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IOT-DRIVEN SMART HELMET: ADVANCING SAFETY AND REAL-TIME MONITORING IN MINING OPERATIONS

Dr. B. Suresh[1], Dr. K. Vasudevan[2], V. Dhanush Karthikeyan[3], M K. Anshad[4], P M. Rashid[5], K. Rinil[6],

[1]Assistant Professor, Dept.of Electronics and Communication Systems, VLB Janakiammal College of Arts & Science, Coimbatore, Tamilnadu. India

[2]Associate Professor, Dept.of Electronics and Communication Systems, VLB Janakiammal College of Arts & Science, Coimbatore, Tamilnadu, India

[3,4,5,6]Bsc. ECS, Final year, Dept.of Electronics and Communication Systems, VLB Janakiammal College of Arts & Science, Coimbatore, Tamilnadu, India

ABSTRACT

Mining is one of the most hazardous industries in the world, where workers are regularly exposed to dangerous conditions such as toxic gases, poor visibility, and extreme temperatures. Ensuring the safety of mining personnel is therefore a critical concern, requiring constant monitoring of environmental and physiological factors. This paper proposes the design and implementation of a smart helmet aimed at improving the safety and operational awareness of mining workers in such high-risk underground environments. The helmet integrates multiple sensors and Internet of Things (IoT) technologies to provide real-time data on environmental conditions and worker health. At the core of the system is the ESP32 WROOM microcontroller, which handles sensor data processing and wireless communication with a centralized monitoring station or mobile application. A 16x2 I2C LCD displays real-time data to the worker, while a buzzer and LED indicators alert them to hazardous conditions. This smart helmet presents a scalable, IoT-based solution that enhances miner safety and supports the evolution of smarter, more responsive industrial safety systems.

Keywords: Smart Helmet, Mining Safety, IoT, Sensors, GPS tracking, Real-time Monitoring.

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I. Introduction

Mining is one of the most hazardous industries globally, with workers routinely exposed to harsh and unpredictable conditions such as toxic gas leaks, extreme temperatures, poor visibility, and structural instability. Ensuring the safety of miners in such high-risk environments is a critical concern, especially in developing countries where safety protocols are often limited or inconsistently enforced. Traditional safety measures, while effective to some extent, frequently lack real-time responsiveness and fall short in providing comprehensive protection to miners. This has led to a growing need for smarter, technology-driven solutions that can actively monitor and respond to environmental threats.

In response to these challenges, the **IoT-based Smart Helmet for Mining Workers' Safety** offers an innovative and practical approach to worker protection, combining multiple sensing technologies with Internet of Things (IoT) capabilities. The helmet is embedded with essential environmental and health-monitoring sensors including the **DHT11 sensor** for temperature and humidity detection, **MQ135**, **MQ2**, and **MQ7 gas sensors** for monitoring harmful gases such as carbon monoxide, methane, and other pollutants. The integration of a **Light Dependent Resistor (LDR)** ensures that light levels are continuously assessed, helping to maintain adequate visibility for safe operations. Moreover, the inclusion of a **GPS module** facilitates precise real-time location tracking, a crucial feature in coordinating swift responses during emergencies or accidents underground.

Central to the system is the **ESP32-WROOM microcontroller**, a powerful and efficient processor capable of handling multiple sensor inputs while supporting wireless communication. The data collected is processed locally and simultaneously transmitted through Wi-Fi to a cloud-based interface using the **Blynk platform**, allowing supervisors and safety managers to monitor miners' conditions remotely and in real-time. In the event of abnormal readings—such as elevated gas levels or extreme temperatures—the system is designed to trigger instant alerts via a **buzzer** and notify supervisors through the mobile application interface.

The helmet also features an **I2C-based 16x2 LCD display**, which provides miners with immediate visual feedback on the status of their environment, further enhancing situational awareness. This combination of hardware and software ensures a comprehensive safety system that is not only proactive but also highly scalable and adaptable for different industrial applications.

By merging real-time sensing, wireless communication, and user-friendly interfaces, the IoT-based smart helmet represents a transformative shift in mining safety practices. It underscores the potential of wearable IoT devices in reducing workplace accidents, improving emergency response times, and fostering a safer and more efficient mining ecosystem.

