

Research Article

IoT BASED COAL MINE SAFETY MONITORING AND ALERTING SYSTEM

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Abstract

Using ESP32 microcontrollers, MQ-4 gas sensors, DHT11 sensors, and integrated buzzer and LED modules, this paper presents an Internet of Things (IoT)-based coal mine safety monitoring and alerting system. Its objective is to continuously monitor temperature, humidity, and gas concentration in order to address safety concerns in coal mining. In order to gather data in real time, ESP32 microcontrollers act as central units that interface with sensors placed throughout the mine. The ESP32's sophisticated algorithms examine data for unusual trends that could point to safety risks like fires or gas leaks. The system provides on-site warnings to mine workers by instantly triggering alarms using buzzer and LED modules upon detection. Additionally, designated staff can monitor and intervene remotely thanks to real-time notifications sent via email or SMS. Mine operators can make well-informed decisions by using a centralized dashboard interface that displays parameters, historical data, and predicted insights. By integrating IoT technology and data analytics, the system provides a complete solution for raising safety standards in coal mining operations, facilitating proactive risk detection, and reducing accidents.

Keywords: IoT-based coal mine safety monitoring, ESP32 microcontrollers, Gas sensors (MQ-4), DHT11 sensor, Alerting system.

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1. INTRODUCTION

An important development in guaranteeing the security of coal mining operations is the Internet of Things-based coal mine safety monitoring and alerting system. The system continuously analyzes environmental conditions by placing a network of IoT devices throughout the mine, including sensors for temperature, humidity, gas concentration, and air quality. Advanced analytics algorithms evaluate this real-time data to quickly identify any anomalies or possible safety risks, such as fires or gas leaks. In order to enable quick response and intervention, immediate notifications are then sent to specified personnel via SMS, email, or mobile application. Additionally, the consolidated dashboard interface provides extensive visualization and analysis features, enabling mine operators to maximize operational efficiency and proactively manage safety hazards. All things considered, this cutting-edge solution is expected to greatly raise safety standards and reduce the possibility of mishaps in coal mining settings (Manasa et al., 2022; Akhila et al., 2022; Mishra et al., 2022). In their framework, Rajnish

Kumar et al. (2022) detect the temperature, strain, and climate in the coal mineshaft by combining the activity of a temperature, tension, and gas sensor with an IOT module. They also use information logging to log all of the data to the cloud. At that moment, an administrator-controlled server page acknowledges the information that has been obtained. The data is processed on a server page, and the device sends out an alert that will be broadcast to the relevant authorities and salvage stations, who will take precautions. Subhadra et al. 2024 reported that it is crucial to keep an eye on the working environment of coal mines since the complexity of the mine environment and the variety of work done there are the main causes of the disasters that occur there. We suggested an alarm system for mine workers as a solution to this issue. This project consists of two sections: the transmitter section and the receiver section. The workers' end will have the transmission section, while the officials' end will have the receiver section. The officials will receive signals through this alert system to take action, and the

