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Smart Helmet for Coal Mine Workers Safety Monitoring with Mobile App

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ABSTRACT

Coal mining involves various risks due to hazardous environmental conditions such as high temperatures, methane, carbon dioxide, and other toxic gases. Frequent accidents in mines highlight the need for advanced safety solutions to protect miners from these dangers. Ensuring the safety and security of workers in underground coal mines requires reliable monitoring and communication systems.

The Smart Helmet is designed to address these safety concerns by incorporating sensors to detect temperature, light, and hazardous gases, along with a GPS tracker for location monitoring. It integrates a GSM module to send emergency SMS alerts to predefined contacts during critical situations, ensuring timely responses. A Wi-Fi-based monitoring system, enabled by the WeMos ESP8266 module, collects real-time data from the sensors and facilitates hazard alerts through an app-based interface and a buzzer system.

This study provides an advanced safety solution for coal mine workers by enabling real-time monitoring of working conditions, rapid emergency alerts, and location tracking. The Smart Helmet enhances situational awareness, reduces accident risks, and supports swift action in emergencies, offering a practical and reliable approach to improving safety standards in the coal mining industry.

Keywords: Smart helmet; Coal mine safety; IoT-based monitoring; GSM module; NodeMCU ESP8266; Gas sensor (MQ-2); Temperature sensor (DHT11); GPS tracking; Wireless communication; Emergency alert system; Blynk app; Hazard detection; Environmental sensors.

1. Introduction

Mining is essential for economic growth, supporting various sectors and creating jobs. However, mining operations, especially deep underground, come with significant safety and health challenges due to unstable environments and exposure to dangerous elements like methane, carbon dioxide, and high temperatures. Ensuring the safety of miners is a priority as they face potential hazards, including toxic gas inhalation, collisions, and cave-ins.

To improve safety, we propose an IoT-based smart helmet system using microcontroller-based technology. This system incorporates a WeMos ESP8266 Wi-Fi module for wireless communication and real-time monitoring of miners' locations. The smart helmet is equipped with a microcontroller circuit that integrates sensors for gas monitoring, and ensuring continuous oversight. Additionally, an emergency button embedded in each helmet allows workers to signal a crisis situation such as gas exposure, bodily harm, or a structural collapse.

The microcontroller-based wireless monitoring system reduces the high installation and maintenance costs associated with wired communication systems in mining environments. By using Wi-Fi-enabled microcontroller circuits, this innovative approach ensures real-time data transmission and improves emergency response times, enhancing overall worker safety and minimizing risks in the mining sector.

1.1. Objectives of the Study

The following are the primary objectives of this study:

1. To enhance miner safety: Equip the helmet with advanced sensors to monitor hazardous gases (such as methane and carbon monoxide), temperature fluctuations, and humidity levels, providing comprehensive protection against environmental risks that could endanger miners' health and safety.

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2. To enable real-time monitoring: Leverage IoT technology to ensure seamless and continuous data transmission, allowing for real-time remote monitoring by supervisors and safety teams. This helps in proactively identifying potential dangers and addressing them before they escalate.

3. To provide emergency alerts: Integrate a robust emergency alert system that includes a user-activated emergency button and a loud buzzer. This ensures that miners can send immediate distress signals in critical situations, improving overall response time.

4. To track location: Implement precise GPS tracking to maintain the real-time location of miners. This feature is vital for quick identification and rescue during emergencies, aiding in efficient evacuation and coordination efforts.

5. To facilitate rapid response: Enable quick decision-making and prompt rescue operations by providing instant alerts and real-time data updates to mine supervisors and response teams. This improves the effectiveness of safety measures and minimizes potential delays during emergency situations.

These objectives aim to create a safer, more connected, and efficient working environment for coal miners, ultimately reducing risk and improving overall safety management.

2. Problem Statement

In the realm of coal mining, safety and efficiency are paramount concerns. Despite advancements in technology and safety protocols, the coal mining industry still faces significant challenges in ensuring the well-being of its workers in the hazardous underground environment. The miles of tunnels and galleries present a complex operational landscape where traditional safety measures often fall short. An accident, including collisions, falls, and exposure to harmful gases, remain persistent threats to the workforce. Moreover, the vast expanse of underground mines poses logistical challenges in monitoring and communicating with miners in real time.

