IoT Driven Smart Safety Waist System Using ESP32 with Zigbee Communication and Emergency Alert System

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Abstract

The increasing need for worker safety in hazardous environments has driven the adoption of intelligent monitoring systems, with occupational accidents causing over 2.7 million deaths globally each year and industrial safety technologies growing at more than 15% annually. Additionally, real-time health monitoring and environmental sensing have become critical in reducing fatal risks in industries such as mining, construction, firefighting, and rescue operations. Traditional safety systems rely on manual supervision and periodic health checks, which are often insufficient in detecting sudden health deterioration, accidents, or environmental hazards. Furthermore, conventional systems lack continuous monitoring, wireless communication, and real-time alert mechanisms, resulting in delayed emergency response and increased risk to human life. To address these challenges, the proposed Zigbee Smart Safety Waist System utilizes the ESP32 microcontroller to develop an intelligent wearable safety solution. The system integrates DHT11 sensors for temperature and humidity monitoring, SpO2 sensors for blood oxygen and pulse rate measurement, and vibration sensors to detect falls or impacts. A GPS module provides real-time location tracking, while Zigbee communication enables reliable wireless data transmission to a remote monitoring station. At the receiver end, another ESP32 processes and displays the data, while a buzzer generates immediate alerts upon detecting abnormal conditions. IoT integration further allows remote monitoring and data logging through cloud platforms. This smart system enhances worker safety, enables rapid emergency response, and provides a scalable solution for real-time health and environmental monitoring in hazardous environments.

Keywords: DHT11 Sensor, ESP32, GPS Tracking, Hazard Monitoring, Internet of Things, SpO2 Monitoring, Wearable Safety System, Wireless Communication, Worker Safety, ZigBee Technology

1. Introduction

The increasing need for safety monitoring systems in healthcare and industrial sectors has become critical due to the rising number of workplace hazards and occupational risks. Globally, millions of workers are exposed to dangerous environments, with reports indicating that over 2.3 million deaths occur annually due to work-related accidents and diseases [1]. Industries such as mining, construction, firefighting, and rescue operations involve high-risk conditions where sudden health issues, environmental changes, or accidents can occur at any time. These scenarios require continuous monitoring of vital health parameters and environmental conditions to ensure timely intervention and worker safety [2]. With advancements in wearable technology and IoT, there is a growing demand for intelligent systems capable of real-time monitoring, wireless communication, and emergency alert generation.

Traditional safety monitoring approaches rely heavily on manual supervision and periodic health checks, which are often insufficient in hazardous environments [3]. Workers are typically monitored through visual inspection or basic safety equipment that does not provide continuous data about their health or surroundings. These methods lack real-time tracking and immediate alert mechanisms, making it difficult to respond quickly during emergencies [4]. Additionally, conventional systems do not integrate multiple sensors or wireless communication technologies, limiting their ability to provide comprehensive safety monitoring. The absence of remote monitoring further reduces the effectiveness of these systems in large-scale or remote industrial sites [5].

In real-time scenarios, these limitations lead to several critical challenges that can compromise worker safety [6]. Sudden incidents such as falls, oxygen level drops, or extreme environmental conditions may go undetected without continuous monitoring systems. Delayed communication and lack of real-time location tracking can hinder rescue operations and increase the severity of accidents [7]. Furthermore, the absence of automated alert systems prevents immediate notification to supervisors or emergency teams. These challenges highlight the need for an intelligent, IoT-based wearable safety system that can continuously monitor health parameters, detect abnormal conditions, and provide instant alerts with location tracking. Such a system enhances worker protection, enables rapid emergency response, and ensures improved safety in hazardous environments.

2. Literature Survey

Pepe et al. [8] proposed a system-on-a-chip ultra-wideband radar sensor for contactless respiratory monitoring that enabled non-invasive measurement of breathing patterns. Ensafi [9] proposed foundational concepts of sensors and biosensors, covering principles, classifications, and applications in healthcare monitoring systems. Chambers et al. [10] proposed the use of digital personal assistants as assistive technology to support patient health and wellbeing through reminders, monitoring, and communication features.

Shankar et al. [11] proposed I-CARES, an IoT-based healthcare system that enabled diagnosis and medication support through connected devices and intelligent data processing. Goldberger et al. [12] proposed PhysioBank, PhysioToolkit, and PhysioNet as integrated resources for analyzing complex physiological signals. Sempionatto et al. [13] proposed a wearable soft electrochemical microfluidic device integrated with iontophoresis for sweat biosensing.

