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Design And Implementation of Wireless-Powered Smart Protective Device for Industrial IOT Applications

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Abstract
This paper presents the design and implementation of a wireless-powered smart protective device for industrial Internet of Things (IoT) applications aimed at enhancing worker safety and health monitoring. The proposed system integrates multiple biomedical sensors, including heart rate, SpO_2, temperature, and ECG, to continuously monitor the physiological condition of workers in real time. In addition, environmental sensors such as gas sensors and electrical conductivity sensors are incorporated to detect hazardous conditions in industrial environments.The system utilizes an Arduino-based microcontroller for data acquisition and processing, while the ESP8266 Wi-Fi module enables real-time data transmission to an IoT platform for remote monitoring and analysis. An RFID module is employed for worker identification and access control, ensuring enhanced workplace security. In case of abnormal health parameters or unsafe environmental conditions, the system generates immediate alerts through a buzzer and IoT notifications.The developed prototype demonstrates reliable performance in continuous monitoring and alert generation, thereby reducing the risk of accidents and improving response time. The integration of wearable sensing, safety compliance mechanisms, and IoT-based supervision provides a comprehensive solution for industrial safety management. This system contributes to creating a safer and more efficient working environment by enabling proactive risk detection and real-time decision-making.

***Keywords:** Industrial IoT, Smart PPE, Worker Safety, Health Monitoring, Arduino, ESP8266, RFID, Gas Detection.*

1. Introduction
Industrial sectors such as manufacturing, construction, and chemical processing involve hazardous environments where worker safety is a major concern. Conventional safety systems rely on personal protective equipment (PPE) and manual supervision, which are insufficient for real-time monitoring and early hazard detection. Recent advancements in Industrial Internet of Things (IIoT) have enabled the development of intelligent safety systems capable of continuous monitoring and automated alert generation. Wearable sensors and IoT platforms allow real-time tracking of physiological and environmental parameters, significantly improving safety management. This paper proposes a wireless-powered smart protective device that integrates health monitoring sensors, environmental sensors, and IoT communication. The system aims to detect early signs of worker fatigue, health abnormalities, and hazardous conditions, thereby preventing accidents and improving industrial safety.

2. Related Work
Several research studies have focused on IoT-based worker safety systems. Wearable devices have been used to monitor vital parameters such as heart rate, temperature, and ECG signals. RFID technology has been widely adopted for worker identification and access control. Previous works have also explored gas detection systems and wireless sensor networks for industrial safety. However, most existing systems lack integration of multiple safety features into a single platform and do not provide real-time

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decision-making capabilities. The proposed system overcomes these limitations by integrating health monitoring, environmental sensing, and IoT-based analytics into a unified smart protective device.

3. Existing System

In current industrial environments, worker safety primarily depends on conventional personal protective equipment such as helmets, gloves, and safety shoes. These systems provide only basic protection and do not support real-time monitoring of worker health or environmental conditions. Some existing systems include standalone sensors for gas detection or temperature monitoring. However, these systems operate independently and lack proper integration with other safety components. They do not continuously monitor vital health parameters such as heart rate, SpO_2, or ECG signals. Moreover, traditional safety systems do not provide real-time data transmission or remote monitoring capabilities. Alerts are often delayed, and there is no centralized system to analyze data and respond immediately to hazardous situations. Due to these limitations, existing systems are reactive rather than proactive, increasing the risk of workplace accidents. Hence, there is a need for an advanced system that integrates health monitoring, environmental sensing, and real-time communication to improve industrial safety. As Shown in Figure 1.

Figure 1 Work Safety

4. Proposed System

The proposed system is a wireless-powered smart protective device designed to enhance industrial safety through real-time monitoring of worker health and environmental conditions. The system integrates multiple sensors to continuously monitor vital parameters such as heart rate, SpO_2, body temperature, and ECG. In addition, environmental sensors are used to detect hazardous conditions such as toxic gas leakage and electrical risks. An Arduino microcontroller acts as the central unit, collecting and processing data from all sensors. The processed data is compared with predefined threshold values to identify abnormal conditions. The system uses an ESP8266 Wi-Fi module to transmit real-time data to an IoT platform, enabling remote monitoring and quick decision-making. An RFID module is incorporated for worker identification and access control. Whenever unsafe conditions are detected, the system immediately generates alerts using a buzzer, ensuring rapid response and preventing potential accidents. Overall, the proposed system provides a reliable, integrated, and real-time solution for improving industrial safety and reducing workplace risks. As Shown in Figure 2.

