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IoT-BASED COAL MINE WORKER SAFETY AND ENVIRONMENT MONITORING SYSTEM WITH CLOUD ANALYTICS

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Abstract: Coal mining remains one of the most hazardous occupations globally, with workers constantly exposed to toxic gas accumulation, extreme temperatures, and oxygen-deficient underground environments. Conventional safety systems rely on manual inspections and threshold-only alarms that trigger regardless of worker presence, leading to delayed responses and frequent false alarms. This work presents an IoT-Based Coal Mine Worker Safety and Environment Monitoring System that integrates real-time environmental sensing with RFID-based personnel tracking and cloud-connected analytics. The system uses the LPC1768 ARM Cortex-M3 microcontroller interfaced with an MQ135 air quality sensor, DHT11 temperature and humidity sensor, and an RC522 RFID module for worker identification. A worker-aware alerting logic activates the emergency buzzer only when hazardous thresholds are breached and at least one worker is confirmed inside the mine, eliminating false alarms during unmanned shifts. An ESP32 Wi-Fi module receives structured data from the LPC1768 over UART and publishes JSON payloads to the Zoho IoT cloud platform via MQTT over a secure TLS connection, enabling remote real-time monitoring and historical analytics. Experimental results confirm accurate multi-parameter sensing, reliable RFID-based worker tracking, and stable cloud data delivery across all tested conditions.

Keywords: IoT, LPC1768, ARM Cortex-M3, ESP32, MQ135, RFID, Zoho IoT, MQTT, Real-Time Monitoring, Coal Mine Safety.

I. INTRODUCTION

Coal mining is recognized worldwide as one of the most dangerous industrial occupations. Workers descend into enclosed underground environments where they face constant exposure to toxic gas accumulation, sudden temperature surges, oxygen deficiency, and the risk of structural collapse. What makes these hazards particularly dangerous is not just their presence, but the absence of a system that can detect them instantly and alert workers and supervisors before conditions become fatal.

Existing mine safety approaches depend on periodic manual inspections and portable handheld gas detectors, making them fundamentally reactive. A supervisor outside the mine has no real-time visibility into gas concentration levels, temperature, or how many workers are currently underground. Traditional alarm systems also trigger purely on sensor readings, regardless of whether any worker is inside the mine, causing frequent false alarms that erode supervisory confidence over time.

This work proposes an IoT-based system that addresses all these limitations in a single unified platform. By combining RFID-based worker tracking with continuous environmental sensing and cloud-connected remote monitoring, the system delivers safety alerts that are accurate, timely, and operationally meaningful. Every design decision — from the RFID entry-exit logic to the condition-aware buzzer activation — is driven by the practical realities of underground coal mine safety.

II. LITERATURE SURVEY

The development of IoT-based coal mine safety monitoring systems has gained significant attention in recent years, driven by the urgent need to reduce fatalities in underground mining operations. Researchers have focused on sensor integration, wireless communication, cloud connectivity, and worker tracking as the core dimensions of effective mine safety solutions.

Bisht et al. [1] presented a real-time IoT safety monitoring system using NodeMCU with MQ-6 methane, MQ-7 carbon monoxide, and DHT11 sensors, with an Arduino RFID module for worker counting and Telegram-based supervisor alerts. Manasa et al. [2] developed a wireless sensor network system using Arduino UNO with DHT11, gas, and IR sensors that transmitted cloud data every two minutes with simultaneous LCD and mobile application display. Saranya et al. [3] proposed a NodeMCU-based system with automatic ventilation control triggered by environmental sensor readings, highlighting cost-effectiveness as a key deployment advantage. Deokar and Wakode [4] emphasized a multi-sensor unified platform monitoring SO_2, NO_2, CO, temperature, and humidity with automated emergency alerts, directly influencing the multi-parameter integration approach in the proposed work. Thilagavathi and Arockiam [5] explored ZigBee-based cloud data logging for historical analysis and post-incident reporting, a concept extended in this work through the Zoho IoT cloud analytics component.

From the reviewed literature, the following key observations can be made:

- Most existing systems lack worker-aware alerting logic and trigger alarms regardless of personnel presence, leading to false alarms.
- RFID-based bidirectional worker tracking with live personnel count is absent in the majority of reviewed implementations.
- Cloud communication in existing systems is often unsecured or lacks structured JSON-based payloads suitable for real-time analytics.
- On-site safety functions in most systems are dependent on network connectivity, making them vulnerable during Wi-Fi outages underground.
- None of the reviewed works integrate edge processing with secure MQTT-based cloud publishing in a two-unit modular architecture.

