IoT-Based Real-Time Wearable Shirt System for Health and Location Monitoring of Workers in the Mining Industry

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IoT-Based Real-Time Wearable Shirt System for Health and Location Monitoring of Workers in the Mining Industry

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Abstract: *This study developed an IoT-based wearable shirt system for real-time health and location monitoring tailored to the needs of workers in the mining industry. The system integrated multiple sensors to track vital signs including heart rate, body temperature, motion, and skin conductance, alongside GPS for location tracking. Powered by dual ESP32 microcontrollers, it achieved reliable data acquisition and transmission to cloud-linked platforms. Validation tests showed 94.63% accuracy in heart rate monitoring and 98.77% for temperature readings. A GSM module enabled real-time SMS alerts, ensuring timely responses to abnormal conditions. The system also featured a web-accessible 3D motion display and performed consistently in various signal environments. Designed to improve safety in hazardous areas, the wearable solution demonstrated strong potential for real-time worker monitoring. Recommendations included improving GPS signal acquisition and integrating waterproof, blood pressure-capable sensors for expanded use in medical and high-risk environments.*

Keywords: SMS, ECG, Real-time monitoring, GPS, GSR

1. INTRODUCTION

The mining industry is inherently hazardous, exposing workers to risks such as toxic gases, high temperatures, and structural collapses. Traditional safety measures often fall short in providing real-time monitoring and rapid response capabilities. The integration of Internet of Things (IoT) technology with wearable devices offers a promising solution to enhance worker safety and health monitoring in such challenging environments.

Recent advancements have led to the development of smart wearable gadgets specifically designed for miners, capable of detecting environmental hazards and physiological parameters to prevent accidents and health issues [1]. These devices can monitor vital signs such as heart rate, body temperature, and blood pressure, transmitting data in real-time to centralized systems for continuous health assessment [2]. Moreover, the incorporation of Wireless Sensor Networks (WSNs) in wearable devices enables efficient communication and data collection, crucial for monitoring miners' health and environmental conditions underground [3].

The application of wearable IoT devices extends beyond health monitoring. For instance, in the steel manufacturing industry, such devices have been employed to enhance worker safety by providing real-time data on environmental conditions and worker location, facilitating prompt responses to hazardous situations [4]. Similarly, in construction, wearable technologies have been utilized for personalized safety monitoring, allowing for the tracking of workers' physiological data and exposure to potential hazards [5]. The integration of smart textiles into wearable devices has further advanced the field, enabling the development of garments that can monitor various health parameters and environmental conditions [6]. These innovations have paved the way for the design of wearable shirts equipped with sensors to monitor miners' health and location in real-time, thereby enhancing safety protocols and emergency response mechanisms.

Furthermore, the implementation of IoT-based wearable health monitoring systems has proven effective in various scenarios, including the remote monitoring of quarantined individuals during health crises, demonstrating the versatility and reliability of such technologies [7]. The continuous evolution of wearable technology and IoT integration underscores the potential for developing comprehensive systems tailored to the specific needs of high-risk industries like mining.

This research aims to design and develop an IoT-based real-time wearable shirt system for health and location monitoring of workers in the mining industry. By leveraging the capabilities of smart textiles, IoT, and wearable technology, the proposed system seeks to enhance worker safety, facilitate prompt emergency responses, and contribute to the overall improvement of occupational health standards in mining operations.

2. MATERIALS AND METHODS

In Fig. 1, the wearable device is equipped with a set of sensors housed within the sensing unit, designed to monitor various physiological aspects of the wearer.

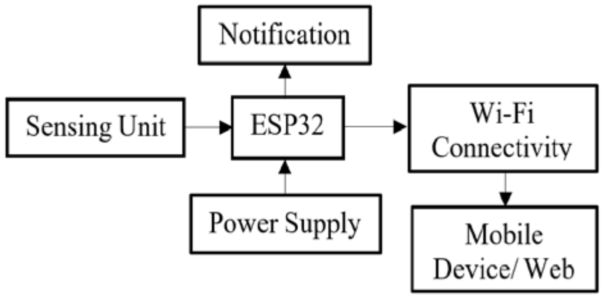


Fig. 1. Block diagram of the system design.

These sensors included a Heart Rate Sensor, which measured the wearer's pulse; a Galvanic Skin Response (GSR) Sensor, which detected skin conductance to assess emotional or physiological arousal; a Temperature Sensor, which recorded body temperature; and a Motion Sensor, which tracked movement and activity levels. Additionally, a Global Positioning System (GPS) module was integrated to determine the wearer's real-time location.

