International Journal of GEOMATE, July, 2024 Vol.27, Issue 119, pp.100-111
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2024.119.4470
Geotechnique, Construction Materials and Environment

RISK WARNING SYSTEMS FOR UNDERGROUND MINING USING IOT SOLUTIONS: A CASE STUDY

*Nguyen Duyen Phong[1], Uong Quang Tuyen[2], and Piotr Osinski[3]

[1]Department of Underground Construction and Mining, Hanoi University of Mining and Geology, Vietnam;
[2]Department of Automation of Mining and Petroleum, Hanoi University of Mining and Geology, Vietnam;
[3]Institute of Civil Engineering, Warsaw University of Life Sciences, Poland

*Corresponding Author, Received: 28 Feb. 2024, Revised: 29 April 2024, Accepted: 01 May 2024

ABSTRACT: In underground coal mining activities in the world in general and in Vietnam in particular, toxic gas incidents often occur, endangering people and equipment safety. Toxic gases originate from underground mines and are difficult to detect by the human senses. In this study, IoT wireless technology is used to connect sensors, based on the Arduino platform to measure toxic gas concentrations providing miners with early warnings to help prevent risks and unfortunate incidents. The application of IoT in early warning of risks and incidents in underground coal mines is highly appreciated in improving the overall monitoring process and contributing to achieving the goal of zero incidents during the mining process. Empirical evidence from studies over the last five years has shown the benefits of using sensors in mines for real-time monitoring in eliminating mining incidents. The toxic gas concentrations are measured using gas detectors using specific electrochemical sensors measured in the ppm range. The data is uploaded through Lora modules, and then transmitted to the Cloud server. Data analyzed by the server is employed to provide early warnings of risks and incidents in underground coal mining activities. This system has been proven suitable for deploying in underground coal mines. The present study shows that reducing the amount of transmitted unnecessary data can be sampled on a larger time scale and still give accurate measurement results, making the entire system more efficient and sustaining a required level of safety using the proposed approach allows uploading the sensor reading into the application and are easy to process and verify.

Keywords: Risks, Underground mining, IoT, Sensor, Mine gas explosion.

1. INTRODUCTION

Currently, underground coal mining often causes a number of threats and hazards. In the mining environment, the emission of toxic gases, including CH4, CO, CO2, and H_2S, often occurs. Another issue is labor accidents such as furnace collapse and flooding. All these lead to potential deaths or injuries and significant economic loss. Therefore, human safety in underground mining is currently ranked top priority in the field of coal exploitation. Stipulating effective measures for prevention against occupational incidents is to be viewed as the motto and development strategy of the coal management industry.

Gas leaks and explosions, water outages, tunnel collapses, etc. all pose serious safety threats in underground coal mines worldwide. A gas explosion accident can cause the death of many coal mining workers. Since the start of coal mining, many miners have been killed by gas explosions. Such incidents have long been a major concern for mining engineers. According to statistics and analysis in many mines around the world, all explosions originate from or around sealed areas. Hence, the atmospheric condition in a closed coal mine area plays an important role in preventing and minimizing accidents related to mine flammable gas and is also necessary for planning and implementing a mine rescue strategy.

The underground mining method is employed when the mineral reservoir is too deep to be reached by open-pit mining or the ground surface is not suitable for open-pit mining. The mine seam is reached from the surface level by vertical wells, inclined wells, or flat furnaces and is divided by levels and mining floors. Coal mining workloads such as drilling, blasting, coal/waste rock loading, and transporting from furnaces are carried out according to mine design and planning. Cutting machines are used to cut and load coal for coal mining longwalls.

In the period from 1995-2023 accidents took place in Vietnam's coal industry, according to statistics (Fig. 1). The largest accidents were due to: furnace collapses 36%; gas asphyxia 4%; gas fire and explosion 9%; water podiums 7%; shockwave 6%; blasting 2%; transportation 21%; and other 15%.

Over the past years, Internet of Things (IoT) technology has been developing in different areas of life, in industry as well as in coal mining in particular [1-7]. Available studies show the current huge advantage of the employment of wireless networks to monitor the mine environment in the field of coal mining. To that end, the application of IoT technology to connect mine environment with early warning sensors is an optimal solution in the current times [8] (Fig. 2).

The manifestation of the IoT appeared right from the early days of the Internet, as the inventors wished to connect the system through a unified network that is possible to be controlled to serve human needs. In the history of IoT development, the automatic drink vending machine placed at Carnegic Melon University in the early 1982s was considered the first device opening this trend. It was programmed to connect with the operator via the Internet to monitor the machine's status and add water as necessary without direct manual check [9].

The concept of IoT was then only really put forth in 1999, as the potential of this trend was revealed, along with the introduction of the Internet as well as the gradual resolution of many scientific and technological barriers.

The prevalent method often applied in coal mines in Vietnam is that the operators manually use individual gas measuring devices to measure gas concentrations at each site. The commonly used measuring methods are non-dispersive infrared (NDIR) sensors and electrochemical gas sensors also equipped with indicator stain tubes depending on the type of gas that the concentration of is measured. Recently nano gas sensing technology has been found very efficient in detecting toxic gas, due to its sensitivity. This method has replaced the use of graphene monolayers serving as sensing materials, then improved by gold nanoparticles [1, 4, 5]. However, the approach of using manually operated devices does not allow updating data regularly, and consequently provides early warning of risks, which may lead to fatal incidents.