III. PROPOSED SYSTEM

The proposed system is an IoT-Based Coal Mine Worker Safety and Environment Monitoring System designed to provide continuous real-time surveillance of underground mine conditions alongside accurate RFID-based worker tracking. The system uses the LPC1768 ARM Cortex-M3 microcontroller as the central on-site processing unit and an ESP32 module as the cloud gateway, working together in a two-unit modular architecture.

The LPC1768 interfaces with the RC522 RFID reader via SPI for worker identification, the DHT11 sensor on GPIO P1.20 for temperature and humidity monitoring, and the MQ135 gas sensor on ADC Channel 2 for continuous air quality measurement. All sensor data is evaluated in real time against predefined safety thresholds: temperature above 45°C, relative humidity above 85%, and MQ135 ADC reading above 2500. When any parameter crosses its threshold and at least one worker is confirmed inside the mine, the system immediately activates the emergency buzzer and switches the 16×2 LCD display to a full emergency warning screen.

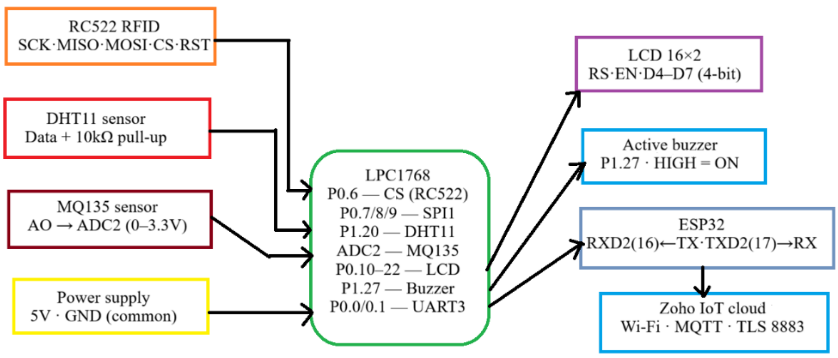

Fig 1: Proposed System

A key feature that distinguishes this system from existing solutions is its worker-aware alerting logic. The gas buzzer is configured to activate only when currentInsideCount ≥ 1, meaning a confirmed worker is present inside the mine. This design eliminates false alarms during unmanned periods — one of the most common causes of alert fatigue in supervisory personnel. The RFID tracking subsystem supports five registered worker cards; each scan at the mine entrance toggles the worker status between inside and outside, maintaining a live and accurate personnel count at all times.

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The ESP32 module receives structured UART messages from the LPC1768 at 9600 baud, assembles a unified JSON payload containing worker name, status, count, temperature, humidity, gas reading, and emergency message, and publishes it to the Zoho IoT cloud platform over a secure MQTT connection on port 8883. The Zoho IoT dashboard provides supervisors with live sensor readings, historical trends, and instant emergency notifications from any location. The on-site safety system on the LPC1768 operates entirely independently of the ESP32 cloud gateway, ensuring that workers receive warnings even if Wi-Fi connectivity is temporarily unavailable.

The 16×2 LCD display provides real-time on-site information including:

- Individual sensor readings — temperature, humidity, and air quality status
- Current worker count confirmed inside the mine
- Worker ENTRY and EXIT events with worker name on RFID scan
- Full emergency warning screen showing hazard type on threshold breach

IV. METHODOLOGY

The methodology of the proposed system is organized into the following steps:

1. Sensor Data Acquisition:
The DHT11 sensor connected to GPIO P1.20 provides temperature and humidity readings through a single-wire digital protocol every two seconds. The MQ135 gas sensor's analog output is connected to ADC Channel 2 of the LPC1768, converting the input voltage to a 12-bit value between 0 and 4095. Multiple ADC samples are averaged per reading cycle to improve stability.

2. RFID-Based Worker Tracking:
The RC522 RFID reader communicates with the LPC1768 via SPI1 at 1 MHz. On detecting a registered card, the firmware matches the UID against the stored worker database and toggles the worker's status between inside and outside, updating the live personnel count. Unregistered cards trigger an ACCESS DENIED response on the LCD and a 500 ms buzzer tone.

