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IMPLEMENTATION OF IOT APPLICATIONS FOR REALTIME MONITORING OF ENVIRONMENTAL SAFETY IN UNDERGROUND MINES

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Abstract: This article explores the Mine Internet of Things (MIoT) system, focusing on its three-layer architecture and the diverse sensors used for real-time monitoring in underground mines. Classifying sensors by application, the study covers parameters such as gas concentrations, temperature, groundwater, and seismic activity. Wired and wireless communication technologies, alongside network topologies tailored for underground mines, are introduced. MIoT applications for safety and production management, including environmental parameter monitoring and hazard detection, are discussed. The article acknowledges challenges such as operational disruption, increased investment, limited sensor battery life, and communication issues. Emphasizing the need for future research, it suggests avenues like self-powered sensors, MIoT standardization, and improved underground wireless communication. In summary, this review provides insights into the current state of MIoT technology in underground mining, highlighting its benefits, challenges, and proposing key areas for advancements, underscoring the potential for improved safety and efficiency in mining operations.

Keywords—Internet of Things (IOT), ESP32 Module, Sensors, Arduino IDE, Webserver.

I Introduction

The integration of Internet of Things (IoT) technology into industrial sectors has ushered in transformative capabilities, and one domain where its impact is particularly pronounced is underground mining. The advent of Mine Internet of Things (MIoT) systems has revolutionized the monitoring and management of critical factors in subterranean environments. In this article, we delve into the foundational elements of MIoT, focusing on its three-layer architecture and the myriad sensors tailored for real-time data collection in underground mines. The MIoT system, built upon a widely adopted IoT framework, comprises layers dedicated to perception, network, and application. These layers collectively empower the system to gather, transmit, and analyze data, offering a comprehensive view of underground mine conditions. Sensor technology, categorized by specific applications, plays a pivotal role in capturing essential parameters such as gas concentrations, temperature, humidity, airflow, and seismic activity. Communication in the challenging subterranean landscape is addressed through a discussion of wired and wireless technologies, accompanied by the exploration of network topologies designed for optimal functionality in underground mines. As MIoT continues to evolve, its applications extend beyond environmental monitoring to encompass safety measures, hazard detection, and overall production management.

While the benefits of MIoT in underground mines are evident, the implementation is not without its challenges. Operational disruptions, increased investment requirements, limited sensor battery life, and communication issues present hurdles that demand attention. Consequently, this article emphasizes the critical need for ongoing research and development. Proposing future directions, including self-powered sensors, MIoT standardization, and advancements in underground wireless communication, we aim to contribute to the ongoing discourse on optimizing IoT applications in underground mining for enhanced safety and production efficiency.

Advantages of the Intelligent Torque Control System:

- Real-Time Monitoring
- Improved Safety
- User-Friendly Interface
- Environmental Parameter Control
- Integration of IoT Technology
- Cost Savings
- Remote Monitoring and Management

II Design Methodology

Designing a Mine Internet of Things (MIoT) system for underground mines involves a structured methodology to ensure its effectiveness, reliability, and adaptability to the challenging mining environment.

ESP32 Microcontroller:

The ESP32 is a versatile microcontroller with built-in Wi-Fi and Bluetooth capabilities. It features a dual-core processor, sufficient GPIO pins, and compatibility with the Arduino IDE, making it suitable for IoT applications.

Temperature and Humidity Sensor:

DHT11 or DHT22: These sensors are commonly used to measure temperature and humidity. They provide digital output and are easy to interface with microcontrollers.

Fire Detection Sensor:

Flame Sensor: An infrared flame sensor can be employed to detect the presence of flames or high temperatures. It typically provides an analog or digital output based on the intensity of the detected infrared radiation.

Gas Sensors:

MQ2 Gas Sensor: Detects general combustible gases, smoke, and LPG.
MQ5 Gas Sensor: Gas leakage detecting equipment in industry, this sensor suitable for detection coal gas.
MQ7 Gas Sensor: Sensitive to carbon monoxide and methane.
MQ135 Gas Sensor: Measures various air quality parameters, including ammonia, benzene, and CO2.

Web Server Platform:

For the web server, you can use the ESP32's built-in capabilities or consider frameworks like:
ESPAsyncWebServer: An asynchronous web server library for ESP32.
WebSocket: Implementing WebSocket for real-time communication with the web interface.

