AI based Smart Helmet for Worker Safety

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Abstract- ***Industrial mining environments present significant hazards to worker health and safety, necessitating proactive monitoring solutions. This research presents the design and implementation of an AI-integrated Smart Helmet developed to provide real-time tracking of both physiological and environmental parameters. The system utilizes a NodeMCU (ESP8266) microcontroller to interface with a MAX30100 pulse oximeter for monitoring heart rate and SpO_2 levels, alongside DHT11 and MQ-series sensors for detecting ambient temperature, humidity, and hazardous gas concentrations. To address physical safety, an MPU6050 inertial measurement unit is employed to detect fall directions and impact anomalies through edge-based processing. Data is transmitted via IoT connectivity to a centralized IP-based server for continuous surveillance and historical analysis. The system is programmed to trigger autonomous buzzer alarms and web-based alerts when safety thresholds are breached, ensuring immediate emergency response. Experimental results validate the system's ability to reduce latency in hazard detection and enhance PPE compliance. This smart helmet offers a scalable, cost-effective framework for safety management in underground mining and other high-risk industrial sectors.***

Keywords Smart Helmet, NodeMCU, IoT, Worker Safety, Fall Detection, MAX30100, Environmental Monitoring.

I.INTRODUCTION

The safety and well-being of workers in high-risk industrial sectors, particularly in underground mining, remains a critical global concern. Mining environments pose significant inherent risks, including exposure to toxic gases, extreme temperatures, and high potential for physical accidents like falls. Traditional safety measures in these settings are often manual and reactive, lacking the capacity for real-time data integration, which can lead to delayed emergency responses during critical incidents. Overall, the system provides an energy-efficient, reliable, and cost-effective solution for improving farm security and reducing crop damage [1].

To address these challenges, there is a growing shift toward incorporating wearable technology into personal protective equipment (PPE). A smart helmet serves as an ideal platform for such technology, allowing for the simultaneous monitoring of a worker's physiological vitals and their immediate environmental conditions. By embedding intelligent sensors directly into the helmet, it becomes possible to transition from passive protection to a proactive safety and health management system [2].

The proposed system integrates a suite of advanced hardware components to ensure comprehensive worker surveillance. At the core of the device is the NodeMCU (ESP8266) microcontroller, which provides a self-contained Wi-Fi networking solution for data transmission. This controller interfaces with the MAX30100 pulse oximeter to capture heart rate and SpO_2 levels, while the MPU6050 acceleration sensor is utilized to detect fall directions. Additionally, DHT11 and Gas sensors are incorporated to monitor humidity, temperature, and the presence of harmful gases in the surrounding atmosphere [3].

Real-time data collected by these sensors is transmitted to a centralized IP address, enabling continuous monitoring and analysis via a web interface. The system is designed with automated safety protocols; if any sensor data exceeds pre-defined safety thresholds, an automatic alert is triggered on the website and a buzzer alarm is activated for an immediate response. By facilitating quick decision-making and emergency coordination, this AI-based smart helmet aims to significantly reduce workplace accidents and health hazards in demanding mining operations [4].

By facilitating quick decision-making and emergency coordination, this AI-based smart helmet aims to significantly reduce workplace accidents and health hazards in demanding mining operations. The implementation of such a system provides a scalable, cost-effective solution for industrial safety management, bridging the gap between traditional protective gear and intelligent workplace surveillance. Ultimately, this research contributes to the goal of "zero-harm" in industrial workspaces by leveraging the Internet of Things (IoT) and sensor fusion technology [5].

II.RELATED WORKS

The evolution of worker safety systems in hazardous environments has been driven by the need for automated, real-time monitoring to replace manual and reactive traditional methods. Early research in this domain established the fundamental necessity of wireless monitoring specifically for coal miners. These foundational studies focused on creating communication networks capable of tracking both the environmental parameters of the mine and the vital signs of the workers. By providing a continuous stream of data, these early wireless systems demonstrated that emergency response times could be significantly improved compared to traditional reporting methods [6].

Subsequent advancements in technology led to the integration of the Internet of Things (IoT) for more sophisticated health surveillance. Research published in 2020 emphasized that continuous monitoring of vital parameters like heart rate and oxygen saturation (SpO_2) is critical for identifying health-related incidents before they become life-threatening. These IoT-based systems allow for the seamless transmission of health data from wearable sensors to a centralized platform, ensuring that medical intervention can be initiated at the first sign of physiological distress [7].

