Coal Mining Monitoring System and Prediction Using Cloud Computing

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Abstract- Coal mining is an essential industrial activity; however, underground mining operations involve several environmental hazards that pose significant risks to the health and safety of workers. Factors such as abnormal temperature and humidity, poor air quality, smoke, fire outbreaks, and other hazardous environmental conditions can lead to serious accidents and loss of human life. Therefore, continuous monitoring of underground mine conditions and the timely generation of warning signals are essential for improving workplace safety.

This project presents the design and development of an ESP32-Based Coal Mine Safety Monitoring and Alert System that monitors critical environmental parameters and provides immediate alerts when abnormal conditions are detected. The proposed system integrates a DHT11 sensor to measure temperature and humidity, a soil-moisture sensor to monitor moisture levels, an MQ135 sensor to detect changes in air quality and smoke concentration, a flame sensor to identify fire conditions, and a digital-output LDR module to determine day and night conditions.

A 16×2 I²C LCD is used to display real-time sensor information and system status. An audible buzzer provides local warnings whenever configured hazardous conditions are detected. Additionally, two relay modules are incorporated into the system: Relay 1 operates according to the LDR-based day and night detection, switching ON during nighttime and OFF during daytime, while Relay 2 is activated when the MQ135 sensor reading exceeds its predefined threshold. To enable remote supervision, the system uses Wi-Fi connectivity to transmit event-based notifications through the Telegram application and upload selected sensor data to the ThingSpeak IoT platform.

Keywords— ESP32, IoT, coal mine monitoring, DHT11, MQ135, flame sensor, LDR, relay, Telegram, ThingSpeak.

I. INTRODUCTION

Coal mining is an essential industrial activity that contributes considerably to energy production and economic growth. Despite its importance, underground coal mining involves numerous workplace hazards that can adversely affect the health and safety of miners. The challenging

underground environment, characterized by limited ventilation, confined working spaces, restricted accessibility, and unpredictable environmental variations, increases the possibility of hazardous incidents. The presence of toxic gases, abnormal temperature fluctuations, excessive moisture, water infiltration, smoke, and accidental fires can create life-threatening conditions. Failure to recognize these risks promptly may result in serious workplace accidents, damage to mining facilities, and significant loss of human life. Hence, implementing continuous environmental monitoring and efficient warning mechanisms is essential to identify potential dangers and improve safety within underground mining operations.

Existing mine safety practices frequently depend on routine inspections and conventional measuring instruments for evaluating underground environmental conditions. However, manual monitoring methods may be insufficient when environmental parameters change rapidly or hazardous conditions develop unexpectedly. Furthermore, underground mining locations often present difficulties in accessibility, communication, and continuous supervision, making it challenging to identify dangerous situations immediately. Any delay in recognizing abnormal conditions can increase the possibility of accidents and complicate emergency response activities. These challenges emphasize the need for automated monitoring arrangements that can continuously acquire environmental data, identify unusual operating conditions, and provide timely alerts to the concerned personnel.

Recent progress in Internet of Things (IoT) technologies, wireless sensor networks (WSNs), embedded computing, and cloud-based communication has created opportunities for developing more efficient environmental monitoring solutions. Through IoT integration, interconnected sensing devices can measure surrounding environmental parameters and transfer the collected information to processing units and remote monitoring platforms. The combination of sensors and microcontrollers enables automated data collection, threshold-based analysis, local warning generation, and remote information sharing. In underground mining applications, these capabilities can support the early recognition of potentially dangerous environmental changes and improve the availability of monitoring information to responsible authorities. Moreover, wireless connectivity and cloud-based services provide an effective means of accessing selected sensor readings remotely, thereby demonstrating the potential of connected monitoring technologies in improving environmental awareness and supporting mining safety management.

