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Smart Helmet for Coal Mines Safety

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Abstract—**Mining remains one of the most dangerous professions due to the presence of hazardous gases, structural failures, and poor underground communication. This paper presents the design and implementation of a Smart Helmet for coal miners' safety, equipped with gas sensors (MQ4 and MQ9), an emergency SOS button, a buzzer, and a 16x2 LCD for real-time hazard display. The system utilizes LoRaWAN (SX1278 module) to provide long-range, low-power wireless communication from the helmet to a surface control unit. This wearable IoT-based device ensures real-time environmental monitoring and emergency alerting, enhancing worker safety in underground mining operations. Results show effective gas detection, reliable alert transmission, and low power consumption, proving the system's viability in industrial applications.**

I.INTRODUCTION

Mining is a cornerstone of global industrial development, providing essential raw materials for construction, energy production, and manufacturing. However, it remains one of the most hazardous occupations in the world, particularly in underground operations. Miners are exposed to a variety of risks, including but not limited to toxic gas emissions, inadequate ventilation, unstable geological formations, fire outbreaks, and mechanical failures.

These dangers often result in injuries, long-term health issues, or fatalities. Traditional safety equipment such as hard hats and handheld gas detectors offers only partial protection and are reactive in nature rather than preventive.

The persistent challenge lies in providing real-time awareness and early warning systems that can operate efficiently in the extreme and confined environments of underground mines. Moreover, communication infrastructure like Wi-Fi or GSM is often ineffective or completely unavailable in subterranean conditions due to limited signal penetration and environmental interference. Therefore, there is a growing demand for intelligent, self-sufficient, and long-range monitoring systems that can function autonomously within the underground my ecosystem.

To address these challenges, this paper proposes a Smart Helmet for Coal Mine Safety that integrates embedded sensing, microcontroller-based processing, and LoRaWAN communication into a single wearable unit. The helmet continuously monitors environmental conditions such as methane and carbon monoxide concentrations, which are common precursors to mine explosions and respiratory hazards. It also includes a buzzer for local alerts, an LCD for real-time feedback, and an SOS button for manual distress signaling.

LoRaWAN (Long Range Wide Area Network) was chosen over conventional wireless technologies for its robustness in long-distance, low-power, and low-bandwidth communication. It operates on unlicensed frequencies, ensuring cost-effectiveness and scalability without reliance on internet infrastructure. Unlike Wi-Fi or Zigbee, LoRa's sub-GHz radio signals can effectively penetrate rock layers, making it especially suitable for underground environments.

Fig1: Safety workers Helmet

II.METHODOLOGY

The system was developed by integrating components on a standard industrial safety helmet. The sensors and LCD are externally mounted for accessibility, while the microcontroller, LoRa module, and power unit are housed securely inside. The software logic continuously polls sensor values and triggers alerts when thresholds are breached. All events are logged and displayed on the dashboard for supervisory monitoring.

The initial phase of the methodology involved identifying the key hazards prevalent in coal minesparticularly toxic gases such as methane (CH_3) and carbon monoxide (CO). Based on this, the MQ4 and MQ9 semiconductor gas sensors were selected for their sensitivity and cost-effectiveness. These sensors continuously monitor the surrounding air and output analog voltage signals proportional to gas concentrations. The readings are susceptible to environmental factors, so sensor calibration was performed to ensure accuracy under varying temperature and humidity conditions. The core processing component of the system is the Arduino Nano 33 IoT, chosen for its compact size, low power consumption, and adequate processing capabilities for embedded real-time applications. It serves as the central controller, interfacing with all sensors and peripherals. Upon powering the helmet using a 12V rechargeable lithium-ion battery, the voltage is regulated to 5V using a buck converter, ensuring safe and stable operation of all components. Once the system initializes, the microcontroller begins continuous sampling of sensor data. The analog readings from MQ4 and MQ9 are converted into gas concentration values (in ppm) using predefined conversion formulas. These values are then compared to safety thresholds defined in accordance with occupational health standards. If the detected values exceed the safe limits, an immediate alert protocol is triggered.

