Intelligent Safety Helmet using IoT for Real-Time Monitoring in Mining Environment

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Abstract
Mining operations pose numerous hazards, including exposure to toxic gases, extreme environmental conditions, and frequent workplace accidents. To enhance the safety of mining workers, this paper proposes the development of an advanced smart helmet system equipped with intelligent monitoring and communication technologies. The primary objective is to reduce accident risks and ensure rapid response during critical situations. The helmet is embedded with various sensors to detect hazardous gases and monitor temperature and humidity levels in real time. It features an emergency alert mechanism, including a panic button, visual display, and warning buzzer, to provide immediate assistance. For seamless communication and emergency management, the system incorporates GSM technology to send alert messages and GPS for real-time location tracking. Additionally, WiFi connectivity enables IoT-based data visualization and remote monitoring via the Blynk app, allowing supervisors to assess environmental conditions continuously. By integrating real-time data acquisition, location tracking, and automated alert systems, this smart helmet aims to improve situational awareness, enable swift emergency response, and ensure a safer working environment for miners.

Keywords: Mining, Helmet, Safety, Sensors, Gas detection, Temperature monitoring, Humidity sensing, Emergency alert, Real-time tracking, GPS, GSM, WiFi, IoT, Blynk app, LCD display, Alarm buzzer, Hazard prevention, Worker protection.

1. Introduction

In today's high-risk mining industry, workers confront severe dangers, including exposure to toxic gases, extreme environmental conditions, and potential structural failures. Despite progress in safety measures, accidents continue due to slow hazard identification and insufficient realtime oversight. To tackle these issues, this project introduces an IoT-enabled smart helmet designed for miners, incorporating cutting-edge sensors and wireless connectivity to improve situational awareness and emergency responsiveness. The helmet is equipped with gas detectors (such as the MQ2 for methane/carbon monoxide), environmental sensors (DHT11 for temperature/humidity), GPS for precise location tracking, and GSM/WiFi modules to relay live data to a cloud-based dashboard via the Blynk IoT platform. Critical functionalities include an emergency panic button, audible/visual warnings, and remote data monitoring, ensuring swift action during emergencies. By harnessing IoT technology, the system seeks to minimize workplace hazards, enhance worker protection, and overcome limitations in current solutions, such as inadequate fatigue tracking or unstable connectivity in subterranean settings. Building on earlier studies in smart safety gear and IoT-driven monitoring systems—as highlighted in the literature review—this work delivers a cost-effective, ergonomic, and all-inclusive design optimized for mining applications. The proposed solution meets industry demands for instant hazard detection, real-time alerts, and adaptable safety measures, supporting the larger vision of sustainable and risk-free mining operations.

2. Related Work

Recent advancements in IoT and sensor technologies have significantly improved safety systems for mining workers. A smart helmet with gas and temperature sensors, Arduino Nano processing, and GPRS-based cloud alerts was proposed, demonstrating real-time hazard detection and accident prevention in mines [1].

Another study developed a lightweight helmet with infrared detectors for hazards like carbon monoxide, though limitations in precision and fatigue monitoring were noted [2].

A different approach integrated MC2, DHT11, and LDR sensors with Arduino to trigger LED/buzzer alerts for environmental hazards, emphasizing real-time monitoring but lacking robust communication protocols [3].

IoT-enabled bracelets were used for fatigue and gas detection in Chinese coal mines, reducing accidents over six months, though deeper integration with helmet systems was needed [4].

Wireless communication technologies like ZigBee were explored for transmitting temperature, humidity, and gas data every 5 seconds, while WiFi-based solutions (e.g., NodeMCU) proved more reliable for real-time alerts via mobile apps [5, 6]. These studies highlight gaps in fatigue assessment, precise GPS tracking, and seamless IoT connectivity—challenges addressed in our project through integrated GSM/WiFi, Blynk-based visualization, and ergonomic design.