The data collected from these sensors was processed by the onboard microcontroller, specifically the ESP32 TTGO T-Call, which aggregated and interpreted the information before transmission. The microcontroller was powered by a dedicated power supply and established a Wi-Fi connection to send the processed data to a monitoring device or web platform for further analysis.

Once the data was collected and processed, the Arduino facilitated its transmission to a connected spreadsheet. This spreadsheet acted as a central database where all recorded information was automatically logged and updated in real time. As new sensor readings were received, the spreadsheet continuously refreshed, ensuring that the latest data was readily available for analysis. This automated process eliminated the need for manual data entry, reducing the risk of human error and improving efficiency. By streamlining data collection, processing, and storage, the system provided a reliable and real-time monitoring solution for tracking the wearer's physiological state and movements.

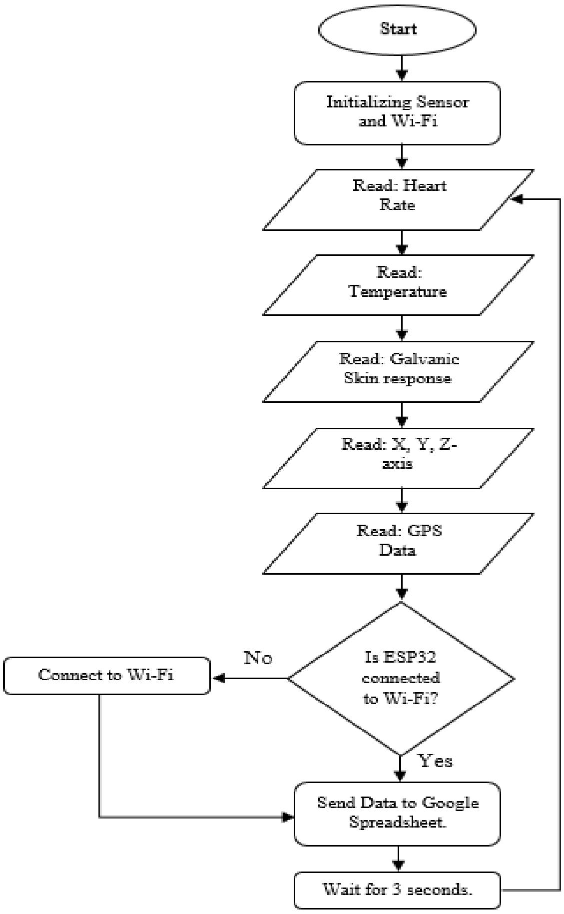


Fig. 2. Flowchart of the wearable shirt monitoring.

In Fig. 2, the system initialized all the connected sensors, including the heart rate sensor, temperature sensor, galvanic skin response (GSR) sensor, XYZ axis sensor, and GPS module. Simultaneously, it attempted to establish a Wi-Fi connection. Once initialization is complete, the microcontroller reads data from all sensors. The system then checked whether the ESP32 was connected to Wi-Fi. If a connection was established, the collected data was transmitted to a Google Spreadsheet. After successfully sending the data, the system waited for 3 seconds before reading all sensor values again. If the ESP32 was not connected to Wi-Fi, it continuously attempted to reconnect. Once the connection was restored, the system proceeded to send the data before repeating the cycle.

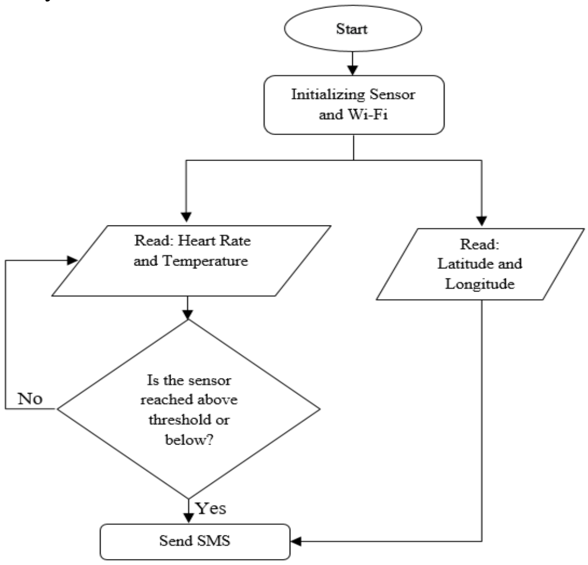
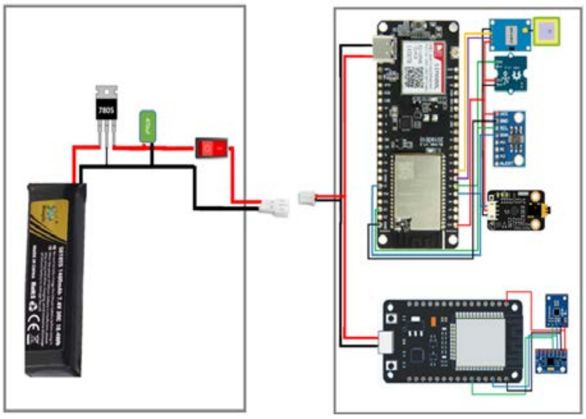


