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Advanced IOT - Based Smart Mining Helmet with LoRa - Enabled Communication for Enhanced Safety

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Abstract: This paper presents the advanced IoT-based smart mining helmet accompanying LoRa-enabled communication for enhanced safety an creative safety resolution created to pro- tect miners by mixing leading technology this Arduino-located headgear is outfitted with MQ vapor sensors a DHT11 hotness and humidity sensor an quick sensor a signs of life sensor an emergency fastener an LCD display and a siren alarm to steadily monitor critical referring to practices or policies that do not negatively affect the environment limits such as smoke aggregation temperature humidness and digger strength while detecting obstacles and falls the Lora-authorized ideas system guarantees general reliable dossier broadcast to a main moni- toring whole even in deep secret environments place common systems may be useless in dangers miners can use the panic button to transmit distress signals while certain-time voice ideas and a siren alarm allow quick alerts for next reaction the LCD display provides live rank amends and the buzzer advises of hazards to a degree poisonous gas uncovering weird pulse rates or dangerous environment by offering evident-opportunity listening proactive alerts and danger reaction capabilities this headgear considerably enhances laborer security and functional efficiency in perilous excavating environments.
Keywords: IoT, Smart Mining Helmet, LoRa Com- munication, Mining Safety, Ultrasonic Sensor, Pulse Rate Sensor, Emergency Button, Real-time Monitoring, Gas Sensor

I. INTRODUCTION

Mining remains one of the most dangerous industries, exposing workers to toxic gases, poor ventilation, cave-ins, and long-term health risks. The mining sector has a high fatality rate compared to other industries, but many accidents could be prevented with better real-time monitoring and emergency response systems. Recent advancements in IoT technology offer a solution through real-time monitoring integrated into Personal Protective Equipment (PPE). This paper introduces an IoT-based smart mining helmet designed to improve miner safety by monitoring health and environmental conditions in real-time. The helmet includes a pulse rate sensor to track heart rate and detect physical stress, a gas sensor to identify hazardous gases like methane and carbon monoxide, and an ultrasonic sensor to detect nearby obstacles and structural hazards. LoRa (Long Range) communication technology enables reliable, low-power data transmission even in deep underground environments where Wi-Fi and Bluetooth signals fail. The collected data is sent to a central system for analysis, triggering alerts for quick action if irregularities are detected, such as toxic gas spikes or increased heart rate. Long-term data analysis helps identify patterns and improve safety measures, reducing accidents and enhancing operational efficiency. IoT-based smart mining helmets represent a sig- nificant step toward improving miner safety and health by providing real-time monitoring and faster emergency response.

II. LITERATURE SURVEY

The integration of Internet of Things (IoT) technology in mining safety systems has been explored extensively in various studies, with promising results in improving real-time monitor- ing and enhancing overall safety. Banik et al. (2023) proposed a smart helmet system using Wi-Fi for environmental monitoring, which showed potential in improving data transmission and hazard detection. However, the short range and high power consumption of Wi-Fi limit its applicability in large-scale mining operations and deep underground environments where signal strength and reliability are critical [1].
Similarly, Yosoon et al. (2021) investigated the use of Zig- Bee for proximity warning systems, which provides reliable short-range data transmission but struggles in environments with high signal interference, such as deep underground mines [2]. A common feature across these studies is the reliance on environmental monitoring sensors, such as gas detectors and temperature sensors, which are essential for detecting hazardous gases and unfavorable environmental conditions.

However, most existing solutions lack the capability to monitor the physiological health of miners, which is crucial for de- tecting early signs of fatigue, cardiovascular stress, and other health issues.

For instance, Paul et al. (2022) developed a system focused on monitoring gas levels and air quality in coal mines but did not include any mechanism for tracking the health status of miners themselves, which remains a significant gap in existing mining safety systems [3]. Health issues, particularly cardiovascular stress and fatigue, are major concerns in mining due to the physically demanding nature of the work and harsh environmental conditions. The absence of physiological monitoring in current systems limits their ability to provide comprehensive safety coverage.

Moreover, most existing systems also lack a manual emer- gency response mechanism. In many cases, miners are not able to signal for help if they encounter a sudden hazard or health issue that the sensors fail to detect. This highlights the need for a manual emergency button, which would enable miners to trigger an immediate alert to the control center in case of an emergency.