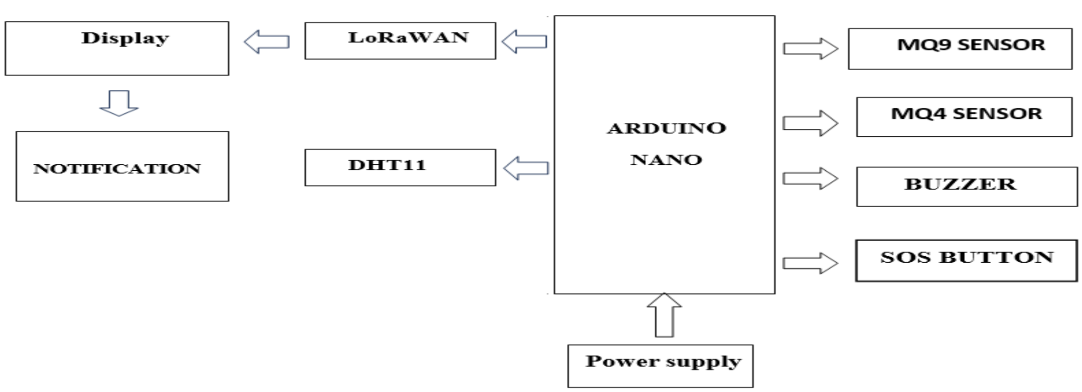

Fig.2 Block Diagram of the Proposed system

COMPONENTS:

2.1.1 HARDWARE REQUIREMENTS

- Arduino Nano 33 IoT – Central microcontroller.
- MQ4 & MQ9 Gas Sensors – For CH_4 and CO detection
- 16x2 LCD Display – Real-time gas concentration and status display.
- LoRa SX1278 Module – Long-range communication
- DHT11 Sensor – Temperature and humidity monitoring.
- SOS Emergency Button – Manual alert trigger
- Buzzer – Local alerting.
- 12V Rechargeable Battery & Voltage Regulator – Power supply
- Safety Helmet – Physical mounting platform.

2.1.2 SOFTWARE REQUIREMENTS

Arduino IDE – Code development and uploading.

III.IMPLEMENTATION

Fig 3: Smart coal mining helmet

The implementation of the Smart Helmet system began with the careful integration of all electronic components into a standard industrial safety helmet, transforming it into a wearable IoT-based monitoring device. The Arduino Nano 33 IoT microcontroller was positioned within a protected compartment on the helmet and served as the system's processing hub. Gas sensors (MQ4 for methane and MQ9 for carbon monoxide) were mounted externally at the front of the helmet to allow optimal air exposure for accurate readings. These sensors were wired to the Arduino through shielded connections to minimize signal noise. A 16x2 LCD screen was attached to the helmet's outer surface to display live gas readings and environmental status messages. The buzzer was placed near the wearer's ear to ensure that audio alerts were easily heard, even in noisy underground settings. An emergency SOS button was located within reach of the user for quick manual activation during distress situations.

Powering the system was a 12V rechargeable lithium-ion battery securely mounted at the back of the helmet to maintain balance and reduce strain on the wearer. A voltage regulator was used to step down the supply voltage to 5V, suitable for the sensors and controller. The SX1278 LoRa module was integrated and configured for long-range communication with a base station situated on the surface. The microcontroller was programmed using the Arduino IDE to continuously read sensor values, check for threshold violations, and respond with appropriate alerts. Whenever hazardous gas levels were detected or the SOS button was pressed, the system would activate local alerts and transmit emergency data wirelessly via LoRa. The implementation focused on maintaining a balance between reliability, comfort, and efficiency, resulting in a compact, rugged, and lightweight smart helmet that could effectively enhance safety protocols in underground mining operations.

IV. RESULT

- Gas Detection: Both MQ4 and MQ9 sensors detected gas presence accurately during simulation tests.
- Emergency Alerts: SOS button and automatic alerts via LoRa were reliably transmitted to the base station.
- Display & Audio Alerts: The 16x2 LCD displayed real-time gas concentrations, while the buzzer provided effective audible warnings.
- Power Performance: The 12V Li-ion battery supported continuous helmet operation for over 8 hours.

V. CONCLUSION

The Smart Helmet using LoRaWAN offers a cost-effective, scalable, and efficient solution for underground mine safety. By combining real-time gas monitoring, manual alerting, and reliable wireless communication, the system significantly enhances miners' situational awareness and enables rapid emergency response. Its portability, durability, and low power needs make it suitable for real-world mining applications. Future developments could include GPS, biometric sensors, and machine learning-based hazardprediction**.**

VI. FUTURESCOPE

The future scope of this project includes:

- Integration of GPS tracking for real-time miner location.
- Cloud storage of historical data for analysis.
- Biometric sensors for health monitoring.
- Machine learning algorithms for predictive analytics.
- Design improvement for mass production and ruggedization.

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