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Guardian Gear: Advancing Safely with Smart Mining Helmet

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***Abstract**: This report describes a new kind of smart helmet for miners that uses a long-range LoRa WAN connection. The helmet provides a complete safety solution with its integrated GPS sensor for tracking location in real-time, temperature and humidity sensors for environmental monitoring, impact sensor for collision detection, and smoke sensor for early hazard identification. Reliable data transmission is ensured via LoRa WAN, even from sites far below the surface. Thanks to greater situational awareness, quicker emergency reaction times, and real-time monitoring, this data which includes location, environmental conditions, and potential hazards allows for safer mining operations. This smart helmet has the potential to drastically lower workplace accidents and improve worker safety by enabling data-driven safety management. It also makes the working environment for miners safer.*

***Keywords**: LoRa WAN, Mining, Real-Time Monitoring, Temperature Sensor.*

I. INTRODUCTION

The mining sector is crucial for providing materials needed for electronics, buildings, and renewable energy. However, mining operations inherently pose safety risks, such as exposure to toxic gases, dust, falling debris, and low visibility. Communication difficulties exacerbate these hazards, especially in subsurface mining. Despite prioritizing safety, mining accidents still claim thousands of lives annually, particularly in coal and rock mining. One primary cause of these accidents is the collapse of mining slopes. While not always fatal, these incidents require immediate attention, which is challenging in dimly lit mines.

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To enhance miner safety, we propose a smart helmet using LoRaWAN (Long Range Wide Area Network) technology. This helmet is more than protective gear; it's a comprehensive safety monitoring system equipped with advanced sensors. These sensors monitor environmental conditions and miner health in real time, ensuring proactive safety measures and improved situational awareness.

The LoRaWAN network supports long-range communication and low battery consumption, enabling extended operation hours and data transmission over large distances within the mine.

Sensor data is sent to a central server for analysis, forming the basis for several safety applications. This enables timely responses to hazards, such as gas leaks or abnormal heart rates, and the identification of safety trends for preventive measures. The smart helmet's specifications, including system architecture, communication protocols, and sensor functions, are detailed in this report. This innovative technology aims to revolutionize mine safety procedures, significantly reducing accidents and fatalities. Mining remains one of the world's most dangerous industries, despite its importance. Traditional safety measures are often reactive, highlighting the need for preventative solutions. The smart helmet, with its integrated sensors and real-time data capabilities, aims to shift the focus towards proactive safety in the mining industry. By monitoring gas levels, dust, temperature, and miner health, the helmet helps ensure safer working conditions and reduces the human cost of mining.

II. LITERATURE SURVEY

A study by Behr, Kumar, and Hancke from the University of Pretoria developed a Smart Helmet for the mining industry to address hazards such as air quality, helmet removal, and collisions. It uses a static chamber method for air quality monitoring, an IR sensor for helmet removal detection, and an accelerometer for impact testing, and surpasses standard wireless transmission capabilities. Despite challenges in sensor integration, the Smart Helmet shows promise in enhancing miner safety, highlighting the importance of technological advancements in risk mitigation [1]. Shabina S. from K. Ramakrishnan College of Engineering developed a Smart Helmet using RF and Wireless Sensor Network (WSN) technologies to enhance safety in underground mines.

The system integrates RF communication for real-time data transmission and worker localization with WSN for monitoring environmental parameters like temperature, pressure, and gas levels. It includes three modules: the helmet, localizer, and control room, and triggers alarms and displays warnings on LCD screens when unsafe conditions are detected. This innovative solution aims to improve mine worker safety by providing real-time sensing, localization, and warning capabilities [2] [8] [9] [10] [11] [12]. Rathod et al. developed a Smart Helmet system for the

mining industry using IoT and ZigBee technology to enhance the safety of coal miners. The system integrates sensors to detect hazardous gases, abnormal temperatures, and humidity levels, providing timely

simulations of gas detection, collisions, and temperature monitoring. This system is a promising solution for enhancing safety protocols in coal mining, with potential improvements through IoT integration and additional sensors

[4]. Charde et al. developed a Smart and Secured Helmet system to enhance safety in coal mining using ZigBee technology for wireless communication. The helmet monitors harmful gases, temperature, and humidity in real-time and detects helmet removal and collisions, triggering alerts via a buzzer. It integrates MQ5 and MQ2 gas sensors, humidity and temperature sensors, heartbeat sensors, and a microcontroller for data processing. The system also features a control station for monitoring miners' conditions and is designed for potential future applications in railway and road safety

