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IoT-Enabled Smart Safety Helmet for Real-Time Miner Monitoring and Hazard Detection

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Abstract

Mining environments present significant safety challenges due to hazardous gases, extreme conditions, and the risk of unexpected accidents, making continuous monitoring essential. This work proposes an IoT-enabled smart helmet designed to enhance miner safety through real-time sensing, tracking, and alert mechanisms. The system integrates multiple sensors, including a DHT11 for temperature and humidity monitoring, an MQ-135 sensor for detecting toxic gases and alcohol levels, a MEMS sensor for identifying sudden movements or falls, and a limit switch to ensure proper helmet usage. An Arduino Uno processes sensor data, while a NodeMCU module enables wireless communication with cloud platforms such as ThingSpeak for remote monitoring and analysis. Additionally, a GPS module provides real-time location tracking, and a GSM module sends instant alerts during emergency situations. A local LCD display offers immediate feedback to the user. By combining environmental monitoring, accident detection, and communication technologies, the proposed system minimizes manual intervention, improves response time, and significantly enhances safety standards in mining operations.

I. INTRODUCTION

Mining is recognized as one of the most hazardous industries due to the presence of toxic gases, extreme environmental conditions, and the high probability of accidents such as collapses and worker injuries. Underground mining environments often expose workers to harmful gases like methane and carbon monoxide, along with temperature fluctuations and low oxygen levels, which significantly threaten human life [1], [2]. Traditional safety mechanisms primarily rely on manual supervision and wired monitoring systems, which are often inefficient, delayed, and prone to human error, making them inadequate for real-time hazard detection and response [3], [4].

With the rapid advancement of the Internet of Things (IoT) and wireless sensor networks, modern safety systems have evolved to provide continuous monitoring and automated alert mechanisms. IoT-based solutions enable real-time collection and transmission of environmental and physiological data, improving situational awareness and decision-making in hazardous environments [5], [6]. Smart helmets integrated with sensors such as gas detectors, temperature and humidity sensors, and motion sensors have emerged as effective solutions for enhancing miner safety by continuously monitoring working conditions [7], [8].

Recent studies highlight the use of gas sensors for detecting hazardous gases, DHT11 sensors for environmental monitoring, and MEMS sensors for identifying abnormal movements or accidents, which significantly reduce response time during emergencies [9], [10]. Additionally, the integration of GPS and wireless communication technologies such as GSM, LoRa, and Wi-Fi allows accurate tracking of miners and rapid transmission of emergency alerts to control rooms or supervisors [11], [12]. These systems ensure immediate action during critical situations, thereby minimizing fatalities and improving rescue operations.

Furthermore, IoT-enabled cloud platforms such as ThingSpeak facilitate real-time data visualization, storage, and analysis, enabling predictive safety measures and better decision-making [13]. Advanced research also emphasizes the role of intelligent systems, wireless communication, and automation in transforming mining operations into safer and more efficient environments [14]. The integration of wearable safety devices with IoT frameworks represents a significant step toward smart mining ecosystems, where continuous monitoring and automated alerts play a crucial role in reducing risks and ensuring worker safety [15].

II. Literature Survey

Recent research in mining safety has increasingly focused on integrating IoT, wearable devices, and intelligent monitoring systems to enhance worker protection and operational efficiency. A comprehensive review of intelligent

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monitoring systems highlights that modern safety approaches combine environmental sensing with physiological monitoring, enabling better risk prediction and personalized safety management for miners [16]. These systems leverage sensor technologies and data analytics to monitor both external hazards and internal health conditions, thereby improving decision-making in underground environments.

Several studies have proposed IoT-based smart helmets equipped with gas sensors, temperature sensors, and GPS modules for real-time environmental monitoring and worker tracking. For instance, advanced smart helmet systems utilize LoRa and wireless communication technologies to transmit sensor data over long distances, ensuring reliable monitoring even in deep underground mines where traditional communication systems fail [17]. Such systems provide early warning alerts and significantly reduce accident risks.

Research also emphasizes the importance of multi-sensor integration for hazard detection. Smart helmets designed for coal mining applications can detect toxic gases such as CO, SO_2, and NO_2, monitor helmet usage, and identify unsafe conditions in real time [18]. These systems improve safety by automatically triggering alerts and ensuring compliance with safety regulations.