3. Threshold Evaluation and Worker-Aware Alerting:
Every two seconds, all measured parameters are compared against predefined safety limits. Emergency Mode activates when any threshold is crossed and currentInsideCount ≥ 1. The buzzer sounds a repeating three-pulse pattern and the LCD switches to a dedicated emergency warning screen. The gas buzzer does not activate when the mine is unoccupied, preventing false alarms.

4. LCD Display and Buzzer Feedback:
During normal operation, the LCD rotates through three screens every two seconds: temperature and humidity, air quality status, and current worker count. Distinct buzzer patterns are used for each event — one beep for worker entry, two beeps for exit, and three repeating pulses for a full emergency — allowing workers to identify event types by sound alone without viewing the display.

5. UART Data Transmission to ESP32:
The LPC1768 transmits structured ASCII messages over UART3 at 9600 baud to the ESP32. Messages are prefixed by type: RFID: for worker events, ENV: for sensor readings, and ALERT: for threshold breach notifications. The ESP32 buffers and parses incoming messages using ArduinoJson and merges all fields into a unified JSON document.

6. Cloud Publishing via MQTT:
The ESP32 connects to Wi-Fi and establishes a TLS-secured MQTT session with the Zoho IoT broker on port 8883. The assembled JSON payload is published at two-second intervals, giving supervisors a complete and current picture of mine conditions from any location. The Zoho IoT platform logs all data with timestamps and triggers instant notifications when the emergency_msg field transitions to EMERGENCY.

V. PROPOSED SYSTEM HARDWARE RESULTS

The proposed IoT-Based Coal Mine Worker Safety and Environment Monitoring System was successfully designed, implemented, and tested under simulated real-time operating conditions. The system was validated across four key areas: environmental sensing accuracy, threshold-based emergency alerting, RFID worker tracking, and cloud data publishing reliability. Results from each area confirm that the system performs accurately and reliably under both normal and emergency conditions.

- The LPC1768 accurately measured temperature, humidity, and air quality readings using the DHT11 and MQ135 sensors. Readings were stable and consistent with minimal noise across extended test sessions.
- The RC522 RFID reader successfully detected registered worker cards at up to 4 cm, correctly toggling worker status on each scan and updating the live personnel count without any missed reads.

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- The LCD display successfully showed real-time rotating screens during normal operation and immediately switched to a dedicated emergency warning screen on threshold breach, clearly indicating the hazard type.
- The worker-aware alerting logic was verified — the gas buzzer activated correctly during threshold breaches only when workers were confirmed inside, and remained silent when the mine was unoccupied.
- The relay-based emergency buzzer produced distinct patterns for each event type, allowing workers to identify entry, exit, and emergency conditions by sound alone without viewing the display.

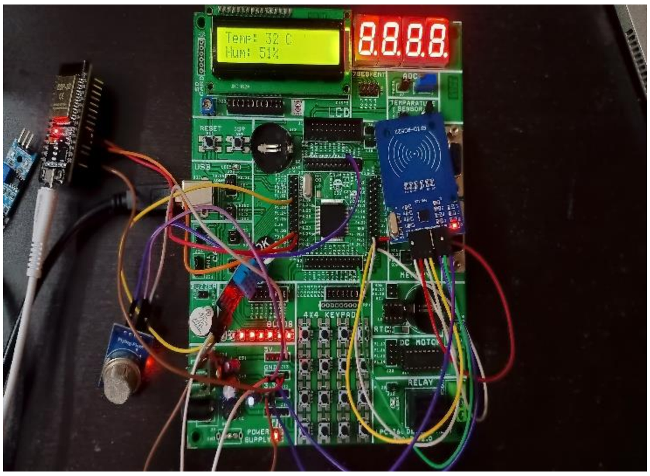

Fig 2: Hardware Design

The automatic emergency recovery behavior was also validated — when conditions returned to safe levels, the system cleared the Emergency Mode, transmitted an emergency: cleared notification to the Zoho IoT cloud, and resumed normal monitoring without any manual intervention. The response time from threshold breach to buzzer activation was within one sensor reading cycle, approximately two seconds, which is well within acceptable limits for underground mine safety applications.