A major area of concern addressed in the literature is the high risk of accidental falls in industrial settings. Researchers have developed specialized fall detection mechanisms that utilize 3-axis accelerometers to identify sudden changes in motion or orientation. These systems are designed to distinguish between normal work movements and a true fall event, immediately triggering an alert to safety supervisors. By incorporating such technology into wearable gear, the time between an accident and the arrival of help is greatly reduced, which is vital in isolated underground zones [8].

Environmental safety monitoring has also been a primary focus of related work, particularly regarding the detection of hazardous gases. Previous implementations have successfully utilized MQ-series sensors to detect the presence of toxic or combustible gases within mines. These systems are often paired with temperature and humidity sensors, such as the DHT11, to provide a holistic view of the atmospheric conditions surrounding the worker. Such multi-sensor approaches ensure that workers can be evacuated promptly if any environmental factor exceeds safe thresholds [9].

Recent literature also highlights the importance of hardware stability in the harsh conditions of mining. Studies have detailed the use of voltage regulators, specifically the 7812 IC, to maintain a consistent power supply for sensitive electronic sensors and microcontrollers. This ensures that data remains accurate and the device remains functional despite the physical demands of the environment. The choice of robust components like the NodeMCU (ESP8266) has also been noted for its ability to provide self-contained Wi-Fi networking solutions that can operate in complex industrial settings [10].

Further research into the "Zero-Harm" philosophy has encouraged the transition from simple protective gear to intelligent personal protective equipment (PPE). This transition is characterized by the embedding of sensors directly into standard equipment like helmets, allowing for hands-free and non-intrusive monitoring. Authors have argued that this approach not only improves safety but also enhances environmental awareness for the worker. By making safety technology a part of the mandatory PPE, compliance is increased and the scope of data collection is broadened [11].

The role of centralized monitoring and automated alerting has been another significant theme in related work. Instead of relying on local alarms that might go unheard, researchers have advocated for transmitting all sensor data to a centralized IP-based server. This allow supervisors to monitor the entire workforce from a single dashboard and coordinate large-scale emergency responses more effectively. Automated protocols that trigger both web alerts and local buzzer alarms have been shown to be the most effective way to ensure immediate awareness of a hazard [12].

Another critical aspect discussed in existing literature is the methodology of photoplethysmography used in sensors like the MAX30100. This non-invasive method works by emitting red and infrared light into the skin to measure light absorption, which determines oxygen levels in the blood. The inclusion of this technology in a smart helmet represents a significant step forward from traditional spot-check medical devices to continuous, wearable vitals tracking. This shift allows for the detection of gradual health deterioration that might otherwise be missed during a shift [13].

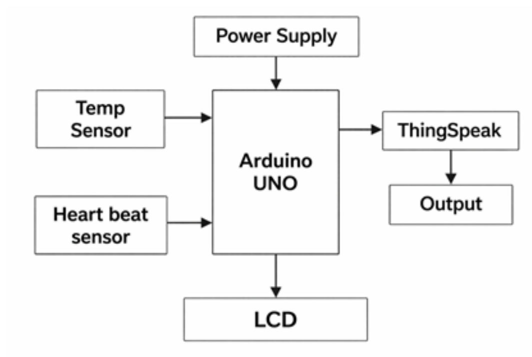
The literature survey also touches upon the use of haptic and auditory feedback for the wearer. By using integrated buzzers, safety systems can provide immediate, direct warnings to the worker without them needing to check a screen or device. This is particularly useful in low-visibility or loud environments where traditional visual cues might be missed. Active buzzers are preferred in these applications for their ease of integration and ability to produce continuous, high-volume sound when safety thresholds are breached [14].

Finally, the synthesized findings from related work suggest that the most effective safety systems are those that employ "sensor fusion"—combining physiological, environmental, and motion data. While older systems focused on a single threat, such as gas leaks, modern wearable solutions aim to provide a comprehensive safety net. This holistic approach, as explored in recent journals, is seen as the future of occupational health and safety in high-risk industries like mining. By building upon these diverse research threads, the current project seeks to provide a more integrated and scalable safety solution [15].