II. OBJECTIVES

The proposed research focuses on the development of an ESP32-based coal mine environmental monitoring and alert system that combines sensor-based data acquisition, automated response mechanisms, and IoT-enabled communication. The system is designed to observe important environmental conditions, recognize predefined abnormal sensor readings, and generate suitable warning signals. It also provides facilities for local monitoring and remote access to collected information. The major objectives of this work are presented below:

A. **Temperature and Humidity Measurement:** To acquire temperature and relative humidity readings using the DHT11 sensor for evaluating changes in the surrounding environment.
B. **Moisture Level Monitoring:** To employ a soil-moisture sensor to identify variations in moisture conditions and distinguish between wet and dry states.
C. **Air-Quality Observation:** To analyze the analog response of the MQ135 sensor and identify significant air-quality and smoke-related variations using predefined threshold levels.
D. **Fire-Related Condition Detection:** To incorporate a flame detection module for recognizing flame indications and initiating the corresponding warning mechanism.
E. **Day and Night Status Detection:** To determine changes in ambient illumination through the digital output of the LDR module and classify the surrounding conditions as day or night.
F. **Audible Warning Mechanism:** To generate acoustic warning signals through a buzzer whenever the monitored parameters satisfy the configured alarm conditions.
G. **Automatic Output Regulation:** To establish sensor-dependent operation of two relay modules, with the first relay responding to LDR-based light conditions and the second relay switching according to the MQ135 threshold status.
H. **Local Monitoring and Display:** To present the acquired sensor information, detected environmental states, and system operating conditions through a 16×2 LCD connected using the I²C interface.
I. **Wireless Alert Transmission:** To utilize the integrated Wi-Fi functionality of the ESP32 for transmitting event-based warning messages to

designated users through the Telegram application.

J. **Remote Data Storage and Visualization:** To establish communication with the ThingSpeak cloud platform for transferring selected sensor measurements, recording environmental data, and facilitating remote observation through internet-connected devices.

III. LITERATURE SURVEY

A. Statistical and Computational Approaches for Environmental Analysis

Researchers have adopted several statistical techniques to examine environmental data and understand the factors influencing air pollution. Commonly used approaches include Principal Component Analysis (PCA), Cluster Analysis (CA), Factor Analysis (FA), and Discriminant Analysis. Among these methods, PCA is particularly valuable for simplifying large datasets and identifying significant patterns among correlated environmental parameters. Artificial Neural Networks (ANNs) have also attracted attention because of their ability to learn complex relationships from collected data and estimate variations in environmental conditions. In particular, Multilayer Perceptron (MLP) models have been explored for forecasting pollutant concentrations and performing time-series analysis. Combining PCA with ANN provides an opportunity to identify important environmental variables and develop predictive models, provided that adequate experimental data are available.

B. Research Developments in IoT-Based Coal Mine Monitoring

The application of IoT technology in underground mining has been investigated as a means of improving environmental supervision and operational safety. Molaei et al. [1] studied the possibilities of introducing IoT technologies into different mining activities, emphasizing their role in improving monitoring and safety management. Arif Hussain et al. [2] presented a wireless monitoring architecture using ZigBee communication, miner identification, and ANN-based methane prediction. Sathishkumar et al. [3] explored a lightweight integration framework that enabled information from underground sensing devices to be collected and displayed through a common interface. Dheeraj et al. [4] developed a cloud-oriented monitoring approach that allowed environmental information to be accessed remotely through mobile devices. These investigations illustrate the growing importance of connected monitoring technologies in underground mining environments.

C. Progression of Conventional Mine Safety Monitoring

Earlier mine safety practices were largely based on physical inspections, portable gas-measuring instruments, and periodic environmental assessments. These procedures provided basic information about underground working conditions but were not always capable of identifying sudden environmental changes immediately. Limited inspection coverage, dependence on personnel, and delays in reporting hazardous conditions were major operational concerns. The development of electronic sensing devices and embedded controllers introduced automated measurement and warning capabilities, providing a foundation for modern continuous monitoring systems.

D. Wireless Sensor Network Applications in Underground Mines

Wireless Sensor Networks (WSNs) have been investigated as a flexible approach for connecting multiple environmental monitoring devices without extensive physical wiring. Distributed sensor nodes can collect information about underground conditions and forward the measurements to a centralized monitoring unit. G. Saranya et al. [5] designed an ARM-controller-based monitoring arrangement for observing temperature, humidity, gas concentration, vibration, and smoke conditions. Their system also incorporated wireless data transmission and ventilation control. Similarly, Dong et al. [6] introduced a monitoring framework combining ZigBee and General Packet Radio Service (GPRS) to transfer underground environmental information and generate mobile notifications. Despite their advantages, WSN implementations must address communication interruptions, restricted battery capacity, and signal degradation caused by underground structures.