In some countries, there are also some studies on wireless networks based on the application of wi-fi networks, and ring wireless networks. However, their disadvantages include poor signal transmission and huge energy consumption as shown in Table 1.

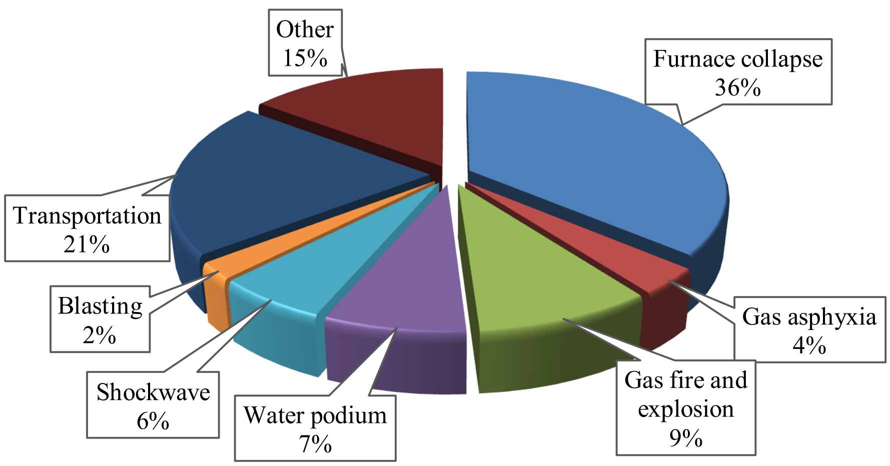

Fig. 1 Statistics on threats and hazards in underground coal mining.

Table 1. Summary of Arduino applications for environmental monitoring systems

Reference	Mine type	Purpose of Field Monitoring System	Microcontroller	Sensor	Communication	Actuator or Other Modules	Additional Analysis
[2]	Underground	Air quality monitoring	Arduino UNO	Gas (MQ2), temperature (LM35)	Li-Fi[1]	Headphone	N/A
[3]	Underground	Air quality monitoring	Node MCU	Gas (Au-ZnO, Au-WO3, Au-TiO2, Au-CuO)	Wi-Fi (ESP8266)	Alarm system	N/A
[4]	Polluted area	Air quality monitoring	Arduino UNO	Gas (MQ2, MQ7, MQ8, MQ9), temperature (LM35)	GSM (SIM900A)	N/A	N/A
[6]	Underground	Air quality monitoring	Arduino UNO, Mega	Gas (MQ2, MQ7)	GSM[2] (SIM800)	Buzzer, LCD, RTC[3]	Regression analysis
[7]	Underground	Air quality monitoring	Arduino UNO	Gas (MQ4, MQ7, MQ9), temperature and humidity (DHT22)	RF[4] (nRF24L01)	N/A	Battery life analysis

(Continued Table 1)

Reference	Mine type	Purpose of Field Monitoring System	Microcontroller	Sensor	Communication	Actuator or Other Modules	Additional Analysis
[10]	Underground	Air quality monitoring	Arduino UNO	Gas (MQ4, MQ7, MG811), temperature and humidity (DHT11)	ZigBee (Xbee)	buzzer, LCD[5]	N/A
[11]	Underground	Air quality monitoring	Arduino Mega	Gas (MQ4, MQ9, MQ135), temperature and humidity (DHT11)	BLE[6] (BLE shield)	N/A	*k*-means clustering
[12]	Underground	Air quality monitoring	Arduino UNO	Gas (MQ2, MQ3, MQ6, MQ7, MQ8, MQ9),	ZigBee (Xbee)	Vacuum pump (T2-03)	PCA[7], LDA[8]
[13]	Underground	Air quality monitoring	Arduino UNO	Gas MQ2, Temperature and humidity (DHT11)	ZigBee	LCD	N/A
[14]	Underground	Air quality monitoring	Arduino Nano	Gas (MQ7)	Bluetooth (HC05)	N/A	COHb[9] calculation
[15]	Underground	Air quality monitoring	Arduino UNO	Gas (MQ6), temperature (LM35), fire sensor	ZigBee (Xbee)	Buzzer	N/A
[16]	Underground	Air quality monitoring	Arduino UNO	Gas (MQ2)	ZigBee (Xbee)	N/A	Probabilistic strategy for potentially explosive area
[17]	Underground	Airflow monitoring	Arduino Mega	Airflow (hot wire sensor, mass flow sensor, orifice plate sensor)	N/A	Centrifugal fan	Ventilation network modeling
[18]	Underground	Airflow monitoring	Arduino UNO	Gas (MQ5, MQ7), Temperature and humidity (DHT11), Dust (GP2Y1010)	Wi-Fi (ESP8277), RF	N/A	N/A

Note: [1]Li-Fi: light fidelity; [2]GSM: global system for mobile communication; [3]RTC: real-time clock; [4]RF: radio frequency; [5]LCD: case-based reasoning; [6]BLE: bluetooth low energy; [7]PCA: principal component analysis; [8]LDA: linear discriminant analysis; [9]COHb: carboxyhemoglobin.