workers will also be informed by a red LED glow, a buzzer, and a display. An Atmega 328 microprocessor and a NodeMCU ESP8266 microcontroller power this monitoring and alerting system. To detect temperature, humidity, and the leaking of several poisonous chemicals, we use MQ2, DHT11, RF transmitters, and receivers. We then notify the workers and other officials to leave the hazardous area. Deokar and Wakode (2017) reported that the particulate matter and gases, such as sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), etc., are the primary causes of air pollution from coal mines. Semiconductor gas sensors are used to track the level of dangerous gas concentrations. Many miners die as a result of falls and unconsciousness caused by many factors, as well as the lack of appropriate medical care at the time. In order to solve this issue, the system notifies the supervisor in an emergency if someone falls for whatever cause. Some employees do not wear helmets because they are unaware of safety precautions. Next, it was successfully determined whether or not a miner had taken off his helmet using a limit switch. Next, it was successfully determined whether or not a miner had taken off his helmet using a limit switch. Additionally, this technology offers an early warning, which will allow all miners inside the mine save their lives before any casualties happen. The system transmits data via GSM and Zigbee technology. For emergency situations, alert switches are located on both the transmitter and receiver sides. In order to increase worker safety and operational reliability, the current project intends to build an Internet of Things (IoT)-based safety monitoring and alerting system for underground coal mine applications. The prevalence of toxic gasses, temperature swings, humidity changes, and fire hazards make coal mining sites extremely dangerous. To ensure safe working conditions and prevent accidents, it is imperative to continuously monitor these environmental indicators. Using IoT-enabled sensors, the suggested system is intended to continuously monitor vital factors including temperature, humidity, and concentrations of hazardous gases in real time. The gathered sensor data is examined to find unusual trends and dangerous circumstances that can point to possible dangers like gas leaks, fires, or ventilation problems. Additionally, the created system has an intelligent alarm mechanism that can instantly notify control room operators and mine workers when dangerous conditions are identified. By enabling timely intervention and quicker emergency response, real-time warnings and remote monitoring capabilities reduce dangers to mining infrastructure and human life. Additionally, by providing ongoing environmental surveillance, data logging, and operational insights, the suggested IoT-based system helps mine operators proactively manage safety-related issues. It is anticipated that the application of the suggested approach will raise overall operational efficiency in underground coal mining environments, lower accident rates, and improve mine safety standards (Thilagavathi & Arockiam, 2023; Srivastav et al., 2022; Kanna et al., 2022).

2. METHODOLOGY

A variety of hardware components for sensing, processing, display, and alarm production are used in the development of the suggested Internet of Things (IoT)-based coal mine safety monitoring system. Together, these elements make it possible to monitor the environment and identify hazards in underground mining settings in real time. The ESP32 microcontroller, MQ-4 gas sensor, DHT11 temperature and humidity sensor, OLED display, buzzer, LED indicators, breadboard, and jumper wires are among the hardware elements used in this project. One of the main risks in coal mines is methane gas, which is detected by the MQ-4 gas sensor. The ambient temperature and humidity conditions within the mining area are measured using the DHT11 sensor. While the buzzer and LED indicators act as warning devices under unusual or dangerous conditions, the OLED display offers real-time viewing of the measured environmental factors. During system implementation, jumper wires and a breadboard are utilized for circuit connections and hardware interfacing (Ali et al., 2022). The suggested safety monitoring system's central processing and communication element is the ESP32 microcontroller. It is an inexpensive, low-power System-on-Chip (SoC) intended for Internet of Things applications and embedded systems. For remote monitoring and alarm creation, the ESP32 is in charge of gathering sensor data, processing environmental data, and sending the monitored data via wireless communication protocols. With a clock frequency of up to 240 MHz, the ESP32's single-core or dual-core 32-bit CPU allows for effective multitasking and real-time data processing. applications for monitoring. Additionally, the controller enhances wireless connectivity possibilities for Internet of Things installations by supporting Bluetooth Low Energy (BLE) and Bluetooth Classic v4.2 communication protocols. Additionally, sophisticated security features like Flash Encryption and Secure Boot guarantee reliable systems and safe data transmission. Physical Local Area Network (LAN) connectivity is also supported via the inbuilt Ethernet Media Access Controller (MAC). The ESP32 microcontroller is ideal for industrial IoT applications and real-time coal mine safety monitoring due to its small size, low power consumption, integrated wireless communication capabilities, and strong computational capability (Kanna et al., 2022). Figure 1 shows the photo of ESP32 microcontroller.