E. Sensor Technologies for Underground Environmental Assessment

The effectiveness of an environmental monitoring system depends on selecting suitable sensing devices for the parameters being observed. MQ-series sensors are frequently employed in experimental monitoring applications to identify changes associated with particular gases and smoke. DHT11 and DHT22 devices are used for measuring temperature and relative humidity, whereas flame detection modules help identify fire-related conditions. Moisture sensors can provide additional information about the moisture present at their installation location. Although these devices are economical and convenient for prototype development, their readings can be affected by environmental variations, calibration requirements, and sensor ageing. Therefore, appropriate calibration and performance evaluation are necessary to obtain meaningful measurements.

F. Cloud-Based Monitoring and Information Storage

Cloud computing provides facilities for collecting, maintaining, and displaying environmental

information obtained from connected monitoring devices. IoT platforms such as ThingSpeak and Firebase can be used to store sensor measurements and provide remote access to recorded information. These services support graphical data presentation, historical observation, and centralized monitoring through internet-connected devices. Cloud-based storage can also provide useful datasets for subsequent environmental analysis. However, successful implementation depends on network connectivity, data protection, platform availability, and reliable information transmission.

G. Machine Learning Approaches for Environmental Prediction

Machine learning has introduced additional possibilities for analyzing historical environmental measurements and identifying patterns associated with potentially hazardous conditions. ANN and MLP architectures have been investigated for estimating gas concentrations and predicting changes in environmental parameters. Unlike conventional monitoring methods that generate warnings based on fixed limits, predictive models can learn relationships between different sensor inputs and estimate possible future variations. Their practical application requires representative datasets, suitable training procedures, and performance validation. Machine learning can therefore complement conventional monitoring techniques when adequate data and computational resources are available.

IV. BLOCK DIAGRAM



Fig.1 Block Diagram

V. HARDWARE REQUIREMENTS

A. ESP32 Development Board

The ESP32 development board acts as the central processing platform of the proposed system. It receives input signals from the connected sensors, processes the acquired information, and performs control operations according to the programmed logic. The board incorporates wireless networking capabilities, which facilitate communication with external applications and cloud services. Its ADC channels and GPIO interfaces enable the integration of analog sensors, digital modules, display units, and output devices. The built-in Wi-Fi facility is also utilized to exchange monitoring information with Telegram and ThingSpeak.

B. DHT11 Temperature and Humidity Sensor

The DHT11 module is used to obtain temperature and relative humidity measurements from the monitored surroundings. It communicates the measured data digitally to the ESP32, where the readings are processed for further use. The acquired environmental information is presented on the LCD, allowing users to observe changes in temperature and humidity during system operation.

C. Soil-Moisture Sensor Module

A soil-moisture sensing module is included to examine variations in moisture content. The sensor generates an analog signal that changes according to the moisture condition detected by its sensing element. The ESP32 reads this signal and interprets the corresponding values to demonstrate the identification of wet and dry conditions within the experimental setup.

D. MQ135 Air-Quality Sensor

The MQ135 module is employed to monitor changes in air-quality-related conditions and smoke responses. The sensor produces an analog output that is supplied to the ESP32 for evaluation. The controller compares the acquired reading with a predetermined threshold value. If the programmed limit is exceeded, the system initiates the associated warning indication and activates the designated relay output.

E. Flame Sensor Module

The flame sensor is used as an input device for identifying the presence of flame-related radiation. It generates a digital indication based on the detected condition, which is interpreted by the ESP32. When a flame indication is registered, the controller executes the programmed alert operation. The module's output logic is checked during implementation to establish whether detection produces a HIGH or LOW signal.

F. Light Dependent Resistor (LDR) Module

The LDR module is incorporated to identify variations in the intensity of surrounding light. Its sensing element responds to changes in illumination, and an onboard comparator converts the detected variation into a digital signal. The ESP32 uses this signal to identify daytime and nighttime conditions. The resulting status determines the switching operation of Relay 1 according to the programmed control logic.

G. 16×2 LCD with I²C Interface

The 16×2 LCD module is utilized as the local information display of the monitoring system. It presents the acquired sensor readings and indicates the current operating condition of the connected devices. The I²C communication interface simplifies circuit connections by requiring fewer GPIO pins than a conventional parallel LCD connection. The I²C address depends on the backpack configuration, with 0x27 and 0x3F being commonly encountered addresses.