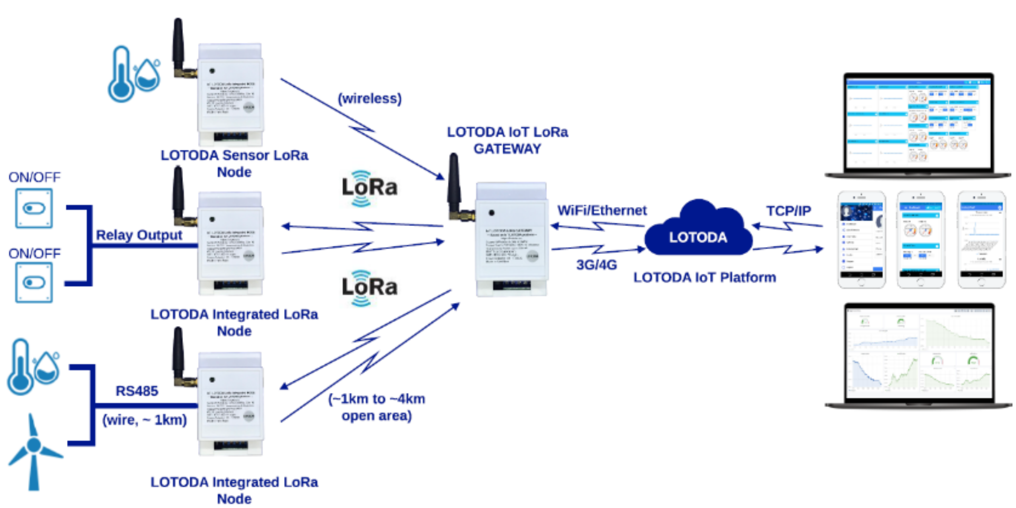

Fig. 2 Model of the mine IoT monitoring system

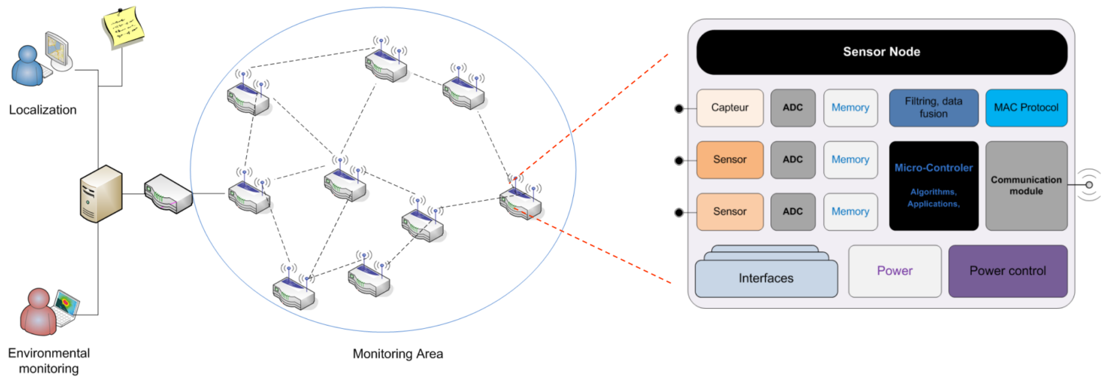

Fig. 3 Simplified sensor networks [19]

Currently, IoT solutions have been successfully implemented in metal and non-metal mines, but the application of this technology in coal mines is still limited. A major barrier to IoT integration in coal mines is due to safety requirements during construction and underground risk control, the complexity of comprehensive integration of mine technical infrastructure, and initial costs for sensor network integration and process automatization. The IoT deployment in coal mines has been a trending research topic since the 2000s and has been widely investigated in China. As IoT was proposed in China by Hu et al., 2013 [20] smart mine monitoring proposal; Tan et al., 2013 [21] proposed mining equipment management; Chen et al., 2012 [22] proposed environmental sensors; Wang et al., 2011 [23] proposed real-time positioning; Meng et al., 2012 [24] proposed coal seam water monitoring; Sun, 2015 [25] proposed accident analysis. In addition to specific applications, some researchers such as Ke, 2010 [26]; Wei et al, 2011 [27]; Wang et al., 2011 [28]; Zhang et al., 2012 [29] published articles focusing on IoT system overview and architectural design.

According to literature review, most projects currently use wi-fi to connect to the Internet. Long-range communication (LoRa) works more efficiently and provides reliable real-time data. Zigbee is a short-range communication technology proposed by Joshi et al., 2022 [30] to transmit data from waste containers to waste collectors. The authors summarized and distinguished the differences between LoRa, Wifi, and Zigbee in Table 2.

In the present study, the research team used LoRa waves to increase wave transmission efficiency and reduce energy costs.

The Internet of Things is a platform where each object and a single person in the world is provided with its identifier and data and information are possible to be transmitted and exchanged through a single network without direct human interaction, or computer manipulation. IoT is based on the convergence of wireless technology and Internet microelectromechanical technology as presented in Fig. 3.

Table 2. Comparison of LoRa, WiFi and ZigBee technologies [31-32].

Features	LoRa	WiFi	Zigbee
Wireless network	Low-power wide area network (LPWAN)	Local area network (LAN)	Personal area network (PAN)
Operating band	433,869, and 915 MHz	2.4 and 5 GHz	815 and 915 MHz
Data rate	50 kbps	11-54 Mbps	20, 40, 100, and 200 kbps
Bandwidth	< 500 kHz	22 MHz	2 MHz
Transmission range	5 km (urban) and 10 km (rural)	100 m	100 m

2. RESEARCH METHODS

Nowadays, the control of coal underground mining risks and incidents requires a synchronous control system solution. In the present study, the research team uses IoT - technology based on mining environmental warning sensors to connect and transfer real-time data from the sensor to the server. This data is analyzed by the software module and then a warning signal is transmitted if the mine environment safety is at risk, triggering potential hazardous incidents.