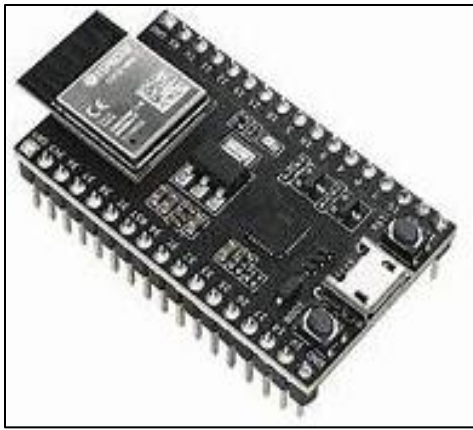


Figure 1: ESP32 microcontroller

A common gas detecting tool for identifying methane (CH_4) gas in the surroundings is the MQ-4 sensor. It is frequently used in applications where ongoing methane concentration monitoring is crucial, such as gas leak detection systems, industrial safety monitoring, and environmental surveillance. Due to its extreme flammability, methane gas accumulation in underground coal mining conditions presents a serious safety risk, requiring dependable gas detection systems. The MQ-4 sensor's working principle is based on how the sensing material's electrical conductivity changes in response to methane gas molecules. The sensor is made of a sensitive semiconductor material whose conductivity varies in direct proportion to the amount of methane in the air. For real-time gas concentration monitoring, the microcontroller transforms these conductivity variations into corresponding electrical signals, which it subsequently processes and analyzes. High sensitivity to methane gas, quick response times, affordability, and ease of interface with microcontrollers like the ESP32 are some of the benefits of the MQ-4 sensor (Figure 2). These features make the sensor ideal for use in Internet of Things-based coal mine safety monitoring systems designed to identify dangerous gas leakage situations and guarantee worker safety (Sathishkumar et al., 2021).



Figure 2: MQ-4 Sensor

A popular low-cost digital temperature and humidity sensor for embedded systems, Internet of Things

applications, and environmental monitoring projects is the DHT11. The sensor is appropriate for real-time monitoring applications in indoor and industrial settings, including underground coal mines, because it is made to measure ambient temperature and relative humidity simultaneously. The sensor measures temperature and relative humidity with an accuracy of roughly $\pm 2^\circ\text{C}$ and $\pm 5\%$, respectively. The DHT11 sensor is frequently used in weather monitoring systems, environmental surveillance, smart home automation, and industrial monitoring systems due to its low power consumption, small size, and simplicity of integration with microcontrollers like the ESP32. The DHT11 sensor in the proposed coal mine safety monitoring system continuously analyzes the humidity and temperature of the surrounding environment to spot unusual variations that might point to dangerous operating conditions. The DHT11 sensor (Figure 3) is better appropriate for prototype development and low-cost monitoring applications because, despite being inexpensive and simple to use, its measurement precision is significantly lower than that of industrial-grade sensors (Porselvi et al., 2021).

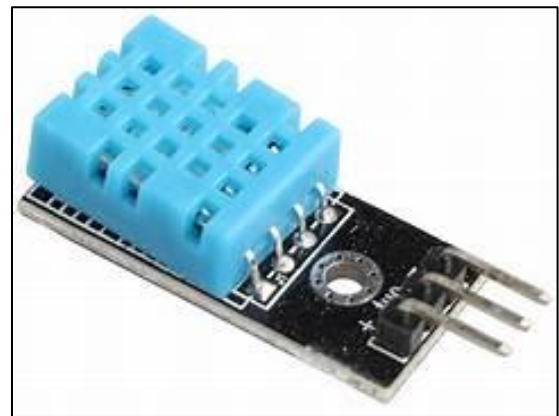


Figure 3: DHT11 sensor

Semi-permanent electronic circuit prototypes are constructed using a breadboard, solderless breadboard, or protoboard. Breadboards are reusable since they don't require soldering or track destruction like perf boards or stripboards do. Because of this, breadboards are also widely used in technology education and among students. Breadboards can be used to prototype a wide range of electronic systems, from tiny analog and digital circuitry to entire central processing units (CPU). Modern breadboards (Figure 4) have higher parasitic capacitance, comparatively high resistance, and less dependable connections that are prone to jostling and physical deterioration when compared to more permanent circuit connection techniques. Signalling is restricted to roughly 10 MHz, and even much below that frequency, some things don't function as intended.