Fig. 3. Flowchart of the SMS Notification

The SMS notification system, as shown in Fig. 3, continuously read data from the heart rate and temperature sensors. It then checked whether the recorded values exceeded or fell below the predefined thresholds. If the heart rate was greater than 120 BPM or less than 60 BPM, the system sent an SMS warning message. Similarly, if the body temperature was above 37°C or below 35°C, an alert was triggered via SMS. If the readings remained within the normal range, the system continued monitoring by repeatedly collecting heart rate and temperature data. In addition to these conditions, the system also read GPS data and automatically sent the user's current location via SMS every 30 seconds. This process ran continuously, ensuring real-time health tracking and immediate notifications in case of abnormal readings.



(a) (b)

Fig. 4. (a) System Develop for power supply and (b) for Esp32.

In Fig. 4, illustrates the power supply configuration, where two ESP microcontrollers are connected in parallel. This setup allows the power supply to distribute voltage and current evenly between both microcontrollers, ensuring stable operation and preventing power imbalances that could affect performance. By connecting them in parallel, each ESP receives an equal share of power, reducing the risk of voltage drops or inconsistencies that might occur in a serial configuration.

Fig. 5. T-Shirt Design

Fig. 5 presents the design of the shirt, which incorporates an advanced anti-collision block structure to maintain flexibility while offering superior protection. The thick EVA padding is strategically placed to provide extra support to critical areas such as the ribs, chest, waist, shoulders, and back. This design ensures both comfort and safety, allowing for unrestricted movement while absorbing impact effectively.

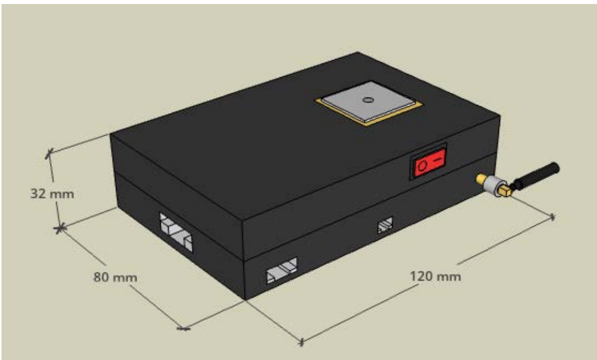


Fig. 6.Wearable device design

As shown in Fig. 6, the wearable device is designed with compact dimensions of 120 × 80 × 32 mm, allowing it to fit seamlessly into everyday clothing. Its small size ensures that it does not interfere with the user's movement or comfort, making it suitable for extended periods of use. The dimensions were carefully chosen to accommodate essential hardware components while keeping the overall form factor minimal and discreet. This compact design enhances the practicality of the device, making it ideal for continuous health and safety monitoring in various work environments, including confined or physically demanding spaces.

Fig. 7. Overall design (a)front and (b)back

3. RESULTS AND DISCUSSIONS

This section presented the findings from testing the IoT-based wearable shirt system for health and location monitoring. It evaluated how the system tracked vital signs and monitored locations in real-time. The process involved powering the device, configuring the sensors, and ensuring proper data transmission. Proper initialization was essential for accurate health monitoring, real-time location tracking, and seamless integration with cloud platforms. This section outlined the steps that were taken to set up the system and verify its functionality.

Table 1. Components specification

Component	Design Considerations
Battery Life	Lasts approximately 8.75 hours on a full charge
Battery Charging Time	Requires 2 hours and 6 minutes for a full charge
Device Gross Weight	Weigh 205 grams, maintaining a lightweight and comfortable design

During the initialization process, the wearer positioned themselves in an open area where the satellite signal could be easily detected. Once the GPS module received a strong signal, it accurately identified the wearer's location. The system then captured the latitude and longitude coordinates and automatically recorded them in a connected spreadsheet. This enabled real-time tracking of the wearer's position and ensured that the location monitoring feature functioned correctly. In Figure 8, Google Maps was used to visualize the location, which helped verify the accuracy of the wearer's position based on the provided latitude and longitude coordinates. This method proved to be a simple and effective way to pinpoint any place using its geographic coordinates.