2.1 System configuration

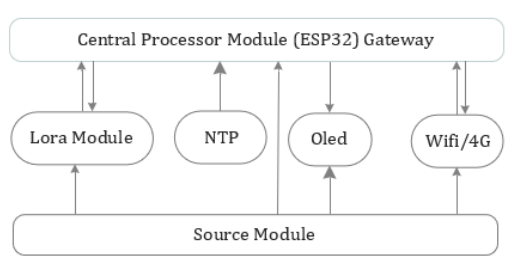

Fig. 4 Gateway structure.

The system includes a central data collection device (Gateway) and sensor blocks (Sensor Nodes). The sensor blocks read values from the sensors, synthesize the data, and then transmit the data through the Lora module to the Gateway. Here, the Gateway receives data, analyzed by each node and displaying it on the screen of the gateway. At the same time, the gateway transmits that data to the server via the internet (wi-fi or 4G).

On the server, there are clocks and graphs that display and store that data on the server. The general structure of the Gateway and Sensor Node is presented in Fig. 4 and Fig. 5, respectively.

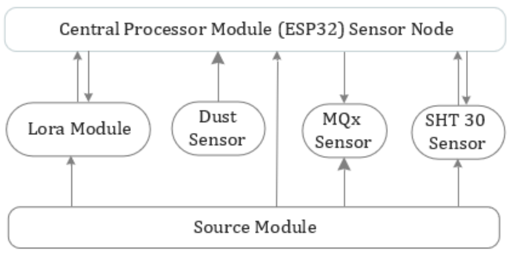

Fig. 5 Sensor Node structure.

2.1.1 Central processing block

In Fig. 6, ESP32 is a low-cost microcontroller system-on-chip (SoC) from Espressif Systems, the developer of the ESP8266 SoC. It is the successor to the ESP8266 SoC and comes in both single-core and dual-core variants of Tensilica's 32-bit Xtensa LX6 processor with integrated Wi-Fi and Bluetooth.

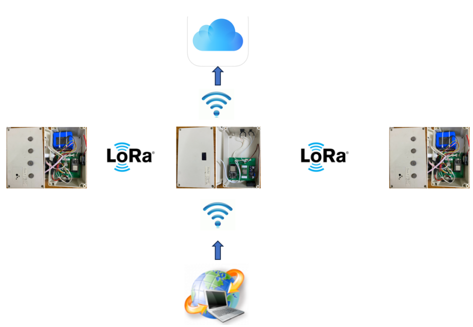

Fig. 6 System model

ESP32, includes ESP8266, and integrated RF components such as a power amplifier, low noise receive amplifier, antenna switch, filter, and RF Balun. This makes designing hardware around the ESP32 very easy. ESP32 is manufactured using ultra-low power 40 nm technology. Therefore, the design of battery-operated applications such as wearables, audio devices, smart watches, etc., remarkably facilitates the usage of ESP32.

Fig. 7 shows a single - or dual-core LX6 32-bit Processor with a clock rate of up to 240 MHz; 520 KB SRAM, 448 KB ROM and 16 KB SRAM RTC; supports Wi-Fi 802.11 B/G/N connection with speeds up to 150 Mbps; supports both Bluetooth v4.2 and classic BLE specifications; 34 programmable GPIOs; 18 12-bit SAR ADC channels and 2 8-bit DAC channels; serial connectivity includes 4xSPI, 2xI2C, 2xI2S, 3xUART; Ethernet MAC for physical LAN communication (requires external PHY); 01 host controller for SD/SDIO/MMC and 01 slave controller for SDIO/SPI; PWM motor and 16 PWM LED channels; Secure boot and Flash encryption; Cryptographic hardware acceleration for AES, Hash (SHA-2), RSA, ECC, and RNG.

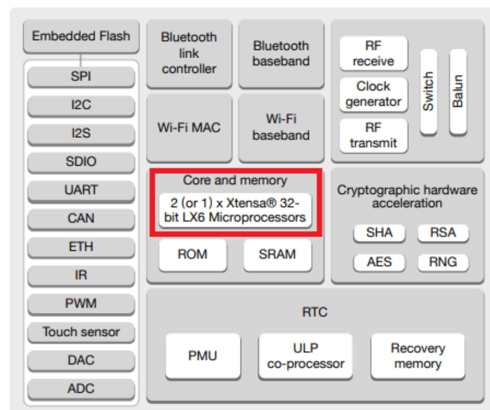

Fig. 7 ESP32 shape and technical parameters

2.1.2 Hardware technical parameters

The power block is responsible for providing operating energy for the system (central processing block, sensor block, auxiliary devices), ensuring continuous and stable operation of the system. The system's power is taken from 220VAC, through a power conversion module to 5VDC to supply processing equipment and sensors. In addition, the system uses a power supply system via lithium batteries, supporting the system to operate when there is a 220VAC power source failure.