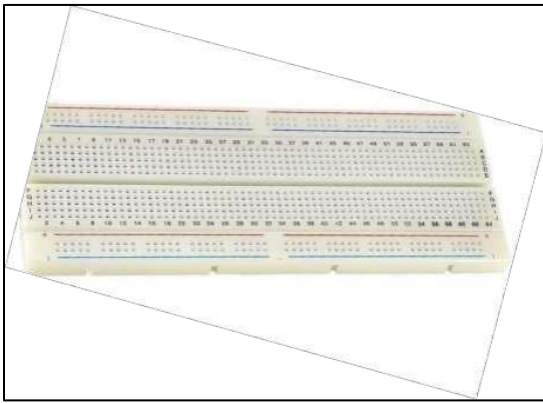


Figure 4: Breadboard

A jump wire (Figure 5), sometimes referred to as a jumper, jumper wire, or DuPont wire, is an electrical wire, or group of them in a cable, with a connector or pin at each end (or occasionally without them—just "tinned"). It is typically used to solderlessly connect the internal or external components of a breadboard, prototype, or test circuit. To install individual jump wires, place their "end connectors" into the slots on a breadboard, a circuit board's header connector, or a piece of test apparatus. An electric cable used to link distant electric circuits for printed circuit boards is called a jumper wire.

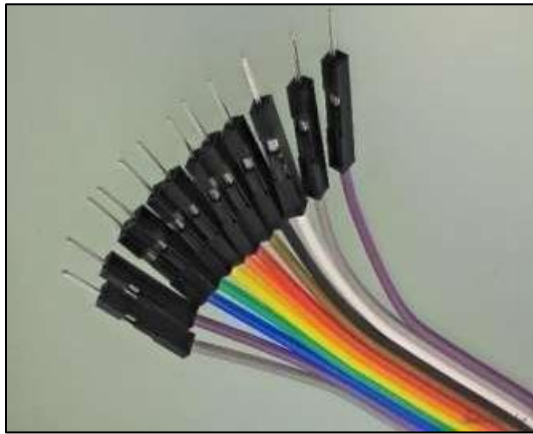


Figure 5: Jumper wire

The OLED display (Figure 6) improves the user experience by giving consumers instant visual feedback that verifies whether access is allowed or prohibited. This display makes it simple to identify and verify user information, such as names, photographs, or access levels. It gives consumers clear instructions or prompts on the OLED display to help them use the device effectively and accurately. System administrators can adjust the visual elements to suit certain requirements thanks to OLED displays' adaptable and adjustable interfaces. The OLED display can help with troubleshooting by displaying error messages in the event of problems such as invalid cards or system malfunctions. Show system status indications that show if the system is operating, in maintenance mode, or having an issue. The screen can display information in real time regarding.



Figure 6: OLED display

Light-Emitting Diodes (LEDs) shown in Figure 7 is an semiconductor devices that, when an electric current flows through them, emit light. To visibly convey the status of access attempts, use LEDs. Light-emitting diodes, or LEDs, are essential components of coal mine safety monitoring and alerting systems. They serve as indicators for a number of circumstances, including machine operation, gas levels, ventilation status, and emergency alarms. Miners and operators can receive clear visual indications by using different colors to indicate different states. Because of their energy economy, robustness, and visibility in low-light conditions—which are frequently encountered in coal mines—LEDs are favored (Nagrle et al., 2021).



Figure 7: Light emitting diode

An electronic gadget that emits sound when an electric current flows through it is called a buzzer (figure 8). To verify successful access, release a brief, pleasant tone. In coal mine safety systems, buzzers offer audible alerts for communication, evacuation, equipment failures, and emergencies. It promotes safety training, connects with monitoring systems, guarantees accessibility in limited visibility, and enhances visual indicators. Redundancy contributes to an all-encompassing safety plan by guaranteeing dependability. By alerting miners to equipment failures or malfunctions, buzzers assist prevent accidents and guarantee that vital apparatus is maintained or repaired on time. During drills or real situations, its sound acts as an evacuation siren, directing miners to safe areas or exits for evacuation protocols (Rudrawar et al., 2022).



Figure 8: Buzzer

EXPERIMENTAL PROCEDURE

The ESP 32 and the sensors receive the supply. The sensors continuously monitor the ESP32's parameters, and the ESP32 then receives the data about parameters like temperature and methane level, humidity, etc. Figures 9 & 10 shows the circuit and block diagram of hardware implementation.