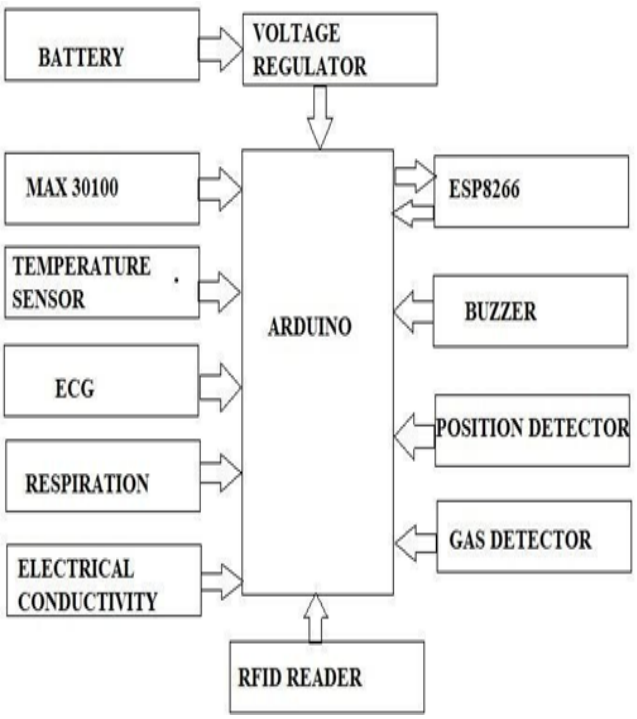

Figure 2 Proposed System

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5. Working Principle

The proposed system operates based on real-time data acquisition, processing, and IoT-based communication. Various sensors such as heart rate sensor, SpO_2 sensor, temperature sensor, ECG sensor, respiration sensor, and gas sensor are continuously used to monitor the health condition of the worker and the surrounding environment. All the sensor data are collected by the microcontroller (Arduino), where initial processing and analysis are carried out. The system continuously compares the obtained values with predefined safety limits. If any parameter exceeds the safe threshold, the system immediately identifies it as an abnormal condition.

The processed data is then transmitted to the IoT platform using a Wi-Fi module. The software application displays all the sensor readings such as BPM, SpO_2, temperature, ECG, respiration, gas levels, and worker details in real-time, as shown in the monitoring interface. This enables continuous remote monitoring by supervisors. As Shown in Figure 3.

Figure 3 microcontroller board

In case of unsafe conditions such as abnormal health parameters or detection of harmful gases, the system activates the alert mechanism. A buzzer is triggered to provide immediate warning to the worker. Additionally, the alert information is displayed on the LCD display and also updated in the IoT application interface. Thus, the system ensures that all parameters are continuously monitored, displayed, and controlled through both hardware (buzzer, display) and software (IoT application), providing a reliable and efficient safety monitoring solution safety.

6. System Implementation

6.1 Hardware Implementation

The hardware system is designed by integrating sensors, a microcontroller, and communication modules for real-time monitoring. As Shown in Figure 4.

Figure 4 Protective Equipment

6.2 Components

1. **Hardware Components**

a) **Power Supply Unit:** The power supply unit provides regulated DC power to all components. It converts AC voltage into DC using rectifiers, filters, and voltage regulators to ensure stable system operation.

b) **Voltage Regulator:** The voltage regulator maintains a constant output voltage regardless of input fluctuations, protecting sensitive electronic components.

c) **Arduino Microcontroller:** Arduino acts as the brain of the system. It collects sensor data, processes it, and controls communication between different modules.

d) **Wi-Fi Module (ESP8266):** This module enables wireless communication by sending real-time data to the IoT platform for remote monitoring and analysis. As shown in Figure 5.

Figure 5 Wi-Fi Module (ESP8266)

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e) MAX30100 Sensor: Used to measure heart rate and SpO_2 levels using photoplethysmography, ensuring continuous health monitoring. As shown in Figure 6.

Figure 6 MAX30100 Sensor

f) Gas Sensor: Detects harmful gases such as carbon monoxide and alerts the system when unsafe levels are detected. As shown in Figure 7.

Figure 7 Gas Sensor

g) RFID Module: Used for worker identification and access control. It ensures only authorized personnel enter restricted areas. As shown in Figure 8.

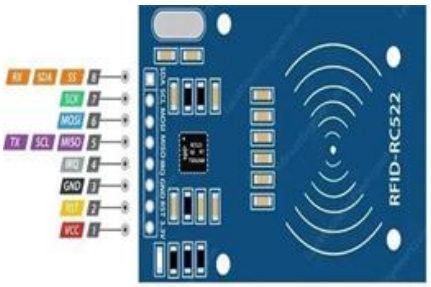

Figure 8 RFID Module

h) Temperature Sensor (LM35): Measures body or environmental temperature and helps detect abnormal conditions like fever or overheating. As Shown in Figure 9.

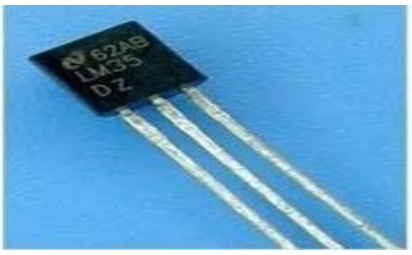

Figure 9 Temperature Sensor

i) Buzzer: Provides audible alerts during emergencies or when unsafe conditions are detected. As Shown in figure 10.