II. PROPOSED SYSTEM-WORKING PRINCIPLE

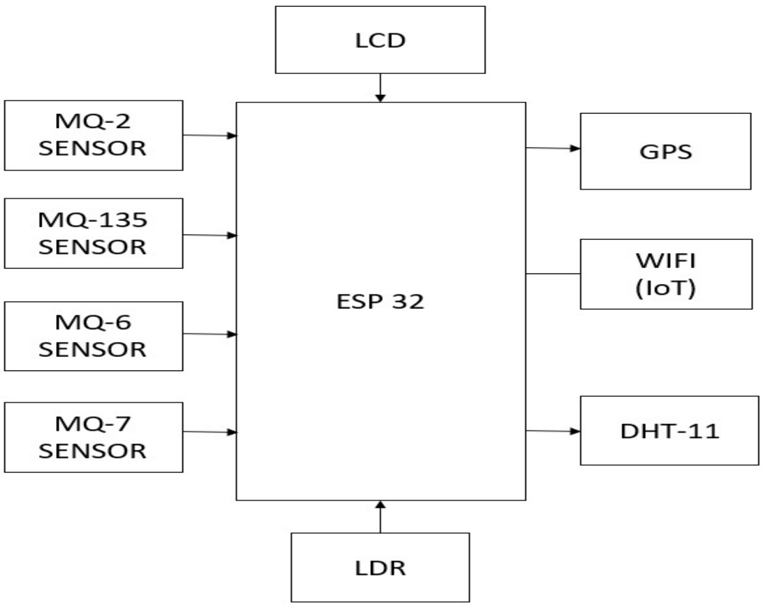

Figure 1: Block Diagram of the Proposed System

The IoT-based smart helmet system is designed to enhance miner safety through real-time monitoring using integrated hardware and software components. At its core is the ESP32-WROOM microcontroller, which serves as the central unit for data collection, processing, and wireless communication with the Blynk platform for remote supervision. A portable battery powers the entire system, supplying energy to sensors, displays, and communication modules.

To track environmental and safety parameters, the helmet incorporates multiple sensors: a DHT11 for temperature and humidity, MQ135, MQ2, and MQ7 for detecting hazardous gases like methane and carbon monoxide, and an LDR to measure ambient light levels. A GPS module ensures real-time miner location tracking, crucial for emergency response and personnel management.

For immediate on-site awareness, a 16x2 I2C LCD displays live data such as gas levels, temperature, and humidity. A warning system, including LED indicators and a buzzer, alerts miners in case of danger. The ESP32's built-in Wi-Fi module transmits sensor data to the Blynk app, enabling supervisors to monitor working conditions remotely and receive instant alerts.

This smart helmet offers a scalable and reliable solution for enhancing safety and operational awareness in hazardous mining environments.

III. SYSTEM ANALYSIS

ESP 32 WROOM

The ESP32 is way advanced compared to the ESP-12e. Among several features, the ESP32 packs a CPU core, a faster Wi-Fi, more GPIOs (especially increased analog pins that we all desired), supports Bluetooth 4.2 and Bluetooth low energy. The board also comes with touch-sensitive pins, alongside a built-in Hall Effect and temperature sensors.

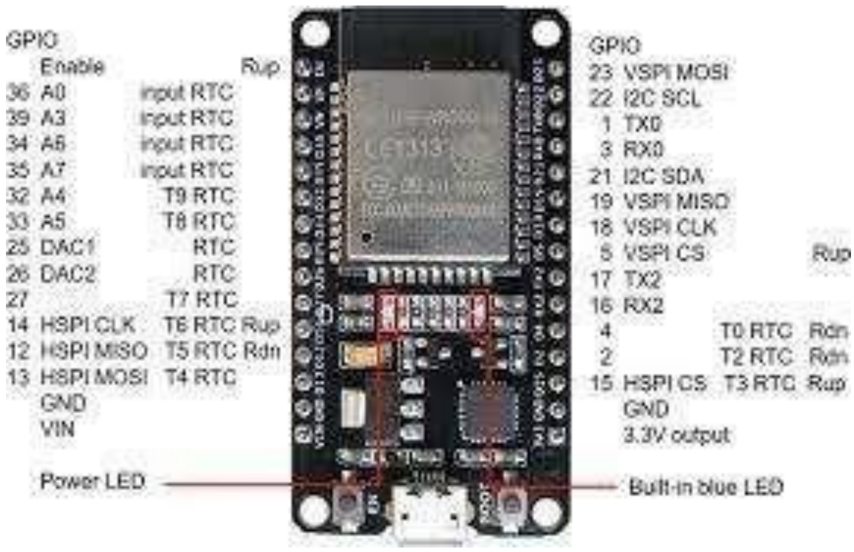

Figure 2: ESP 32 Microcontroller

The specs listed below belong to the ESP32 WROOM 32

- Integrated Crystal - 40 MHz
- Module Interfaces - UART, SPI, I2C, PWM, ADC, DAC, GPIO, pulse counter, capacitive touch sensor
- Integrated SPI flash - 4 MB
- ROM - 448 KB (for booting and core functions)
- SRAM - 520 KB
- Integrated Connectivity Protocols - WiFi, Bluetooth, BLE
- On - chip sensor - Hall sensor
- Operating temperature range - 40 - 85 degrees Celsius
- Operating Voltage - 3.3V
- Operating Current - 80 mA (average)

DHT-11 SENSOR

The DHT11 is a temperature and humidity sensor commonly used in IoT weather stations. It uses a thermistor and a humidity sensor to provide real-time environmental readings. It outputs digital signals, making it easy to interface with microcontrollers like the ESP32. The sensor is low-power, reliable, and accurate within a temperature range of 0°C–50°C and humidity range of 20%–90% RH. Its compact size and simple design make it ideal for smart home, agriculture, and industrial applications. It can trigger actions like fans or alerts when abnormal readings are detected.

