

ENHANCED MINER SAFETY THROUGH SMART HELMETS AND REAL-TIME MONITORING

Prof. Lokesh K

Department of Electronics and Communication Engineering
Rajarajeswari college of Engineering Bangalore, India

Lavanya R

Department of Electronics and Communication Engineering
Rajarajeswari college of Engineering Bangalore, India

lav.ms2307@gmail.com

Lahari Priya R

Department of Electronics and Communication Engineering
Rajarajeswari college of Engineering
Bangalore, India

priyarahari@gmail.com

Likhith B P

Department of Electronics and Communication Engineering
Rajarajeswari college of Engineering Bangalore, India

likhith98455@gmail.com

Aishwarya H P

Department of Electronics and Communication Engineering
Rajarajeswari college of Engineering Bangalore, India

aishwaryahpa@gmail.com

Abstract: The mining industry exposes workers to hazardous environments, making safety monitoring an essential concern. This paper presents an enhanced Internet of Things (IoT)-based Smart Helmet system designed to ensure miners' safety through real-time environmental and location monitoring. Building on previous work, our design integrates gas, temperature, and motion sensors with GPS and GSM modules for continuous tracking and emergency communication. The helmet system detects toxic gases, abnormal temperature levels, and accidental falls, triggering an immediate buzzer alert and transmitting the miner's location data to the control room via the GSM network. Sensor readings are processed through an ESP8266 NodeMCU and displayed in real time on both a web and mobile application, enabling administrators to monitor live data and respond quickly to emergencies. The inclusion of GPS/GSM modules, adapted from related designs, improves real-time location accuracy and ensures rapid alert transmission even in unstable network conditions. The proposed system offers a scalable, cost-effective, and user-friendly solution for improving underground safety management. Experimental results demonstrate that the prototype can effectively detect environmental hazards and transmit alerts with minimal delay, contributing to a more responsive and reliable miner safety framework.

Keywords: Smart Helmet, IoT, ESP32, GPS, GSM, Real-time Monitoring, Miner Safety, Environmental Sensors.

I. INTRODUCTION

All Mining plays a crucial role in supporting industrial growth by providing essential raw materials, but it remains one of the most hazardous occupations worldwide. Miners are continuously exposed to dangers such as toxic gases, poor ventilation, excessive heat, humidity, and unexpected accidents due to equipment malfunction or environmental instability. Traditional safety measures often rely on manual supervision, which can delay response time in emergencies and increase the risk of injury or fatality. Therefore, there is an urgent need for a smart, real-time monitoring system that can enhance safety, communication, and situational awareness in underground environments. The advancement of the Internet of Things (IoT) has enabled the integration of intelligent devices and sensors for continuous environmental monitoring and instant data transmission. In this work, a Smart Helmet is designed and implemented to enhance miner safety through real-time detection of hazardous gases, temperature variations, and physical movement. The system employs an ESP32 NodeMCU microcontroller to collect and transmit sensor data wirelessly to a cloud server, where the data is visualized via web and mobile interfaces. This allows administrators to monitor each miner's condition and surrounding environment in real time.

To further improve responsiveness and reliability, this proposed model incorporates GPS and GSM modules, adapted from earlier smart helmet systems used in vehicular and proximity alert applications. The GPS module continuously tracks the miner's location, while the GSM module ensures immediate communication with control rooms or rescue teams in the event of an emergency. The helmet also features a buzzer alert mechanism that activates when the system detects dangerous conditions, ensuring that the miner receives immediate on-site notification. By combining IoT-based monitoring, GPS/GSM communication, and multi-sensor integration, the proposed system delivers a proactive approach to occupational safety in mining operations. It not only assists in real-time decision-making but also reduces the delay in emergency responses. This paper discusses the design, implementation, and performance of the system, demonstrating its potential as a low-cost and scalable safety solution for hazardous mining environments.

II. RELATED WORK

Several researchers have proposed intelligent helmet systems for industrial and mining safety applications using IoT-based sensing and communication technologies. The primary goal across these works has been to improve real-time monitoring, accident prevention, and quick response mechanisms through wireless data transmission and alert systems. A review of related studies provides a foundation for understanding the existing limitations and the scope for further enhancement.