An IoT-enabled mining helmet with gas (LPG/CO/smoke), environmental, and impact sensors was designed. Using ZigBee and NodeRed, it achieved a 200m wireless range in cave tests, though sensor calibration was required. Sleep mode reduced power consumption by 39mA, but breakout boards limited efficiency gains [7].

3. Proposed System

The IoT-based smart helmet is designed to enhance mining safety through real-time monitoring of hazardous gases (e.g., methane, carbon monoxide), temperature, humidity, and worker location. Unlike existing systems reliant on short-range wireless technologies like ZigBee or Bluetooth, our solution leverages WiFi and GSM for seamless communication between un The system comprises several key components. Sensors include an MQ2 Gas Sensor for detecting hazardous gases like methane and CO, a DHT11 Sensor for monitoring temperature and humidity, and a NEO 6M GPS for tracking worker location for emergency response. An Emergency Switch allows for manual triggering of alerts. For Communication Modules, the system uses ESP8266 WiFi to transmit real-time data to the cloud via IoT protocols, and a GSM Modem to send emergency SMS alerts to predefined contacts. Alert Mechanisms consist of a Buzzer and LCD Display for local, immediate hazard notification, and the Blynk App for remote visualization of sensor data and emergency notifications.derground miners and surface supervisors, ensuring robust connectivity even in deep mines.

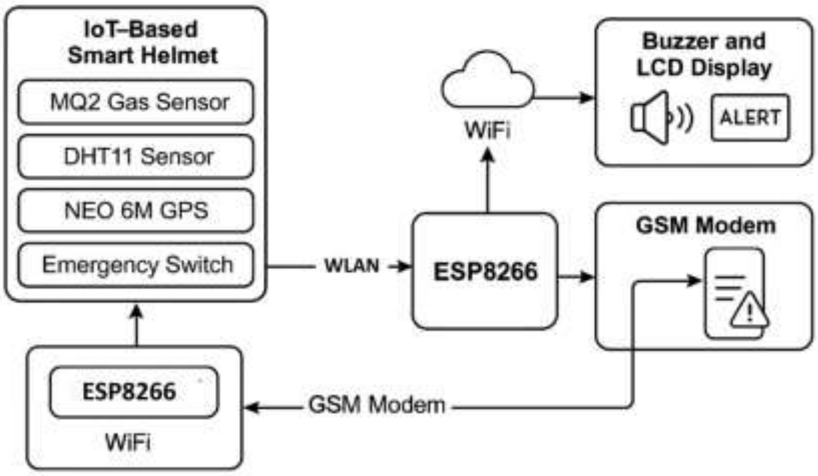

Figure 1: Proposed block diagram of IoT based Safety Helmet for mining workers

Figure 1 illustrates the overall architecture of the proposed system, showing how sensor inputs are processed by the ESP8266 and communicated through WiFi/GSM modules to both local and remote alert systems.The system's workflow begins with Data Collection, where sensors continuously monitor environmental parameters. This data is then processed by a microcontroller, such as ESP8266, and transmitted via WiFi or GSM to the Blynk cloud platform during Data Transmission phase. Finally, for Alert Generation, if predefined thresholds are exceeded (e.g., high gas concentration), the system automatically triggers audible and visual alerts (buzzer, LCD), sends emergency SMS messages via GSM, and provides real-time updates to supervisors on the Blynk app.

4. System Design

Main Components description

a. ESP8266 Wi-Fi Module

Figure 2: NodeMcu ESP8266

As illustrated in Figure 2, the ESP8266 is a low-cost, high-performance Wi-Fi microcontroller with a full TCP/IP stack, enabling seamless IoT integration. It combines a 32-bit Tensilica processor (operating at 80–160 MHz), on-chip memory (64 KB instruction RAM, 96 KB data RAM), and GPIO pins for sensor interfacing. Its built-in Wi-Fi module (802.11 b/g/n) supports both station (STA) and access point (AP) modes, allowing flexible wireless communication. In this project, the ESP8266 serves as the central processing unit, aggregating data from gas (MQ2), temperature/humidity (DHT11), and GPS sensors, then transmitting it to the Blynk cloud via Wi-Fi for real-time monitoring. Its low power consumption (~80 mA during transmission) and compatibility with Arduino IDE make it ideal for embedded safety systems like the smart helmet.

