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OPTIMIZED GAS MONITORING FOR UNDERGROUND MINING USING WSN

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Abstract:

Underground mining environments often contain hazardous gases such as methane and carbon monoxide, posing severe risks to worker safety. Continuous monitoring is essential, but traditional wired systems are costly and difficult to maintain. This project presents an Optimized Gas Monitoring Wireless Sensor Network (WSN) for Underground Mining. The system integrates gas sensors with wireless sensor nodes to enable real-time data transmission to a central gateway. Energy efficiency is achieved through duty-cycling, which reduces power consumption and extends network lifetime. The prototype offers a cost-effective and practical approach to enhancing mine safety and reliability.

Keywords — **Underground mining, central gateway, duty-cycling.**

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1. INTRODUCTION

Underground mining exposes workers to hazardous gases like methane, hydrogen sulphide, and carbon monoxide, creating risks of explosions, toxicity, and suffocation. Traditional wired monitoring systems are expensive and difficult to maintain, while wireless sensor networks offer a more flexible solution but face energy constraints. This project presents an optimized wireless gas monitoring system using ESP32 and ESP8266 with ESP-NOW communication. Sensor nodes detect gas concentrations and transmit data efficiently using duty-cycling to extend battery life. The system continuously evaluates gas levels against safety thresholds and triggers alerts during hazardous conditions. It also enables centralized monitoring and data logging for improved decision-making. Overall, the proposed system offers a low-cost, reliable, and energy-efficient solution to enhance safety in underground mining and other industrial environments.

2. LITERATURE SURVEY

[1] I. Alfonso, C. Gómez, K. Garcés, J. Chavarriaga, "Lifetime Optimization of Wireless Sensor Networks for Gas Monitoring in Underground Coal Mining,".

[2] B. W. Jo, D. Khan, et al., "An Internet of Things System for Underground Mine Air Quality Monitoring and Pollutant Prediction,".

[3] Y. Zhang, X. Yang, et al., "An Integrated Environment Monitoring System for Underground Coal Mines — WSN Subsystem with Multi-Parameter Monitoring,".

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[5] M. Theissen et al., "LoRa Propagation and Coverage Measurements in Underground Mines".

[6] S. Sadeghi, et al., "Applications of Wireless Sensor Networks to Improve Occupational Safety and Health in Underground Mining A Systematic Review,".

3. PROBLEM ANALYSIS AND PROPSED SOLUTION

3.1 *Problem Statement*

Develop a wireless sensor network to monitor hazardous gases in underground mines in real time, while optimizing node energy consumption to extend battery life and ensure timely safety alerts.

3.2 *Objectives of The Project*

1. To design a wireless sensor network for detecting hazardous gases in underground mining.

2. To enable reliable wireless transmission of gas data to a central monitoring unit.

3. To provide real-time alerts for ensuring mining safety and apply energy optimization techniques such as duty-cycling and low-power modes to extend sensor node lifetime.

3.3 *Methodology*

The methodology involves designing two ESP32-based sensor nodes integrated with MQ135 and MQ7 gas sensors and powered through a buck converter. The MQ135 measures methane (analog) and detects H_2S (digital), while the MQ7 measures carbon monoxide. Sensor readings are converted into gas concentration values using calibration formulas. Wireless communication is established using ESP-NOW, where sensor nodes transmit structured data packets (node ID, CH_4, CO, H_2S status) to an ESP8266 main node.

The main node receives and processes the data in real time. It compares values against safety thresholds and activates a buzzer alert when hazardous conditions are detected. Simultaneously, data is sent to a laptop via serial communication for display and logging. This approach ensures low power consumption, reliable data transmission, and effective real-time gas monitoring. It also enhances safety by enabling early detection of hazardous gas conditions in industrial and underground environments.

3.4 *Block Diagram*

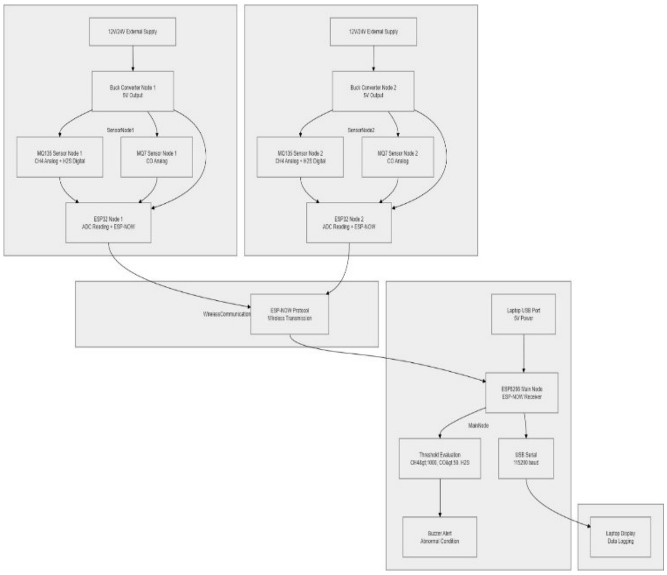

Figure 1: Block Diagram

This block diagram represents a wireless multi-node gas monitoring system designed to detect hazardous gases at two different sensing locations and send the data to a central monitoring unit.

