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IOT – Based Smart Helmet for Industrial Safety with Real-Time Monitoring and Hazard Detection

Er.Khaja Mohideen[1], Prabhakaran R[2], Irfan Hameed S[3], Ravi Kumar A[4], Mohammed Rilwan S[5]

[1]AssistantProfessor, Aalim Muhammed Salegh College Of Engineering, Chennai, Tamilnadu, India
[2,3,4,5] Student, Aalim Muhammed Salegh College Of Engineering, Chennai, Tamilnadu, India

I. ABSTRACT

In mining industries, ensuring worker safety is paramount due to the presence of hazardous conditions such as toxic gas accumulation, high temperature fluctuations, poor visibility, and the risk of physical accidents. Traditional safety gear offers basic protection but lacks the ability to sense or respond to environmental threats in real time, which can lead to delayed emergency responses and increased accident rates. This project proposes an Internet of Things (IoT)-based smart safety helmet designed specifically for miners, integrating a gas leak sensor (MQ-2), a temperature and humidity sensor (DHT11), an ultrasonic sensor for obstacle detection, and a local alert buzzer. The helmet continuously monitors environmental parameters, transmitting real-time data to cloud-based IoT platforms for remote monitoring. Immediate audio alerts notify the wearer upon detection of hazardous conditions, while supervisors can track data remotely to ensure timely intervention. The helmet design prioritizes portability, ergonomic comfort, cost efficiency, and scalability, making it a promising solution for deployment in hazardous mining environments and various other industrial sectors requiring real-time safety monitoring.

II. INTRODUCTION

Mining environments are inherently hazardous due to the presence of combustible and toxic gases, extreme temperatures, limited lighting, and the risk of physical injury from falling debris or equipment. While traditional helmets protect against physical impacts, they do not provide any intelligence regarding the environmental conditions surrounding the worker. This lack of awareness can contribute to accidents, injuries, or fatalities, especially when dangerous gases accumulate or when a miner is unaware of nearby obstacles or overheating conditions. With the advent of the Internet of Things (IoT), it has become feasible to develop smart wearable devices capable of continuously sensing environmental conditions, processing data locally, and transmitting alerts and status updates remotely in real time. Smart safety helmets equipped with multiple sensors can detect and warn against imminent hazards, significantly reducing risk and improving response times. This paper presents a design and implementation of an IoT-enabled smart helmet tailored for mining safety. The helmet integrates gas detection, temperature and humidity monitoring, and proximity sensing with an alert system and IoT data transmission. The aim is to create a lightweight, energy efficient device that not only protects but also actively monitors the miner's environment, thereby enhancing overall operational safety and allowing supervisory staff to make informed decisions based on real-time data.

III. LITERATURE REVIEW

Recent years have seen increasing research efforts into sensor-based wearable safety devices aimed at industrial workers. Bhosale et al. (2020) developed a smart helmet with RF communication and gas sensors; however, its lack of internet-based connectivity limited remote supervision and data analytics capabilities. Patil and Pawar (2021) created a Bluetooth- enabled helmet to detect accidents with buzzer alerts, but Bluetooth's short communication range and dependency on paired devices limit its effectiveness in large mining operations with dispersed personnel. Sharma et al. (2022) introduced a multi- sensor wearable vest incorporating gas and temperature sensors but faced challenges related to device portability and user comfort due to the bulkiness of the design. Other solutions have incorporated GPS tracking or heart rate monitoring but lacked comprehensive environmental sensing or cloud integration. The proposed system differentiates itself by integrating multiple environmental sensors into a compact helmet form factor, leveraging Wi-Fi-based IoT platforms for real-time cloud data transmission and visualization. This enables continuous remote monitoring by supervisors, timely alerts to miners, and scalable deployment across extensive mining sites.

IV. PROBLEM STATEMENT

Mining workers often face sudden environmental hazards that are difficult to detect without specialized equipment. The build-up of toxic gases like methane or carbon monoxide, elevated temperatures causing heat stress, and hidden obstacles pose constant threats. Unfortunately, conventional safety gear does not provide real-time hazard detection or alerts, increasing the risk of accidents and delayed emergency responses. The absence of intelligent, wearable, multi- sensor safety devices results in preventable injuries and fatalities. Furthermore, lack of remote monitoring hampers supervisory staff from taking proactive safety measures. Therefore, a robust, cost-effective, and portable safety helmet integrated with realtime environmental sensing, local alerting, and IoT connectivity is necessary to enhance miner safety and operational efficiency.

V. OBJECTIVES

Design and develop a multi-sensor safety helmet capable of monitoring critical environmental parameters relevant to mining hazards.

Detect hazardous gases including LPG, methane, and carbon monoxide through the MQ-2 sensor. Continuously measure temperature and humidity to identify potentially dangerous thermal conditions using the DHT11 sensor. Employ ultrasonic sensors to detect nearby obstacles or falling hazards to prevent physical accidents. Integrate an immediate audio alert system via a buzzer to notify miners of dangerous conditions.

Implement real-time data transmission to a cloud platform, enabling continuous remote monitoring and logging. Ensure ergonomic helmet design for comfort, durability, and ease of use in harsh mining environments. Validate the system through rigorous testing and calibration to ensure accuracy, responsiveness, and reliability.