The center controls the operation of the entire system. The master's central processing block has a particularly important task in the system, sending synchronization signals to the slaves, requiring the slaves to send received data to the master. After the data is processed and synchronized, the master continues to send data to the server, cloud, and web interface.

The warning block is controlled by the master and slave. When the received values exceed the set or safe threshold, a signal is sent to the speakers, lights, and horn to warn the user.

The power output block closes and disconnects relay contacts according to the control of the microcontroller output, thereby controlling electrical devices (220VAC). At the same time, it isolates the power circuit and control circuit.

Table 3. Table hardware specifications

Specification	Sensor Model			
	MQ-9	MQ-4	MQ-135	DTH11
Voltage	5.0 V	5.0 V	5.0 V	3-5V
Detection	CO and CG *	Methane	NH_3, smoke, CO_2	Temperature and Humidity
Measurement Range	10-1000 ppm (CO), 100-10,000 ppm (CG)	200-1000 ppm	10-300 ppm NH_3	20-90% RH **, 0-50°C
Accuracy	±5%	±5%	±5%	±5% RH, ±2°C Temperature
Sensitive Material	SnO_2	SnO_2	SnO_2	-
Configuration	3-pin	4-pin	4-pin	4-pin
Digital/Analog	Analog	Both	Both	Digital

* Combustible Gas, ** Relative Humidity.

The sensor block is the slave's central processing block, responsible for reading the sensors' signals, synthesizing the received data, receiving signals sent from the master, then synchronizing the data and transmitting data to the master.

The web server receives data from the central processing block, saves the state, and the values received from the master are transferred to the Server. The web server stores values to display on the web interface, so the operator can monitor them at any time. At the same time, control data is synchronized with the system.

Administrators can change the alarm settings on the user interface when they have the highest access rights. Users can only monitor the status of the system such as sensor values sent back, and graphs showing the above values. A summary of sensor specifications is presented in Table 3.

2.1.2 OLED screen

SSD1306 0.96-inch sized OLED screen provides a good visual display with a frame of 128x64 pixels. In addition, the screen is also compatible with most state-of-the-art microcontrollers via I2C communication port. The monitor uses SSD1306 driver and with its compact design promptly helps develop DIY products or other applications.

Technical specifications

- Driver: SSD1306
- Compatible with Arduino, 51 Series, MSP430 Series, STM32/2, CSR IC, ...
- Low power consumption: 0.08W (fullscreen)
- Brightness and contrast can be adjusted
- Communication standard: I2C (through 2 pins SCL, SDA)
- Operating voltage: 3V-5V DC
- Operating temperature: -30÷70°C
- Screen size: 0.96 inches (128x64 pixels)
- Module size: 26.70×19.26×1.85 mm (1,030,760.07 inches).

2.1.7 Sensor communication block

The sensor communication block is designed as an Arduino Shield, which is a feature expansion board and connection ports for Arduino. The Shield is designed with the following features (Fig. 8).

- The communication circuit with the electrochemical sensor uses OPAMP LM358 connected to the Arduino board via the ADC pin.
- The communication circuit with the semiconductor sensor can adjust the voltage on the sensor's filament via a PWM signal. The output of the circuit connects to the Arduino's ADC pin.
- Connectors to connect to sensors with I2C interface, sensors with PWM output.
- The power supply block uses IC LM2596 to stabilize the input voltage to create a voltage for the Arduino, IC TL431 to create a voltage of 3.3V, 2.5V for variables using low voltage levels, IC LM7805 to create a voltage of 5V for the devices. Other common sensors.
- In addition, the board also integrates a real-time module using IC DS1307 to create a reference time for monitoring values.

2.2 Programming Software

Programming the ESP32 NodeMCU. Because this is an Arduino-compatible board, the structure of a program for this circuit will follow the structure of a program written for an Arduino board including 2 main parts:

- Setup function: called only once when the circuit is started.
- Setup function: called only once when the circuit is started.

The first step to get acquainted is to write a program for ESP to control an LED light that flashes every 1 second. Components needed to be prepared include 1 ESP32 NodeMCU circuit and 15mm LED.

3. SOFTWARE SYSTEM

The authors used the C programming language running on the Arduino platform to write codes for the microcontroller (Fig. 9) and used the Java programming language running on the Node-Red platform to program data transmission from the sensor to the server (Fig. 10).

