Power System Technology
ISSN:1000-3673

*Received: 16-04-2025* *Revised: 05-05-2025* *Accepted: 15-06-2025*

# Design and Implementation of a Coal Mine Safety System Using Low-Cost Embedded Electronics and IoT Connectivity

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## ABSTRACT

Safety is the most important part of the mining industry for miners. The safety of miners in the mining environment has become a major challenge. To avoid these kinds of natural disasters, they follow some basic precautions. Accidents still occur in underground mines due to unexpected disasters. Disasters in these coal mines are caused by the complexity of the mining environment and the various tasks performed in the coal mines. At any cost, therefore, the communication network must not be interrupted at any time and under any conditions. To solve this problem, there is an IOT system that monitors the security measures and reports on the mobile app, the system has fire sensors, temperature sensors, humidity sensors, etc., and also an alarm buzzer and LED lights in it. These sensors are assembled into a single Arduino board and connected to a mobile application. This system monitors basic safety measures, and the goal is to develop an affordable system that will increase the safety of workers in the mining environment and the status of workers will be able to be monitored via IOT. The use of Arduino microcontrollers, sensors, buzzers and LED lights that increases the safety of coal mining. The system uses sensors to monitor environmental conditions and triggers alerts via LED lights and a buzzer if potential hazards are detected. Simultaneously optimizing the mobile application for interaction and communication via wi-fi modem, providing real-time updates. The goal of this integrated solution is to provide coal mining workers with advanced safety features and leverage available technologies for a safer work environment.

## I. INTRODUCTION

The mining industry plays a vital role in the economic development of many countries, especially in the extraction of essential resources like coal. However, underground mining continues to pose serious hazards to miners due to its complex and unpredictable working

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environment. Despite the implementation of safety regulations and precautionary measures, mining accidents resulting from fires, gas leaks, equipment malfunctions, and structural collapses still occur frequently. These accidents not only threaten human lives but also impact productivity and incur significant economic losses.

With the advancement of technology, the integration of Internet of Things (IoT) systems in industrial applications has emerged as a promising solution for enhancing safety and monitoring conditions in real-time. In particular, IoT-enabled safety systems are capable of collecting data from the environment through a network of sensors, analyzing it, and providing timely alerts to prevent accidents. These systems can be crucial in underground coal mines where visibility is low and manual inspection is often insufficient.

This paper presents a cost-effective and practical IoT-based safety monitoring system designed specifically for underground coal mining environments. The system includes multiple sensors—such as fire, temperature, and humidity sensors—assembled on an Arduino microcontroller board, with real-time data relayed to a mobile application via Wi-Fi. The inclusion of LED indicators and a buzzer enables immediate visual and auditory alerts in hazardous situations. By leveraging this integrated solution, mining authorities can continuously monitor environmental parameters and worker safety, ensuring a proactive response to potential dangers. The proposed system aims not only to reduce accident rates in mines but also to demonstrate the effective use of accessible microcontroller technology and IoT applications in industrial safety. The following sections detail the system architecture, components used and working methodology, in simulated underground mining conditions.

## II. DESIGN METHODOLOGY

The system is developed to address the pressing safety challenges faced by workers in underground coal mining environments. Accidents caused by gas leaks, extreme temperatures, or fire outbreaks remain prevalent due to the harsh and dynamic conditions in mines. The design methodology aims to create a robust, real-time, and low-cost monitoring solution that enhances worker safety through timely detection and alert mechanisms.

This embedded system integrates multiple environmental sensors, namely gas**,** temperature**,** humidity**,** and vibration sensors—that continuously monitor surrounding conditions. These sensors are connected to an Arduino Uno microcontroller, which acts as the core processing and control unit. The microcontroller collects analog/digital data from each sensor, processes it, and communicates the results through a Wi-Fi-enabled IoT platform for real-time monitoring. When hazardous thresholds are breached, visual (LED) and audible (buzzer) alerts are triggered immediately to warn workers on-site.

Additionally, sensor readings and system status updates are displayed on an LCD screen,

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ensuring both visibility and interpretability of environmental conditions. By integrating cloud connectivity, the system also allows remote supervisors or safety personnel to monitor operations in real time from outside the hazardous zone.

### 2.1 Component Specifications

The components used in the proposed coal mine safety monitoring system have been carefully selected based on their cost-effectiveness, functional accuracy, and compatibility with the Arduino platform. Each component contributes significantly to achieving the system's safety objectives. The gas sensor plays a critical role in detecting combustible or toxic gases such as methane and carbon monoxide, which are prevalent in mining environments. By identifying gas concentration levels that exceed predefined safety thresholds, the system can promptly trigger alert mechanisms to prevent suffocation or explosion-related accidents.

The temperature sensor continuously monitors ambient conditions, helping to identify risks such as overheating equipment, underground fires, or inadequate ventilation. In parallel, the humidity sensor assesses moisture levels that could influence air quality and operational safety, while the vibration sensor is used to detect abnormal ground movements or potential structural collapses, allowing timely evacuation in case of seismic activity. To alert miners effectively, a buzzer serves as the primary audible warning device, activated immediately during hazardous conditions. Complementing this, color-coded LED indicators provide clear visual feedback—each mapped to a specific environmental threat (e.g., red for gas, yellow for heat, and blue for humidity)—thereby improving situational awareness.