For the body movement parameter, the system used motion sensors to track the movement of the wearer. It showed the position of the body along the X, Y, and Z axes, which represented side-to-side, forward-and-backward, and up-and-down directions. This helped detect whether the body was tilting, falling, or changing direction. The device was also connected to a network and provided an IP address that could be accessed through a browser. By opening this IP address, users were able to view real-time updates of how the object or person was moving or tilting, allowing for remote monitoring of the wearer's physical activity and orientation.

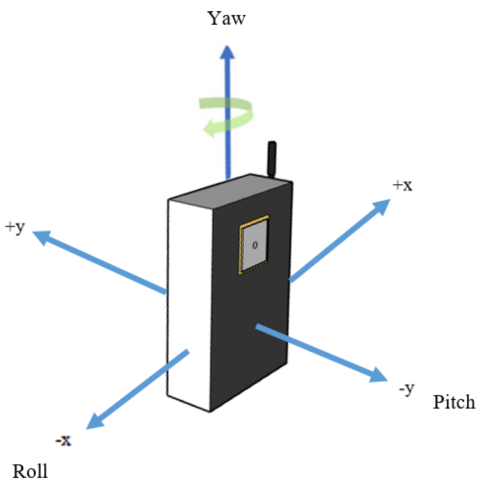


Fig. 8. Orientation and polarity.

In Fig. 8, the orientation and XYZ axis polarity of the sensor were illustrated, showing how the device interpreted the wearer's body movements as a 3D object. When the wearer tilted sideways—either to the left or right—it affected the X-axis; tilting to the left corresponded to the negative direction, while tilting to the right corresponded to the positive direction. Forward and backward leaning was represented on the Y-axis, with forward leaning indicating movement toward the positive Y-axis, and backward leaning indicating the negative Y-axis. Rotation of the body, such as turning left or right, was captured by the Z-axis and referred to as yaw. Together, these three axes provided a complete representation of the wearer's orientation and movements, which was valuable for applications such as posture monitoring, motion tracking, and balance analysis.
To calculate these angles, the system typically used data from sensors like accelerometers (for pitch and roll) and magnetometers (for yaw). The values were derived using trigonometric formulas, particularly the arctangent function (atan2), which helped compute angles from the ratios of vector components.

$$\theta = \text{Pitch} = \arctan\left(\frac{-Ax}{\sqrt{Ay^2+Az^2}}\right)\left(\frac{180}{\pi}\right) \qquad \text{(Eq. 1)}$$

$$\emptyset = \text{Roll} = \arctan\left(\frac{-Ay}{\sqrt{Ax^2+Az^2}}\right)\left(\frac{180}{\pi}\right) \qquad \text{(Eq. 2)}$$

$$\psi = \text{Yaw} = \arctan\left(\frac{-Mx}{My}\right)\left(\frac{180}{\pi}\right) \qquad \text{(Eq. 3)}$$

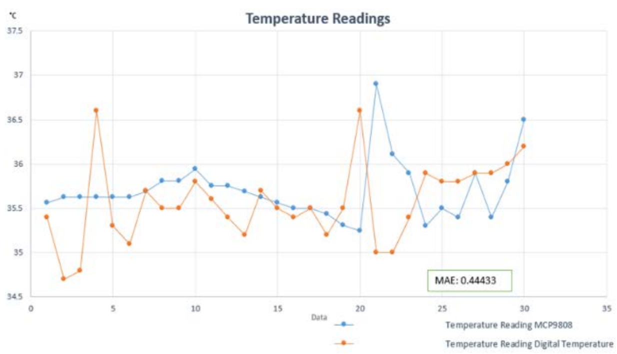


Fig. 9. Temperature Accuracy Readings

In Fig. 9, the comparison between the temperature readings from the MCP9808 sensor and a digital temperature reference device is shown. This comparison was made to check how accurate the MCP9808 sensor is. After collecting 30 temperature readings from both the MCP9808 sensor and a digital thermometer, the absolute error for each pair of values was calculated. The total sum of all absolute errors was 13.33. Using the Mean Absolute Error (MAE) formula. The result showed an MAE value of 0.44433.