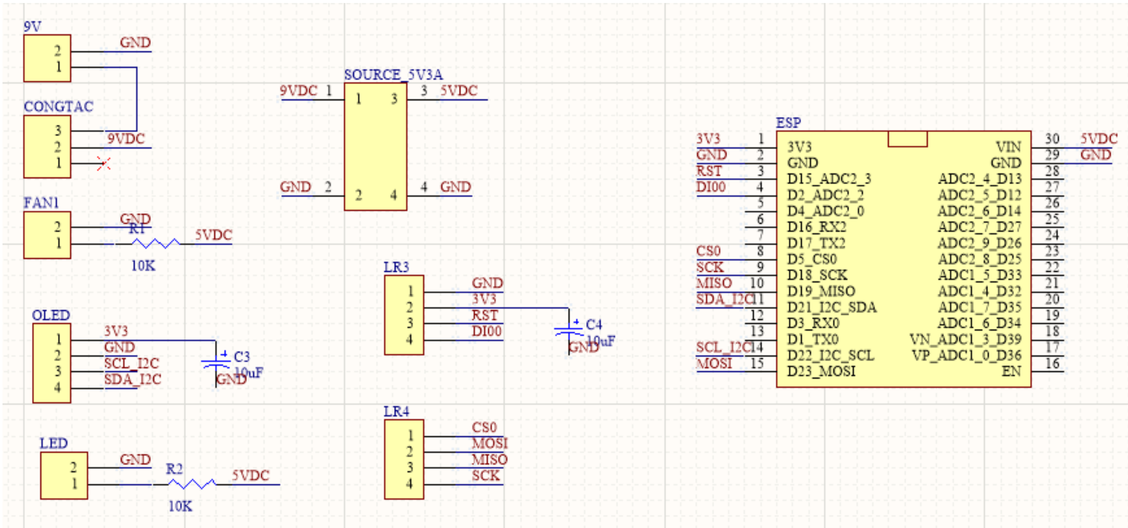

Fig. 8 Sensor circuit board (Sensor node).

Fig. 9 Arduino software for programming the microcontroller (The data and the full code can be provided upon request).

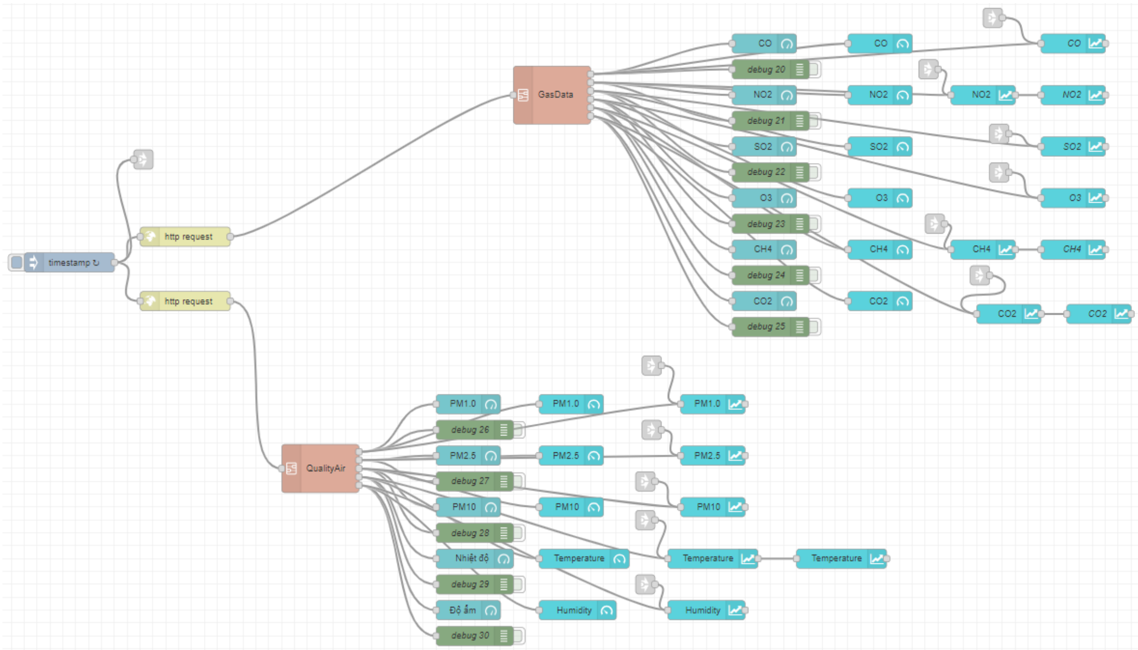

Fig. 10 Node-RED software for programming data transmission from the sensor to the server

(Data and code can be provided upon request).

4. RESULTS AND DISCUSSION

The causes of accidents in underground mines (mainly coal mines) are usually associated with gas leaks, wall collapse, equipment physical contact, low oxygen concentrations and other operational conditions. Currently, in the Vietnamese mining industry in general and the coal mining sector in particular, IT has been introduced to monitor equipment location, environmental quality, and surface subsidence, warning miners of potential risks to ensure health and safety.

Table 4. Table of allowable limits and threshold values for some sensors (modified after Majee [33])

Sensing Items	Sensor Name	Permissible Limits	Threshold Set
Methane, Butane, and natural gas	MQ-4	Less than 10%	12%
Combustible gas and smoke	MQ-02	Less than 30%	30%
Sulfides, Benzene, and Ammonia	MQ-135	Less than 25%	30%
Temperature	DHT11	25-40ºC	50ºC
Humidity	DHT11	15-70%	70%

In a study by Majee, 2016 [33], an allowable value threshold for sensors (Table 4) and automated operation of IoT-based safety and monitoring systems in underground coal mines was proposed. The present research used ZigBee technology and the ESP8266 Wi-fi module as a wireless data transmission network to transmit data from sensors to the server. In case the sensor measurement values exceed the value threshold in Table 4, an alarm signal will be activated to warn miners.

4.2 Experimental Measurement Results

For environments that meet the current standards, the system will display a green warning signal (satisfactory) as presented in Fig. 11. If the allowable threshold is exceeded, the orange warning signal is activated, whereby the supervisor needs to provide warnings and figure out preventive measures to avoid unfortunate incidents.

Here the system displays data in two forms: image and numerical:

- With image format, details can be displayed separately for each measurement point (Fig. 11). The image format can be viewed as a panorama of measurement points at the same time to provide early warnings of risks and incidents in the underground mining environment (Fig. 12).
- With numerical form: the authors uploads data to an Excel file for storage (Fig. 13).