III.PROPOSED METHOD

The proposed system integrates a suite of wearable sensors into a smart helmet to provide real-time monitoring of a worker's health and immediate environmental conditions. Controlled by a NodeMCU (ESP8266) microcontroller, the system utilizes a MAX30100 pulse oximeter to track vital signs like heart rate and SpO_2, while an MPU6050 sensor is employed to detect fall directions for enhanced safety. Simultaneously, the helmet monitors atmospheric hazards using a DHT11 sensor for temperature and humidity and a Gas sensor for detecting toxic substances. All collected data is transmitted to a centralized IP address for live surveillance, where any breach of predefined safety thresholds triggers automatic web-based alerts and activates an integrated buzzer for an immediate emergency response.

IV.BLOCK DIAGRAM



Block diagram

The provided block diagram depicts the functional architecture of a safety monitoring system centered around an Arduino UNO microcontroller. The process begins with the Power Supply module, which provides the necessary electrical energy to the central controller and all interfaced peripherals. During the data acquisition phase, a Heart beat sensor captures the user's real-time physiological status, while a Temp Sensor monitors ambient conditions for potential environmental hazards. The Arduino UNO processes these incoming signals, evaluating them against predefined safety thresholds and simultaneously updating a local LCD to provide the worker with immediate on-site data visibility. For remote oversight, the processed information is transmitted to ThingSpeak, an IoT platform that enables real-time cloud-based surveillance and historical analysis. In the event of a threshold breach, the system triggers the final Output stage, which involves automated alerting mechanisms to ensure a rapid emergency response.

V.METHODOLOGY

Principle of Functioning

The proposed AI-Based Smart Helmet for Worker Safety operates to ensure real-time protection and health monitoring in high-risk industrial environments. A NodeMCU (ESP8266) or Arduino Uno acts as the central controller, continuously monitoring physiological and environmental parameters. A MAX30100 pulse oximeter and DHT11 sensor measure the worker's heart rate, SpO_2 levels, and ambient temperature/humidity to detect abnormal health conditions or heat exhaustion. In addition, an MPU6050 acceleration sensor is positioned within the helmet to detect fall directions or sudden physical impacts. The collected data is processed by the controller, and the system status is displayed in real-time on an integrated LCD. When abnormal health vitals, hazardous gas concentrations, or fall events are detected, the system immediately triggers protective actions, including activating a local buzzer alarm and sending an automated alert to the web dashboard for supervisor intervention.

Hardware & Alerts

The hardware components of the system include a NodeMCU (ESP8266) or Arduino Uno, MAX30100 pulse oximeter, MPU6050 acceleration sensor, DHT11 humidity and temperature sensor, Gas sensor, LCD display, buzzer, and a regulated power supply unit. The microcontroller acts as the central hub, processing sensor inputs and coordinating the system's real-time responses. The integrated LCD provides local, real-time information regarding heart rate, SpO_2 levels, and environmental status for immediate worker awareness. If abnormal physiological vitals, hazardous gas concentrations, or physical fall events are detected, the buzzer generates an audible alert to warn the wearer instantly. Simultaneously, the system leverages IoT connectivity to send automated alert messages to a centralized web dashboard, notifying authorized supervisors about the detected safety issue to facilitate rapid emergency coordination.

Power Requirements

The system operates using a regulated 12 V power supply, which provides stable power to the NodeMCU (ESP8266) or Arduino Uno controller, sensors, display unit, and other electronic components. Proper voltage regulation, achieved through a 7812 voltage regulator IC, ensures accurate sensing, reliable IoT communication, and safe operation of the entire monitoring framework. This integrated circuit acts as a fixed linear regulator that maintains a consistent 12 V output, protecting sensitive modules like the MAX30100 and MPU6050 from electrical fluctuations. This robust power configuration enables the system to function continuously, offering a reliable, low-cost, and efficient solution for maintaining the safety of industrial installations and ensuring uninterrupted worker surveillance.