H. Active Buzzer Module

The active buzzer is incorporated to provide an audible indication whenever the system identifies a condition that satisfies the programmed alarm criteria. It receives a control signal from the ESP32 and produces an acoustic warning to notify nearby users. If the electrical requirements of the buzzer exceed the permissible current of the controller's GPIO output, an external switching driver is required.

VI. Two-Channel Relay Module

The two-channel relay module is responsible for controlling two separate electrical outputs based on the information received from selected sensors. Each relay channel operates independently according to the programmed conditions.

1. **Relay 1 – LDR-Based Control:** The first relay responds to the digital status of the LDR module. It is switched ON when nighttime conditions are detected and switched OFF during daytime.
2. **Relay 2 – MQ135-Based Control:** The second relay operates according to the analog output of the MQ135 sensor. It is activated when the sensor reading exceeds the configured threshold and deactivated when the reading falls below the specified limit.

This arrangement demonstrates the use of sensor-dependent switching for automated output management.

VII. Power Supply and Interfacing Components

The electrical supply section provides the necessary regulated power to operate the controller and its associated modules. Interconnecting wires are used to establish communication and power connections between the individual circuit components. Appropriate voltage compatibility and a common ground reference are maintained to support reliable circuit operation. Additional interfacing or voltage-protection arrangements are incorporated wherever necessary to ensure that the connected modules operate safely within the electrical limits of the ESP32.

VIII. SOFTWARE REQUIREMENTS

The development of the proposed ESP32-Based Coal Mine Safety Monitoring and Alert System requires an appropriate software environment to manage sensor interfacing, data processing, output control, and wireless communication. The Arduino Integrated Development Environment (IDE) is selected for programming the ESP32 microcontroller. The required hardware support package and software libraries are incorporated to establish communication between the controller, peripheral devices, and cloud-based applications.

A. Arduino Integrated Development Environment (IDE)

The Arduino IDE is utilized to develop the firmware responsible for the operation of the proposed monitoring system. The installation of the ESP32 board package enables the programming environment to support the selected microcontroller during code compilation and program uploading. The developed firmware controls the sequence of operations, including sensor initialization, environmental data collection, comparison of sensor readings with predefined threshold values, and execution of corresponding output responses.

Furthermore, the program manages the LCD display, buzzer activation, relay switching, and wireless network connection. The integrated Wi-Fi functionality of the ESP32 facilitates the transmission of alert messages through Telegram and the transfer of selected monitoring data to the ThingSpeak cloud platform.

B. Software Libraries Used

Different software libraries are incorporated to simplify hardware communication and provide the functions required for implementing the proposed system. The role of each library is explained below.

1. **Adafruit DHT Sensor Library:** This library is used to establish communication with the DHT11 module and obtain temperature and relative humidity measurements for environmental monitoring.
2. **Adafruit Unified Sensor Library:** It provides common sensor-related data structures and interface functions that support compatible Adafruit sensor libraries.
3. **LiquidCrystal_I2C Library:** This library enables the ESP32 to exchange information with the 16×2 LCD through the I²C communication protocol. It supports the display of sensor readings and operational messages.
4. **UniversalTelegramBot Library:** It facilitates communication between the ESP32 and the Telegram Bot API, allowing the transmission of automatic notifications when programmed monitoring conditions are satisfied.

5. **ArduinoJson Library:** This library is employed to construct and process JSON-formatted information, which is required for structured data communication with external internet services.
6. **ThingSpeak Library:** It provides the necessary functions for transferring selected environmental measurements to the ThingSpeak platform, supporting online data storage, visualization, and remote monitoring.