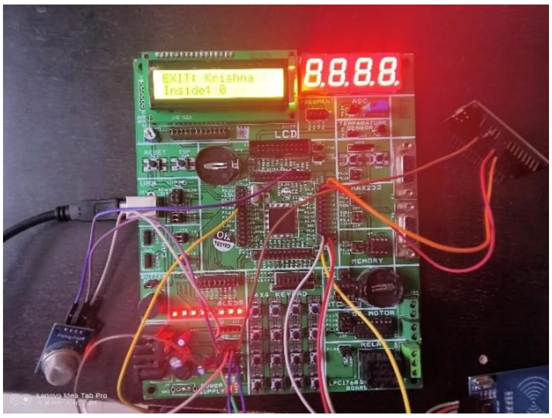

Fig 3: Normal Operating LCD Screens

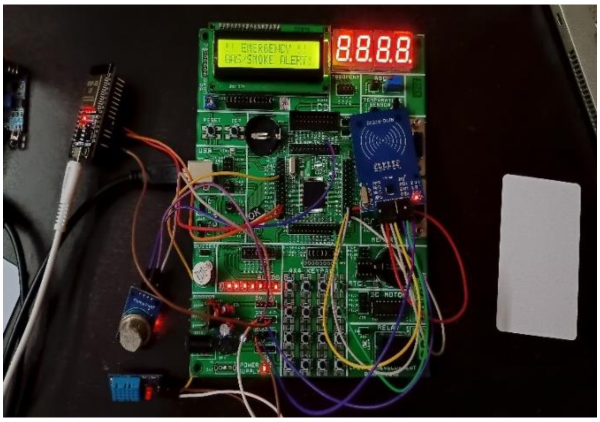

Fig 4: Emergency Alert and RFID Tracking

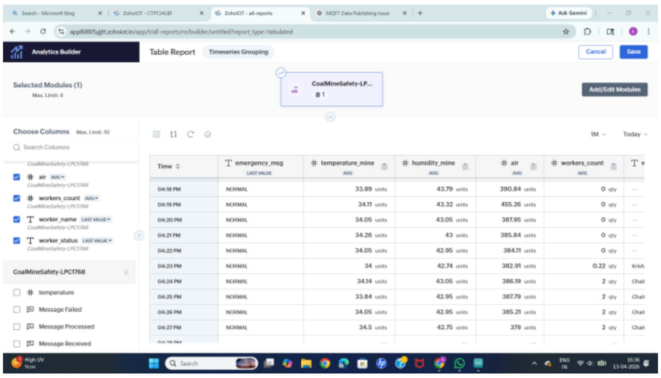

Fig 5: Zoho IoT Cloud Dashboard Output

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All sensor readings, worker entry and exit events, and emergency notifications were successfully published to the Zoho IoT cloud platform via the ESP32 MQTT gateway. Data publishing was reliable across all test sessions with no packet loss observed under stable Wi-Fi conditions. The emergency_msg field transitioned correctly between NORMAL, EMERGENCY, and CLEARED states in response to all tested threshold breach and recovery scenarios, confirming end-to-end communication integrity from sensor to cloud.

VI. CONCLUSION

This work successfully developed an IoT-Based Coal Mine Worker Safety and Environment Monitoring System using the LPC1768 ARM Cortex-M3 microcontroller, RC522 RFID reader, DHT11 temperature and humidity sensor, MQ135 air quality sensor, and ESP32 Wi-Fi module with Zoho IoT cloud integration. The system effectively monitored critical underground parameters in real time, maintained accurate RFID-based worker tracking, and delivered prompt on-site emergency alerts through buzzer and LCD display.

The implementation of worker-aware alerting logic — where emergency alarms activate only when hazardous conditions coincide with confirmed worker presence — significantly improved the practical reliability of the system by eliminating false alarms during unmanned periods. The two-unit modular architecture ensured that all on-site safety functions remained fully operational independent of cloud connectivity, making the system deployable in the network-constrained environments typical of underground coal mines. The secure MQTT-based cloud communication over TLS provided remote monitoring and historical data logging accessible to supervisors from any location.

Overall, this project demonstrates that an intelligent, low-cost, and scalable mine safety monitoring system can be built using widely available embedded hardware and cloud IoT platforms, with genuine potential to reduce accident risks and improve worker safety in real coal mining operations.

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