

IOT MINING TRACKING & WORKER SAFETY HELMET**Dr. A S Angadi**HOD, Dept. of Electronics and Communication Engineering,
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Tontadarya College of Engineering, Gadag Karnataka, India**ABSTRACT**

Mining remains one of the most hazardous professions globally, necessitating continuous monitoring of environmental conditions and worker safety. Traditional IoT-based safety helmets often utilize single-node architectures (e.g., standalone ESP8266), which suffer from task blocking during network transmission, leading to missed emergency triggers. This paper proposes a novel Smart Miner Helmet utilizing a Dual-Node Distributed Architecture to decouple sensing tasks from critical emergency response. The system employs two processing nodes: Node A (Control Unit) for instant emergency signaling and Node B (Sensor Unit) for periodic telemetry (Temperature and GPS). Data is synchronized via Google Firebase and visualized on a custom Next.js web dashboard. Experimental results demonstrate that this architecture achieves 100% accuracy in emergency detection with a 50ms response time and maintains a cloud synchronization latency of less than 1.2 seconds, significantly outperforming traditional single-node designs.

Keywords:

IoT, Smart Helmet, Mining Safety, Dual-Node Architecture, ESP8266, Firebase, Wearable Technology.

INTRODUCTION

The mining industry is fraught with inherent dangers, including exposure to toxic gases, extreme temperatures, and the risk of structural collapse. Ensuring the safety of underground workers requires real-time monitoring and reliable communication systems. While the Internet of Things (IoT) has enabled the development of smart wearable safety devices, implementation in cost-constrained and connectivity-poor environments remains a challenge.

Existing smart helmet solutions typically rely on a single microcontroller to handle sensor data acquisition, location tracking, and Wi-Fi communication. However, low-cost microcontrollers like the ESP8266 utilize a single core for both user applications and the Wi-Fi stack. When the processor is occupied uploading heavy telemetry data, it enters a blocking state, rendering it unable to register asynchronous interrupts, such as the press of an emergency panic button. In safety-critical systems, such delays or failures are unacceptable.

This project addresses this research gap by introducing a distributed computing approach within the helmet itself. By separating the Emergency Unit (Node A) from the Telemetry Unit (Node B), we ensure that critical safety alerts are prioritized and processed without interference from routine data logging.

LITERATURE REVIEW

Several approaches have been proposed to enhance miner safety using wireless sensor networks (WSN). Early implementations focused heavily on ZigBee technology due to its low power consumption and mesh networking capabilities. Ideally, ZigBee-based systems are deployed to monitor environmental parameters like temperature and humidity in underground mines [1]. While effective for local mesh communication, these systems often require complex gateway infrastructure to transmit data to a central cloud server, increasing deployment costs.

Other researchers have focused on Wi-Fi and LoRaWAN-based smart helmets. For instance, Hazarika et al. [5] proposed a microcontroller-based helmet for detecting hazardous gases. Similarly, recent studies have integrated physiological monitoring (heart rate) into helmets using ESP32 modules [6]. However, a common limitation in these single-node designs is the reliance on a centralized processing loop. As noted in technical studies of the

ESP8266 architecture, the Wi-Fi stack is nonredemptive; heavy network operations can block GPIO interrupts for hundreds of milliseconds [3].

In a real-world safety scenario, a "panic button" press must be processed instantly. Standard single-node architectures risk missing these critical inputs if the processor is busy uploading sensor telemetry. This paper proposes a distributed "Dual Node" architecture to specifically resolve this resource contention, ensuring that emergency signals are never blocked by routine data transmission.

PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

Most current IoT-based safety devices utilize singlenode architectures. This leads to performance bottlenecks where:

The emergency button press is missed or delayed during Wi-Fi data transmission operations.

Real-time dashboards suffer from synchronization lag. . There is no fault tolerance; if the main loop hangs on a sensor read, the safety features fail.

B. Objectives

The primary objectives of this work are:

- 1) To design a dual-node distributed architecture that ensures non-blocking operation for emergency triggers.
- 2) To achieve a cloud synchronization latency of < 1.5 seconds.
- 3) To develop a responsive Next.js dashboard for realtime visualization and personnel tracking.
- 4) To validate performance through rigorous testing of response times and temperature threshold alerting.