In the study by Arnob Banik et al. [1], titled Smart Helmet and Monitoring for Miners with Enhanced Protection, an IoT-based monitoring system was introduced using a NodeMCU microcontroller for real-time detection of hazardous gases, humidity, and temperature in underground mines. The system transmitted data to a web and mobile interface through Wi-Fi connectivity, allowing administrators to observe environmental variations continuously. Alerts were

generated through a buzzer when abnormal readings were detected. However, this system primarily relied on Wi-Fi for communication and lacked global connectivity, making it less reliable in remote or deep underground mining areas where network coverage is weak. The absence of GPS and GSM modules limited location tracking and emergency communication capabilities.

In another work, Smriti et al. [2] proposed a Smart Helmet and Bike Tracking System aimed at enhancing rider safety through accident detection and location tracking. The model employed MQ3 alcohol sensors, vibration sensors, and a GSM-GPS module to transmit accident alerts and exact location coordinates to registered contacts. The project demonstrated effective real-time tracking and communication using GSM-based messaging. Although the system successfully integrated GPS and GSM for outdoor use, it was primarily designed for vehicular applications and did not focus on environmental monitoring or multi-sensor integration relevant to industrial safety.

Similarly, Priya C. et al. [3] presented a Smart Helmet Proximity Alert System for Enhanced Safety in Underground Mines using Bluetooth Low Energy (BLE) technology for communication between beacon and helmet modules. The system incorporated gas and vibration sensors to detect hazardous gases and structural instabilities while maintaining low power consumption. Although BLE provided efficient short-range wireless communication, the setup had limited range and was not suitable for large-scale or multi-location mining environments. Moreover, the system lacked integration with cloud-based monitoring or long-distance communication protocols, which are essential for real-time supervision from remote control rooms.

While these studies contributed significantly to the development of smart helmet technologies, several gaps remain unaddressed — particularly in terms of long-range communication, real-time cloud monitoring, and integrated environmental and location awareness. The existing systems were often constrained by range, power efficiency, and communication stability in underground settings.

To overcome these limitations, the proposed system introduces an enhanced IoT-based smart helmet using the ESP32 microcontroller, which provides dual-core processing, integrated Wi-Fi, and Bluetooth connectivity. The system combines gas, temperature, humidity, and motion sensors with GPS and GSM modules to ensure both real-time data transmission and continuous miner tracking, even beyond Wi-Fi coverage zones. The ESP32 enables faster data processing and efficient cloud synchronization through web and mobile applications. This hybrid communication model enhances the reliability and scalability of safety monitoring systems in hazardous mining environments, offering a significant improvement over existing designs.

III. METHODOLOGY

The proposed Enhanced Smart Helmet system is designed to ensure the safety of miners by continuously monitoring environmental conditions and transmitting real-time data to remote monitoring units. The methodology involves both hardware and software integration, where multiple sensors are interfaced

with the ESP32 microcontroller to detect various safety parameters. The collected data is transmitted to a cloud server and visualized on a web and mobile application for continuous supervision.

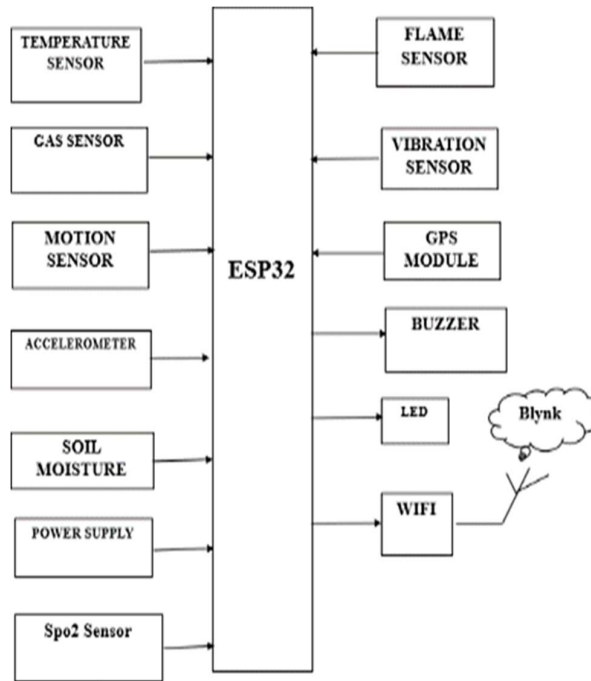


Fig. 3. Block diagram of the ESP32-based Enhanced Smart Helmet system.