Performance Comparison Table:

Parameter	Specification / Metric	Description
Central Controller	NodeMCU (ESP8266) / Arduino Uno	Acts as the main control unit that processes sensor data, monitors safety conditions, and manages IoT communication.
Health Monitoring	MAX30100 Pulse Oximeter	Continuously measures the worker's heart rate and oxygen saturation (SpO_2) to detect physiological distress or fatigue.
Motion Detection	MPU6050 Acceleration Sensor	Monitors 3-axis motion and orientation to identify sudden impacts, falls, or abnormal physical movements.
Climate Monitoring	DHT11 Sensor	Tracks ambient temperature and humidity levels to prevent heat-related illnesses and ensure a safe working environment.
Gas Surveillance	MQ-Series Gas Sensor	Detects the presence of toxic or combustible gases, ensuring timely evacuation in the event of a leak.
Status Display	I2C LCD Display	Provides real-time visual readings of health vitals and environmental status for immediate on-site monitoring.
Alert System	Buzzer	Generates an instant audible alarm when safety thresholds are breached or a fall event is detected.
Remote Notification	IoT / Web Dashboard	Transmits real-time data to a centralized IP or cloud platform (ThingSpeak) for

		remote supervisor oversight.

Table 1: *Performance Comparison Table*

Table 1 The proposed AI-based smart helmet system uses a NodeMCU (ESP8266) or Arduino Uno as the main controller to monitor and manage worker safety operations. A MAX30100 pulse oximeter and DHT11 sensor continuously measure physiological and environmental parameters to detect abnormal conditions such as health distress or heat exhaustion. An MPU6050 acceleration sensor is used to identify unauthorized physical impacts or fall events during work. The system status and real-time sensor readings are displayed on an integrated LCD for immediate on-site monitoring. When abnormal health vitals, hazardous gas levels, or falls are detected, a buzzer provides an instant audible alert and the system sends automated notification messages to a centralized web dashboard. The entire system operates using a regulated 12 V power supply, ensuring reliable and safe operation in high-risk industrial environments.

Table 2: Comparative Analysis of Conventional Techniques and the Developed Approach

Parameter	Existing Methods	Proposed Approach (Our System)
Safety Monitoring	Manual check-ins and periodic site inspections; incidents are often detected too late.	Continuous, real-time monitoring using a multi-sensor suite for instant detection of hazards.
Health Tracking	Reactive medical response only after a worker reports symptoms or an accident occurs.	Proactive health surveillance using pulse oximetry to identify vital sign anomalies before they escalate.
Fall Detection	Reliance on co-worker observation or manual distress calls from the injured party.	Automated fall detection using 3-axis accelerometers that trigger immediate alerts upon impact.
Environmental Awareness	Static, wall-mounted gas detectors that may not represent the worker's immediate micro-environment.	Personalized, wearable gas and climate sensors integrated into the helmet for localized safety data.
Alert Mechanism	Manual sirens or radio communication which can be delayed or missed in noisy environments.	Instantaneous dual-alert system featuring a local audible buzzer and remote web-based notifications.
Data Accessibility	Logbooks or localized data storage that requires physical retrieval for analysis.	Seamless IoT integration providing live cloud-based data access and historical logs for safety audits.

Table 2 The proposed AI-based smart helmet system significantly improves worker safety by combining real-time physiological monitoring, automated fall detection, and remote IoT alerts. The MAX30100 and DHT11 sensors detect health distress and environmental hazards early, while the MPU6050 acceleration sensor identifies sudden impacts or falls. A buzzer provides an immediate local audible alert, and the NodeMCU or Arduino sends instant notifications to a web dashboard, eliminating the need for manual check-ins. This approach enhances reliability, responsiveness, and overall personnel protection compared to conventional safety methods.

VI.CONCLUSION

The AI-Based Smart Helmet represents a significant advancement in industrial safety by effectively bridging the gap between passive protection and proactive real-time monitoring. By integrating a multi-sensor suite with IoT connectivity, the system successfully automates the detection of physiological distress, environmental hazards, and physical accidents such as falls. Utilizing a NodeMCU (ESP8266) or Arduino Uno as a central controller ensures that vital data—including heart rate, SpO_2, and gas concentrations—is processed and transmitted instantaneously to both a local LCD and a remote web dashboard. This integrated approach significantly reduces emergency response times through a dual-alert mechanism, utilizing a local buzzer for the wearer and automated cloud notifications for supervisors. Ultimately, the implementation of a stable 12V power supply and robust hardware components ensures that the system remains reliable in demanding environments, offering a scalable and cost-effective solution for modern occupational health and safety challenges.

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