[5]. Bushra Tabassum, Dr. Baswaraj Gadgay, and Veeresh Pujari (2018) developed an intelligent helmet for detecting hazardous events in the mining sector. The helmet addresses four main hazards: air quality, fire, helmet removal, and mercury detection. It monitors dangerous gases like CO, SO2, NO2, and particulate matter. Helmet removal is detected using an off-the-shelf IR sensor after initial development attempts failed. Additionally, the helmet includes a fire sensor for fire safety. This smart helmet aims to enhance miner safety by identifying and responding to these critical hazards

[6]. C.J. Beher, G. Hancke, and Anuj Kumar (2018) developed a smart helmet for the mining industry that monitors air quality and detects harmful events. The helmet addresses three main hazards: air quality, helmet removal, and collisions. It uses an off-the-shelf IR sensor to detect helmet removal after initial development attempts failed. Additionally, it classifies collisions as hazardous when miners are struck on the head with a force exceeding 1000 on the Head Injury Criterion (HIC). This intelligent headgear aims to enhance miner safety by identifying and responding to these critical hazards

[7]. Paulchamy, Dr. B. (2019) developed an intelligent miner's helmet with Zigbee-based destructive event detection and air quality monitoring. This smart helmet aims to enhance safety for miners, who often face serious hazards. While traditional LED helmets are popular due to their low power consumption and lightweight, they do not improve safety beyond lighting. The smart helmet collects sensor data and transmits it via Zigbee wireless sensor alerts to mitigate risks. It addresses three main hazards: air quality, helmet removal, and collisions, using gas sensors, an IR sensor, oximeters, atmospheric pressure sensors, and temperature and humidity sensors. This system aims to revolutionize mining safety protocols and redefine industry safety standards

[3]. Suriyakrishnaan et al. developed a Smart Safety Helmet for coal mining to reduce risks in underground environments. The helmet integrates sensors for methane and carbon monoxide detection, collisions, temperature, and humidity, all connected to an ATmega328 microcontroller. It uses RF technology to transmit real-time data, providing immediate alerts via a buzzer and LCD. The system enables proactive monitoring of environmental conditions, demonstrated through

networks to a central control unit, providing real-time monitoring and enhancing [10]. Dineshkumar Ponnusamy et al. (2021) introduced a Lora WAN-enabled Smart Helmet for the Mining Sector, focusing on employee health and air quality. Rising fatalities due to hazardous gases in mining areas underscore the importance of monitoring total volatile organic compounds (VOCs) and carbon dioxide. Elevated TVOC levels can lead to various health issues such as fatigue, nausea, and respiratory distress.

III. PROBLEM STATEMENT

While miners play a crucial role in society, they constantly face perilous conditions such as falling objects and exposure to toxic gases. Despite the paramount importance of ensuring miner safety, existing safety regulations and monitoring initiatives may fall short of addressing all their needs. To bridge these gaps, our state-of-the-art smart helmet for mining redefines safety protocols by offering real-time communication and hazard detection, significantly bolstering miner protection. Prioritizing miner safety and productivity, we aim to mitigate risks, ensure safe working environments, and foster a more resilient and sustainable mining sector.

IV. OBJETCIVES

The main objectives of the project are:

1. Toxic Gas Level Detection: Real-time alerts to hazardous levels of toxic gases to prevent health issues and fatalities.
2. Temperature and Humidity Monitoring: Implementation of sensors to monitor temperature and humidity levels for worker well-being.
3. Fall and Collision Detection: Advanced systems to identify and alert workers and supervisors in accidents.
4. Real-time Communication Enablement Integration of robust communication functionalities like two-way radios or wireless systems for seamless coordination and safety.

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V. METHODOLOGY

A. Transmitting End

Toxic Gas Level Detection

And Temperature/Humidity Monitoring:

1. Connect the DHT-11 sensor to Arduino Uno to measure temperature and humidity.
2. Connect the MQ-135 sensor to measure toxic gas levels.
3. Read sensor data using Arduino Uno.
4. Define thresholds for toxic gas levels and temperature/humidity for triggering alerts.

Fall and Collision Detection:

5. Utilize the collision sensor to detect falls or collisions
6. Implement logic to trigger alerts in case of detected falls or collisions.

Real-time Communication Enablement:

7. Integrate the LoRa transceiver module with Arduino Uno for wireless communication.
8. Establish communication protocols for transmitting sensor data and alerts.
9. Implement error-checking mechanisms for reliable data transmission.