In response to these pressing issues, there is an urgent need for innovative solutions that can revolutionize safety standards and operational efficiency in coal mining. This paper explores the development and implementation of a Smart Helmet specifically designed for coal mines. By integrating cutting-edge technologies such as IoT sensors, real-time monitoring systems, and communication modules, the Smart Helmet aims to provide miners with enhanced situational awareness, early hazard detection, and seamless communication capabilities.

Through a comprehensive analysis of the challenges faced by coal miners and the potential of emerging technologies, this paper delves into the design, functionalities, and anticipated benefits of the Smart Helmet system. It highlights the transformative impact such a solution could have on mitigating risks, optimizing operations, and safeguarding the lives of coal miners working deep underground.

3. Existing System

(a) Helmet with Bluetooth Connectivity

Description: This system enables wireless communication between the helmet and nearby devices, such as smartphones or central control stations. **Drawback:** Bluetooth connectivity may be unreliable in deep, underground mines or in areas with limited signal strength.

(b) Helmet with Lighting System

Description: Built-in LED lights provide clear illumination for workers in dark mine shafts. **Drawback:** Battery life may be limited, requiring frequent recharging or replacement. Overheating of lights could lead to discomfort or failure during extended use.

(c) Zigbee-Enabled Smart Helmet

Description: Utilizes Zigbee communication for low-power, short-range communication in mines. Includes sensors for environmental monitoring and emergency alerts. **Drawback:** Zigbee has limited range (10-100 meters) and is affected by underground obstructions. Network latency can occur if too many devices are connected.

4. Literature Survey

(a) Smart Helmet Systems for Enhanced Worker Safety in Underground Coal Mines: A Comprehensive Survey

Reference: Zhang, L., Wei, D., & Li, H. (2019). Smart Helmet Systems for Enhanced Worker Safety in Underground Coal Mines: A Comprehensive Survey. *International Journal of Mining Science and Technology, 29*(6), 889-900.

This survey provides a comprehensive overview of smart helmet systems designed for improving worker safety in underground coal mines. It discusses the integration of advanced technologies such as real-time monitoring, gas detection, and communication systems into helmets to mitigate accidents and ensure a safer working environment.

(b) Integration of IoT and Wearable Technology in Coal Mining Safety: A Review

Reference: Sharma, A., Kumar, V., & Singh, R. (2020). Integration of IoT and Wearable Technology in Coal Mining Safety: A Review. *Journal of Coal Science & Engineering*, *26*(4), 765-778.

This review explores the integration of IoT (Internet of Things) and wearable technology in enhancing safety measures in coal mining environments. It examines various sensors and communication protocols used in smart helmets, along with their effectiveness in monitoring environmental conditions and detecting hazards.

(c) Advancements in Sensor Technologies for Smart Helmets in Coal Mining: A Literature Review

Reference: Chen, Y., Wang, S., & Liu, L. (2018). Advancements in Sensor Technologies for Smart Helmets in Coal Mining: A Literature Review. *Safety Science, 110*, 363-375.

This literature review examines recent advancements in sensor technologies integrated into smart helmets for coal mining applications. It discusses the capabilities of sensors such as accelerometers, gyroscopes, and gas detectors in detecting and alerting miners to potential hazards, thereby improving safety outcomes.

(d) Wireless Communication Systems for Smart Helmets in Underground Coal Mines: A Survey

Reference: Gupta, S., Sharma, R., & Jain, P. (2017). Wireless Communication Systems for Smart Helmets in Underground Coal Mines: A Survey. *Journal of Mining and Environment, 8*(3), 541-553.

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This survey focuses on wireless communication systems integrated into smart helmets for underground coal mines. It evaluates various communication protocols, such as Zigbee and Wi- Fi, and assesses their suitability for transmitting real-time data from helmets to control centers, facilitating prompt response to emergencies.

(e) Reducing Risks in Coal Mines with Sensor-Integrated Smart Helmets

Reference: Garcia, M., Lopez, R., & Davis, K. (2024). Reducing Risks in Coal Mines with Sensor-Integrated Smart Helmets. *Safety Innovations in Mining*, 12(2), 75-88.