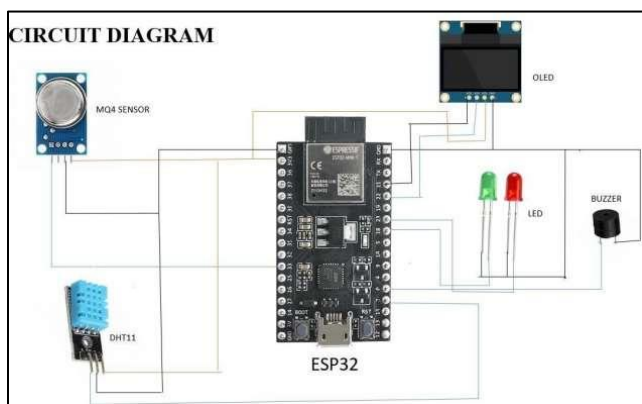


Figure 9: Circuit diagram of hardware implementation

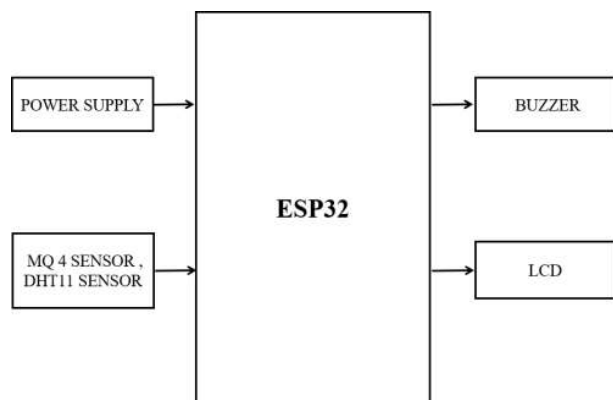


Figure 10: Block diagram of hardware implementation

Look for unusual trends that can point to possible safety risks like fires or gas leaks. When safety issues are discovered, send out instant alerts to mine workers. Use real-time alerts for prompt intervention and remote monitoring.

3. WORKING

Methane gas in the coal mine is detected by the MQ-4 sensor. Early detection of possible gas leaks, which could result in

explosions or health risks for miners, is essential. The coal mine's temperature and humidity are measured by the DHT11 Sensor. In addition to ensuring that miners have the best possible working circumstances, monitoring these data might reveal possible hazards like overheating machinery or excessive humidity. As the central 32 processing unit, the ESP32 interfaces with all of the sensors, LED indicators, buzzer, and Firebase to transmit and manage data. It gathers information from the sensors, processes it, and, if required, sends out alarms or interacts with the control room.

Here, LEDs serve as visual indicators and give miners instant input on the state of the environment. Different colored LEDs, for instance, can indicate severe signals that call for an immediate evacuation, high gas levels, or safe circumstances. In noisy settings or circumstances where visual cues might not be readily apparent, the buzzer acts as an auditory alarm system to warn miners. Real-time communication with the control room is facilitated using Firebase. It makes it possible to remotely monitor sensor data, provide alarms, and manage the system. In order to protect miners, the control room can receive alerts, keep an eye on the mine's circumstances, and take necessary action.

Real-time sensor data is continuously monitored by the system. When predetermined thresholds are exceeded, it uses algorithms to analyze the data and send out notifications. These notifications can be transmitted to the control room via Firebase for more comprehensive administration, as well as to the local system (LEDs, buzzer) for quick action by miners. Operators can monitor sensor readings, get alerts, and interact with miners as needed thanks to the control room interface. It should offer easy-to-use controls for efficient system management as well as clear data display.

