

Underground Tunnel Monitoring Safety System for Workers Using IoT

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Abstract: Mining and underground tunnel environments are among the most hazardous working conditions worldwide due to the presence of toxic gases, high temperature, humidity, poor ventilation, and limited communication infrastructure. These conditions significantly increase the risk of accidents, suffocation, explosions, and occupational health issues. Traditional monitoring systems rely mainly on manual inspection methods, which are inefficient for continuous real-time safety assessment. To address these limitations, the proposed "Underground Tunnel Monitoring Safety System for Workers using IoT" is developed using Internet of Things (IoT) technology. The system continuously monitors environmental parameters using sensors such as MQ-7, MQ-135, DHT11, pressure sensor, and ultrasonic sensor integrated with an ESP8266 Node MCU. The collected data is transmitted wirelessly for real-time monitoring and analysis. In case of hazardous conditions, the system triggers immediate alerts through buzzer alarms, LED indicators, and emergency notifications. The proposed system is cost-effective, scalable, and suitable for industrial safety applications, with potential enhancement using cloud computing and intelligent data analytics techniques.

Keywords: IoT, Underground Tunnel, Worker Safety, ESP8266 Node MCU, Gas Detection, Smart Monitoring System

I. INTRODUCTION

Mining industries play a vital role in global economic development by extracting essential natural resources such as coal, iron, and minerals. However, underground mining environments are inherently dangerous due to toxic gases, poor ventilation, and unstable environmental conditions [16].

Workers in underground tunnels are frequently exposed to harmful gases such as carbon monoxide, methane, ammonia, and carbon dioxide, which can cause suffocation, explosions, and severe health hazards. Similar challenges have been highlighted in wireless sensor network-based safety monitoring studies [17], [18].

Environmental challenges such as extreme temperature, humidity, and low visibility further increase operational risks. Traditional manual inspection methods are insufficient for real-time monitoring and fail to detect sudden environmental changes effectively [19].

The emergence of IoT technology has enabled smart monitoring systems that allow real-time sensing, data transmission, and remote supervision [21]. These systems significantly enhance safety by integrating multiple sensors and communication technologies into a unified framework.

The proposed system integrates MQ-series gas sensors, environmental sensors, and ESP8266 Node MCU for continuous monitoring of underground conditions. This approach aligns with modern IoT-based industrial monitoring frameworks designed for real-time safety applications [19], [21][22-180].



II. LITERATURE SURVEY

Many researchers have investigated underground tunnel monitoring and industrial safety systems using wireless communication and sensor-based technologies. Most of the existing studies focus on gas detection, environmental parameter monitoring, and emergency alert systems for hazardous environments. Wireless sensor network (WSN)-based approaches have been widely used in mining safety applications to measure environmental parameters such as toxic gas concentration and temperature, and transmit the collected data to a centralized control station for analysis and decision-making purposes [16]–[18]. However, these systems often suffer from limited communication range, network instability, and lack of real-time responsiveness in critical situations [19].

Several IoT-enabled industrial monitoring solutions have also been proposed for hazardous and remote environments. These systems integrate smart sensors with microcontrollers and cloud-based platforms to achieve real-time environmental monitoring, remote accessibility, and instant alert generation [20], [21]. Despite these advantages, many existing IoT systems are restricted to basic environmental parameters and do not support advanced functionalities such as robotic inspection or multi-modal sensing integration [22].

In addition, robotic-based underground monitoring systems have been developed to reduce human exposure to dangerous environments. These systems utilize obstacle detection sensors and wireless communication modules to navigate underground tunnels and collect environmental data efficiently [18], [21]. However, the high implementation cost and system complexity limit their adoption in small-scale industries and practical field applications [19].

Some conventional safety monitoring systems also rely on GSM-based communication for emergency alerts and SMS notifications. These systems enable rapid information transfer during hazardous events such as gas leakage or tunnel collapse. Nevertheless, GSM networks often face connectivity issues and unreliable communication in deep underground environments [20].