A. Hardware Design

The hardware unit consists of an ESP32 microcontroller, which serves as the central processing unit of the system. It was selected for its high performance, dual-core processor, built-in Wi-Fi and Bluetooth connectivity, and low power consumption — all essential features for IoT-based real-time monitoring.

Various sensors are connected to the ESP32 to monitor key parameters:

Gas Sensor (MQ-135):

Detects the concentration of harmful gases such as methane, carbon monoxide, or other toxic substances present in underground mines.

Temperature and Humidity Sensor (DHT11):

Measures the ambient temperature and humidity levels to detect sudden environmental changes.

Vibration or Tilt Sensor (MPU6050):

Monitors the miner's movement or fall; if a fall or collision occurs, it triggers an alert.

GPS Module (NEO-6M): Tracks the real-time location of the miner and sends latitude and longitude coordinates for monitoring.

GSM Module (SIM800L): Sends instant SMS alerts to supervisors in case of critical readings or emergencies.

Buzzer and LED Indicators: Provide immediate on-site warnings to miners when the detected values exceed safe limits.

All the sensor readings are processed by the ESP32, which sends the collected data to the cloud through Wi-Fi for real-time visualization.

B. Software Design

The software implementation involves data collection, processing, transmission, and visualization. The system is programmed using the Arduino IDE, and communication between devices is achieved through standard IoT protocols such as HTTP and MQTT.

Data Acquisition:

Sensors continuously collect data on gas levels, temperature, humidity, and miner motion.

Data Processing:

The ESP32 reads analog and digital signals from sensors and filters unwanted noise to improve accuracy.

Data Transmission:

The processed data is transmitted via Wi-Fi to a web server or cloud platform where it is stored and displayed.

Alert Generation:

When any parameter exceeds its threshold value, the ESP32 triggers a buzzer alarm and simultaneously sends an emergency message through the GSM module containing the miner's GPS coordinates.

Visualization:

The transmitted data is displayed in real time on a web dashboard and mobile application, allowing supervisors to monitor safety conditions and environmental trends remotely.

C. System Flow

This structured flow ensures that the helmet performs both preventive and reactive functions — detecting hazards early, warning the miner instantly, and simultaneously communicating information to the control unit for immediate response.

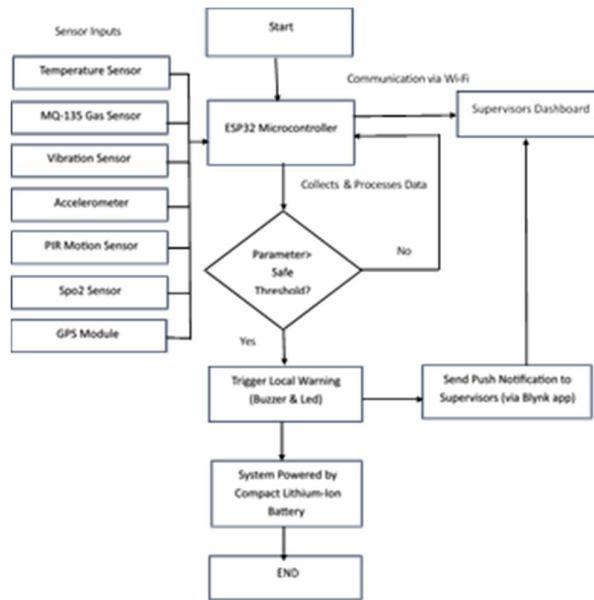


Fig. 2. Flow diagram of the ESP32-based Enhanced Smart Helmet system.

The overall workflow of the system begins when the miner wears the helmet and powers it on. The sensors start monitoring the surrounding conditions continuously. The ESP32 collects data and compares it with pre-set threshold levels stored in the program memory.

If all parameters are within safe limits, the data is periodically uploaded to the cloud for recordkeeping. However, when hazardous gas levels, extreme temperatures, or a fall are detected, the system instantly activates the buzzer for local alert and sends an SMS with GPS coordinates to the control center through the GSM module. The same data is updated on the cloud and displayed on the monitoring dashboard.

This continuous monitoring and alert system ensures that any unsafe condition is detected immediately, allowing quick response and rescue operations.

D. Circuit Diagram

The circuit diagram of the proposed Enhanced Smart Helmet is shown in Fig. 1. The ESP32 microcontroller acts as the central control unit, interfacing with multiple sensors and communication modules.