4. PROGRAM

```
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include <DHT.h>
#include <Arduino.h>
#if defined(ESP32)
#include <WiFi.h>
#elif defined(ESP8266)
#include <ESP8266WiFi.h>
#endif
#include <Firebase_ESP_Client.h>
#include "addons/TokenHelper.h"
#include "addons/RTDBHelper.h"
#define WIFI_SSID "Sobii##"
#define WIFI_PASSWORD "sobi..com"
// Insert Firebase project API Key
#define API_KEY
"AIzaSyBQt0Dt5HnOAs_HkBYhG8tOltVIprl23vY"
#define DATABASE_URL "mine-safety-f689c-default-rt
db.asia-southeast1.firebaseio.com"
```

```

//Define Firebase Data object
FirebaseData fbdo;
FirebaseAuth auth;
FirebaseConfig config;
float temp;
unsigned long sendDataPrevMillis = 0;
bool signupOK = false;
#define SCREEN_WIDTH 128 // OLED display width, in pixels
#define SCREEN_HEIGHT 64 // OLED display height, in pixels
#define DHTPIN 33 // DHT11 data pin connected to D33
#define DHTTYPE DHT11 // DHT sensor type
#define BUZZER_PIN 13 // Buzzer pin connected to D35
#define BUZZER_FREQUENCY 1000 // Desired frequency in Hertz
#define BUZZER_THRESHOLD 3100 // Threshold value in parts per million (ppm) for activating the alarm
#define SENSOR_PIN 32 // MQ-4 sensor pin connected to D32
#define LED_PIN_NORMAL 2 // LED pin for normal condition
#define LED_PIN_ALARM 12 // LED pin for alarm condition
// Declaration for an SSD1306 display connected to I2C (SDA, SCL pins)
#define OLED_RESET -1 // Reset pin # (or -1 if sharing Arduino reset pin)
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RESET);
DHT dht(DHTPIN, DHTTYPE);
void setup() {
  Serial.begin(115200);
  WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
  Serial.print("Connecting to Wi-Fi");
  while (WiFi.status() != WL_CONNECTED){
    Serial.print(".");
    delay(300);
  }
  Serial.println();
  Serial.print("Connected with IP: ");
  Serial.println(WiFi.localIP());
  Serial.println();
  /* Assign the api key (required) */
  config.api_key = API_KEY;
  /* Assign the RTDB URL (required) */
  config.database_url = DATABASE_URL;
  /* Sign up */
  if (Firebase.signUp(&config, &auth, "", "")){
    Serial.println("ok");
    signupOK = true;
  }
  else{
    Serial.printf("%s\n",
    config.signer.signupError.message.c_str());
  }
}

/* Assign the callback function for the long running token generation task */
config.token_status_callback = tokenStatusCallback; //see addons/TokenHelper.h
Firebase.begin(&config, &auth);
Firebase.reconnectWiFi(true);
dht.begin();
Serial.begin(9600);
// Initialize DHT sensor
dht.begin();
// Initialize OLED display
if(!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) {
  Serial.println(F("SSD1306 allocation failed"));
  for(;;);
}
display.clearDisplay();
display.setTextSize(1);
display.setTextColor(SSD1306_WHITE);
display.setCursor(0,0);
display.println(F("Hello world"));
display.display();
// Set buzzer pin and LED pins as output
pinMode(BUZZER_PIN, OUTPUT);
pinMode(LED_PIN_NORMAL, OUTPUT);
pinMode(LED_PIN_ALARM, OUTPUT);
}

void loop() {
  // Read MQ-4 sensor value
  int sensorValue = analogRead(SENSOR_PIN);
  Serial.print("MQ-4 Sensor Value: ");
  Serial.print(sensorValue);
  Serial.println(" ppm");
  // Activate buzzer and LED if sensor value exceeds threshold
  if (sensorValue > BUZZER_THRESHOLD) {
    digitalWrite(BUZZER_PIN, HIGH);
    digitalWrite(LED_PIN_ALARM, HIGH);
    delay(3000); // Sound and light for 3 seconds
    digitalWrite(BUZZER_PIN, LOW);
    digitalWrite(LED_PIN_ALARM, LOW);
    digitalWrite(LED_PIN_NORMAL, LOW); // Turn off normal condition LED
  } else {
    digitalWrite(BUZZER_PIN, LOW);
    digitalWrite(LED_PIN_ALARM, LOW);
    digitalWrite(LED_PIN_NORMAL, HIGH); // Turn on normal condition LED
  }
  // Read DHT11 temperature and humidity
  float temperature = dht.readTemperature();
  float humidity = dht.readHumidity();
  // Check if DHT11 readings are valid
  if (!isnan(temperature) && !isnan(humidity)) {
    Serial.print("Temperature: ");