The proposed system addresses these limitations by integrating multiple sensing modules, IoT-based communication, and robotic monitoring capabilities into a unified framework. It enables continuous real-time monitoring of gas concentration, temperature, humidity, pressure, and obstacle detection, while using ESP8266 Node MCU for reliable wireless data transmission to the control room [16]–[22].

III. SYSTEM DESIGN

3.1 System Overview

The Underground Tunnel Monitoring Safety System is designed using IoT technology and a smart robotic monitoring unit. The system continuously monitors environmental conditions inside underground tunnels to improve worker safety and reduce accidents.

The project consists of four main sections:

1. Input Section (Sensors)
2. Processing Unit
3. Communication Section
4. Output Section

All sections work together to monitor harmful gases, temperature, humidity, pressure, and obstacles inside tunnels.



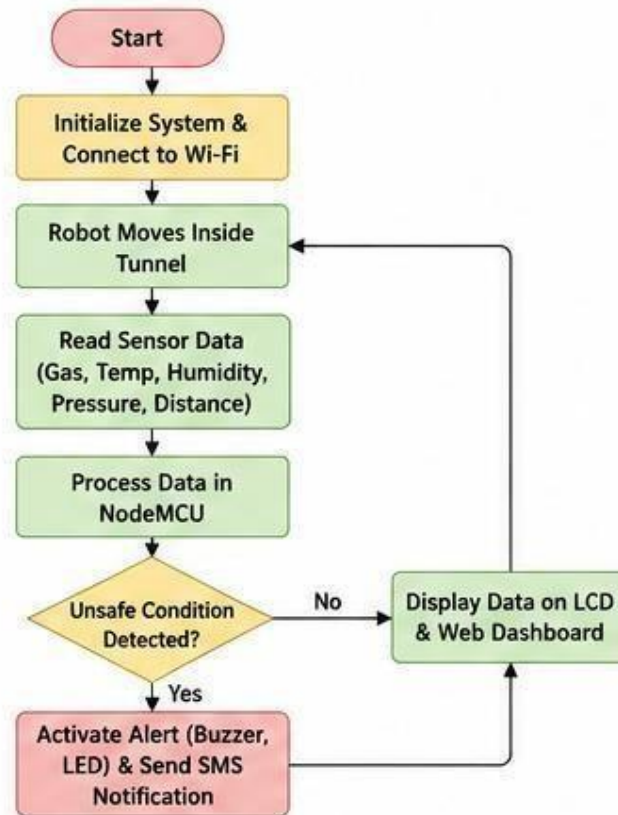


Figure: System

3.2 Components Used

1. ESP8266 Node MCU

ESP8266 Node MCU is the main microcontroller used in the project. It acts as the brain of the entire monitoring system. The controller collects sensor data, processes environmental information, and transmits the data wirelessly using Wi-Fi communication technology.

2. MQ-7 Gas Sensor

MQ-7 is a gas sensor used to detect carbon monoxide (CO) gas. Carbon monoxide is highly poisonous and dangerous for workers inside underground tunnels.

The sensor continuously monitors gas concentration levels and sends analog data to the ESP8266 Node MCU. If gas concentration exceeds the safety limit, the system immediately activates warning alerts.

3. MQ-135 Gas Sensor

MQ-135 sensor is used to monitor air quality and detect harmful gases such as smoke, ammonia, benzene, carbon dioxide, and toxic gases.

This sensor helps identify unsafe environmental conditions inside tunnels and improves worker safety.

4. DHT11 Sensor

DHT11 sensor measures temperature and humidity conditions inside underground tunnels.



The sensor continuously monitors environmental conditions and sends digital data to the controller for processing.

5. Pressure Sensor

The pressure sensor monitors atmospheric pressure conditions inside tunnels. Sudden pressure changes may indicate dangerous environmental conditions.

6. Ultrasonic Sensor

Ultrasonic sensor is used for obstacle detection and distance measurement in the robotic monitoring system. The sensor helps the robot move safely inside tunnels by avoiding collisions with obstacles.

7. LCD Display

LCD display shows real-time monitoring data such as gas levels, temperature, humidity, pressure, and system status.