b. MQ2 Gas Sensor

Figure 3: MQ2 Gas Sensor

The MQ2 gas sensor shown in Figure 3 is a versatile, low-cost semiconductor sensor designed to detect multiple hazardous gases, including methane (CH_4), carbon monoxide (CO), smoke, and liquefied petroleum gas (LPG). It operates on the principle of chemical resistivity, where the sensor's tin dioxide (SnO_2) layer reacts with target gases, causing a change in resistance proportional to gas concentration. Key features include:

- Wide Detection Range: 300–10,000 ppm (adjustable via potentiometer).
- Analog & Digital Output: Provides real-time voltage readings (0–5V) for precise gas concentration measurement and a digital trigger for threshold-based alerts.
- Fast Response Time: Heater preheating (~24–48 hours for stable readings) ensures reliability in dynamic environments like mines.

c. Temperature and Humidity Sensor

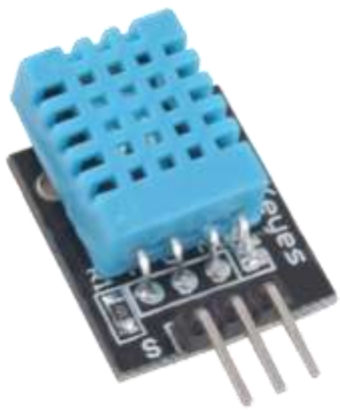

Figure 4: DHT-11 Sensor

The DHT11 shown in Figure 4 is a low-cost digital temperature and humidity sensor widely used in environmental monitoring applications. It features a resistive humidity measurement component and a thermistor for temperature sensing, providing reliable readings with a humidity range of 20–80% (±5% accuracy) and a temperature range of 0–50°C (±2°C accuracy). The sensor communicates via a single-wire serial interface, making it easy to integrate with microcontrollers like the ESP8266 used in this project. Its compact size, low power consumption, and fast response time (1–2 seconds) make it ideal for real-time monitoring in the smart helmet, ensuring miners are alerted to unsafe temperature or humidity levels in hazardous mining environments.

d. Neo 6M GPS Module

Figure 5: GPS Module NEO 6M

The NEO-6M shown in Figure 5 is a compact, high-sensitivity GPS receiver that provides real-time location tracking (latitude/longitude) with ±2.5m accuracy. It features UART interface, 50-channel satellite acquisition, and low power consumption (67mA), making it ideal for wearable safety devices. Integrated with the smart helmet, it enables precise miner tracking and emergency rescue coordination in underground environments.

e. GSM Modem

Figure 6: GSM Modem

The GSM modem enables critical cellular communication in the smart helmet, providing SMS-based emergency alerts when hazards like gas leaks or falls are detected. Operating on 2G/3G networks (850/900/1800/1900MHz), it ensures reliable connectivity in remote mining areas where WiFi is unavailable. The modem shown in Figure 6, powered by 5V with low standby current (~20mA), uses AT commands to send predefined emergency SMS alerts - including GPS coordinates (from NEO-6M) - to supervisors for rapid rescue response. With a typical response time under 15 seconds, this failsafe communication backup features a SIM card slot for network access and robust construction for harsh mining environments. When integrated with the system's sensors and microcontroller, the GSM modem provides two-way communication capability, ensuring miners can summon help even in connectivitychallenged underground locations.

f. 16x2 LCD Display

Figure 7: 16x2 LCD Display

An LCD screen shown in Figure 7 is an electronic display module that uses liquid crystal to produce a visible image. The 16×2 LCD display is a very basic module commonly used in DIYs and circuits. The 16×2 translates a display of 16 characters per line in 2 such lines. In this LCD, each character is displayed in a 5×7 pixel matrix.