```

```

Serial.print(temperature);
Serial.println(" °C\t");
Serial.print("Humidity: ");
Serial.print(humidity);
Serial.println(" %");
} else {
Serial.println("Failed to read from DHT sensor!");
}
// Display readings on OLED
display.clearDisplay();
display.setTextSize(1);
display.setTextColor(SSD1306_WHITE);
display.setCursor(0,0);
display.print("MQ-4 Sensor: ");
display.print(sensorValue);
display.println(" ppm");
display.print("Temp: ");
display.print(temperature);
display.println(" C");
display.print("Humidity: ");
display.print(humidity);
display.println(" %");
display.display();
if (Firebase.ready() && signupOK && (millis() -
sendDataPrevMillis > 15000 || sendDataPrevMillis == 0)){
sendDataPrevMillis = millis();
// Write an Int number on the database path test/int
if (Firebase.RTDB.setFloat(&fbdo, "Temperature/float",
temperature)){
Serial.println("PASSED");
Serial.println("PATH: " + fbdo.dataPath());
Serial.println("TYPE: " + fbdo.dataType());
}
else {
Serial.println("FAILED");
Serial.println("REASON: " + fbdo.errorReason());
}
if (Firebase.RTDB.setInt(&fbdo, "SensorValue/int",
sensorValue)){
Serial.println("PASSED");
Serial.println("PATH: " + fbdo.dataPath());
Serial.println("TYPE: " + fbdo.dataType());
}
else {
Serial.println("FAILED");
Serial.println("REASON: " + fbdo.errorReason());
}
if (Firebase.RTDB.setFloat(&fbdo, "Humidity/float",
humidity)){
Serial.println("PASSED");
Serial.println("PATH: " + fbdo.dataPath());
Serial.println("TYPE: " + fbdo.dataType());
}
else {
Serial.println("FAILED");

```

```

Serial.println("REASON: " + fbdo.errorReason());
}
}
// Delay for stability
delay(1000);
}

```

5. CONCLUSION

To sum up, the deployment of an Internet of Things-based coal mine safety monitoring and alerting system that makes use of an ESP32, MQ-4 sensor, buzzer, DHT11 sensor, and visual indicators such LEDs and OLED displays is a major step forward in guaranteeing the security of coal workers. This system provides real-time monitoring of critical environmental factors, such as temperature and gas levels, by integrating many sensors and communication technologies. This is essential for the early detection of possible risks. The ESP32 offers a stable and dependable platform for data processing and communication, facilitating easy integration with various sensors and guaranteeing effective data transfer to a central monitoring station. The MQ-4 sensor reduces the risk of explosions or asphyxia by precisely detecting methane gas levels and providing prompt alarms in the event of hazardous concentrations. In addition, the addition of a buzzer acts as an auditory alert, warning miners to flee or take appropriate safety measures in the event of an emergency. The DHT11 sensor's integration also makes it possible to monitor temperature and humidity levels, which are crucial for evaluating the mine's general environmental conditions. Additionally, by giving miners and supervisors clear and understandable feedback, visual indicators like LEDs and OLED displays improve situational awareness.

This real-time data visualization makes it easier to make decisions and guarantees a quick reaction to possible safety risks. In summary, the IoT-based coal mine safety monitoring and alerting system described here not only raises the bar for safety in coal mines but also improves the general security and well-being of miners. This system is a monument to the unrelenting pursuit of innovation in guaranteeing workplace safety in hazardous areas by utilizing cutting-edge technologies and intelligence monitoring capabilities (Ansari et al., 2021; Jo & Khan, 2017).

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CONFLICT OF INTEREST

There is no conflict of interest among the authors.

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