

ZIGBEE SMART SAFETY WAIST

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ABSTRACT

Safety monitoring systems have become increasingly important in modern healthcare and industrial environments, especially for individuals working in hazardous conditions. Workers such as miners, construction laborers, firefighters, and rescue personnel are often exposed to dangerous environments where sudden health problems, environmental changes, or accidents may occur. Continuous monitoring of vital health parameters and environmental conditions is necessary to ensure their safety. Therefore, the Zigbee Smart Safety Waist System is designed to monitor a person's health conditions and transmit emergency alerts to a remote monitoring station. The proposed system is built around the ESP32 microcontroller, which acts as the central processing unit. Several sensors are integrated into the wearable device to monitor the user's condition. The DHT11 sensor measures temperature and humidity levels, while the SpO2 sensor monitors blood oxygen levels and pulse rate. A vibration sensor is used to detect sudden movements, impacts, or falls that may indicate an accident. In addition, a GPS module is used to track the real-time location of the user. The collected data is processed by the ESP32 and displayed on an LCD display for local monitoring. For wireless communication, the system uses Zigbee technology to transmit sensor data from the wearable device (transmitter module) to a remote monitoring station (receiver module). At the receiver side, another ESP32 processes the received data and displays the information on an LCD screen. A buzzer is activated when abnormal conditions are detected, providing immediate alerts. The system also integrates IoT technology to enable remote monitoring through internet-based platforms. By combining wearable sensors, wireless communication, and IoT monitoring, the proposed Zigbee Smart Safety Waist system provides an efficient solution for real-time health monitoring and emergency alert generation, thereby improving the safety and protection of workers in hazardous environments.

Key words: ESP32, Zigbee Communication, IoT-Based Monitoring, Smart Safety Waist System, Health Monitoring, GPS Tracking, SpO2 Sensor, DHT11 Sensor, Vibration Detection, Emergency Alert System, Wearable Safety Device.

1. INTRODUCTION

In modern industries such as mining, construction, oil and gas plants, firefighting, and rescue operations, worker safety has become a critical concern due to the presence of hazardous environmental conditions and high-risk operational activities. Workers are frequently exposed to extreme temperatures, oxygen deficiency, toxic surroundings, physical injuries, and accidental falls that may lead to serious health complications or even loss of life. Traditional monitoring systems mainly depend on manual supervision and periodic inspections, which are often insufficient for detecting sudden emergencies in real time. In many situations, workers may not be able to communicate their condition during accidents, causing delays in rescue and medical assistance. Therefore, the development of intelligent wearable safety systems capable of continuously monitoring health and environmental parameters has become essential for improving industrial safety.

Recent advancements in embedded systems, wireless communication, and Internet of Things (IoT) technologies have enabled the implementation of smart monitoring solutions that provide real-time data acquisition, automated alert generation, and remote supervision. These technologies significantly improve emergency response time and enhance the overall safety and health management of industrial

workers operating in dangerous environments. The proposed IoT-based Zigbee Smart Safety Waist System is developed as an advanced wearable healthcare and industrial safety monitoring solution that continuously observes the worker's physical condition and surrounding environmental parameters. The system is centered around the ESP32 microcontroller, which acts as the primary processing and communication unit responsible for collecting sensor data, processing information, and controlling wireless communication modules.

The DHT11 sensor is used to monitor temperature and humidity conditions, while the MAX30105 sensor continuously measures heart rate and blood oxygen saturation (SpO₂) levels to evaluate the worker's health status. A vibration and fall detection sensor is incorporated to identify sudden movements, impacts, or accidental falls, and a GPS module provides real-time location tracking for emergency rescue operations. Zigbee wireless communication technology is utilized to establish reliable low-power communication between the wearable transmitter and receiver monitoring units. At the receiver side, another ESP32 microcontroller processes the received information and displays the monitoring data on an LCD module while also activating an emergency buzzer during abnormal situations. Furthermore, IoT cloud integration enables remote monitoring through web and mobile applications, allowing supervisors to perform live health tracking, emergency alert management, and continuous worker safety monitoring from remote locations.