Each sensing node is powered by a 12 V/24 V external supply, which is stepped down to 5 V using a buck converter to provide the correct operating voltage for the sensors and controller.

In Sensor Node 1, an MQ135 gas sensor measures methane (CH_4) as an analog signal and provides a digital H_2S indication, while an MQ7 gas sensor measures carbon monoxide (CO) as an analog signal. These sensor outputs are connected to an ESP32, which reads the analog values through its ADC and processes the gas concentration data. The same arrangement is repeated in Sensor Node 2, where another ESP32 collects gas readings from a second set of MQ135 and MQ7 sensors.

After collecting the gas values, both ESP32 nodes transmit their data wirelessly using the ESP-NOW communication protocol, which enables direct low-power communication between the sensor nodes and the main receiver without requiring a Wi-Fi router.

The transmitted data is received by an ESP8266 main node powered from the 5 V laptop USB port. This main controller acts as the central receiver and continuously compares the incoming gas readings against preset safety thresholds, such as CH_4 > 1000 ppm, CO > 50 ppm, and H_2S detection present.

If any gas concentration exceeds its safe limit, the controller activates a buzzer alert to warn of an abnormal environmental condition. Simultaneously, the ESP8266 sends all received sensor data to a laptop through USB serial communication at 115200 baud, where the information can be displayed and stored for real-time monitoring and data logging. This architecture allows multiple remote gas sensing points to be monitored centrally in a simple and efficient wireless safety system.

An additional feature of this system is its expandable design, where multiple remote sensing nodes can be added using the same ESP32 and ESP-NOW communication, allowing a single ESP8266 receiver to monitor several locations at the same time. The buck converter improves power efficiency by converting the 12 V/24 V supply into a stable 5 V output with less heat generation. The analog outputs from the MQ135 gas sensor and MQ7 gas sensor can be calibrated in software so the measured voltages correspond more accurately to gas concentration levels. At the main node, the ESP8266 can process multiple readings and average them before comparing them with threshold values, which helps reduce false alarms caused by noise or temporary fluctuations. The system also supports serial data logging, so gas readings can be stored on the laptop for analysis, maintenance records, and long-term safety monitoring.

At the central receiver, the ESP8266 can perform data filtering and averaging before making alarm decisions to reduce false triggering caused by electrical noise or temporary fluctuations. For example, the controller can average several sensor samples over a few seconds before comparing them with safety thresholds. The serial communication to the laptop allows software such as Arduino Serial Monitor, Python logging scripts, or spreadsheet tools to record timestamped gas data for later analysis.

3.5 *Requirements*

a) Hardware Requirements

The hardware setup includes two sensor nodes and one main node for gas detection and alerting. Each sensor node uses an ESP32 board with MQ135 and MQ7 sensors.

A buck converter (LM2596) provides 5V power from sources like a 12V battery or adapter. Components are connected using jumper wires, placed in an enclosure, and may include a 100kΩ potentiometer for adjustment.

The main node uses an ESP8266 board with a piezoelectric buzzer and 100Ω resistor, connected to a laptop via USB. A breadboard and multimeter are used for prototyping and calibration.

b) Software Requirements

The software requirements include Arduino IDE with ESP32 and ESP8266 board packages, ESP-NOW, WiFi.h, and Serial communication libraries, along with tools like Arduino Serial Monitor or Putty for monitoring.

The main node uses an ESP8266 board with a piezoelectric buzzer and 100Ω resistor, connected to a laptop via USB. A breadboard and multimeter are used for prototyping and calibration

The sensor nodes (ESP32) use these tools with custom gas calibration formulas, while the main node (ESP8266) handles communication and alert processing.

For calibration, MQ135 (Methane) and MQ7 (CO) use constants with Rs/R0-based formulas, and MQ135 (H2S) uses a potentiometer-set digital threshold (~10–20 ppm).

For gas sensor calibration, MQ135 (Methane) uses constants A = 2.3 and B = -0.44 with a formula based on Rs/R0 ratio, while MQ135 (Hydrogen Sulphide) uses a potentiometer-adjusted digital threshold (around 10–20 ppm). MQ7 (Carbon Monoxide) uses constants A = 4.5 and B = -0.52 with a similar Rs/R0-based formula for ppm calculation.

4. RESULTS AND DISCUSSIONS

The developed wireless gas monitoring system successfully detects hazardous gases such as methane and carbon monoxide using MQ-4 and MQ-7 sensors. The sensor nodes continuously monitor gas concentrations and transmit real-time data to the central gateway using LoRa communication. During testing, the system demonstrated stable and reliable wireless transmission within the required range.

The alert mechanism worked effectively, as the buzzer was triggered immediately when gas levels exceeded predefined safety thresholds.

The implementation of duty-cycling and low-power operation significantly reduced energy consumption, allowing the sensor nodes to operate efficiently for extended periods.

