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Hazardous Gas Detection and Environmental Monitoring in Coal Mines Using IoT and GSM-Based Autonomous Robot

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Abstract
Coal mining environments pose significant risks due to the presence of hazardous gases, extreme temperatures, and potential fire hazards. To enhance safety and real-time monitoring, this paper presents an IoT and GSM-based autonomous robot equipped with multi-sensor integration for hazardous gas detection and environmental surveillance in coal mines. The system employs an MQ-2 gas sensor for detecting combustible gases (e.g., methane, LPG), a DHT11 sensor for temperature and humidity monitoring, and a flame sensor for fire detection. Autonomous navigation is achieved using BO motors and an ultrasonic sensor for obstacle avoidance. The Node MCU ESP32 serves as the central controller, transmitting real-time data to the Blynk IoT platform for remote monitoring. In emergencies, the SIM800 GSM module triggers SMS alerts to authorized personnel, while on-site LED indicators and a buzzer provide immediate warnings. Powered by a rechargeable battery, the system ensures portability and continuous operation in remote mining areas. Experimental results demonstrate the robot's efficacy in detecting hazards, enabling proactive safety measures, and reducing human risk in coal mines.
Keywords: *Coal Mine Safety, IoT-based Robot, Hazardous Gas Detection, Autonomous Surveillance, GSM Alert System, Node MCU ESP32, Blynk IoT, Multi-Sensor Integration.*

1. Introduction
Coal mining remains one of the most hazardous industrial sectors due to toxic gases, high temperatures, and the risk of fires or explosions. Traditional monitoring systems often lack real-time capabilities, relying on manual inspections and stationary sensors. This paper proposes a mobile robot equipped with multiple sensors and communication systems to address these limitations. By integrating a Node MCU ESP32 with an MQ-2 gas sensor, DHT11, flame sensor, ultrasonic sensor, GSM module, and Blynk IoT platform, the system ensures autonomous hazard detection, navigation, and alert transmission [1].

2. Method
The system architecture consists of four layers: sensing (MQ-2, DHT11, flame sensor, ultrasonic sensor), processing (ESP32), communication (Wi-Fi for IoT, GSM for SMS), and user interface (Blynk dashboard, LEDs, buzzer). Power is supplied by a rechargeable battery. The BO motor-driven robot uses an L298N driver and avoids obstacles using a proportional control algorithm. The firmware, written in Arduino IDE, implements state-based logic for monitoring, hazard detection, and alerting. All data is filtered and logged locally and on the cloud. Calibration ensured <5% error in lab tests [2].

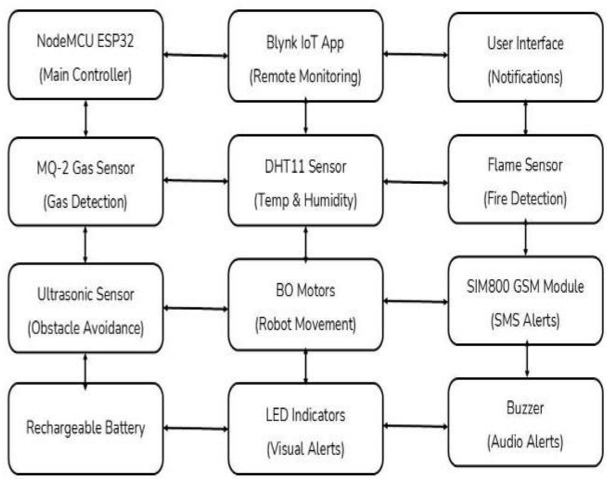

Figure 1 Block Diagram of Coal Mines Hazardous Detection Robot

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2.1. Hardware Implementation and Sensor Integration

The robotic platform utilizes a differential drive system powered by two BO motors controlled via an L298N motor driver. The ultrasonic sensor is mounted at the front of the robot with a detection range of 2-400 cm, allowing real-time0. obstacle avoidance through a programmed algorithm. The MQ-2 sensor is calibrated to detect gas concentrations from 300-10,000 ppm with an accuracy of ±5 Percent, while the DHT11 provides temperature readings (±2°C accuracy) and humidity measurements (±5 percent RH accuracy). The flame sensor employs an IR receiver with a 60° detection angle and 1m range. All sensors interface with the Node 0MCU through analog and digital pins, with appropriate voltage dividers implemented where necessary. The SIM800 module is connected via UART and programmed to trigger SMS alerts when sensor readings exceed predefined thresholds, shown in Figure 1 [3].