2. LITERATURE SURVEY

S. Sharma, R. Patel, and M. Gupta [1] proposed a wearable safety monitoring system designed for industrial workers using embedded sensor technology. The system continuously monitors environmental parameters such as temperature and humidity and transmits the collected data to a monitoring station. The researchers emphasized that continuous monitoring of environmental conditions can help reduce accidents in hazardous workplaces. However, the system mainly focuses on environmental monitoring and does not include health monitoring sensors such as SpO₂ or pulse sensors.

A. Kumar and P. Singh [2] developed an IoT-based wearable safety system for workers operating in hazardous industrial environments. Their system integrates sensors to monitor environmental parameters and transmits the information through wireless networks to remote monitoring platforms. The authors highlighted the importance of remote monitoring for improving worker safety. However, the system does not provide location tracking or fall detection mechanisms that are essential during emergency situations.

J. Patel, S. Shah, and P. Mehta [3] introduced a smart wearable health monitoring system designed to track vital parameters such as heart rate and body temperature. The system uses microcontroller-based processing and wireless communication to transmit health data to a monitoring station. The researchers demonstrated that wearable health monitoring devices can help detect abnormal conditions at an early stage. However, their system focuses mainly on health monitoring and does not include environmental monitoring or accident detection features.

M. Hasan and K. Rahman [4] proposed a smart worker safety monitoring system using sensor networks and wireless communication technologies. The system collects environmental data such as temperature and gas levels and transmits the information to a remote monitoring center. The authors highlighted that early detection of hazardous environmental conditions can prevent accidents. However, the system lacks health monitoring capabilities and real-time location tracking.

R. Das, P. Roy, and S. Dutta [5] developed a wireless safety monitoring system designed for industrial environments. The system collects sensor data and transmits it through wireless communication networks to a monitoring platform. The study demonstrates the advantages of wireless sensor networks

in improving safety management. However, the proposed system does not integrate wearable health monitoring sensors or accident detection mechanisms.

T. Nguyen and H. Lee [6] proposed an IoT-based smart worker monitoring system that collects health and environmental data and transmits it to cloud-based monitoring platforms. The system allows supervisors to monitor worker conditions in real time. The researchers emphasized that IoT technology can improve workplace safety by enabling continuous monitoring. However, the system lacks location tracking capabilities and fall detection features.

S. Roy and P. Dutta [7] developed an intelligent wearable health monitoring device capable of monitoring pulse rate and body temperature. The system transmits the collected data to a remote monitoring platform using wireless communication technology. The study highlights the importance of wearable health monitoring devices in medical and industrial applications. However, the system does not include environmental monitoring or emergency alert systems.

K. Sharma and A. Verma [8] designed a microcontroller-based worker safety monitoring system capable of detecting environmental hazards. The system includes temperature and gas sensors that help identify dangerous conditions in industrial environments. The authors emphasized that early detection of environmental hazards can significantly reduce accident risks. However, the system does not include wearable health monitoring sensors or GPS tracking.

P. Gupta and S. Mehta [9] proposed a smart accident detection system that uses vibration sensors to detect sudden impacts or falls. The system can generate alerts when abnormal vibrations are detected. The researchers demonstrated that vibration sensors can effectively detect accidents in real-time applications. However, the system does not include health monitoring features such as oxygen level monitoring.

M. Ahmed et. al, [10] developed an IoT-based health monitoring system designed to monitor physiological parameters such as heart rate and oxygen levels. The system transmits sensor data to a cloud platform where it can be analyzed remotely. The authors emphasized that IoT-based health monitoring systems can improve patient safety and remote medical care. However, the system does not include environmental monitoring or accident detection capabilities.