The limitations of Wi-Fi and ZigBee in terms of range and power consumption have led to the increasing adoption of LoRa (Long Range) communication technology in recent mining safety studies. LoRa's ability to penetrate physical obstacles and maintain reliable communication over long distances makes it an ideal solution for underground mining environments. Sawant et al. (2020) developed an Arduino- based smart helmet for coal mine safety using environmental sensors and real-time data transmission, but the use of Wi- Fi limited the range and effectiveness of the system in deep mining environments [4].

This study builds on the work of previous researchers by integrating both environmental and physiological monitoring into a single helmet using LoRa technology. The smart min- ing helmet proposed in this research includes a pulse rate sensor to track the miner's heart rate, a gas sensor to detect dangerous gases such as methane and carbon monoxide, and an ultrasonic sensor to monitor proximity to obstacles and structural hazards. The use of LoRa technology ensures that data is continuously transmitted to the control center even in deep underground conditions, overcoming the range and interference limitations of Wi-Fi and ZigBee. The system also includes a manual emergency button, allowing miners to trigger an immediate alert to safety personnel if they face an emergency situation that the automated sensors fail to detect. This comprehensive integration of environmental and physiological monitoring, combined with reliable long-range communication, ensures enhanced safety and rapid emergency response in mining operations.

III. METHODOLOGY

The proposed IoT-based smart mining helmet is designed with an integrated system of sensors and a LoRa commu- nication module. The helmet continuously monitors both the environmental conditions and the physiological state of the miner, transmitting the collected data to a central control system for real-time analysis and alert generation. Fig. 1 consists of the major blocks of the smart helmet which are:

1) Arduino UNO
2) Sensor Segmentation
3) Output Devices
4) IOT

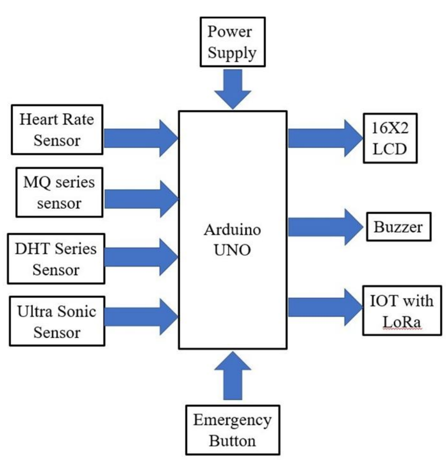

Fig. 1. Block Diagram for Smart Helmet for Miners

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A. Sensor Integration

The helmet includes several key sensors:

1) *Gas Sensor (MQ-2)::* This sensor is used to detect harmful gases like methane (CH4) and carbon monoxide (CO) that are commonly found in underground mines. These gases pose significant risks, as methane is highly explosive, and carbon monoxide can lead to asphyxiation.
2) *Heart Rate Sensor:: The pulse rate sensor monitors the miner's heart rate, providing real-time data on their health status.* The sensor is critical for detecting signs of fatigue, stress, or abnormal heart conditions. If the pulse rate goes beyond predefined safety thresholds, an alert is generated
3) *Ultrasonic Sensor::* This sensor measures the distance between the miner and surrounding objects, such as the roof of the mine or nearby machinery. It helps prevent accidents by alerting the miner if they are too close to obstacles.
4) *Temperature Sensor(DHT-11)::* The DHT11 is a digi- tal sensor that measures temperature and humidity using a capacitive humidity sensor and a thermistor. It outputs data through a single-wire interface, measuring humidity from 20 to 90 percent (±5) and temperature from 0°C to 50°C (±2) with a sampling rate of 1 Hz. Affordable and easy to use, it's ideal for weather monitoring and environmental control.

B. Communication and Data Processing

The LoRa module enables long-range, low-power data transmission from the helmet to the control center, ensuring extended operation without frequent battery changes—ideal for mining shifts. Sensor data is sent every few seconds to the server for real-time analysis. If gas levels or pulse rates exceed safe limits, an alert is triggered on the helmet and at the control center for immediate action.