Power Supply:

Depending on the power requirements of your components, consider appropriate power sources:
Battery: For remote locations, you may need rechargeable or replaceable batteries.
Power Adapters: For components requiring constant power, use suitable adapters.

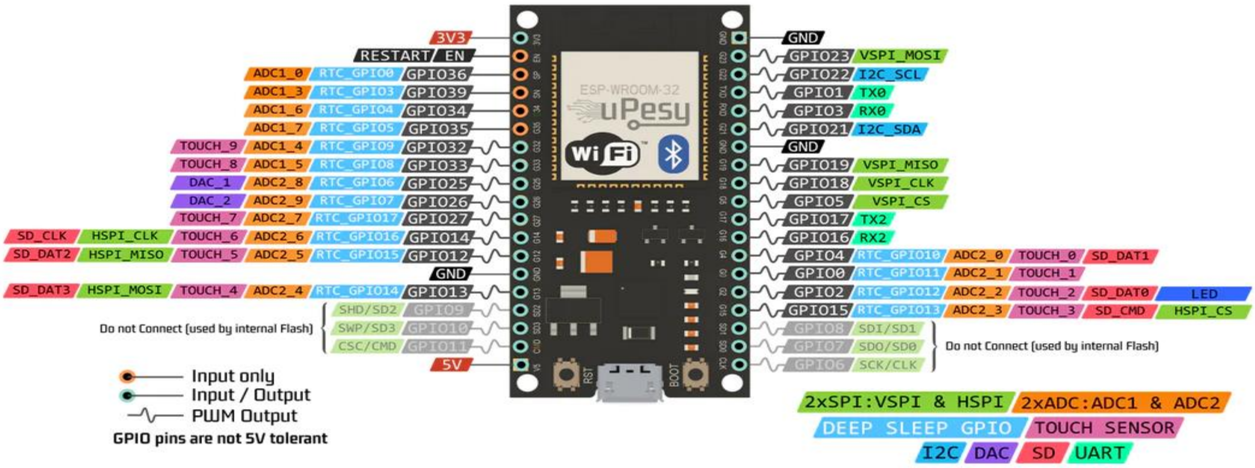


Fig-1 ESP32 Module

Fig-2 MQ2, MQ5, MQ7, MQ136 Sensors

Fig- 3 DHT11 Humidity and Temperature Sensor

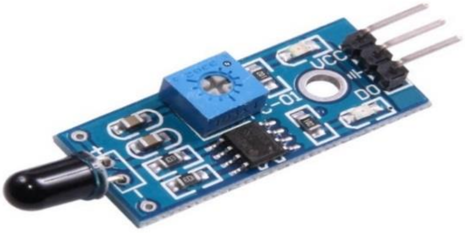


Fig- 4 Fire Detection Sensor

Fig- 5 ADXL335 Triple Axis Linear Accelerometer

III. Implementation

Improvements in IoT Application for Production, Safety, and Environmental Monitoring in Underground Mines
was implemented by connecting components as per the below block diagram.