Fig. 11 Warning interface of the measuring system

Fig. 12 Node measurement results interface

Table 5. Digital data of measurement results

created_at	entry_id	field1	field2	field3	field4	field5	field6
2024-05-10T17:31:13+07:00	1	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:15+07:00	2	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:17+07:00	3	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:19+07:00	4	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:21+07:00	5	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:23+07:00	6	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:25+07:00	7	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:27+07:00	8	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:29+07:00	9	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:31+07:00	10	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:33+07:00	11	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:35+07:00	12	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:37+07:00	13	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:39+07:00	14	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:41+07:00	15	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:45+07:00	16	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:46+07:00	17	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:48+07:00	18	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:50+07:00	19	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:52+07:00	20	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:54+07:00	21	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:56+07:00	22	0.5	0.01	0	0.02	0	1296
2024-05-10T17:31:58+07:00	23	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:00+07:00	24	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:02+07:00	25	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:04+07:00	26	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:06+07:00	27	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:08+07:00	28	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:10+07:00	29	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:12+07:00	30	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:14+07:00	31	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:51+07:00	32	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:52+07:00	33	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:54+07:00	34	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:56+07:00	35	0.5	0.01	0	0.02	0	1296
2024-05-10T17:32:58+07:00	36	0.5	0.01	0	0.02	0	1296
2024-05-10T17:33:00+07:00	37	0.5	0.01	0	0.02	0	1296
2024-05-10T17:33:02+07:00	38	0.5	0.01	0	0.02	0	1296

feeds

4.3 Discussion

In the present paper, studies using Arduino in mining industry have been collected and statistical trends analyzed and presented. Arduino is a microcontroller that can be applied in many different environments and tools. However, according to mining statistics, the use of Arduino for underground mine monitoring has been studied mostly for open pit mines. The reason is that underground mining operations pose more risks to the safety of mines, equipment, communication, and other related safety issues, other than those occurring in open pit mines.

5. CONCLUSION

In the study, the authors presented the research on data transmission method that uses LoRa waves based on the usage of open-source hardware Arduino platform in the underground coal mining industry to help improve wave transmission and underground coal mining risk and incident monitoring capacity, which is suitable for developing countries. In the present research, the use of microcontrollers is the basis for the development of the smart coal mining industry.

The warning system results obtained online, represent the measuring time interval in seconds. The experiment performed in the present study shows that the reduction of the amount of data, could be achieved by collecting hourly sampled information on hazardous gas concentrations. The authors recommend that users reduce the amount of data transmitted, and still give accurate measurement results.

The research results can immediately be put into application and are easy to manufacture and verify. On the market today, industrial sensors are always available with reasonable costs, particularly not dependent on warning system manufacturers. Bearing in mind all the findings great attention needs to be paid to selecting the measuring devices and their reliability. More research needs to be undertaken on the combination of monitoring wireless networks and applying devices of different specifications to avoid any misleading records that could put the operational mining site in danger.

6. ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by Vietnamese Ministry of Education and Training under Grant No. B2022-MDA-07.

7. REFERENCES

[1] Anitha K. and Seshagiri T. Implementation of Wireless Sensor in Coal Mine Safety System using ZigBee, International Research Journal of Engineering and Technology (IRJET), 6(5), 2019, pp. 1467-1472.

[2] Kolli P.S.S.V.N., Visalakshi P., and Chervith Chowdary P. Coal mine safety system using Li-Fi technology, International Journal of Advance Research, Ideas and Innovations in Technology, 5(2), 2019, pp. 1288-1291.

[3] Subhrapratim N., Anup D., Prithviraj P., Saikat R.C., Jamuna K.S., and Subir K.S. Nano Structured Gas Sensing Device and Its Application in Underground Mines, In Proceedings of the 2018 IEEE Electron Devices Kolkata Conference (EDKCON), Kolkata, India, 24-25 November 2018, pp. 445-449.

[4] Rajalakshmi R., and Vidhya J. Toxic Environment Monitoring Using Sensors Based on Arduino, In Proceedings of the 2019 IEEE International Conference on System, Computation, Automation and Networking (ICSCAN), Pondicherry, India, 29-30 March 2019.

[5] Kugan R.S., Gobi Krishnan R, Mohan M, Gowtham V, and Praveena R. Coal mine monitoring and alert system with data acquisition, International Journal of Innovative Research in Advanced Engineering (IJIRAE), 6(3), 2019, pp. 186-191.

[6] Nisal S., and Elvitigala C.S. IoT Proactive Disaster Management System for Mines. In Proceedings of the 18th International Symposium on Advanced Intelligent Systems (ISIS2017), Daegu, Korea, 11-14 October 2017.

[7] Emre Ü., Taner A., Özlem A., and Yalçın Ç. Power management for Wireless Sensor Networks in underground mining, In Proceedings of the 24th Signal Processing and Communication Application Conference (SIU), Zonguldak, Turkey, 16-19 May 2016.

[8] Wang G., Zhao Z., and Ning Y. Design of Compressed Sensing Algorithm for Coal Mine IoT Moving Measurement Data Based on a Multi-Hop Network and Total Variation, Sensors (Basel), 18(6), 2018, pp. 1-17.