g. Buzzer

Figure 8: Buzzer

A buzzer shown in Figure 8 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.

h. Portable Rechargeable Sensor Headlight

Figure 9: BL-TL72

The Portable Rechargeable Sensor Headlight BL-TL72 shown in Figure 9 is a hands-free LED light with motion-sensor activation, multiple brightness modes, and a long-lasting rechargeable battery. Lightweight and water-resistant, it's ideal for mining, outdoor, or repair tasks.

Software requirements description

a. Aurduino IDE

Figure 10: Arduino IDE

The Arduino IDE (Integrated Development Environment) is a versatile and user-friendly platform designed for programming and uploading code to Arduino-compatible boards. As shown in Figure 10, it provides a simple interface where users can write, edit, compile, and upload code written in the Arduino programming language, which is based on C/C++. The IDE includes a built-in library manager, serial monitor, and debugger, making it easier for beginners and professionals alike to develop and test embedded systems. Compatible with Windows, macOS, and Linux, the Arduino IDE supports a wide range of boards beyond the Arduino Uno, such as ESP8266 and ESP32.

b. Blynk App

Figure 11: Blynk Application

The Blynk App as shown in Figure 11 is a cloud-based platform that displays real-time data from the smart helmet, including gas levels, temperature, humidity, and GPS location. It allows supervisors to monitor miners remotely and receive instant alerts during emergencies, ensuring quick response and enhanced safety.

5. Implementation

This intelligent safety helmet system provides real-time, low-cost, and efficient monitoring of hazardous mining conditions, significantly enhancing miner safety. It continuously tracks gas concentrations (methane, carbon monoxide), temperature, humidity, and miner location. The helmet, powered by a 3.7V lithium-ion battery, acts as a transmitting unit, with the NodeMCU ESP8266 microcontroller integrating MQ2 gas, DHT11 temperature/humidity, and NEO-6M GPS sensors. An emergency switch allows manual alert triggering. As shown in Figure 12, the system's workflow involves constant sensor monitoring. If readings exceed safe thresholds (e.g., high gas, temperature), a buzzer sounds, a 16x2 LCD displays warnings, and the GSM module sends SMS alerts with sensor values and GPS coordinates to designated contacts. Data is also streamed to the Blynk app for remote monitoring. In emergencies, the switch triggers immediate alerts with location data for rapid rescue. WiFi uploads data to the Blynk IoT cloud, while GSM acts as a backup for alerts in areas without internet. This continuous monitoring and layered alert mechanism makes the intelligent helmet an effective solution for enhancing safety in hazardous mining operations.