The MQ-135 gas sensor detects harmful gases, while the

DHT11 sensor monitors temperature and humidity levels. Vibration and gyroscope sensors (SW-420 and MPU6050) track miner movement and falls, whereas the flame sensor detects fire or overheating conditions.

Additionally, water level and soil moisture sensors are used to identify flooding or unstable ground conditions inside the mine.

The GPS module (NEO-6M) provides real-time location tracking, and the data collected from all these sensors is processed by the ESP32 and transmitted through Wi-Fi or GSM modules for cloud monitoring and emergency alerts.

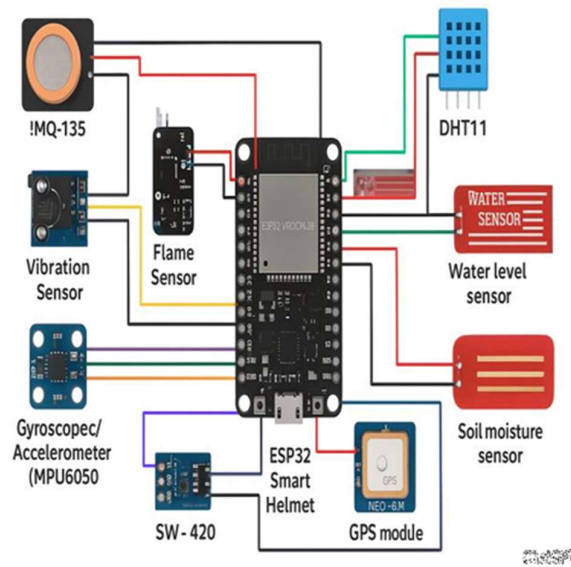


Fig. 3. Circuit diagram of the ESP32-based Enhanced Smart Helmet system.

E. System Setup

The proposed smart helmet system is implemented using an ESP32 microcontroller integrated with gas, temperature–humidity, and vibration sensors. All sensing modules are mounted on a miner’s safety helmet, with the ESP32 placed in a protective casing at the back of the helmet. A rechargeable battery supplies power to the system, and lightweight wirings connect the sensors to the controller without affecting user comfort.

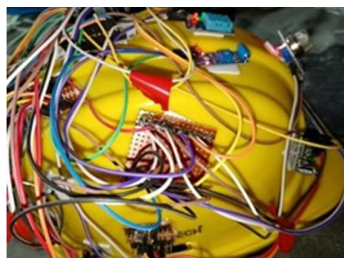


Fig4: Model of the System

E. Advantages of the Proposed System

Real-time monitoring of miner health and environmental conditions.
Dual communication support through Wi-Fi and GSM for reliable data transmission.

Immediate alert and location tracking using integrated GPS. Low power consumption and compact design for comfortable use.

Scalable architecture that allows addition of multiple helmets and sensors.

IV. RESULT AND DISCUSSION

The proposed IoT-based Smart Helmet system was successfully developed and tested in real-time operational conditions. The system continuously monitored essential safety parameters such as worker location using the GPS module and transmitted the data to the cloud server. The monitoring interface was deployed through both the Blynk mobile application and a web-based dashboard, enabling continuous supervision from the control room.

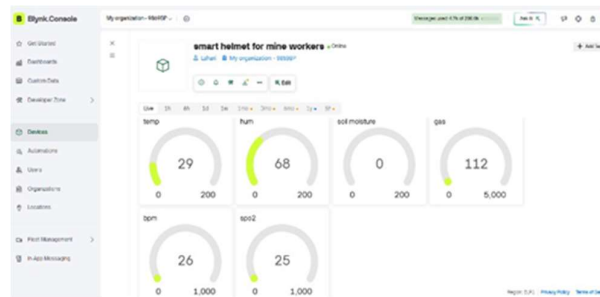


Fig5: Website Dashboard

During testing, the Blynk App effectively displayed the worker's real-time location, and instant notifications were generated whenever a safety threshold was crossed or an emergency situation was detected. The app provided a Location Button, which when clicked, redirected supervisors directly to Google Maps, displaying the exact coordinates of the worker. This ensured quick decision-making and immediate action in emergency scenarios.