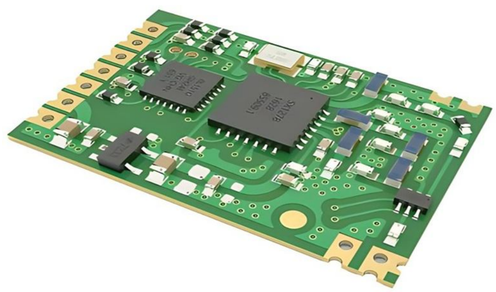

Fig. 2. Zigbee Module with LoRa

C. Manual Emergency System

In addition to automatic alerts, the helmet is equipped with a manually activated emergency button. This button allows the miner to send an immediate distress signal if they encounter an unexpected hazard that the sensors have not detected. The emergency alert takes precedence over other data transmissions, ensuring that it is delivered to the control center without delay.

D. Arduino UNO

The Arduino Uno is a popular microcontroller board based on the ATmega328P, featuring 14 digital I/O pins (6 for PWM), 6 analog inputs, and a 16 MHz quartz crystal. It operates at 5V and can be powered via USB or an external supply. Programmed using the Arduino IDE with C/C++, it's widely used for prototyping and DIY projects due to its simplicity and versatility.

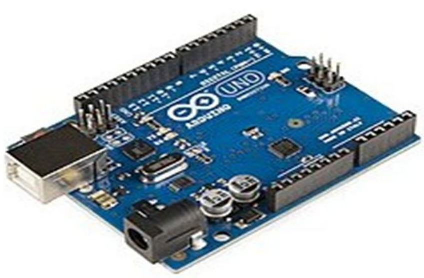

Fig. 3. Arduino UNO

IV. IMPLEMENTATION

The implementation of the smart mining helmet involves the integration of hardware components, including sensors, microcontrollers, and communication modules, with software for data analysis and alert generation. The helmet is powered by a microcontroller (Arduino UNO), which serves as the central processing unit for the system. The microcontroller collects data from the sensors, processes it, and sends it via the LoRa module to the control center.

A. Hardware Setup

The MQ-2 gas sensor is calibrated to detect concentrations of methane and carbon monoxide, with thresholds set accord- ing to OSHA (Occupational Safety and Health Administration) guidelines for workplace safety. The gas sensor is placed on the helmet's exterior to ensure that it can accurately detect ambient gas levels. The ultrasonic sensor is positioned at the top of the helmet, providing a clear line of sight for detecting obstacles up to a range of 400 cm. The pulse rate sensor is mounted inside the helmet to maintain constant contact with the miner's head. This placement ensures accurate heart rate measurements, even in physically demanding conditions. The sensor data is collected every 5 seconds and compared against predefined normal heart rate ranges (60-100 BPM for resting heart rate). Any deviation from this range triggers an alert.

B. Software and Data Management

The microcontroller is programmed using Arduino IDE and is responsible for sensor data acquisition and processing. The

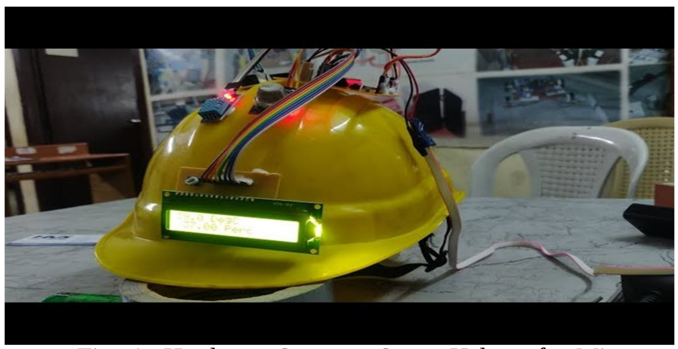

Fig. 4. Hardware Setup os Smart Helmet for Miners

data is transmitted using the LoRa protocol, which supports long-range communication with minimal power consumption. At the control center, the data is received and analyzed using a custom-built IoT dashboard. The dashboard displays real-time sensor readings and generates alerts if any parameter exceeds safe limits. The software also includes a data logging feature, which records historical sensor data for later analysis. This data can be used to identify trends in environmental conditions and miner health, helping to improve safety protocols over time.

V. RESULTS AND DISCUSSION

The prototype of the smart mining helmet was tested in a controlled environment designed to simulate real underground mining conditions. The test environment included various gases, obstacles, and temperature fluctuations to assess the performance of the sensors and communication system.

