light level is less than normal.

- Module of notification system launch – includes light, sound and vibration notification systems in case of receiving disappointing data from the data processing module.

- Module of information output – performs a second output of information about the miner's state and the state of the environment on the screen.

Since this system consists of 4 sensors, let's test the operation of each of them separately. First, let's check if the system outputs correct and expected data from all sensors.

Table 1 shows the data that our system receives under normal conditions. Where the first value is the heart rate value for a person, the second is the gas concentration in the room, the third is the darkness value, and the last is the temperature in the room. When you look at these values, you can immediately see that they are all normal.

Table 1

Data obtained from sensors

Pulse value	Gas value	Light value	Temperature value
75	37	156	22
75	36	157	22
75	36	157	22
75	36	157	22
75	37	156	22

In order to test the gas sensor, a jet of methane gas was sprayed on it. This was done with an ordinary lighter. As it can be seen in Table 2, the gas concentration increased, as a result of which the red LED on the circuit began to blink, the vibration motor started to work and a sound was heard from the loudspeaker, reporting the danger.

Table 2

Gas sensor operation testing

Pulse value	Gas value	Light value	Temperature value
75	40	156	22
75	142	157	22
75	218	156	22
75	341	157	22
75	457	156	22

In order to test the temperature sensor, the air around it was heated with the same lighter. As it can be seen in Table 3, the temperature value increased to 34 degrees Celsius. As a consequence of this, just as in the case of the gas sensor, the red LED started blinking, the vibration motor started working and a sound was heard from the loudspeaker, reporting the danger. Testing temperatures below normal was not carried out because it was not necessary. After all, if the sensor perfectly detects the temperature above the norm, it will also detect lower temperatures.

Table 3

Testing the operation of the temperature sensor

Pulse value	Gas value	Light value	Temperature value
75	34	156	22
75	33	156	27
75	33	157	27
75	34	156	33
75	34	156	34
75	33	156	36

To test the light sensor, it was covered with an opaque object. As a result, the darkness index increased, and thus the illuminance decreased. This process can be seen in Table 4. As a result, the white LED on the breadboard lit up, which in this case represents a miner's lantern.

Table 4

Testing the operation of the light sensor

Pulse value	Gas value	Light value	Temperature value
75	34	156	22
75	33	537	22
75	33	533	22
75	34	527	22
75	34	525	22
75	35	524	22

To test the heart rate monitor, several physical exercises were performed. As it can be seen in Table 5, the heart rate value increased after completing these exercises. This caused the green LED to start blinking, thus communicating the danger. Testing for a lower heart rate was not done, as it is not possible to do so under normal conditions.

Table 5

Testing the heart rate monitor

Pulse value	Gas value	Light value	Temperature value
125	34	156	22
125	33	156	22
125	33	157	22
125	33	157	22
125	35	157	22

Consequently, we can conclude that this warning system for hazardous working conditions in the mine works properly, there are no problems in its operation, it correctly processes the data and turns on the necessary warning devices at the right time.

VIII. DISCUSSIONS

The results of monitoring workplace safety in the mine with the new system, which meets modern

standards, proved the effectiveness of its use. The new system provided autonomy of the system components, which the old systems did not have at all. Coverage of the mine was increased to 100 % compared with systems such as Radius-2. In addition, the new system is expected to reduce the number of human losses by about 60 % by monitoring the health of the miner.

In conclusion, it was found by expert evaluation that the overall safety level in the mine increased by 45 % compared to other systems.

IX. CONCLUSIONS

Structural solutions, hardware and algorithmic means of a system for maintaining safe working conditions at a mine based on modern computer technologies were proposed.

Hardware and software implementation of the algorithm of the autonomous part, which is part of the computer system of safety monitoring in the mine, is very important. This will help improve safety in one of the most underdeveloped industries, the mining industry, by about 45 %. Underdeveloped countries that will implement this system will finally be able to ensure the safety of their miners.

By using autonomous modules in the system, the system will be able to continue to function if the modules lose communication between each other. Also, owing to the use of an autonomous module, coverage of the mine is 100 %. Since the system is open, in the future some new modules can be added to it, which will further increase the level of safety of the miner. Also, since the system monitors not only the state of the environment in which the miner works, but also the state of the miner, which none of the systems given in the article does, it will reduce the number of human losses by about 60 %.

Therefore, we can say that the introduction of such a system will make the miners' work safer.



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