S. Patel and V. Shah [11] designed a smart wearable device capable of monitoring worker health conditions in hazardous environments. The system collects physiological data and transmits it to remote monitoring stations using wireless communication. The study highlights the importance of wearable safety devices in improving workplace safety. However, the system lacks GPS-based location tracking.

R. Mehta et. al, [12] introduced an embedded safety monitoring system that uses multiple sensors to monitor environmental and physiological conditions. The system provides real-time monitoring of worker safety parameters. The researchers demonstrated that integrating multiple sensors can improve the reliability of safety monitoring systems. However, the system does not include IoT-based remote monitoring features.

A. Rahman et. al, [13] proposed an IoT-enabled worker safety monitoring platform capable of transmitting sensor data to cloud servers. The system allows supervisors to remotely monitor worker conditions and environmental parameters. The study emphasizes that IoT technology can improve safety management in hazardous industries. However, the system does not include GPS-based location tracking.

P. Singh and R. Kumar [14] developed a wearable health monitoring system designed to detect abnormal physiological conditions. The system collects sensor data and transmits it to monitoring platforms using wireless communication. The authors highlight that wearable monitoring systems can

improve emergency response time. However, the system does not include environmental monitoring features.

D. Fernandes et. al, [15] proposed a wireless worker safety monitoring system that uses sensor networks to monitor environmental conditions. The system transmits sensor data to monitoring stations for analysis. The research highlights the importance of wireless sensor networks in industrial safety applications. However, the system does not integrate health monitoring sensors.

3. PROPOSED SYSTEM

The proposed IoT-based Zigbee Smart Safety Waist System is designed to provide continuous industrial worker health and safety monitoring using embedded and IoT technologies, as shown in Figure 1. The wearable transmitter unit is integrated into a smart safety waist belt and is centered around the ESP32 microcontroller, which performs data acquisition, processing, and communication functions. Multiple sensors are connected to the ESP32, including the DHT11 sensor for temperature and humidity monitoring, the MAX30105 sensor for heart-rate and SpO2 measurement, and a vibration/fall detection sensor for accident identification. A GPS module is incorporated to provide real-time location tracking and live coordinate monitoring of the worker. The sensed data are displayed locally through a 16×2 LCD module for immediate observation and monitoring. In addition, the ESP32 supports Wi-Fi and HTTP-based IoT communication for cloud connectivity and internet-enabled healthcare applications. The processed information is transmitted wirelessly through a Zigbee transmitter module, enabling low-power and reliable real-time communication between the wearable node and the remote monitoring station.