Chowdhary et al. [14] proposed a survey on digital transformation in healthcare, focusing on technologies such as IoT, artificial intelligence, and cloud computing. Dobrota et al. [15] proposed a secure data transmission method using electrocardiogram (ECG) signals and named data networking for protecting health-related data. Parimi et al. [16] proposed a machine learning-based system for multilevel stress detection using ECG signals and feature selection techniques.

Islam [17] proposed an IoT-based system for environmental quality monitoring and cloud data logging, enabling real-time data acquisition and storage. Venkatraman et al. [18] proposed an integrated mobile health (mHealth) and vehicular sensor-based emergency notification system for long-distance drivers.

Bond et al. [19] proposed wearable technology-based metrics to predict operator performance during cardiac catheterization using physiological data. Duong et al. [20] proposed a Very High-Speed Integrated Circuit Hardware Description Language (VHDL)-based controller design for photoplethysmography-based heart rate monitoring systems.

3. Proposed System

Figure 1 illustrates the transmitter module of the Zigbee Smart Safety Waist system built around the ESP32. This wearable unit integrates multiple sensors such as DHT11 (temperature and humidity), SpO2 (oxygen level), vibration sensor (fall detection), and GPS (location tracking). A regulated power supply ensures stable operation. The ESP32 processes all sensor data and transmits it wirelessly using a Zigbee transmitter module to the receiver unit. This module is responsible for continuous real-time monitoring of worker health and environmental conditions.

Step 1: Power Supply Initialization: The regulated power supply provides stable voltage to the ESP32 and all sensors, ensuring reliable wearable operation.

Step 2: Environmental Monitoring (DHT11 Sensor): The DHT11 sensor measures temperature and humidity to detect unsafe environmental conditions such as excessive heat or humidity.

Step 3: Health Monitoring (SpO2 Sensor): The SpO2 sensor monitors blood oxygen levels and pulse rate, helping detect health abnormalities in the worker.

Step 4: Motion and Fall Detection: The vibration sensor detects sudden shocks, abnormal movements, or falls, indicating possible accidents.

Step 5: Location Tracking (GPS Module): The GPS module provides real-time location data, which is crucial during emergencies for quick rescue operations.

Step 6: Data Processing and Transmission: The ESP32 processes all sensor inputs and transmits the data wirelessly using the Zigbee transmitter (Tx) module to the receiver section.

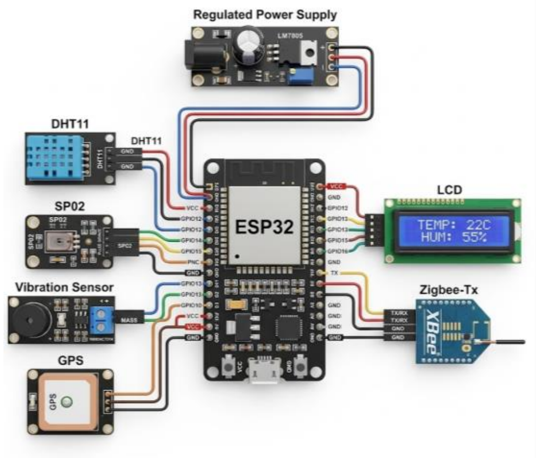

Figure 1: Zigbee Smart Safety Waist – Transmitter Module.

Figure 2 illustrates the receiver module of the Zigbee Smart Safety Waist system, where the ESP32 acts as the central processing unit. The Zigbee receiver (Rx) collects transmitted data from the wearable transmitter module. The ESP32 processes this data and displays it on an LCD while generating alerts through a buzzer in case of abnormal conditions. Additionally, IoT connectivity enables remote monitoring through cloud platforms. This module serves as the monitoring station for ensuring worker safety.

Step 1: Power Supply Initialization: A regulated power supply ensures stable operation of the ESP32 and connected modules in the receiver unit.

Step 2: Data Reception via Zigbee: The Zigbee receiver (Rx) receives real-time sensor data transmitted from the wearable transmitter module.

Step 3: Data Processing Using ESP32: The ESP32 processes the received data and checks for abnormal conditions such as high temperature, low oxygen levels, or fall detection.

Step 4: LCD Display Output: The LCD displays real-time parameters such as temperature, humidity, oxygen levels, and worker location for monitoring purposes.

Step 5: Buzzer Alert System: If any abnormal condition is detected, the buzzer is activated to provide immediate alerts to nearby personnel.