However, some limitations were observed. MQ sensors require sufficient warm-up time for accurate readings, and their performance may vary with environmental conditions. Additionally, their higher power consumption due to internal heating elements can affect battery life.

Despite these limitations, the system provides a reliable, low-cost, and efficient solution for real-time gas monitoring and early hazard detection. With further improvements such as better sensor calibration and use of low-power gas sensors, the system can be enhanced for more accurate and long-term deployment in underground mining environments.

Figure 2: Output On Serial Monitor

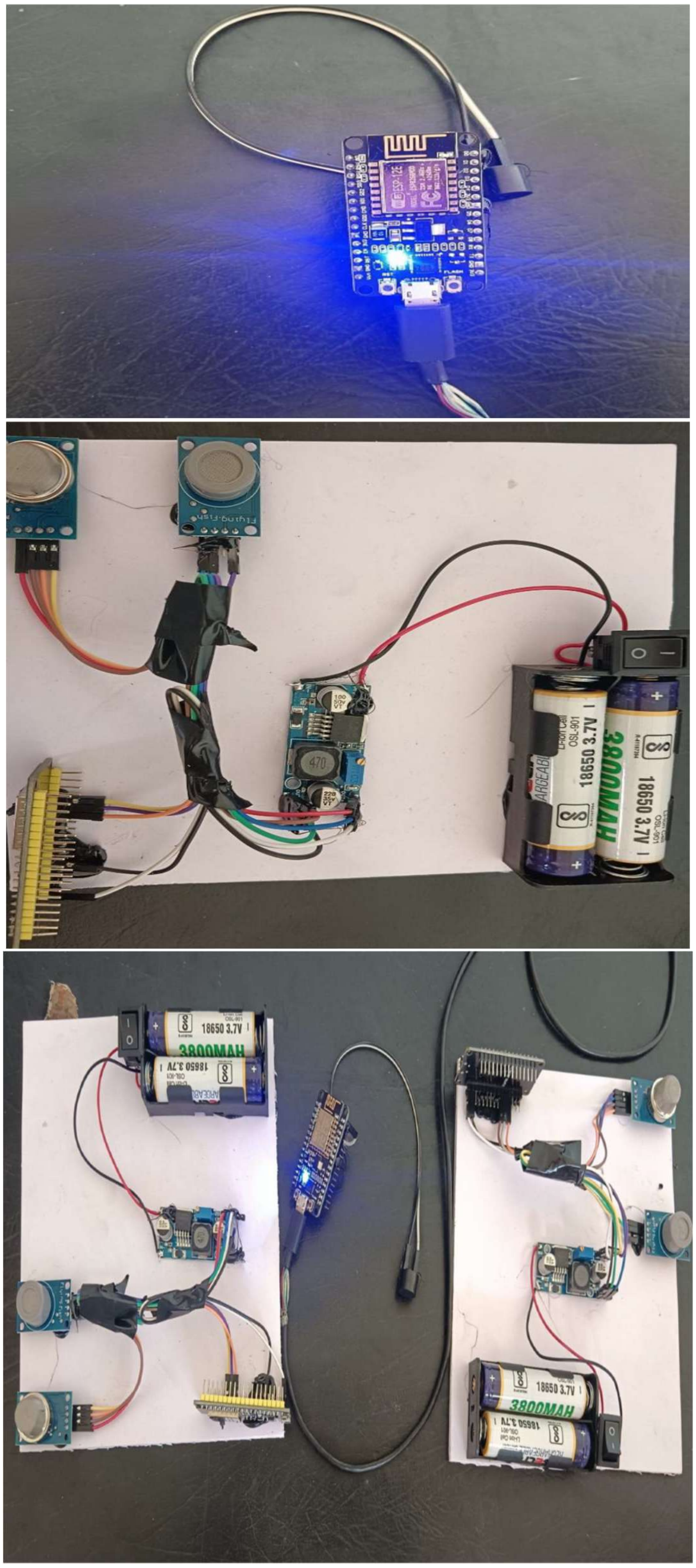

Figure 3: Circuit Connection of Optimized Gas Monitoring For Underground Mining

5. CONCLUSION AND FUTURE SCOPE

The wireless sensor network provides a practical and cost-effective solution for toxic gas monitoring in industrial environments. By integrating MQ135 and MQ7 sensors with ESP32 nodes, the system enables detection of methane, carbon monoxide, and hydrogen sulphide, while the ESP-NOW protocol ensures reliable communication without the need for internet connectivity, making it suitable for remote applications. The ESP8266-based main node processes the received data and triggers alerts through a buzzer when gas levels exceed safe limits, with real-time monitoring supported via a laptop connection. Overall, the system offers an efficient, low-cost, and scalable approach to industrial gas safety, with scope for future improvements such as better power management, environmental compensation, and cloud-based integration.

Future improvements can include adding cloud connectivity (MQTT/IoT platforms) for remote monitoring and alerts, integrating temperature and humidity compensation to improve sensor accuracy, and implementing battery optimization techniques like deep sleep and solar power. The system can also be enhanced with data logging (SD card or cloud), LCD/OLED display for local readings, and expansion to support more sensor nodes for wider area coverage.

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