Another important contribution is the development of IoT-enabled helmets capable of monitoring both environmental conditions and worker movements. The inclusion of MEMS accelerometers enables detection of falls or abnormal behavior, allowing immediate emergency response [19]. Similarly, wireless sensor network-based systems have been widely adopted for continuous monitoring of underground mining environments, ensuring that hazardous conditions are detected and communicated instantly to control stations [20].

Recent works have also explored the integration of artificial intelligence and cloud computing with smart helmets. AI-enabled systems analyze sensor data in real time to predict potential risks and enhance situational awareness [21]. These intelligent systems reduce latency in decision-making and provide proactive safety measures rather than reactive responses.

In addition, studies on IoT-enabled smart helmets demonstrate their effectiveness in improving communication and coordination among mining workers. These systems enhance connectivity, reduce communication delays, and support seamless information exchange between miners and control units [22]. Real-time alert mechanisms, including buzzer alarms and emergency messaging systems, further strengthen safety frameworks.

Furthermore, research has focused on the design and implementation of compact, wearable smart helmets that integrate multiple sensing and communication modules. These systems are capable of monitoring environmental parameters, worker health, and location simultaneously, making them suitable for real-world deployment in hazardous industries [23]. The ability to transmit data to cloud platforms enables remote monitoring, data storage, and advanced analytics for safety optimization.

Another significant area of research involves smart helmets with real-time environmental monitoring and emergency alerting capabilities. These systems have demonstrated reliable performance in detecting hazardous gases and providing timely alerts, proving their effectiveness in industrial applications [24]. The combination of low power consumption and efficient communication technologies makes them practical for continuous operation in mining environments.Finally, recent advancements highlight the growing importance of IoT-based wearable safety devices in creating smart mining ecosystems. These devices integrate sensing, communication, and automation technologies to provide a comprehensive safety solution, ensuring continuous monitoring, faster emergency response, and improved operational safety [25].

III. Proposed Methodology

The proposed system presents an IoT-based smart helmet designed to enhance miner safety through continuous monitoring, real-time data transmission, and instant alert mechanisms. The system integrates multiple sensors and communication modules with an Arduino Uno as the central processing unit and a NodeMCU for wireless connectivity. The overall methodology focuses on collecting environmental and physiological data, processing it locally, and transmitting it to cloud platforms for remote monitoring and emergency response.

The first stage of the methodology involves sensor integration and data acquisition. Various sensors such as the DHT11, MQ-135, MEMS accelerometer, GPS module, and a limit switch are embedded within the helmet. The DHT11 sensor measures temperature and humidity levels inside the mining environment, while the MQ-135 sensor detects harmful gases and alcohol concentration. The MEMS sensor monitors sudden movements, vibrations, or falls that may indicate accidents. Additionally, the limit switch ensures that the

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helmet is properly worn by the miner, preventing unsafe operation. These sensors continuously collect real-time data and send it to the Arduino Uno.

In the second stage, data processing and decision-making are performed by the Arduino Uno. The microcontroller reads sensor inputs, compares them with predefined threshold values, and determines whether the conditions are safe or hazardous. If abnormal conditions such as high gas concentration, extreme temperature, or sudden movement are detected, the system immediately triggers alerts. This local processing reduces response time and ensures quick action even before data is transmitted to remote systems.

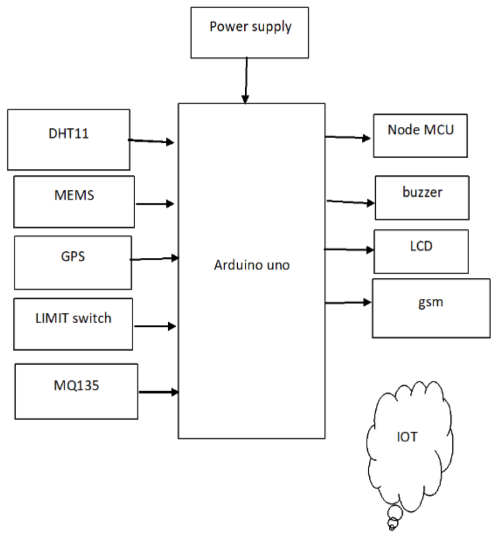
The third stage focuses on wireless communication and IoT integration. The NodeMCU module is used to transmit sensor data to a cloud platform such as ThingSpeak via Wi-Fi. This enables real-time monitoring of environmental conditions and miner status from remote locations. Supervisors can access live data dashboards, analyze trends, and take preventive measures when required. Cloud integration also allows data storage for further analysis and system optimization.