Block Diagram

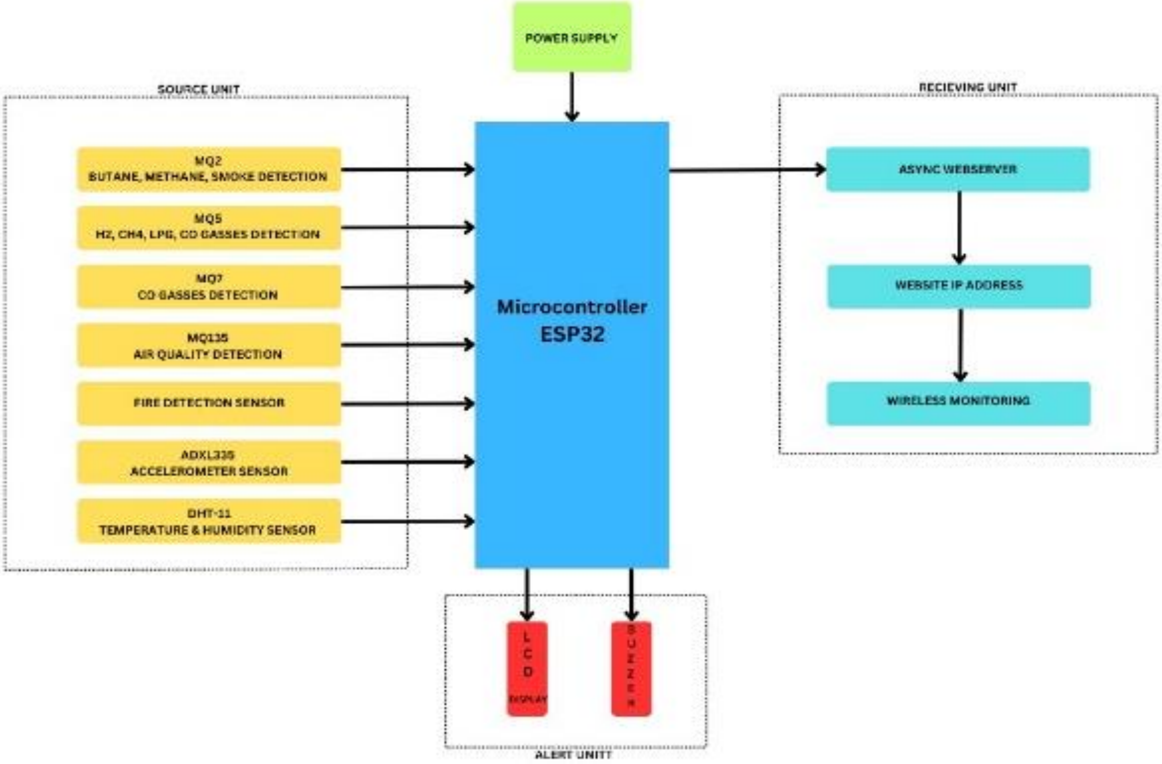


Fig. 4. Workflow Diagram for Improvements in IoT Application for Production, Safety and Environmental Monitoring in Underground Miner

Project Workflow:

The project consists of three layers which are Control layer, Network layer and the application layer. Here are the brief explanations of this three layers

1) Control Layer:

ESP32 Setup: The ESP32 serves as the central controller and falls under the control layer. Set up the ESP32 with appropriate libraries and tools for sensor interfacing and communication. Connect the MQ3, MQ5, MQ135, MQ7 gas sensors, DHT11, and ADXL335 to the ESP32. The ESP32, as the control layer, manages the acquisition of data from these sensors. The control layer is responsible for acquiring raw data from sensors. Process the raw sensor data within the control layer, which may include calibration and unit conversion.

2) Network Layer:

Networking and Communication: Configure the ESP32 to connect to a Wi-Fi network. The network layer manages the communication between the ESP32 and the web server. This involves setting up the appropriate network protocols for data exchange. Implement a web server on the ESP32 using libraries like ESP Async Web Server. The web server, residing in the network layer, facilitates communication between the control layer and the application layer.

3) Application Layer:

Data Presentation on Web Interface: The application layer encompasses the web server and the user interface components. Develop HTML, CSS, and JavaScript files for the web interface. This layer is responsible for presenting sensor data to users in a meaningful way. Implement mechanisms for real-time updates on the web interface. The application layer manages the dynamic display of sensor data, utilizing AJAX requests or WebSocket communication.

Security Considerations: Implement basic security measures for the web server within the application layer. This could include setting up user authentication or using secure communication protocols.

Optimizations and Refinements: The application layer is involved in optimizing the user interface and refining the user experience. Considerations for power efficiency (if applicable) and code optimization fall within this layer.

IV. Results and Discussions

The results of the MIoT system implementation in the underground mining environment demonstrated notable advancements in real-time monitoring and management. The key findings are asfollows

:Environmental Parameter Monitoring: The MIoT system effectively monitored and recorded various environmental parameters, including gas concentrations, temperature, humidity, and airflow. Real-time data acquisition provided a comprehensive view of the underground conditions.