An LCD display module (16x2 with I2C interface) is employed to present real-time sensor readings and system statuses, ensuring ease of use and transparency for on-site operators. At the heart of the system is the Arduino Uno microcontroller, powered by the ATmega328P chip, which handles data acquisition, sensor integration, threshold analysis, and alert activation. This microcontroller was chosen for its reliability, low cost, and wide community support. Finally, an IoT communication module (such as the ESP8266) enables real-time data transmission to a remote cloud server, allowing for continuous logging, remote monitoring, and historical analysis of environmental conditions within the mining site.

### 2.2 Integration Strategy

The system architecture is modular, allowing ease of upgrade and maintenance. Sensors are connected to the appropriate analog/digital input pins of the Arduino board. Sensor data is acquired at fixed intervals and compared against pre-defined safety thresholds. When unsafe conditions are detected, the Arduino triggers the buzzer and LED indicators, simultaneously transmitting alerts to the cloud via the IoT module. This integration of low-cost embedded electronics with wireless communication technologies ensures a scalable, responsive, and

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affordable safety solution for the mining sector.

### 2.3 System Architecture

The architecture of the proposed safety monitoring system as shown in figure 2.1 is designed with modularity, scalability, and real-time responsiveness in mind. The system consists of four core layers:

- Sensing Layer

This layer comprises the gas, temperature, humidity, and vibration sensors strategically placed in underground mining zones. These sensors continuously sense environmental parameters and relay raw data to the microcontroller.

- Processing Layer

The Arduino Uno microcontroller serves as the processing unit. It aggregates sensor data, filters noise, applies threshold comparisons, and controls the actuation of warning components (buzzer and LEDs). It also formats the data for transmission via the communication module.

- Communication Layer

The ESP8266 Wi-Fi module (or any compatible IoT module) establishes a connection to a wireless access point and uploads sensor data to a remote monitoring platform, such as ThingSpeak, Firebase, or a custom cloud server.

- Interface Layer

This includes the LCD screen, which displays real-time data locally, and the cloud- based dashboard, where remote users can visualize live sensor data, historical logs, and receive alerts.

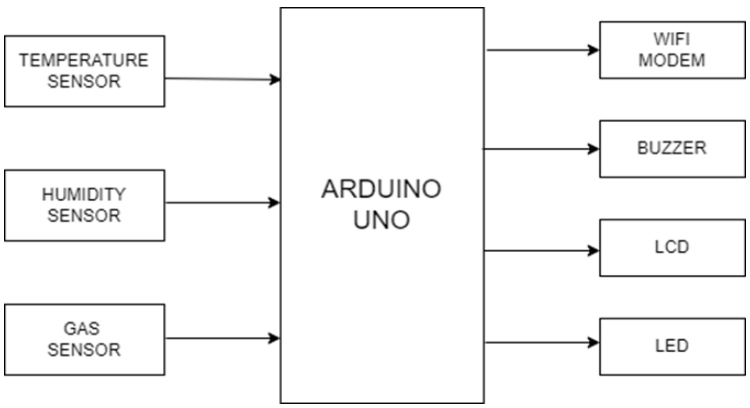


**Figure 2.1: System Architecture of the IoT-Based Coal Mine Safety Monitoring System**

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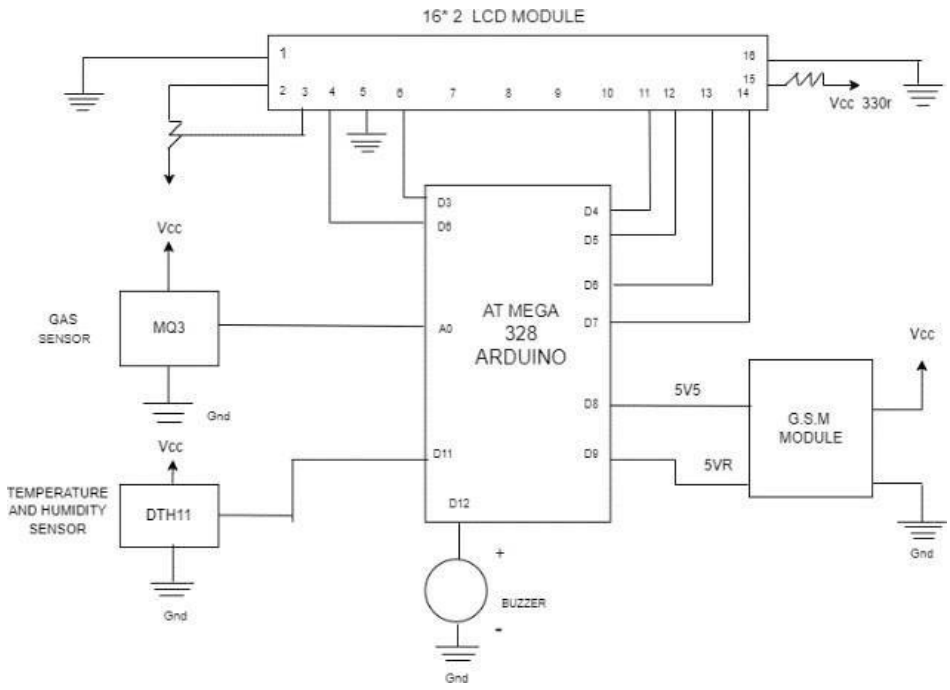