This review examines the latest advancements in smart helmet systems for coal mines, focusing on technologies such as real-time environmental monitoring, gas detection, and GPS-based tracking. It emphasizes their role in reducing accidents and enhancing safety for workers in hazardous environments.

(f) Enhanced Safety Systems for Coal Mines Using Smart Helmets

Reference: Johnson, L., Wang, Y., & Patel, R. (2024). Enhanced Safety Systems for Coal Mines Using Smart Helmets. *Safety Science and Mining Technology*, 36(4), 400-415.

The study explores integrating safety mechanisms, including real-time alerts and biometric sensors, into smart helmets for accident prevention.

(g) Energy-Efficient Smart Helmets for Prolonged Mining Operations

Reference: Zhang, T., Liu, P., & Wei, H. (2023). Energy-Efficient Smart Helmets for Prolonged Mining Operations. *Journal of Applied Mining Technologies*, 19(2), 120-135.

This research focuses on optimizing power consumption in smart helmets equipped with sensors and communication systems, ensuring long-term use during extended mining shifts.

(h) Smart Helmet Applications in Hazardous Environments: Coal Mining Use Cases

Reference: Johnson, P., Ahmed, K., & Zhao, R. (2023). Smart Helmet Applications in Hazardous Environments: Coal Mining Use Cases. *Mining and Industrial Safety Journal*, 27(3), 310-325.

The study evaluates real-world use cases where smart helmets have successfully detected hazardous conditions like gas leaks and structural instability, leading to improved worker safety.

5. Proposed System

5.1. Working Principle

✓ **Sensors and Data Collection**

• Gas Sensors (e.g., MQ-2): To detect harmful gases like methane (CH_4), carbon monoxide (CO), and oxygen levels. • Temperature Sensors: To monitor the temperature in the mine. • LDR Sensor (Light-Dependent Resistor): Detects the level of light in the surrounding environment. • Alerts the worker if the light levels fall below a safety threshold, indicating a potential power outage or poor visibility.

✓ **Signal Processing**

• The data collected from sensors is processed using a microcontroller or microprocessor (e.g., ESP8266 NodeMCU). • The system evaluates whether the measured values exceed pre-set safety thresholds (e.g., unsafe gas concentrations or sudden impacts). • GPS data is processed to determine the worker's location and movement.

✓ **Real-Time Alerts**

If any hazardous condition is detected, the helmet triggers alerts via: • Buzzer or Alarm: To warn the worker immediately. • LED Indicator: For visual alerts in low-light conditions.

✓ **Wireless Communication**

• GPS Data Transmission: Worker location data is sent to a central monitoring system using Wi-Fi or RF module.
• Environmental Data Sharing: Alerts and sensor readings are transmitted in real-time to supervisors for prompt action.

✓ **Environmental Adaptability**

• The rugged design protects sensors and components from dust, heat, and physical shocks, making it suitable for harsh mining environments.

✓ **Power Supply**

• A rechargeable battery powers the helmet, with energy-efficient components ensuring prolonged usage.

✓ **GPS Tracking System**

• Enhances worker safety by enabling quick responses during emergencies, ensuring accurate tracking in the complex and vast mining environment.