Integration and Communication:

10. Combine sensor data and location information (if necessary) into a unified data packet
11. Transmit the data packet wirelessly

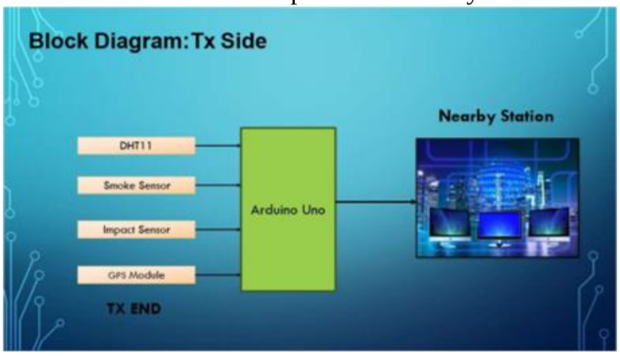

Fig 1. Block Diagram at the Transmitting End

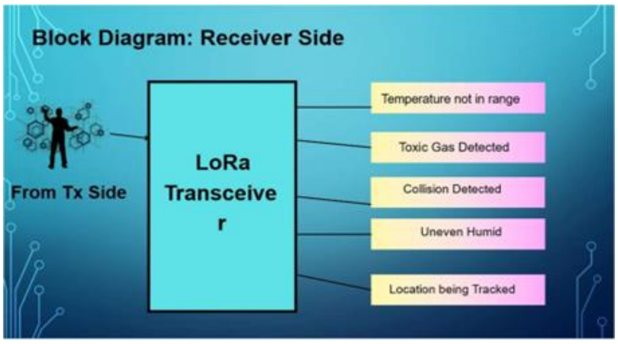

Fig 2. Block Diagram for the Receiving End

The block diagram representation for the end user and the transmitter has been shown in Fig 1. Block diagram at the transmitting end and Fig 2. Block diagram for the receiving end.

Receiving End:

Data Reception and Processing:

1. Set up another Arduino Uno with a LoRa transceiver module to receive data packets.
2. Configure the LoRa transceiver to listen for incoming data.

Data Interpretation and Alerting:

3. Receive the sensor data packet and extract relevant information.
4. Compare the received data with predefined thresholds for toxic gas levels, temperature, humidity, and collision/fall detection.

Real-time Communication Enablement:

6. Implement bidirectional communication for sending acknowledgment signals back to the transmitting end.
7. Ensure robust error handling and retransmission mechanisms for reliable communication.

VI. RESULTS

A. Hardware Part Results

In order to ensure that the smart helmet model effectively improves miner safety through the integration of cutting- edge technology for real-time hazard identification and communication, a number of crucial actions must be taken. The hardware assembly first entails mounting a number of sensors and parts within the helmet, such as temperature and humidity sensors, GPS modules, accelerometers for impact testing, gas sensors (MQ5, MQ2), and an infrared sensor for detecting helmet removal. A central microcontroller, like an Arduino Uno or an ATmega328, is connected to these sensors and is responsible for processing the data that is gathered. The helmet's communication system combines ZigBee and RF technology to deliver dependable real-time data transfer even in the demanding underground mining environment. Long-range communication with low power consumption is made possible by the LoRa transceiver and the MT76813DBI antenna, allowing for continuous monitoring without the need for frequent battery replacements. Below shown Figure 3. Overview of SmartHelmet represents the hardware model of proposed system.

Figure 3. Overview of Smart Helmet

The respective testing for each part was done successfully and the expected output was obtained.

B. Software Part Results

The data that is sent by microcontroller from helmet side will be received by LoRa receiver at base station side and the front end display of the various parameters are displayed as shown in the following figures. Fig 5. Display of the receiver end shows the the setup of the receiver end.

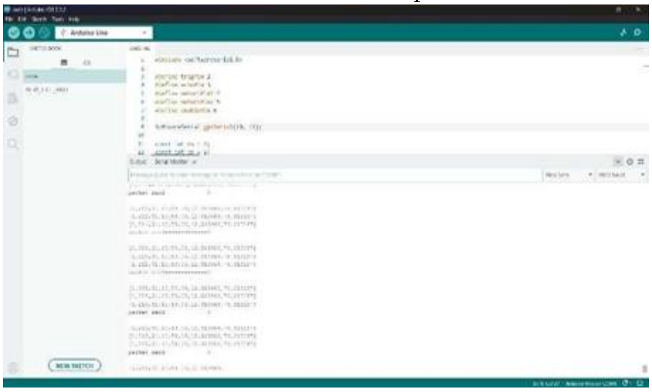

Fig 4. Packets Being Sent from the Transmitter End

After the successful setup of the transmitting end the packets were being started to transmit to the receiver end and its been shown in the Fig 4. Packets being sent from the transmitter end.

Fig 5 . Display of the Receiver End

With the help of Csharp the front end was developed which displays the value obtained from the transmitter end which can be seen in Figure 7. Front End display at the Base station. The overall proposed model design is shown in the Fig 6. Overall model view.