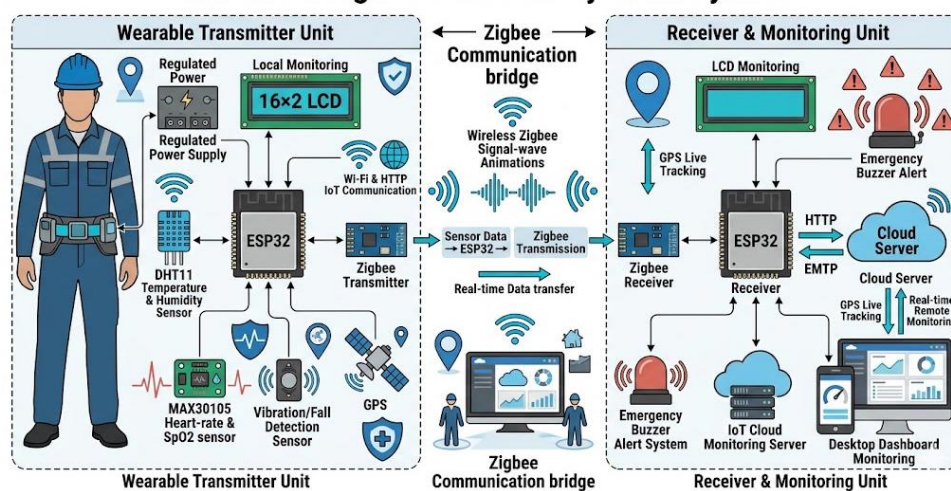


Figure 1: The system architecture of IoT-based zigbee smart safety waist

The receiver and monitoring unit is responsible for collecting, analysing, and displaying the transmitted sensor information for remote healthcare supervision and emergency management. A Zigbee receiver module connected to the ESP32 receiver continuously receives sensor data transmitted from the wearable transmitter section through the Zigbee communication bridge. The receiver ESP32 forwards the acquired information to an LCD monitoring display, IoT cloud server, mobile dashboard, and desktop monitoring system for real-time visualization and analysis. The cloud platform enables remote monitoring, GPS live tracking, data storage, and continuous healthcare analytics through HTTP communication protocols. An emergency buzzer alert system is integrated to generate immediate warnings whenever abnormal conditions such as fall detection, low SpO2 levels, or unsafe environmental conditions are identified. The Zigbee communication bridge ensures stable wireless serial communication with low latency and reduced power consumption suitable for industrial

environments. Overall, the proposed architecture provides an efficient smart healthcare and industrial safety monitoring framework capable of supporting real-time sensing, cloud integration, and rapid emergency response mechanisms.

4. RESULTS AND DISCUSSION

The Results and Discussion section evaluates the performance and functionality of the proposed ESP32-based biometric monitoring and tracking system through a series of experimental tests. The integrated hardware modules, including the fingerprint sensor, GPS receiver, LCD display, and communication components, were successfully deployed and validated under real-time conditions. The obtained results demonstrate accurate user authentication, reliable location tracking, and efficient data display capabilities. Furthermore, the system effectively transmitted and visualized location information on a monitoring platform, confirming its operational reliability. The discussion highlights the effectiveness, accuracy, and practical applicability of the proposed solution for secure monitoring and tracking applications.

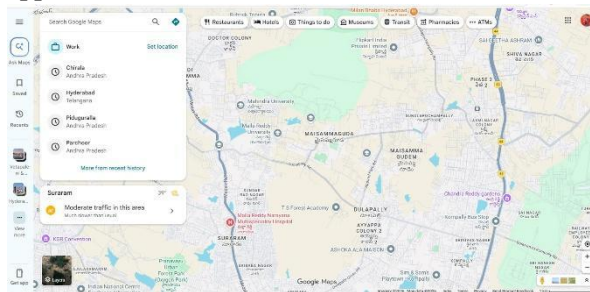


Figure 2. Real-Time GPS Location Tracking and Map Visualization of the Proposed System

Figure 2 illustrates the real-time location tracking functionality of the proposed ESP32-based biometric monitoring and tracking system. The GPS module continuously acquires geographic coordinates, which are displayed on the 16×2 LCD interface and transmitted to the monitoring platform. The obtained latitude and longitude values are visualized on Google Maps, enabling accurate tracking of the user's current location. The displayed map confirms successful communication between the embedded device and the location monitoring application. Experimental results demonstrate that the system can reliably capture, process, and present real-time positioning information, thereby enhancing user safety, remote monitoring, and emergency response capabilities.

5. CONCLUSION

The Zigbee Smart Safety Waist System is designed to provide real-time health and safety monitoring for workers operating in hazardous industrial environments such as mining, construction, firefighting, and rescue operations. The system uses an ESP32 microcontroller to collect and process data from sensors including the DHT11 temperature and humidity sensor, MAX30105 heart-rate and SpO2 sensor, vibration/fall detection sensor, and GPS module for live location tracking. The collected information is transmitted wirelessly through Zigbee communication to the receiver and monitoring unit for continuous observation. An LCD display and emergency buzzer are integrated to provide local monitoring and instant alert generation during abnormal situations. The integration of IoT technology enables remote monitoring through cloud, mobile, and web-based platforms for real-time supervision and emergency response. Overall, the proposed system improves worker safety by providing continuous monitoring, accident detection, and reliable wireless communication in dangerous working environments.

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