Figure 1. Working Principle

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5.2. Workflow

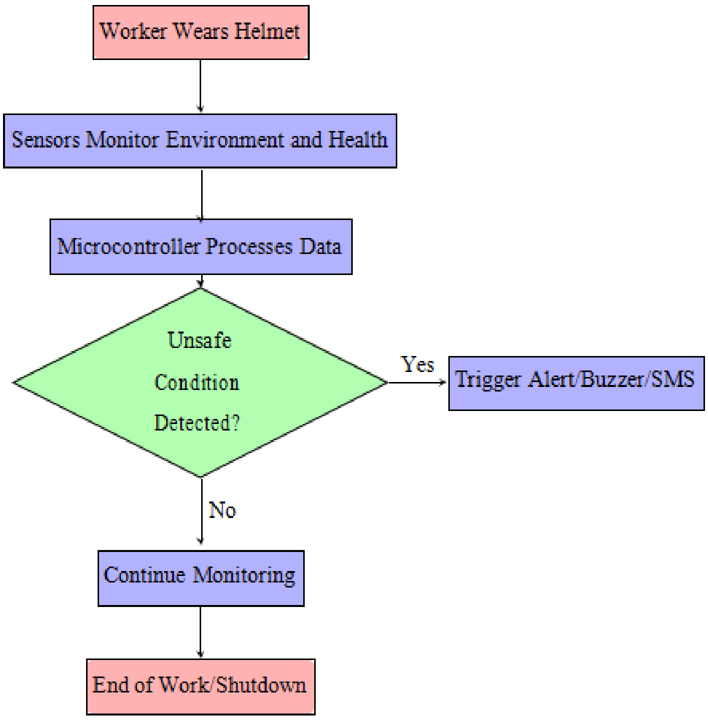

Figure 2. Workflow

6. Methodology

6.1. System Methodology

The proposed system consists of an IoT-based smart helmet, which helps underground workers in many ways. It tells the predetermined services of coal miners, such as the gas sensor, Temperatures, humidity, and many other things that are essential for the safety of the miners. This helmet is made up of a helmet with detectors. The transmitter segment has a microcontroller which receives input from several sections such helmet temperature, LDR and gas sensor. At a particular instance, when a harmful event happens, the helmet transfer alert towards the application is fixed on several different areas of the coal mines.

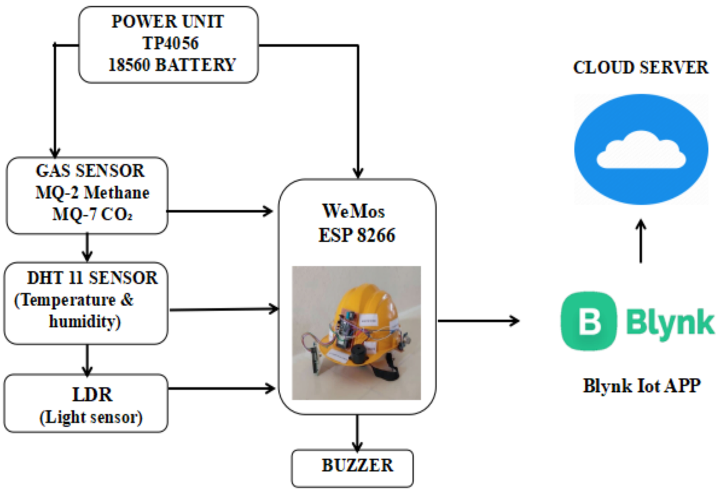

Figure 3. Hardware and Software used

6.2. Flow of Hardware Section

The hardware section of the smart helmet system consists of various sensors such as a gas sensor (MQ-2,) for detecting hazardous gases and a DHT11 sensor for monitoring temperature and humidity. These sensors are connected to a microcontroller (e.g., Wemos D1 R1 ESP8266), which serves as the central processing unit. A power unit supplies energy to the system, ensuring consistent operation.

Additional components like an LDR (light sensor), GPS module for location tracking, and an emergency switch are integrated for enhanced functionality. The processed data triggers alerts through a buzzer, providing immediate feedback to the user and enabling communication to remote monitoring systems.

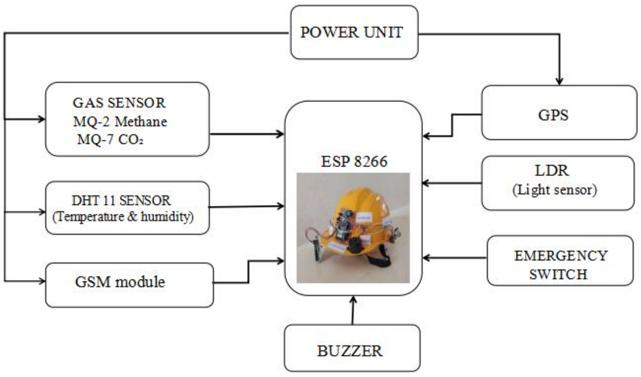

Figure 4. Flow of hardware section

6.3. Flow of Software Section

The software flow of the smart helmet system involves seamless integration with the hardware and cloud services, as shown in the diagram. The data from the Arduino is processed through the software layer, which includes the Blynk IoT platform for real-time monitoring and control.