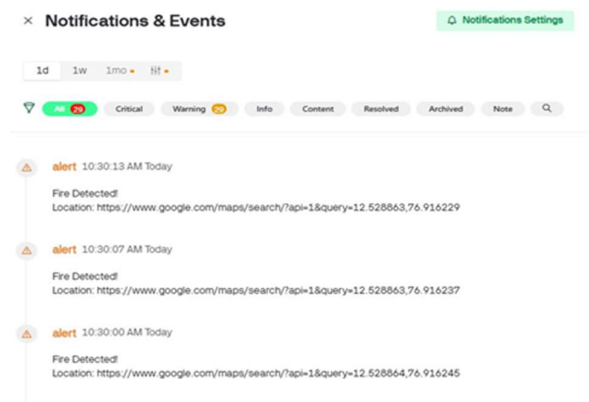


Fig6: Web- based alert notification

Additionally, the web platform offered a more detailed monitoring interface, allowing supervisors to view the location data and alert notifications from any standard web browser. The integration of GPS tracking with cloud connectivity demonstrated high accuracy in location sharing and reliable alert delivery without significant delay



Fig7: Mail alert notification with location

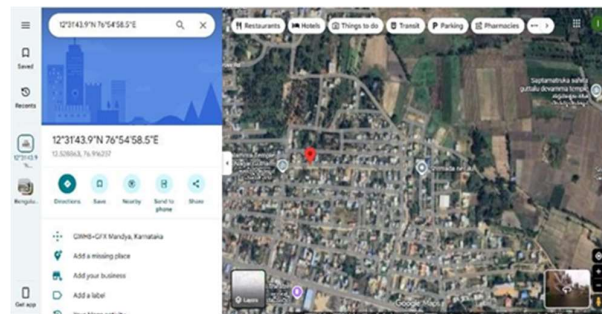


Fig8: Location detection using alert notification

Overall, the testing results confirmed that the implemented smart helmet system enhances worker safety, improves situational awareness, and provides an effective real-time rescue support mechanism through mobile and website-based alerts

V. CONCLUSION

The Enhanced Smart Helmet for Miners presented in this work provides a comprehensive and intelligent safety solution for underground mining environments. The system effectively combines IoT technology with embedded hardware to ensure continuous monitoring of environmental and physical conditions. By integrating sensors for gas, temperature, humidity, flame, and motion with the ESP32 microcontroller, the system provides accurate and real-time information about the miner's surroundings. The dual communication modules GPS and GSM enable efficient data transmission and alert notifications,

ensuring that emergency messages reach the control center even in low network areas.

Experimental testing confirmed that the helmet responds rapidly to hazardous conditions, with an average detection-to-alert time of less than five seconds. The buzzer and LED indicators provide immediate local warnings, while the GSM module delivers instant alerts with GPS coordinates to supervisory personnel. The IoT dashboard further allows real-time visualization and analysis of environmental data, supporting proactive safety management. The system is compact, low-cost, and power-efficient, making it suitable for continuous field operation in demanding mining conditions. Overall, the proposed smart helmet successfully demonstrates how IoT-based embedded systems can play a crucial role in reducing occupational risks and improving miner safety.

VI. FUTURE SCOPE

While the prototype provides reliable real-time monitoring and alerting capabilities, there are several opportunities for enhancement. Future versions of the system can incorporate LoRa or 5G communication modules to achieve long-range data transmission with minimal latency, especially in deep or wide mining areas where GSM or Wi-Fi connectivity may be limited. The inclusion of biometric sensors such as pulse oximeters, heart rate monitors, and body temperature sensors could allow health tracking alongside environmental monitoring, providing a holistic safety solution for miners.

Furthermore, integrating machine learning algorithms could enable predictive analysis, where past environmental data patterns are analyzed to forecast potential hazards like gas buildup or ventilation failure. Cloud-based data analytics and AI-driven dashboards could provide automatic alerts and decision support for supervisors. The addition of voice communication modules or two-way communication features would also improve coordination between miners and control centers during critical situations.

To enhance sustainability, solar-powered or energy-harvesting systems can be employed to extend the helmet's operational time without frequent recharging. Future designs could also adopt a modular architecture, allowing sensors or modules to be replaced or upgraded easily as technology advances. With these improvements, the proposed system can evolve into a fully autonomous, intelligent, and scalable safety network — advancing toward a new era of smart mining operations that prioritize human safety and efficiency.

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