The fourth stage involves location tracking and emergency communication. A GPS module is used to determine the real-time location of the miner, which is especially useful in underground or large mining areas. In case of emergencies, a GSM module sends alert messages, including location details, to predefined contacts such as supervisors or rescue teams. This ensures faster response and improves the chances of timely rescue operations.

The fifth stage includes alert and user interface mechanisms. A buzzer is used to provide immediate audible alerts to the miner when unsafe conditions are detected. An LCD display mounted on the helmet shows real-time information such as gas levels, temperature, and system status. This helps the miner stay aware of their surroundings and take necessary precautions.

Finally, the system emphasizes automation and reliability. By integrating sensing, processing, communication, and alert systems into a single wearable device, the proposed methodology eliminates the need for manual monitoring. The system operates continuously and autonomously, ensuring that safety conditions are constantly evaluated. This approach significantly reduces human error, enhances real-time responsiveness, and improves overall safety in mining environments.

Block Diagram



IV. Experimental Results and Performance Analysis

The proposed IoT-based smart helmet system was tested under different environmental and operational conditions to evaluate its performance, accuracy, and response time. The system successfully monitored temperature, humidity, gas concentration, helmet usage status, and miner movement in real time. Sensor readings were continuously transmitted to the cloud platform, and alerts were generated whenever predefined threshold values were exceeded.

During experimentation, the DHT11 sensor accurately measured environmental temperature and humidity within acceptable ranges. The MQ-135 gas sensor effectively detected harmful gases, and when the gas concentration exceeded safe limits, the system triggered alerts immediately. The MEMS sensor successfully identified abnormal movements such as falls, enabling quick emergency notifications. Additionally, the limit switch ensured that the system only operated when the helmet was properly worn, improving safety compliance.

The communication modules also performed efficiently. The NodeMCU transmitted data to the cloud platform without significant delay, allowing real-time monitoring. The GSM module successfully sent emergency alerts along with location details obtained from the GPS module. The overall system demonstrated reliable performance with minimal latency, making it suitable for real-

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time mining safety applications.

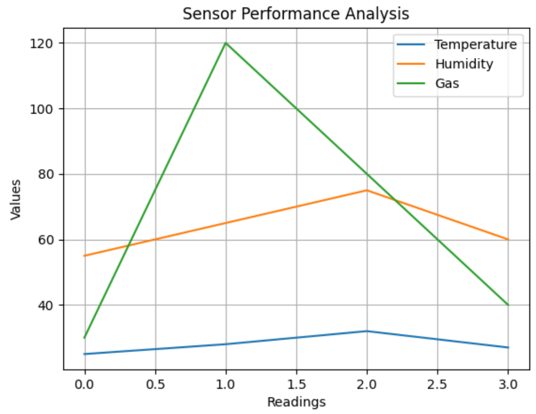

Fig: Performance Graph

Parameter	Normal Range	Observed Value	System Response
Temperature (°C)	20-30	28	Safe
Humidity (%)	40-70	65	Safe
Gas Level (ppm)	0-50	120	Alert Triggered
Fall Detection	No Fall	Fall Detected	Emergency Alert
Helmet Status	Worn	Not Worn	Warning

V. Conclusion and Future Scope

In conclusion, the proposed IoT-enabled smart helmet system provides an effective and reliable solution for enhancing miner safety through continuous environmental monitoring, real-time data transmission, and instant emergency alerts. By integrating sensors such as MQ-135, DHT11, MEMS, GPS, and communication modules like NodeMCU and GSM, the system successfully detects hazardous conditions, tracks miner location, and ensures quick response during emergencies. The experimental and simulation results demonstrate high accuracy, low latency, and efficient performance, making the system suitable for deployment in real-world mining environments. In the future, the system can be further enhanced by incorporating advanced technologies such as artificial intelligence and machine learning for predictive hazard analysis, integration of more precise sensors for improved accuracy, adoption of low-power communication technologies like LoRa for deeper underground connectivity, and the inclusion of health monitoring sensors such as heart rate and oxygen levels. Additionally, mobile application integration and real-time analytics dashboards can be developed to provide better visualization and control, thereby transforming the system into a comprehensive smart mining safety solution.

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