The Blynk app communicates wirelessly with the hardware, enabling users to access data and receive alerts on their mobile phones. Simultaneously, data is uploaded to a cloud server via the web portal, allowing for remote storage and analysis. This dual interaction between software and hardware ensures effective monitoring, user interaction, and data availability.

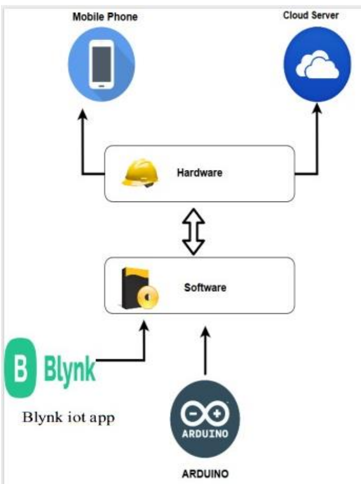

Figure 5. Flow of software section

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7. Hardware and Software Description

7.1. Hardware Description

(a) Wemos D1 R1 ESP8266: The Wemos D1 R1 ESP8266 is a versatile development board designed for IoT applications, combining the functionality of a Wi-Fi-enabled microcontroller with the simplicity of Arduino programming. Powered by the ESP8266 chip, it features a 32-bit processor, built-in Wi-Fi support, and multiple GPIO pins for connecting sensors and actuators.

The board operates at 3.3V internally, with a voltage regulator allowing 5V input through its USB port. With 4MB of flash memory, it supports various communication protocols like UART, SPI, I2C, and PWM, making it suitable for real-time data monitoring, automation, and wireless communication. The Wemos D1 can be programmed using the Arduino IDE or other environments and serves as a cost-effective solution for projects like home automation, remote monitoring, and web server hosting. Its compact design, low power consumption, and extensive community support make it ideal for beginners and professionals working on IoT systems.

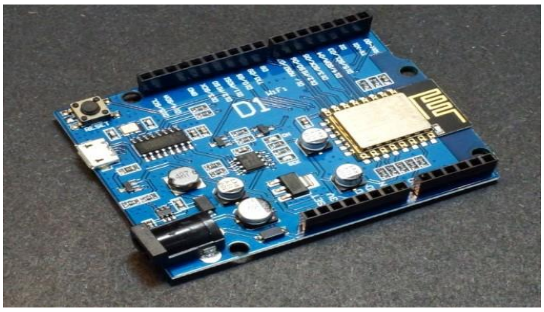

Figure 6. Wemos D1 R1 ESP8266

(b) MQ2 Sensor: MQ2 gas sensor is an electronic sensor used for sensing the concentration of gases in the air such as LPG, propane, methane, hydrogen, alcohol, smoke and carbon monoxide. MQ2 gas sensor is also known chemiresistor. It contains a sensing material whose resistance changes when it comes in contact with the gas. This change in the value of resistance is used for the detection of gas.

Figure 7. MQ2 Gas Sensor

(c) DHT11 Temperature and humidity sensor: The DHT11 is an essential, ultra low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air. It spits out a digital signal on the data pin. It's relatively simple to use but requires careful timing to grab data. The only real downside of this sensor is you can only get new data from it once every 2 seconds. So sensor readings can be up to 2 seconds old when using the library. The two primary varieties of RFID readers are handheld and fixed. Whereas

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chosen readers are normally installed in a certain location, such as a warehouse or a production line, handheld readers are portable and may be carried about. Several frequencies, such as low frequency (LF), high frequency (HF), ultra-high frequency (UHF), and microwave frequencies, are used by RFID readers and RFID tags to interact. The application and the distance between the reader and the tag determine the type of frequency that is employed.