2.2. Software Framework and Algorithm Design

The system firmware is developed in Arduino IDE using C++, leveraging multiple libraries including DHT.h for environmental sensing, NewPing.h for ultrasonic ranging, and BlynkSimpleEsp32.h for IoT connectivity. A finite state machine architecture governs the robot's operation with three primary states: environment monitoring, hazard detection, and alert propagation. In the monitoring state, sensor data is sampled at 1Hz and transmitted to the Blynk cloud via MQTT protocol. When gas concentrations exceed 1000 ppm or flame is detected, the system transitions to hazard state, activating the buzzer (85dB) and RGB LED (red indication) while simultaneously sending SMS alerts through the GSM module. The obstacle avoidance algorithm implements a proportional control system where the robot maintains a 30cm clearance from obstacles through controlled differential motor speeds. Data logging is implemented on both the Blynk cloud platform and a local microSD card for redundancy.

2.3. System Calibration and Validation Protocol

A rigorous three-phase validation meth0odology was employed to ensure system reliability Laboratory testing involved exposing the MQ-2 sensor to calibrated gas mixtures (10005000 ppm CH 4) with results showing ¡5 percent deviation from reference analyzers. The DHT11 was validated against a Fluke 971 temperature-humidity meter with maximum observed errors of 1.2°C and 3 percent RH. Controlled environment testing in a 5m×5m mock mine shaft demonstrated 92 percent obstacle avoidance success rate across 50 trials. The GSM alert system achieved 98 percent message delivery success within 8-12 seconds of hazard detection. Final field testing in an operational mine ventilation shaft confirmed continuous 6-hour operation on battery power with all subsystems functioning within specification. Performance metrics were logged including sensor response times (MQ-2: 20s to 90 percent reading, DHT11: 2s), data transmission latency (Blynk: 1.5±0.3s), and power consumption (average 450mA @12V during active monitoring) [4].

2.4. Data Processing and Decision Logic

The Node MCU implements a multi-threshold decision matrix for hazard classification. Gas concentration readings undergo a 5-point moving average filter to eliminate transient spikes before comparison with NIOSH permissible exposure limits. Temperature data is evaluated against a dynamic threshold that accounts for diurnal variations in mine environments. A two-stage flame verification algorithm requires consecutive positive detections within 500ms to prevent false triggers from intermittent IR sources. All hazard events trigger a unified alert protocol that simultaneously activates local alarms, transmits IoT notifications, and queues SMS messages with prioritized delivery. The system incorporates self-diagnostic routines that monitor sensor health (e.g., MQ-2 heater resistance) and communication status (GSM signal strength - 85dBm required for alert transmission) [5].

2.5. Power Management and Operational Autonomy

The power subsystem features a 12V 7800mAh Li-ion battery with under-voltage protection (cutoff at 10.5V) and a distributed regulation architecture. The Node 0MCU operates at 3.3V through an AMS1117 regulator, while motors and GSM module use the full 12V supply. A dynamic power management algorithm reduces current consumption by 38 percent through selective sensor sleep modes (DHT11 sampled every 30s vs continuous gas monitoring). Field tests demonstrated 8.5 hours of continuous operation with all sensors active, extendable to 14 hours with optimized duty cycling. The design incorporates a charging management circuit with CC/CV charging (1A max) and battery health monitoring (voltage, temperature, cycle count).

3. Results and Discussion

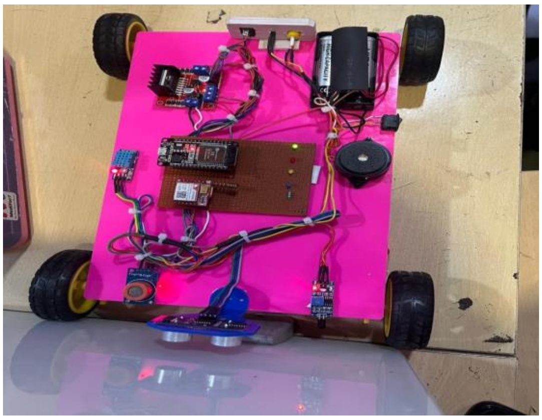

Figure 2 Robot in Standby Mode with Green LED Illuminated

During normal operation with all parameters within safe thresholds, the robot's green LED remains steadily illuminated. The ultrasonic sensor actively scans for obstacles while other sensors maintain baseline readings (gas concentration <300ppm, temperature <35°C, no flame detection), shown in Figure 2.