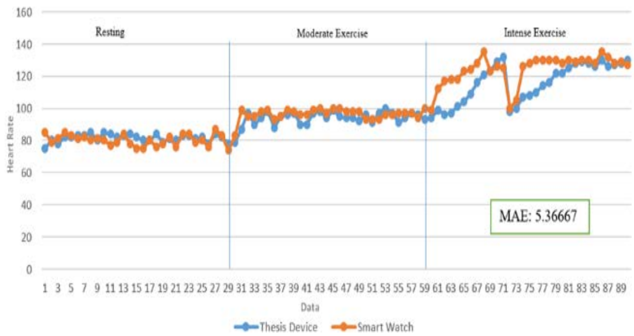
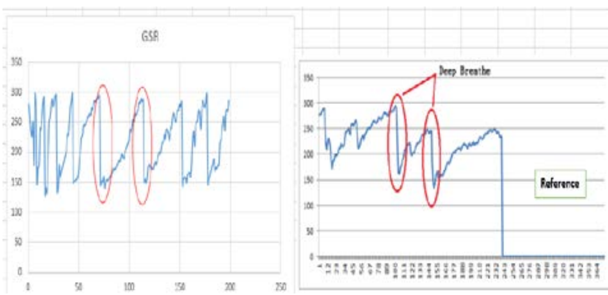


Fig. 10. Overall heart rate accuracy reading

After combining all the data from resting to intense exercise as shown in figure 44, the total absolute error is 483, and the Mean Absolute Error (MAE) is 5.37 (rounded). The absolute error of 483 reflects the overall difference between the heart rate readings of the Gravity ECG sensor and the smartwatch across all stages. The MAE of 5.37 means that, on average, the two devices' heart rate readings differ by 5.37 beats per minute. This MAE value is a good indication of how closely the two devices performed overall, showing that, on average, the heart rate measurements are consistent between them, even as activity intensity increases. To express this MAE as a percentage accuracy, it is necessary to relate it to the typical heart rate range. For this analysis, a standard heart rate of 100 beats per minute is used as the reference point.



(a) (b)

Figure 11. (a) Actual and, (b) Reference Data of GSR

In the Galvanic Skin Response (GSR) system, the SEEED Studio Grove GSR sensor was used as the reference device, as shown in Figure 13(b). This device was known for its accuracy in measuring skin conductivity using electrodes, which were typically placed on the fingers for the most direct and responsive readings. However, since the goal of the project was to integrate the system into a wearable shirt design, the placement of the electrodes had to be adapted. Instead of the fingers, the electrode was positioned on the upper right back shoulder.

This location was chosen because it allowed the electrodes to stay in contact with the skin in a more practical and comfortable way while wearing the shirt, without limiting the wearer's movement. The upper back also provided a relatively stable surface with less sweat variation compared to the hands, which helped in obtaining more consistent GSR readings while still maintaining the wearable concept. This adjustment supported the overall design goal of creating a functional, real-time monitoring system that fit naturally into daily use, especially in work environments like mining.

The system successfully sent all SMS messages to the receiver, as shown in Figure 14. As long as there was a stable mobile signal—even with just one signal bar—the device was able to transmit messages without issue. It used a TTGO SIM800L module to send messages through a cellular network. This ensured that important alerts or updates were still delivered, even in low-signal areas.

Table 2. SMS delivery time by signal strength (TTGO SIM800L)

Signal Strength	Signal Description	Estimated Delivery Time
4 Bars	Excellent Signal	1–3 seconds
3 Bars	Good Signal	3–5 seconds
2 Bars	Fair Signal	5–10 seconds
1 Bar	Weak Signal	10–20 seconds
0 Bars (No Signal)	No Connectivity	SMS will fail to send

Each bar represented a different level of signal quality, as shown in Table 2. To ensure the system performed well, especially during emergencies, a timer was configured for each signal bar. This setup allowed testing of how quickly the SMS was delivered depending on the strength of the cellular signal. By analyzing the time delays at each signal level, the system's reliability and responsiveness were evaluated, ensuring it could send alerts promptly even when signal strength varied in real-world mining or remote conditions.

4. CONLUSION

This study successfully designed, developed, and tested an IoT-based wearable shirt system aimed at enhancing health and safety monitoring for workers in the mining industry. By integrating multiple sensors—including ECG, GSR, temperature, motion, and GPS—into a wearable platform powered by ESP32 microcontrollers, the system demonstrated real-time tracking of vital signs and physical location with high accuracy and reliability. The deployment of dual ESP modules ensured efficient data processing, overcoming transmission delays when handling multiple sensors. Field tests confirmed the system's accuracy, with heart rate and temperature sensors achieving 94.63% and 98.77% accuracy respectively, while GSR readings remained consistent despite modified electrode placement. Moreover, the system's SMS notification feature proved effective in various signal conditions, offering timely alerts in emergency scenarios. The overall findings highlight the feasibility and practical utility of the developed system for real-time monitoring in hazardous environments, contributing to improved occupational health standards and emergency responsiveness in the mining sector.

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