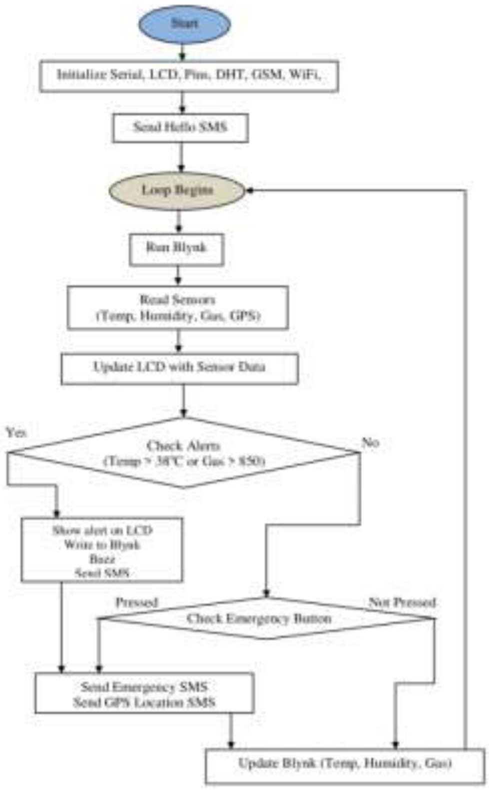

Figure 12: Flow Chart of Smart Helmet

6. Result and Discussion

As shown in Figure 13, the smart safety helmet developed using IoT has shown effective performance in hazardous mining environments. Its main goal is to safeguard miners by detecting unsafe gas levels, high temperature, and humidity, while also enabling emergency alerts. During testing, the system accurately detected toxic gases and environmental changes, and sent alerts via buzzer, LCD, and SMS with GPS coordinates. The emergency button was also functional, allowing the miner to send alerts manually.

Figure 13: Outlook of smart helmet and LCD Displaying Temperature, Humidity and Gas Measurement Values.

As shown in Figure 14 and 15, the helmet continuously shared data through the Blynk app, confirming its real-time monitoring capability. Overall, the results show that the helmet operates reliably based on sensor inputs and miner interaction, providing timely warnings and location tracking.

Figure 14: Blynk App showing Real-Time Measurement Values

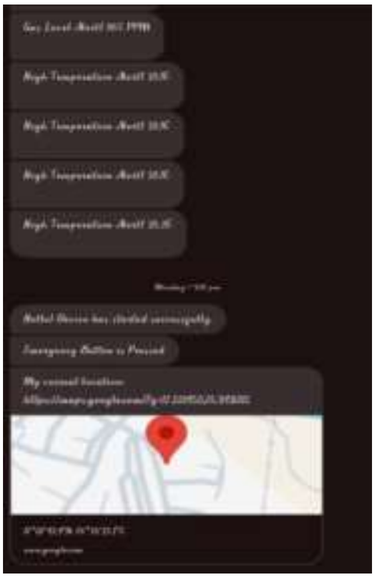

Figure 15: High Temperature and Gas Alert SMS

Compared to previously developed smart helmets and safety systems reviewed in the literature, our proposed IoT-based smart helmet provides a significantly more comprehensive and reliable safety solution for mining environments. While earlier systems [1][2][3] focused on limited functionalities such as gas detection or basic alert mechanisms, they lacked robust communication capabilities and did not address issues like real-time tracking or emergency responsiveness. In contrast, our helmet integrates GSM and WiFi modules, allowing for dual-channel communication—ensuring reliable data transmission and SMS alerts even in low-connectivity areas. Unlike systems relying solely on ZigBee or GPRS [5][7], which suffer from range and latency issues, our use of the Blynk IoT platform with ESP8266 enables seamless real-time data visualization and monitoring through a smartphone app. Furthermore, unlike IoT bracelets [4], which lacked integration with location tracking and emergency controls, our design includes GPS-based miner tracking and a manual emergency button for instant alerts. The inclusion of an LCD display and buzzer also offers local, on-device awareness—something missing or underdeveloped in other solutions. These enhancements make our system more practical, ergonomic, and responsive to the dynamic needs of underground mining safety, thereby addressing multiple gaps identified in related work and offering a more advanced and reliable solution.

7. Conclusion

The implementation of an IoT-based smart safety helmet for miners has proven to be a significant step toward enhancing safety in hazardous underground environments. By integrating various sensors with GSM and GPS modules, the system continuously monitors vital environmental parameters such as gas concentration, temperature, and humidity, while also tracking the miner's location in real time. The timely transmission of alerts through SMS and mobile applications ensures that any abnormal conditions are immediately communicated to concerned authorities, thereby enabling rapid response and reducing potential risks. This project demonstrates that the fusion of IoT with wearable safety gear can drastically improve workplace safety standards in the mining industry. The system's reliability, low cost, and ease of deployment make it a practical solution for large-scale adoption. Overall, the smart helmet offers a scalable and efficient approach to safeguarding miners' lives through proactive monitoring and instant communication. Future versions could incorporate biometric sensors (e.g., heart rate, fatigue detection) to monitor miners' health in real time.

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