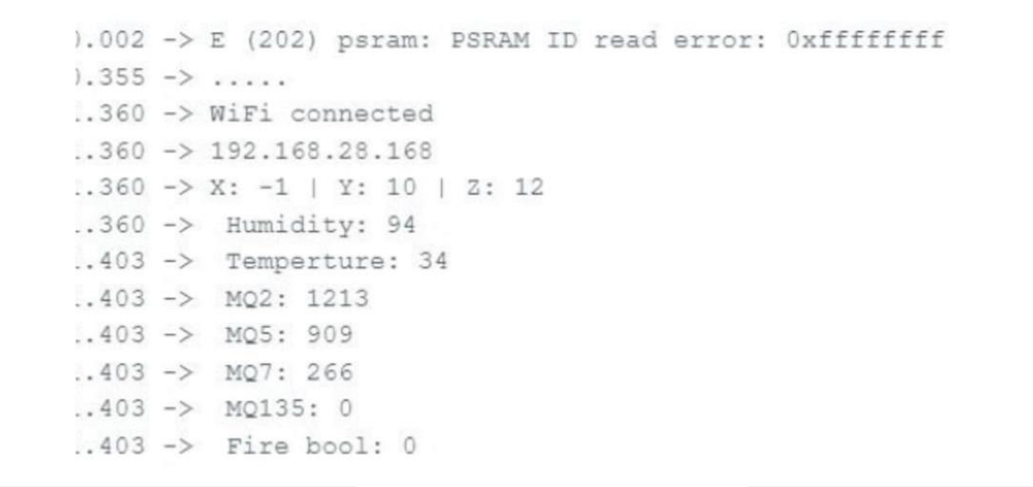
Safety and Hazard Detection: The integration of sensors, including fire detection and gas sensors (MQ2, MQ3, MQ7, MQ135), successfully identified potential safety hazards. Timely alerts and warnings were generated, enabling swift responses to mitigate risks and ensure the safety of personnel.

Personnel and Equipment Positioning: MIoT applications for personnel and equipment positioning were successful in providing accurate and up-to-date location information. This feature enhanced overall safety management, aiding in emergency response and evacuation procedures.

Production Safety Management: The MIoT system contributed to production safety management by continuously monitoring ground support integrity and seismic activity. This proactive approach helped prevent accidents and disruptions, leading to improved operational efficiency.

Web Server Interface: The web server platform provided a user-friendly interface for remote monitoring. Users could access real-time data, receive alerts, and make informed decisions, contributing to effective management and control of underground mining operations.

Challenges and Limitations: Despite the successes, challenges were identified, including operational disruptions, additional investment requirements, limited sensor battery life, and issues related to the quality of underground communication. These challenges need to be addressed for widespread and seamless implementation of MIoT technology in underground mines.



```
).002 -> E (202) psram: PSRAM ID read error: 0xffffffff
).355 -> .....
..360 -> WiFi connected
..360 -> 192.168.28.168
..360 -> X: -1 | Y: 10 | Z: 12
..360 ->  Humidity: 94
..403 ->  Temperture: 34
..403 ->  MQ2: 1213
..403 ->  MQ5: 909
..403 ->  MQ7: 266
..403 ->  MQ135: 0
..403 ->  Fire bool: 0
```

Fig 5: Serial Monitor Output

V.Prototype

The prototype model of an Internet of Things application for real-time environmental safety monitoring in underground mines is depicted in the picture below. It uses a variety of sensors together with an ESP32 low-power, high-accuracy microcontroller. The MQ2, MQ135, MQ5, MQ7, fire detector, and dht11 LCD 20*4 device for showing the findings of several sensors are among the many sensors employed in our prototype. The web page that displays the findings uses Async webserver library and is a cloud storage platform. The web page was created with the Arduino IDE (Integrated Development Environment) with integrated C code using HTML (Hypertext Markup Language) and CSS (Cascading Style Sheets)