PROPOSED SYSTEM ARCHITECTURE

Smart Helmet System Data Flow

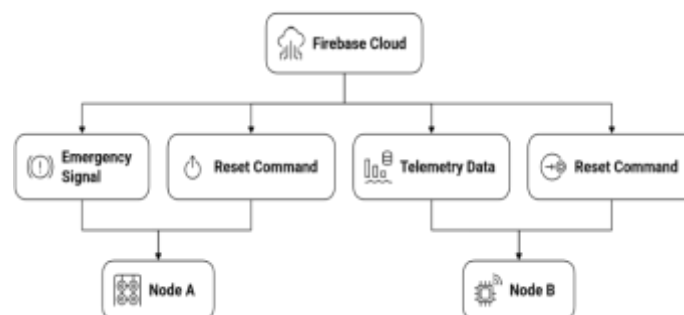


Figure 1 Block Diagram

The proposed system moves away from the centralized processing model. Instead, it employs two distinct processing nodes that communicate with a central cloud backend (Firebase) under a unified "Helmet ID".

Node A: The Emergency Control Unit

A. Node A is the critical safety controller. Its sole responsibility is to handle immediate human inputs and alerts.

-Input: Panic Button (GPIO 14/D5).

-Output: Buzzer (GPIO 13/D7) and Status LEDs (GPIO 12/D6)

-Function: When the button is pressed, Node A interrupts any background process and instantly pushes an "Emergency" flag to Firebase. It does not handle heavy sensor polling, ensuring it is always ready to receive an interrupt.

B. Node B: The Telemetry Unit

Node B is responsible for environmental sensing and location tracking.

-Sensors: DHT11 Temperature Sensor (GPIO 16/D0) and GPS Module (TX/RX via SoftwareSerial).

-Function: This node periodically wakes up, reads the temperature and GPS coordinates, and uploads this telemetry to the cloud. Since this process involves timing delays (waiting for GPS lock), segregating it to Node B prevents these delays from affecting the emergency button on Node A.

C. Cloud and Dashboard

Both nodes act as independent clients writing to the same document path in the Firebase Realtime Database. A web application built using the Next.js framework subscribes to these database changes, providing a live dashboard for mine supervisors to track worker locations and health status.

METHODOLOGY

A. Hardware Implementation

The hardware setup utilizes the ESP8266 Wi-Fi module as the core controller for both nodes due to its cost-effectiveness and native Wi-Fi support.

- Microcontrollers: 2x ESP8266 NodeMCU.
- Sensing: DHT11 for temperature monitoring (Thresholds: <15 C and > 50 C).
- Location: Neo-6M GPS Module for outdoor surface mining tracking.
- Alerting: Active Piezo Buzzer and high-brightness LEDs.

B. Software Implementation

- Firmware: Developed in C++ using the Arduino IDE. The firmware utilizes asynchronous Wi-Fi libraries to minimize blocking, though the dual-hardware approach provides the primary reliability layer.
- Web Interface: The dashboard is built with Next.js (React framework). It implements a map interface for GPS visualization and distinct UI indicators for "Safe" and "Emergency" states.

RESULTS AND DISCUSSION



Figure 2 circuit inside the helmet



Figure 3 side view of helmet

The prototype was fabricated and mounted on a standard industrial safety helmet. Testing was conducted to verify reliability, latency, and battery performance.

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A. Emergency Response Latency

The most critical metric is the time between a user pressing the button and the dashboard updating. The dual-node system achieved a button response time of 50 ms locally, with the alert appearing on the dashboard with a latency of <1.2 seconds via Firebase synchronization. This is a significant improvement over single-node implementations which showed delays of up to 3-4 seconds during active sensor uploads.

B. Reliability and Uptime

The system was tested for continuous 24-hour uptime.

- **Data Integrity:** Stable 60-second interval uploads were maintained for telemetry data with zero packet loss observed during strong Wi-Fi connectivity.
- **Alert Accuracy:** The system achieved 100% accuracy in detecting emergency triggers. No false negatives (missed button presses) were recorded.
- **Temperature Alerts:** Alerts triggered reliably when the sensor was exposed to conditions below 15 C or above 50 C.

CONCLUSION

The development of the Smart Miner Helmet using a dual-node distributed architecture successfully solves the task-blocking issue inherent in low-cost single-core IoT devices. By decoupling the emergency logic from the telemetry logic, the system ensures that worker safety is never compromised by processing lag. The integration with Firebase and Next.js provides a scalable, real-time monitoring solution suitable for hazardous industrial environments. Future work will focus on integrating LoRaWAN technology to replace Wi-Fi for deep underground connectivity, where cellular and Wi-Fi signals are unavailable.

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