**Figure 2.2 : Circuit Diagram of Coal Mine Safety Monitoring System**

## III. RESULTS AND DISCUSSION

Analysis of coal mine people' protection tracking and warnings yielded considerable effects. First, the sensor works on recognition error, revealing the fact. Confidence in detecting unfavorable environmental conditions is essential to make certain the machine is powerful in protective the fitness of workers inside the harsh environments surrounding mining. Real-time tracking capability is another important function as the gadget can provide actual-time updates about the painting surroundings and surroundings, permitting it to reply to converting situations. In a simulated emergency scenario, the system informs its web site by giving appropriate warnings in a timely way. These features are important to ensure well-timed intervention and minimize employee safety risks. Additionally, the vicinity monitoring feature has verified to be powerful, imparting immediate records approximately who is operating in our construction. This suitable situational focus can assist enhance coincidence prevention and emergency response efforts. The fall detection function is every other essential part of the gadget that reliably simulates falls and allows receiving timely indicators from correct vicinity statistics. This potential is important for providing speedy assistance to careworn workers and lowering the severity of ache. Additionally, dependable communication between wearable devices and the center ensures the constant connection is important for effective tracking and coordination, even in tough terrain.

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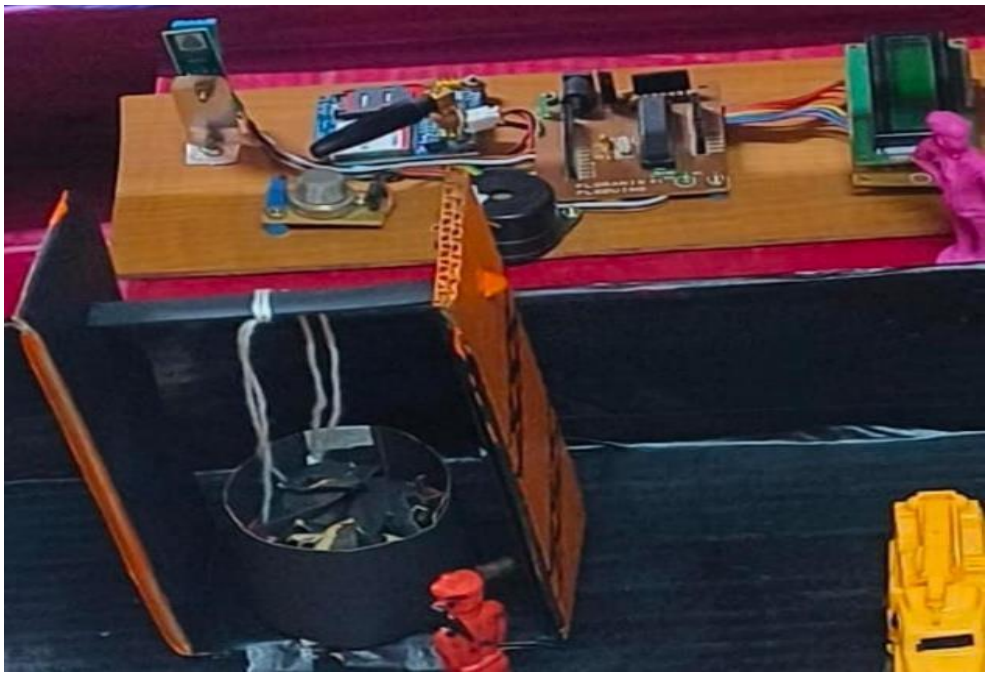

**Figure 3.1 : Implementation of an IoT-Integrated Safety Monitoring System for Coal Mines**

## IV. CONCLUSION AND FUTURE ENHANCEMENT

This research represents a comprehensive and innovative approach to enhancing safety measures within coal mining environments. Through the integration of advanced sensor technologies, Arduino boards, and an Internet of Things (IoT) platform, the proposed system proactively monitors and detects potential hazards, providing timely alerts to mitigate risks and improve overall worker safety. To further strengthen the system's effectiveness, future enhancements may include the integration of additional advanced sensors capable of detecting particulate matter, toxic gases, and specific chemical compounds relevant to mining activities, thereby offering a more comprehensive assessment of environmental threats. Additionally, incorporating machine learning algorithms for predictive analysis based on historical sensor data could enable the system to anticipate potential hazards and improve response times, contributing to a more proactive and intelligent safety framework. Furthermore, enhancing the IoT platform with advanced data analytics, visualization tools, and real-time dashboards would provide deeper insights into environmental trends and support informed decision-making, ultimately promoting a safer and more responsive mining ecosystem.

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