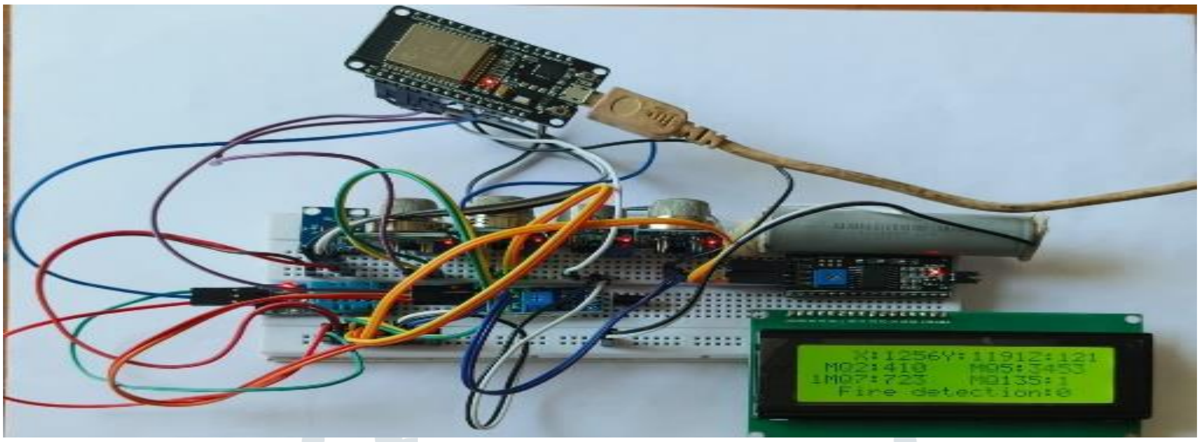
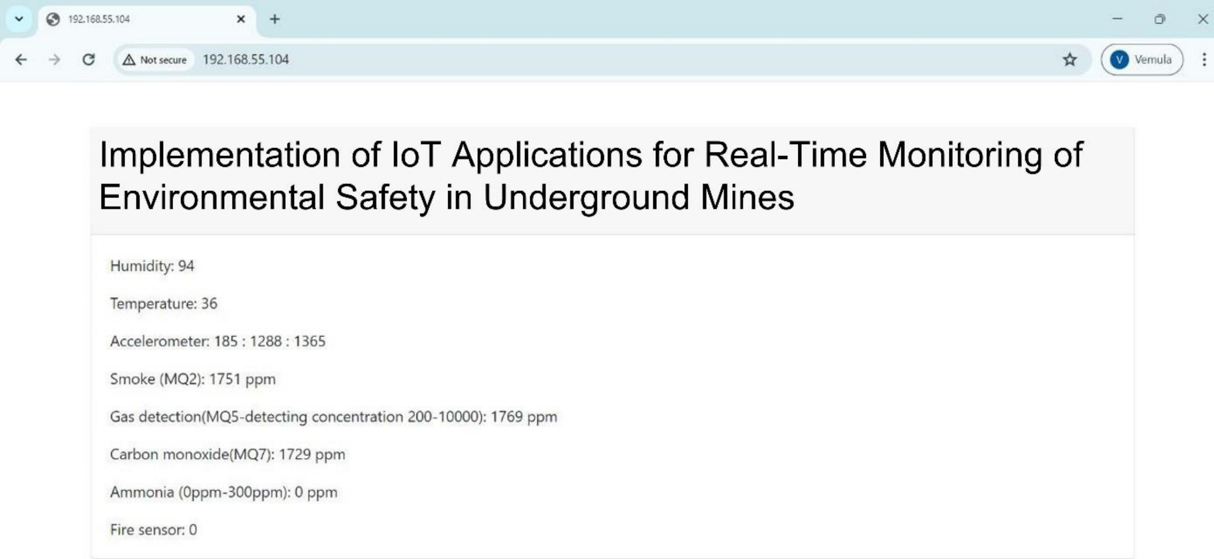


Fig 6. Prototype model



Implementation of IoT Applications for Real-Time Monitoring of Environmental Safety in Underground Mines

Humidity: 94

Temperature: 36

Accelerometer: 185 : 1288 : 1365

Smoke (MQ2): 1751 ppm

Gas detection(MQ5-detecting concentration 200-10000): 1769 ppm

Carbon monoxide(MQ7): 1729 ppm

Ammonia (0ppm-300ppm): 0 ppm

Fire sensor: 0

Fig 7. Webpage outputs

VI. Conclusions

In conclusion, the MIoT system demonstrated its potential to significantly enhance safety, environmental monitoring, and production efficiency in underground mines. The comprehensive review of environmental parameters, safety measures, and production management showcased the versatility and effectiveness of the implemented technology. The successful integration of sensors, the ESP32 microcontroller, and a web server platform provided a holistic solution for real-time monitoring and decision-making. The results highlight the importance of MIoT in addressing critical challenges in underground mining operations. The findings from this project lay the foundation for future advancements, emphasizing the importance of ongoing innovation to overcome challenges and improve the applicability and effectiveness of MIoT applications in underground mines.

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