Figure 8. DHT11 Temperature sensor

(d) SIM-800 GSM Modem: A GSM modem is a specialized modem that accepts a SIM card and operates over a subscription to a mobile operator, just like a mobile phone. From the mobile operator's perspective, a GSM modem looks just like a mobile phone. When a GSM modem is connected to a computer, this allows the computer to use the GSM modem to communicate over the mobile network. While these GSM modems are most frequently used to provide mobile internet connectivity, many can also be used to send and receive SMS and MMS messages. GSM modem must support an "extended AT command set" for sending/receiving SMS message GSM modems can be a quick and efficient way to get started with SMS, because a special subscription to an SMS service provider is not required. In most parts of the world, GSM modems are a cost- effective solution for receiving SMS messages because the sender pays for the delivery. To begin, insert a GSM SIM card into the modem and connect it to an available USB port on your computer.

Figure 9. GSM Module

(e) Buzzer: A buzzer often emits a loud, constant, and frequently unpleasant sound. It is commonly employed as an alarm or warning signal in industrial settings or during emergencies. Generally speaking, "buzzer" and "beeper" are frequently used interchangeably, and their precise meanings can differ depending on the situation.

Figure 10. Buzzer

(f) NEO 6M GPS Module: For serial communication, it uses a UART interface. it is simple to integrate with a variety of microcontrollers. It requires a DC input between 3.3 and 5 volts because it has a built-in voltage regulator. It is equipped with a "patch antenna" style of antenna. It performs well at a baud rate of 9600 and requires ample space since it needs a clear line of sight to the satellites.

Figure 11. GPS module

7.2. Software Description

(a) Arduino IDE: The Arduino IDE (Integrated Development Environment) is an open-source software platform used for writing, compiling, and uploading code to Arduino and compatible microcontroller boards like the Wemos D1 ESP8266. It provides a user-friendly interface with features like a code editor, syntax highlighting, predefined libraries, and a serial monitor for debugging and real-time data monitoring. The IDE supports cross-platform usage and allows users to write programs in a simplified version of C/C++. It includes a Board Manager to support various microcontrollers and enables easy uploading of code via USB. Widely used in IoT and embedded projects, the Arduino IDE simplifies programming for beginners and professionals alike.

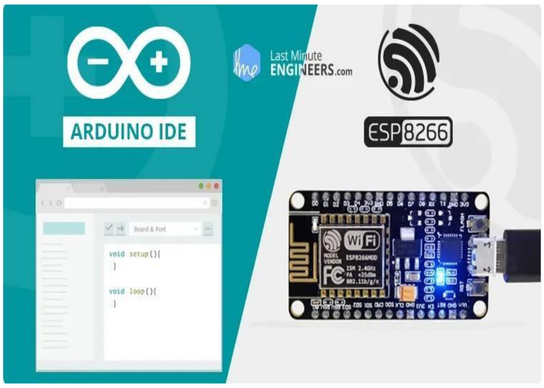

Figure 12. Arduino IDE

(b) Blink APP: The Blynk app is a powerful IoT platform that enables users to build and control IoT devices through a smartphone or tablet. It provides a user-friendly interface for creating customizable dashboards to monitor and control connected devices in real-time. With Blynk, users can design their own interface by adding widgets like buttons, sliders, graphs, and displays, which communicate with the hardware using Wi-Fi, Bluetooth, or cellular networks. The app works in tandem with the Blynk server and library, allowing seamless integration with microcontrollers such as Arduino, ESP8266, ESP32, and Raspberry Pi. Blynk simplifies complex IoT tasks like remote monitoring, data visualization, and device control. It also supports notifications, scheduling, and device-to-device communication, making it a versatile tool for projects like smart homes, industrial monitoring, and

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personal automation. Its ease of use, cross- platform compatibility, and scalability make Blynk ideal for both beginners and advanced IoT developers.

Figure 13. Blink app

8. Experimental Results

✓ This section discusses the results of the proposed system. The sensors sense the environmental conditions around the miner working in underground mining. All the real time data is updated on the web by using IoT with the help of Thing speak.

✓ If any of the environmental parameters exceeds its standard value the miner, co-miners, supervisor and the control station get notify by buzzer.

✓ If any hazardous event occurred in the mine in such case the control station will be able to provide the rescue team as early as possible.