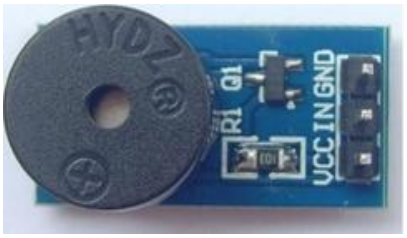

Figure 10 Buzzer

j) ECG Sensor: Monitors the electrical activity of the heart for advanced health tracking. As Shown in Figure 11.

Figure 11 ECG Sensor

6.3 Software Implementation

The system is programmed using Arduino IDE with Embedded C. The software initializes all sensors and continuously reads data from them. The collected data is processed and compared with predefined threshold values. If any abnormal condition is detected, the system activates the buzzer and sends data to the IoT platform through the Wi-Fi module. The software also manages RFID-based identification and ensures continuous monitoring through a looping process, enabling real-time response to potential hazards.

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6.4 Components

1. **Arduino IDE:**

Arduino IDE is used to write, compile, and upload code to the microcontroller. It provides a simple interface for development.

2. **Embedded C Language:**

Embedded C is used to program the microcontroller for sensor integration, data processing, and control operations.

3. **IoT Cloud Platform:**

The cloud platform stores and visualizes data. It allows real-time monitoring and historical data analysis.

4. **Communication Protocol (Wi-Fi):**

Wi-Fi enables data transmission between hardware and cloud using TCP/IP protocols.

5. **Data Processing & Alert System:**

Processes sensor data and generates alerts when abnormal conditions are detected.

7. Applications

The proposed smart protective device can be effectively used in a wide range of industrial and hazardous environments to enhance worker safety, health monitoring, and risk management.

- **Manufacturing industries:** Continuous monitoring of worker health and detection of unsafe conditions in production areas .
- **Chemical industries:** Detection of toxic gas leakage and prevention of exposure to harmful substances.
- **Construction sites:** Monitoring worker physical condition and reducing the risk of accidents in dynamic environments.
- **Mining industries:** Ensuring safety by detecting hazardous gases and low oxygen levels in underground operations.
- **Electrical industries:** Identification of electrical hazards and prevention of shock-related incidents.
- **Oil and gas sectors:** Real-time monitoring in high-risk zones such as refineries and drilling sites.
- **Fire and safety departments:** Assisting in emergency situations by tracking health status and environmental risks.
- **Smart industrial environments (Industry 4.0):** Integration with IoT systems for centralized monitoring and automation

8. RESULTS AND DISCUSSION

8.1 Results

The developed system was tested to evaluate its performance in monitoring worker health and environmental safety. The sensors successfully measured vital parameters such as heart rate, SpO_2, body temperature, and ECG signals with reliable accuracy. The gas sensor effectively detected harmful gases, and the electrical conductivity sensor identified unsafe electrical conditions. The Arduino microcontroller processed the sensor data efficiently and generated alerts without noticeable delay. Real-time data transmission was achieved through the ESP8266 Wi-Fi module, enabling continuous monitoring on the IoT platform. The buzzer alert system was triggered immediately when abnormal conditions were detected.

8.2 Discussion

The experimental results indicate that the system provides reliable and continuous monitoring of both physiological and environmental parameters. The integration of multiple sensors improves the overall safety coverage compared to conventional systems. The use of IoT communication enables remote monitoring and faster decision-making, reducing response time during emergencies. The system operates with low latency and maintains stable performance under different conditions. However, the system can be further improved by enhancing sensor accuracy, reducing power consumption, and integrating advanced technologies such as artificial intelligence for predictive analysis. Overall, the proposed system demonstrates significant potential in improving industrial safety and preventing workplace accidents.

Conclusion

This paper presented the design and implementation of a wireless-powered smart protective device for industrial safety using IoT technology. The primary objective of the work was to address the limitations of traditional safety systems, which lack real-time monitoring and early hazard detection capabilities. The results and discussion confirm that the proposed system successfully monitors both worker health parameters and environmental conditions in real

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time. The integration of sensors for heart rate, SpO_2, temperature, ECG, gas detection, and electrical conductivity enables comprehensive safety coverage within industrial environments. The system effectively identifies abnormal conditions and generates immediate alerts, ensuring quick response and minimizing potential risks. Furthermore, the incorporation of IoT technology allows continuous data transmission and remote monitoring, improving decision-making and safety management. The use of RFID enhances security by enabling proper worker identification and access control. Overall, the proposed system provides a reliable, efficient, and cost-effective solution for improving industrial safety. It significantly reduces the chances of workplace accidents by enabling early detection of hazards and continuous monitoring. Hence, the system effectively addresses the problem identified and demonstrates strong potential for real-world industrial applications.

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