IX. ADVANTAGES

1. Economical System Development: The proposed prototype utilizes an ESP32 controller along with affordable and readily accessible electronic modules. This approach reduces implementation costs while providing a practical setup for studying IoT-based environmental monitoring.
2. On-Site Monitoring and Warning: The system incorporates a 16×2 LCD to present the measured sensor values and current operating status. An audible buzzer is also included to notify nearby individuals whenever the programmed alarm conditions are triggered.
3. Wireless Alert Communication: Through the ESP32's integrated Wi-Fi capability, the system communicates with the Telegram application to deliver automatic event notifications. This feature allows authorized users to receive updates about detected abnormal conditions without being physically present near the monitoring unit.
4. Online Data Recording and Visualization: The ThingSpeak cloud platform is used to receive and store selected sensor readings. Its graphical interface allows users to examine recorded measurements, observe environmental changes, and access monitoring information remotely.
5. Sensor-Based Independent Relay Control: The system employs two relay channels with separate operating conditions. Relay 1 is activated according to the nighttime status detected by the LDR module, while Relay 2 responds to changes in the MQ135 sensor output when its configured threshold is exceeded.
6. Flexible and Expandable Design: The modular arrangement of the proposed prototype allows additional sensing devices and electronic control modules to be incorporated in future developments. This flexibility makes the platform useful for academic experiments and further investigation of IoT-enabled environmental monitoring techniques.

X. FUTURE SCOPE

1. Implementation of Advanced Gas Detection Technology: Future development can incorporate specialized, calibrated gas-monitoring instruments to measure methane (CH_4), carbon monoxide (CO), oxygen (O_2), and hydrogen sulphide (H_2S). These sensors would provide more specific information about gas concentrations and improve the environmental assessment capabilities of the proposed system.
2. Expansion of Water-Level Detection: The monitoring platform can be upgraded by integrating industrial water-level measurement devices to identify rising water levels and potential flooding conditions. Deploying multiple sensing units at different locations would also support wider environmental coverage.
3. Advanced Data Recording and System Diagnostics: Additional features such as onboard data storage, alert confirmation, automatic message retransmission, and watchdog-based fault identification can be introduced. These functions would help preserve important monitoring records and identify possible failures in the hardware or communication network.
4. Improvement in Data Communication Security: Future implementations can adopt secure communication methods using authenticated TLS connections and encrypted credential storage. These measures would help protect sensor information and prevent unauthorized access during communication with remote monitoring platforms.
5. Integration of Emergency Power Facilities: A backup battery arrangement can be incorporated to maintain the operation of the monitoring unit during unexpected power interruptions. Power-monitoring circuits can also be added to identify supply failures and generate corresponding warning messages.
6. Development of an Interactive Web Dashboard: A web-based monitoring application can be developed to provide centralized access to environmental measurements, historical performance graphs, sensor operating conditions, and previously generated warning events. This would improve the accessibility and interpretation of monitoring information.

XI. CONCLUSION

This research presents the design and development of an ESP32-based monitoring prototype that combines embedded systems and Internet of Things (IoT) technology for observing environmental conditions. The developed model utilizes multiple sensor modules to collect environmental information, which is processed by the ESP32 controller to identify conditions that satisfy predefined alarm criteria. The monitoring arrangement covers temperature, relative

humidity, moisture variations, air-quality responses, flame indications, and surrounding light conditions.

For effective system operation, a 16×2 LCD is incorporated to display the acquired sensor information, while an audible buzzer provides local warnings when programmed abnormal conditions are identified. In addition, two relay channels perform independent switching operations based on the LDR and MQ135 sensor readings. The wireless communication facility of the ESP32 further enables the transmission of event-related messages through Telegram and the uploading of selected sensor data to ThingSpeak for remote access and graphical analysis.

The experimental model illustrates how different sensing devices, automatic control functions, and internet-based communication facilities can be combined into a compact and economical monitoring platform. Its modular configuration also provides scope for incorporating advanced sensing technologies, improved communication mechanisms, and additional monitoring facilities in subsequent developments.

Despite these capabilities, the developed model has certain limitations concerning its suitability for actual underground mining operations. The implemented hardware and sensing modules are intended for educational and experimental purposes and have not undergone certification for mine-safety applications. Consequently, their measurements and warning functions cannot be considered a substitute for approved industrial protection systems. Any future implementation in an operational mine would require detailed safety assessment, calibrated gas-detection instruments, certified intrinsically safe components, rigorous testing, and adherence to the applicable mining regulations.

In conclusion, the proposed prototype provides a practical foundation for exploring IoT-enabled environmental monitoring and automated alert generation. Further research and engineering improvements are necessary before such a system could be considered for use in real underground mining environments.

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