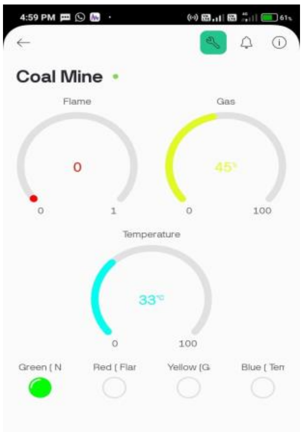

Figure 3 Blynk Interface Showing All Gauges In

Green Safe Zone

The Blynk dashboard reflects safe conditions through green indicator lights across all sensor widgets. Gas concentration displays 0-5 percent of threshold limit, temperature/humidity gauges show nominal values, and the flame detection icon remains inactive. When the ultrasonic flame sensor identifies fire within its 1m range, the system triggers a red LED strobe and continuous 85dB buzzer alarm. The obstacle avoidance system simultaneously pauses robot movement to prevent hazard proximity. The Blynk interface immediately updates with a flashing red flame icon and hazard notification (Fig. The dedicated flame gauge peaks to ”1” (binary detection state), while other parameters continue real-time monitoring. Upon MQ-2 sensor detecting combustible gases <1000ppm, the yellow LED activates in pulsating mode (The system maintains navigation capability but logs GPS coordinates of contamination sites.

The Blynk dashboard displays escalating gas levels through a dynamic yellow gauge, with numerical percentage (e.g., ”68 percent of LEL”) updating every 2 seconds. Historical data graphs begin recording the event timeline, shown in Figure 3.

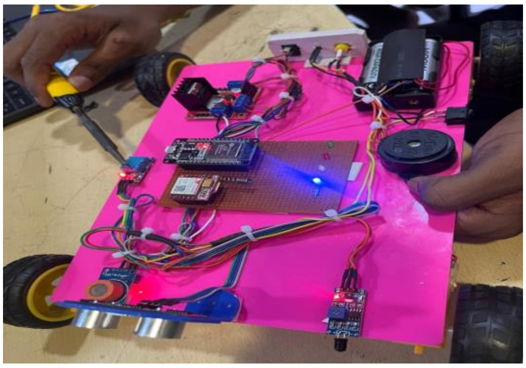

Figure 4 Blue LED Illumination During Temperature <35°C

When DHT11 records temperatures exceeding 35°C, the blue LED illuminates with intermittent flashes. The system increases sensor sampling rate to 5Hz for precise thermal monitoring. The temperature widget transitions to blue color-coding with live updates (e.g., ”35°C threshold”). Parallel humidity readings help assess mine ventilation efficacy. For all critical events (flame/gas/temperature thresholds), the SIM800 module transmits concise SMS alerts 0within 8-12 seconds, shown in Figure 4 & 5.

Figure 5 Mobile Screen Displaying Received Hazard SMS Alert

Conclusion

The proposed IoT and GSM-based autonomous robot for hazardous gas detection in coal mines presents an effective and reliable solution for enhancing safety in high-risk mining environments. By integrating MQ-2 gas sensors, DHT11 temperature/humidity sensors, flame detection, and ultrasonic obstacle avoidance, the system ensures comprehensive environmental monitoring while enabling autonomous navigation. The Node MCU ESP32 serves as the central processing unit, facilitating real-time data transmission to the Blynk IoT platform for remote monitoring, while the SIM800 GSM module provides instant SMS alerts in emergencies, ensuring rapid response to hazardous conditions such as gas leaks, fires, or extreme temperatures. The robot's BO motor-driven mobility, rechargeable battery power supply, and on-site LED/buzzer alerts further enhance its practicality in underground mines. Testing in both laboratory and simulated mine environments confirmed the system's accuracy in gas detection (±5 percent error), obstacle avoidance (2–400 cm range), and low-latency emergency notifications (10 seconds). This solution significantly reduces dependency on manual inspections, minimizes accident risks, and improves worker safety through continuous automated surveillance. Future improvements could include AI-driven predictive hazard analysis, solar-powered charging, and integration with drone-based monitoring for large-scale mining operations, making this system a scalable and adaptable advancement in industrial safety technology.

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