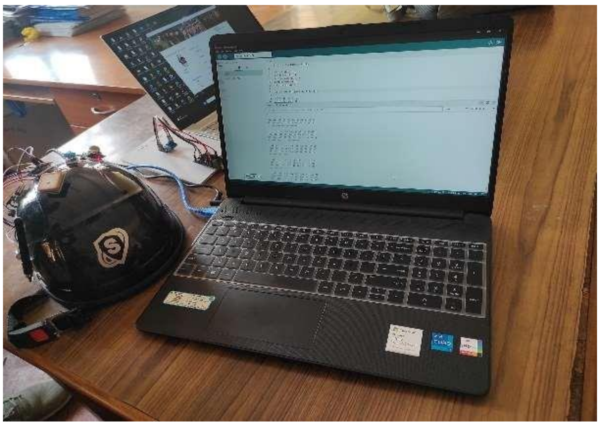

Fig 6. Overall Model View

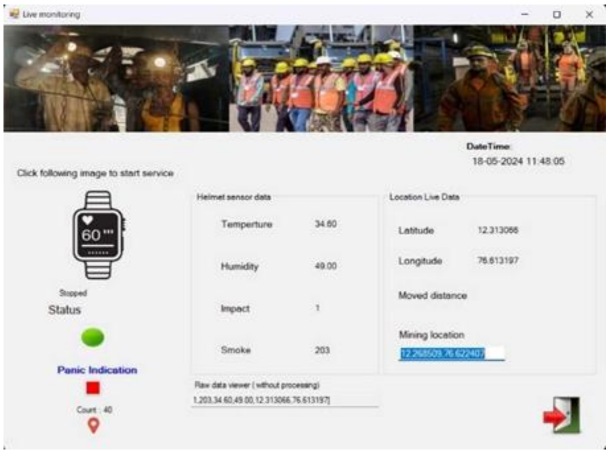

Fig 7. Front end Display at Base Station

VII. CONCLUSION

A notable development in mining safety technology is the creation and application of smart helmet systems. These creative ideas handle important mining environment dangers like air quality, helmet removal, and collisions by combining cutting-edge sensors and LoRaWAN communication technologies. Even in the harsh circumstances of subterranean mines, these smart helmets rely on dependable real-time monitoring and data transfer thanks to a mix of IoT technologies and LoRaWAN. These helmets greatly improve the safety and well-being of miners by combining GPS modules, accelerometers, temperature and humidity monitors, gas sensors and full hazard identification with instantaneous notifications. Microcontrollers like the Arduino Uno[6] and ATmega328 are integrated to provide effective data processing and timely reactions to dangerous situations. With the help of the MT76813DBI antenna and LoRa transceivers, long- range communication may be achieved with low power consumption, allowing for continuous monitoring and fewer battery changes. These systems have undergone extensive testing and calibration, which has shown their efficacy in actual mining situations and highlighted their potential to completely change mine safety procedures. In addition to providing instantaneous hazard detection and alert capabilities, the smart helmets also provide proactive monitoring, allowing miners to swiftly take preventative action. This all-encompassing approach to safety emphasises how crucial technological developments are to reducing dangers and safeguarding miners' lives.

FUTURE SCOPE

With so much room for growth and development, the mining smart helmet system presents a number of promising avenues for improving worker safety and productivity in the mining sector.

1. Enhanced Sensor Integration: More sensors may be added to the smart helmet in later versions for even more thorough monitoring.

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To further enhance safety precautions, consider incorporating biometric sensors to track the oxygen and heart rates of miners or integrating sophisticated gas sensors that can identify a broader variety of hazardous materials.

2. Enhanced Communication Systems: The real-time data transmission capabilities of the smart helmets may be further improved by upcoming advancements in communication technology, such as the creation of 5G networks. This would make communication possible even in the most remote and deep places, more quickly and reliably.

3. Energy Efficiency and Sustainable Power Sources: Using low-power components and[5] better battery technology, for example, will help make smart helmets more energy-efficient in the future. The helmets' operational life might be further increased by including sustainable power sources, like as solar panels or energy collecting from miner motions, which would require less frequent recharging.

4. Integration with Current Mining Infrastructure: To establish a comprehensive environment for safety and operational monitoring, the smart helmet system can be further connected with current mine management systems. This will facilitate smooth data exchange and all-encompassing safety management, enhancing operational effectiveness and decision-making.

5. Scalability and Customisation: As technology advances, scalable and adaptable solutions can be created to meet the needs of various mining operations, ranging from massive industrial mines to more intimate artisanal ventures. This would enable a wider spectrum of mining operations to utilise cutting-edge safety technology.

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Authors Contributions	All authors have equal participation in this article.

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