8. L298N Motor Driver

The L298N motor driver controls the movement of motors used in the robotic system. It helps the robot move forward, backward, left, and right inside tunnels.

IV. WORKING METHODOLOGY



Figure: Working steps

The proposed system operates using continuous environmental sensing, real-time processing, and wireless communication, similar to existing IoT-based industrial monitoring frameworks [19], [21].

Gas sensors (MQ-7 and MQ-135) continuously monitor toxic gases such as carbon monoxide and air pollutants. These techniques are widely used in wireless sensor network-based safety systems for hazardous environments [16], [17].

Environmental parameters such as temperature and humidity are measured using the DHT11 sensor, while pressure variations are monitored to detect abnormal underground conditions.



The ultrasonic sensor is used for obstacle detection, enabling safe navigation of the robotic unit inside tunnels. Similar sensor fusion techniques have been widely adopted in IoT-enabled monitoring systems for industrial safety applications [18].

All sensor data is processed by the ESP8266 Node MCU, which acts as the central control unit. The processed information is transmitted wirelessly to the control room using Wi-Fi communication technology, supporting real-time monitoring and alert generation [21].

Energy-efficient system design principles are also incorporated to ensure long-term operation in underground environments with limited power resources [20].

V. ADVANTAGES

This system enables continuous real-time monitoring of tunnel environments to maintain a safe and controlled working atmosphere. It supports early identification of hazardous gases, allowing timely preventive actions before conditions become dangerous. Through IoT-based wireless communication, the system ensures fast and efficient transmission of sensor data to the monitoring station. An integrated emergency alert mechanism immediately informs workers and authorities when abnormal or unsafe conditions are detected. This significantly enhances worker safety and helps minimize the risk of accidents and fatalities.

The system is cost-effective, making it suitable for deployment across various industrial sectors, while its simple installation and low maintenance requirements reduce operational complexity. It also incorporates obstacle detection and robotic monitoring features, which allow inspection of high-risk or inaccessible underground areas without endangering human life. Overall, the proposed solution is well-suited for hazardous environments, offering reliable monitoring and effective safety management.

VI. APPLICATIONS

This tunnel monitoring and safety system can be applied across multiple industrial sectors. It is particularly useful in coal and gold mining operations for continuously tracking environmental conditions and ensuring the safety of underground workers. The system is also suitable for railway tunnel networks, where real-time monitoring is essential for safe and reliable transportation.

In construction tunneling projects, it helps identify potential hazards during excavation activities and improves overall site safety. It is equally valuable in hazardous industrial environments where continuous detection of toxic gases and unsafe conditions is critical. Furthermore, the system can be integrated into smart industrial safety frameworks to support automated monitoring, real-time data acquisition, and rapid emergency response. Overall, this solution enhances operational safety, efficiency, and risk management in underground and industrial applications.

VI. FUTURE SCOPE

The project can be further improved using advanced technologies such as:

- Artificial Intelligence for accident prediction
- Cloud-based data monitoring
- GPS worker tracking systems
- Mobile application integration
- Advanced wireless communication systems
- Smart automation technologies
- AI-based environmental analysis

These improvements will make underground monitoring systems more intelligent, accurate, and efficient.



IX. CONCLUSION

The IoT-based Underground Tunnel Monitoring Safety System offers an effective approach to enhance worker safety in underground environments. It continuously tracks environmental parameters such as harmful gas levels, temperature, humidity, pressure, and the presence of obstacles using smart sensors integrated with wireless communication technology.

The proposed system enables real-time monitoring, instant emergency alerts, and improved communication between underground workers and the control room. It plays a vital role in minimizing accidents, enhancing response time during emergencies, and ensuring safer underground operations.

This solution is cost-effective, dependable, and easy to deploy, making it well-suited for mining industries and tunnel-based applications. The system can be further enhanced in the future by incorporating advanced technologies such as artificial intelligence, cloud computing, and GPS-based tracking to improve accuracy, efficiency, and overall safety performance.

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