✓ This system connects the Arduino to the computer. To build this system, open-source solutions were provided, and components used in the proposed safety alert system, such as the MQ-2, Gas Sensor, ESP32, DHT11and others, can be easily connected with the Arduino platform.

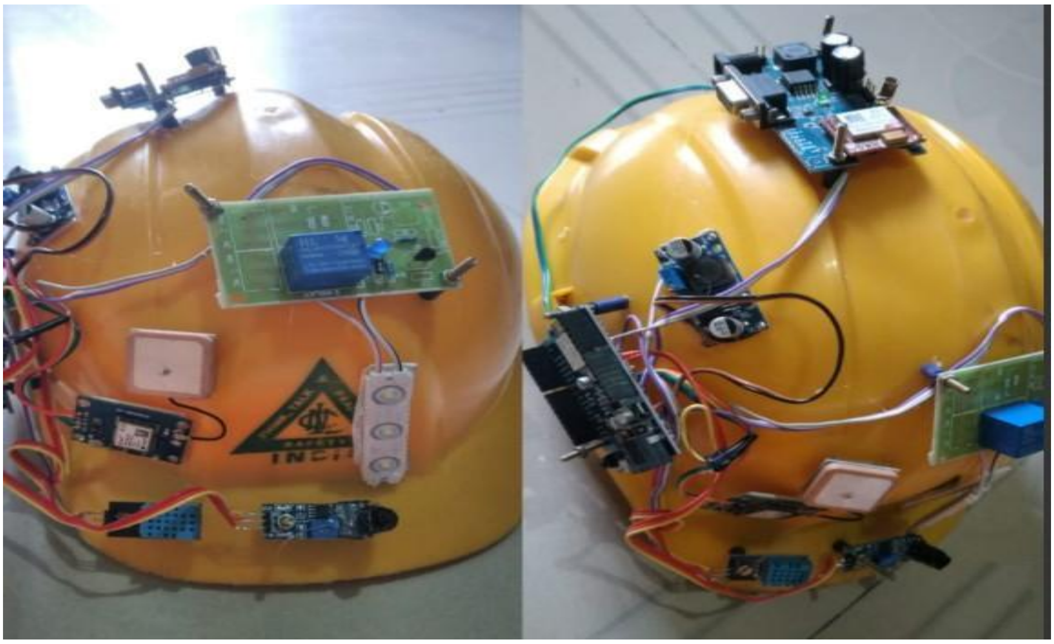

Figure 14. Outlook of smart helmet

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Figure 15. Blynk App notification

9. Conclusion and Future Scope

9.1. Conclusion

In conclusion, the smart helmet for mining workers is a cutting-edge technology that incorporates several sensors and communication modules to provide safety to workers in hazardous environments. The helmet includes a gas sensor (MQ2) to detect harmful gases, a DHT11 temperature and humidity sensor to monitor the environment, an emergency switch, a buzzer, a GSM modem for sending SMS emergencies, GPS location tracking, an WeMos ESP 8266 Wifi module for IoT communication, and a Blynk app for data visualization. The gas sensor MQ2 detects hazardous gases, and the DHT11 temperature and humidity sensor keeps track of the environment's temperature and humidity. The emergency switch enables the worker to request help in case of any emergency. The information collected by the sensors, and the buzzer alerts the worker in case of any danger. The GSM modem sends SMS emergencies to the designated contacts, and GPS location tracking ensures that workers can be located in case of an emergency. The ESP 8266 Wifi module provides IoT communication, and the Blynk app helps visualize the data collected by the sensors.

9.2. Future Scope

• AI and Machine Learning: Leveraging AI to predict potential hazards based on collected data trends and alert workers before conditions become dangerous.

• Improved Connectivity: Integration with 5G networks for faster data transmission and better real-time communication capabilities.

• Cost Reduction: Refining the design and production process to make the technology more affordable and accessible for widespread adoption.

• Voice-Activated Control: Integrating voice command technology to allow workers to control helmet functions hands-free for greater convenience and safety.

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Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors made an equal contribution in the Conception and design of the work, Experimentation, Drafting the article, and Critical revision of the article. All the authors have read and approved the final copy of the manuscript.

Availability of data and material

Not applicable for this study.

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