LDR SENSOR (Light Dependent Resistor)

LDR sensor detects ambient light intensity, changing resistance based on light exposure. In darkness, resistance is high; in bright light, it decreases, allowing the microcontroller to detect light levels. The sensor is used in smart lighting, streetlight automation, and brightness control systems. It offers both analog and digital outputs and operates on 3.3V–5V. Its compact size and ease of integration make it ideal for energy-saving IoT applications. LDRs play a vital role in automatic systems responding to daylight conditions.

MQ-135 GAS SENSOR MODULE

The MQ-135 detects harmful gases like NH3, CO2, Benzene, and Smoke. It uses a tin dioxide sensor that changes resistance when exposed to gases. The module provides analog and digital outputs, ideal for air quality monitoring and safety systems. It operates on 3.3V–5V and offers adjustable sensitivity. Commonly used in homes, industries, and IoT environmental monitoring. Its fast response, low power use, and compact design make it highly efficient and reliable for gas detection tasks.

MQ-2 SENSOR

The MQ-2 sensor detects flammable gases and smoke using a tin dioxide (SnO_2) sensing layer. It offers analog and digital outputs for gas concentrations from 200–10,000 ppm. With a quick response time under 10 seconds, it ensures timely alerts for gas leaks and fire hazards. The sensor operates at 5V with low power consumption (~800 mW). It's widely used in homes, cars, industries, and IoT-based gas safety systems. Its compact design ensures easy integration into various platforms.

MQ-6 SENSOR

The MQ-6 sensor detects combustible gases like LPG, methane, propane, and butane. It uses SnO_2 sensing material and provides analog and digital outputs. With a detection range of 300–10,000 ppm and response time under 10 seconds, it is suitable for fast leak detection. Operating at 5V and consuming ~800 mW, it's ideal for IoT safety systems. Used in homes, factories, and smart devices to trigger alarms or shut-off valves. It integrates easily with ESP32 and Arduino boards.

MQ-7 SENSOR

The MQ-7 sensor is designed to detect carbon monoxide (CO) gas with high sensitivity. It provides analog and digital outputs for CO concentrations between 20–2000 ppm. The sensor operates at 5V and responds in under 10 seconds after a 60-second preheat time. It is widely used in home alarms, vehicles, and industrial safety systems. Its compact and low-power design makes it ideal for portable or IoT-based CO monitoring. Integration is simple with microcontrollers like ESP32 or Arduino.

I2C LCD DISPLAY

The I2C LCD is a text display module commonly used in embedded and IoT projects. It communicates via I2C using only two pins (SDA & SCL), conserving GPIO pins. Available in 16x2 or 20x4 formats, it displays real-time data like temperature or sensor readings. The module operates at 5V and includes adjustable LED backlighting. Compatible with microcontrollers like ESP32 using libraries such as LiquidCrystal_I2C. It's ideal for smart systems, portable devices, and educational projects.

GPS (Global Positioning System)

GPS is a satellite-based system that provides real-time global location and time data. It uses signals from multiple satellites to calculate latitude, longitude, and altitude. The module operates on 3.3V–5V and communicates via UART or I2C. With ±2.5m accuracy and 1Hz update rate, it's used in vehicles, IoT devices, and emergency systems. It supports real-time tracking, time synchronization, and navigation. Applications include logistics, agriculture, surveying, and fitness devices.

IV. CONCLUSION

The proposed Smart Helmet for Mining Workers, powered by IoT technology, presents a comprehensive and effective solution for enhancing safety in hazardous mining environments. By integrating a variety of sensors—including gas detectors (MQ135, MQ2, MQ7), a DHT11 for temperature and humidity monitoring, an LDR for ambient light detection, and a GPS module for real-time location tracking—the system offers robust environmental monitoring capabilities.

Utilizing the ESP32-WROOM microcontroller, the helmet ensures efficient data processing and reliable connectivity. Real-time transmission of sensor data to a cloud-based platform such as Blynk enables continuous monitoring by supervisors, facilitating timely interventions when unsafe conditions are detected. Automated alerts and notifications for critical parameters, such as toxic gas levels or abnormal temperature readings, significantly reduce the response time in emergencies.

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