[9] https://en.wikipedia.org/wiki/Internet_of_things #cite_note-14

[10] Sumit K.S. Real Time Monitoring System for Mine Safety Using Wireless Sensor Network (Multi-Gas Detector), National Institute of Technology Rourkela, Rourkela, India, 2015, 54 p.

[11] Jo B., and Khan R. M. A. An Internet of Things System for Underground Mine Air Quality Pollutant Prediction Based on Azure Machine Learning, Sensors (Basel), 18(4), 2018, pp. 1-20.

[12] Cristhian M.D.A., Pablo A.G.M., and Rafael A.A.R. Wireless Smell System for Hazardous Gases Detection, Chemical engineering transactions, Vol. 68, 2018, pp. 391-396.

[13] Suryanarayana S., Prashanth S.P., Abhijeet K., and Shiva S.A. Wireless Surveillance and Safety System for Mine Workers Using ZigBee, International Journal of Creative Research Thoughts (IJCRT), 6(2), 2018, pp. 1420-1427.

[14] Vancho A., Zoran D., Dalibor S., and Stojance M. Methodology for evaluation of the evacuation time in case of fire in underground mines. In Proceedings of the XII Стручно советувањеодобласта на подземната и површинската експлоатација (Родекс-Ровекс 2019), Strumica, Macedonia, 1-3 November 2019.

[15] Anitha K., and Seshagiri T. Implementation of Wireless Sensor in Coal Mine Safety System using ZigBee, International Research Journal of Engineering and Technology (IRJET), 6(5), 2019, pp. 1467-1472.

[16] Emil P., Gabriel-Ioan I., Ionut-Alin P., and Lorand B. Increasing the Safety of People Activity in Aggressive Potential Locations, Analyzed through the Probability Theory, Modeling/Simulation and Application in Underground Coal Mining, Engineering, 11(02), 2019, pp. 93-106.

[17] Oscar O., Rodriguez D., David F., Novella R., Emmanuel W., and Edinson F.M. Benchmark for analysis, modeling and control of ventilation systems in small-scale mine, In Proceedings of the 2019 International Conference on Control, Automation and Diagnosis (ICCAD), Grenoble, France, 2-4 July 2019, pp. 198-203.

[18] Aditi N., Roshani W., Priti N., Ketan M., Kalyani R., Ganesh R., and Pushpa C. Coal Mine Safety Monitoring and Alert System, International Journal of Advanced Research in Science, Communication and Technology. Doi: 10.48175/ijarsct-v4-i3-033, 2021, pp. 200-206.

[19] Abdellah C., Wissam F., Hussein T.M., and Xavier F. Design of wireless sensor network for mine safety monitoring, 2011 24th Canadian Conference on Electrical and Computer Engineering (CCECE), 2011.

[20] Hu S., Tang C., Yu R., Liu F., Wang X. Intelligent coal mine monitoring system based on the Internet of Things. IEEE 2013 3rd International Conference on Consumer Electronics, Communications and Networks (CECNet); Xianning, China. Nov. 20-22, 2013; pp. 380-384.

[21] Tan Z.L., Zhang C.L., Yu J.Z. Research on construction of equipment management system in coal mines based on application of AI, IoT. Coal Mine Machinery, 2013.

[22] Chen Y., Meng F.W., Guo H.C. Design of

detection system for mine oxygen concentration based on Internet of Things. Electronic Design Engineering, 2012.
[23] Wang X., Zhou T.Z., Zhao D. Research and realization of real time location system in coal mine based on internet of things. Coal Mine Machinery, 2011.
[24] Meng X., Wang J., Gao Z. Research on coal seam floor water inrush monitoring based on perception of AI, IoT coupled with GIS. Engineering; pp 467-476.
[25] Sun J., 2015. Accident analysis and big data and Internet of Things in coal mine. Industry and Mine Automation; 2012, pp. 1-5.
[26] Ke H. The key technologies of AI, IoT with development and applications. Radio Frequency Ubiquitous Journal, 2010.
[27] Wei Q., Zhu S., Du C. Study on key technologies of Internet of Things perceiving mine. Procedia Engineering. 2011, pp 2326-2333.
[28] Wang Y., Zhao B.C., Chen J.F., Liu Y.L. Internet of things technology and application in coal mine industry. Computer Knowledge and Technology, 2011.
[29] Zhang Y., Fu G., Zhao Z., Huang Z., Li H., Yang J. Discussion on application of AI, IoT technology in coal mine safety supervision. Procedia Engineering. 2012, pp. 233-237.
[30] Joshi L.M., Bharti R.K., Singh R., Malik P.K. Real Time Monitoring of Solid Waste with Customized Hardware and Internet of Things. Comput. Electr. Eng. 2022, 102, 108262.
[31] Sohag M.U., Podder A.K. Smart Garbage Management System for a Sustainable Urban Life: An IoT Based Application. Internet Things 2020, 11, 100255.
[32] Reis P., Pitarma R., Gonçalves C., Caetano, F. Intelligent System for Valorizing Solid Urban Waste. In Proceedings of the Iberian Conference on Information Systems and Technologies, CISTI, Barcelona, Spain, 18-21 June 2014; IEEE: Piscataway, NJ, USA, 2014.
[33] Majee A. IoT Based Automation of Safety and Monitoring System Operations of Mines, International Journal of Electrical and Electronics Engineering (SSRG - IJEEE), 3(9), 2016, pp. 17-21.