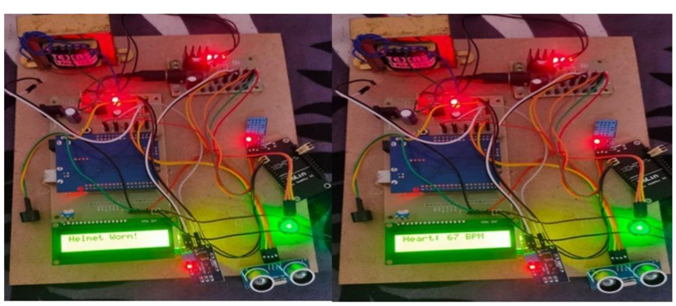

Fig. 5. Helmet and Sensor Result

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A. Sensor Performance

The MQ-2 gas sensor performed reliably, detecting methane and carbon monoxide levels with a high degree of accuracy. The sensor triggered an alert when methane concentrations reached 5 percentage of the lower explosive limit (LEL), in line with safety standards. The pulse rate sensor successfully

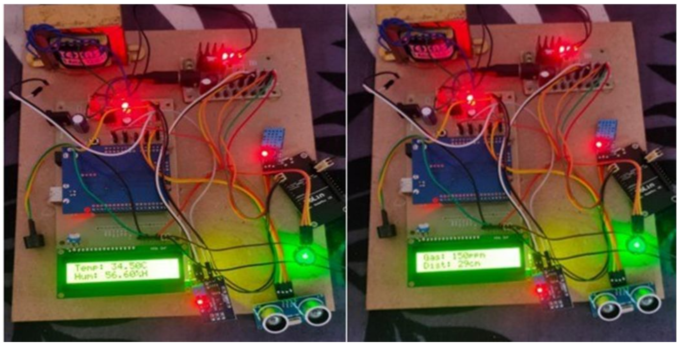

Fig. 6. Sensor Output

monitored the miner's heart rate and detected abnormal read- ings when the subject was subjected to physical exertion. The system generated alerts when the pulse rate exceeded 120 BPM, indicating potential stress. The ultrasonic sensor detected obstacles at varying distances with an error margin of less than 5 cm. This high level of accuracy is crucial for preventing collisions with walls or machinery in low-visibility environments.

B. Communication Reliability

The LoRa communication module demonstrated excellent performance in transmitting data over long distances. During the tests, the module maintained stable communication up to 300 meters in an underground tunnel with several obstructions. This range can be extended in open areas, making LoRa an ideal choice for mining applications. The low power consump- tion of the LoRa module also allowed the helmet to operate continuously for over 12 hours on a single battery charge. The emergency button was tested by manually triggering alerts, and the system responded instantly, sending high-priority alerts to the control center. The overall results indicate that the helmet can significantly improve both miner safety and operational ef- ficiency by providing early warnings of hazardous conditions.

VI. CONCLUSION

The Advanced IoT-Based Smart Mining Helmet provides a comprehensive solution for enhancing miner safety in under- ground environments. By integrating environmental sensors, physiological monitoring, and LoRa-enabled communication, the system ensures real-time data transmission and early detection of hazards. The inclusion of a manual emergency button further enhances the safety system, allowing miners to send distress signals in the event of an unforeseen emergency. The prototype has demonstrated high accuracy in detecting gas leaks, monitoring heart rate, and identifying proximity to obstacles, all while maintaining reliable communication over long distances. This system can be scaled and deployed across mining operations to reduce accidents, improve response times, and ultimately save lives. Future work will focus on in- tegrating machine learning algorithms for predictive analysis, allowing the system to anticipate hazardous conditions based on historical data. Additional sensors, such as temperature and vibration sensors, could also be included to provide even more comprehensive monitoring.

VII. FUTURE ENHANCEMENTS

While the current system is highly effective, several en- hancements can further improve its functionality. Machine learning algorithms can be integrated into the system to predict potential hazards by analyzing historical sensor data. This would enable the system to provide early warnings before con- ditions become dangerous, allowing for preventive measures to be taken. Additional sensors could be added to monitor more environmental parameters. For example, vibration sensors could detect signs of structural instability, while temperature sensors could monitor extreme heat conditions that might pose a risk to miners. Integrating edge computing into the helmet could also improve response times by processing data locally on the device, reducing the need to send all data to the control center for analysis. Moreover, battery life can be optimized further through advanced power management techniques, allowing the helmet to operate for longer periods without needing a recharge. As IoT technology continues to evolve, these enhancements will further strengthen the role of smart mining helmets in ensuring miner safety.

VIII. ACKNOWLEDGMENT

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