VI. METHODOLOGY

1. Component Selection and Specifications

MQ-2 Gas Sensor: Sensitive to combustible gases like LPG, methane, and carbon monoxide, with fast response times and easy integration. Essential for detecting toxic and explosive gas leaks. DHT11 Temperature and Humidity Sensor: Provides stable measurements within a moderate range, sufficient for detecting heat stress or abnormal humidity levels affecting miner health. Ultrasonic Sensor (HC-SR04): Measures distance by emitting ultrasonic pulses and detecting their echo, effectively sensing obstacles or changes in proximity to surrounding objects. Buzzer: Produces an audible alarm when hazardous conditions are detected, ensuring immediate local alerting. Microcontroller (NodeMCU/ESP32): Central processing unit with built-in Wi-Fi for data acquisition, processing, threshold comparison, alert triggering, and cloud communication. Power Supply: Rechargeable 3.7V lithium-ion battery chosen for compactness, reliability, and sufficient capacity to support long shifts.

2. System Architecture

All sensors are strategically mounted on the helmet to cover relevant areas without impeding user movement or comfort. The microcontroller polls sensor data at predetermined intervals (e.g., every 2 seconds).

Thresholds are set based on safety standards: gas concentration levels as per OSHA guidelines, temperature limits relevant to miner safety, and obstacle detection distances sufficient to prevent collisions. Upon detecting readings beyond safe limits,the microcontroller immediately activates the buzzer for local warning and simultaneously pushes data to the IoT platform for supervisor alerts. The platform supports graphical visualization, historical logging, and threshold- based notifications to enable timely interventions.

3. IoT Integration

Using NodeMCU/ESP32 Wi-Fi capability, sensor data is transmitted via HTTP or MQTT protocols to platforms like ThingSpeak or Blynk.

These platforms offer dashboards that display real-time sensor readings, generate alerts, and maintain logs for safety audits.

4. Testing and Calibration

Controlled experiments simulate hazardous conditions: introducing LPG gas to validate MQ-2 response, applying heat to test temperature/humidity sensors, and placing objects at various distances to verify ultrasonic accuracy. The system's latency from hazard detection to buzzer activation was measured, ensuring alerts occur within 1–2 seconds for rapid response. Calibration involved comparing sensor outputs with industrial-grade instruments to ensure accuracy within ±5%.

VII. SYSTEM DESIGN

Block Diagram :

Working Principle:

*Sensors continuously monitor environmental data.

*Microcontroller compares readings against thresholds.

*On detecting danger, buzzer sounds instantly for wearer alert.

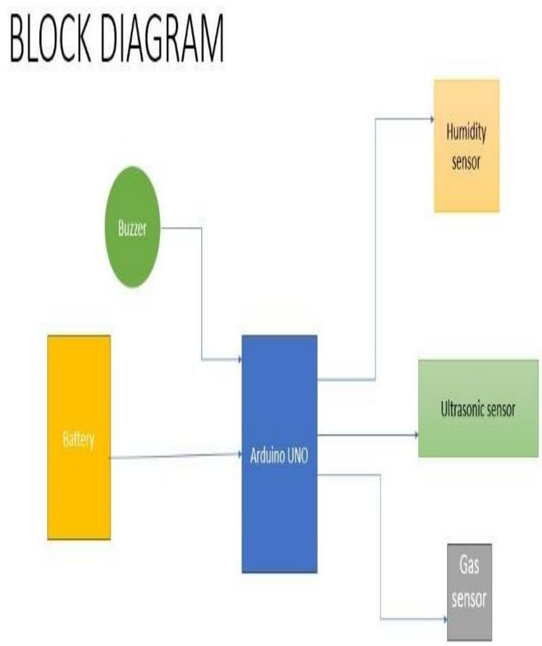
*Sensor data streams wirelessly to the cloud for remote monitoring.

Power Management:

Low-power design strategies, such as sensor polling intervals and microcontroller sleep modes, optimize battery life to support 8+ hour mining shifts without recharge.

Ergonomics and Helmet Integration:

All components are miniaturized and enclosed in durable casings to prevent damage. The helmet’s weight distribution ensures comfort and no hindrance to miner mobility. Wiring is concealed to avoid snagging hazards.



VIII. RESULTS

The prototype was subjected to comprehensive testing:

Gas Detection: MQ-2 sensor identified LPG presence within 2 seconds; buzzer activated immediately, and cloud dashboard updated in near real time. Temperature and Humidity: DHT11 sensor readings showed consistent accuracy; changes were reflected promptly on the IoT dashboard. Obstacle Detection: Ultrasonic sensor reliably detected objects within 20 cm, triggering buzzer alerts to prevent collisions. IoT Connectivity: Data transmission to ThingSpeak/Blynk was stable with minimal latency (<500 ms), ensuring supervisors receive timely updates. The system demonstrated reliability, responsiveness, and user-friendly alerting, confirming its potential for real mining environments.

IX. CONCLUSION

This project successfully developed an IoT- enabled smart helmet that integrates multi- parameter sensing to enhance miner safety. By detecting hazardous gases, abnormal thermal conditions, and nearby obstacles in real time, and providing immediate alerts both locally and remotely, the helmet significantly mitigates occupational risks. The design balances functionality, cost- effectiveness, energy efficiency, and ergonomics, making it suitable for scalable deployment across mining operations. Future work may incorporate GPS for location tracking, health monitoring sensors (heart rate, oxygen saturation), advanced analytics for predictive hazard detection, and integration with mine-wide emergency response systems. This smart helmet represents a meaningful advancement in mining safety technology and provides a foundation for further innovations in industrial wearable safety devices.

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