Step 6: IoT-Based Remote Monitoring: The ESP32 sends processed data to a cloud server via IoT, enabling remote monitoring, data logging, and analysis through web or mobile applications.

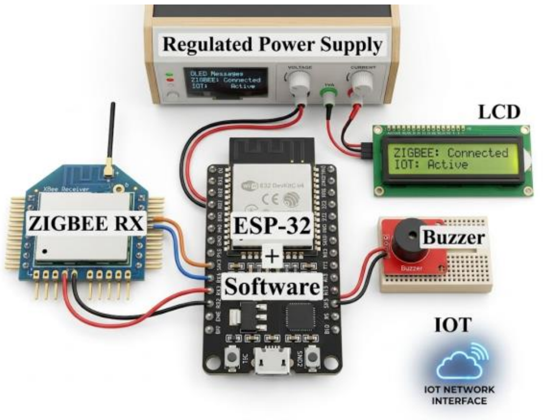

Figure 2: Zigbee Smart Safety Waist – Receiver Module

3.1 Working Procedure

The flowchart of the Zigbee Smart Safety Waist system as shown in Figure 3 consists of two main sections: the transmitter module (wearable device) and the receiver module (monitoring station). The transmitter module is responsible for collecting sensor data from the worker and transmitting it wirelessly to the receiver module. The receiver module receives the transmitted data and displays the information for monitoring purposes.

In the transmitter module, a regulated power supply provides stable DC voltage to all system components. The ESP32 microcontroller acts as the main controller that collects and processes data from the sensors. The DHT11 sensor measures temperature and humidity levels around the worker, while the SpO2 sensor monitors the blood oxygen level and pulse rate. The vibration sensor detects sudden movements or impacts that may indicate a fall or accident. The GPS module provides the geographical location of the worker in real time. All the collected sensor data is processed by the ESP32 microcontroller.

After processing the sensor data, the ESP32 transmits the information through a Zigbee transmitter module. Zigbee communication technology is used because it provides reliable wireless communication with low power consumption, which makes it suitable for wearable devices.

In the receiver module, a Zigbee receiver module receives the transmitted data from the transmitter. Another ESP32 microcontroller processes the received information and displays it on an LCD display for monitoring purposes. If abnormal conditions such as low oxygen levels, high temperature, or sudden vibration are detected, the system activates a buzzer to generate an alert. The receiver module may also transmit the data to an IoT platform so that supervisors can monitor worker conditions remotely.

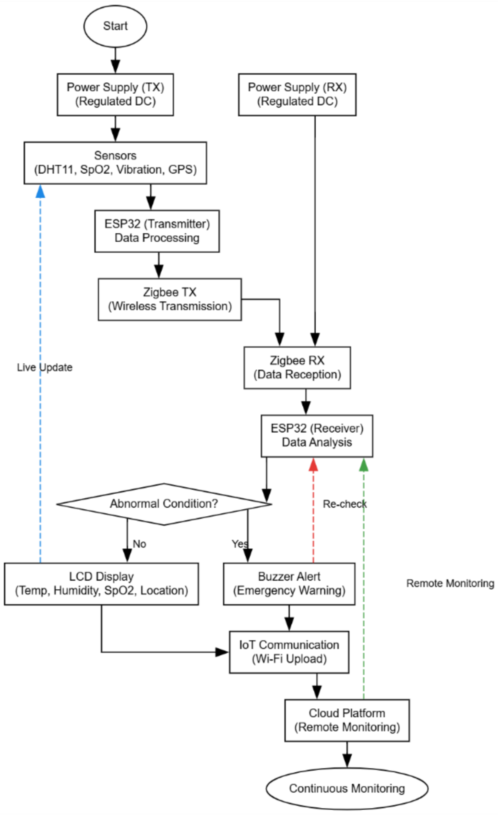

Figure 3. Proposed Working Procedure.

4. Results and Discussion

Figure 4 illustrates the Zigbee transmitter module integrated with sensors such as temperature, humidity, vibration, SpO2, and GPS. The ESP32 processes the sensor data and wirelessly transmits the information to the receiver unit using Zigbee technology.

Figure 5 shows the Zigbee receiver unit used in the smart safety waist monitoring system. The ESP32 microcontroller receives health and environmental data from the transmitter through Zigbee communication and displays the parameters on the LCD screen for real-time monitoring.

Figure 6 presents the IoT web server interface used for remote monitoring of the user's health parameters. The dashboard displays real-time values of temperature, humidity, vibration status, heart rate, SpO2 level, and GPS location along with timestamps.

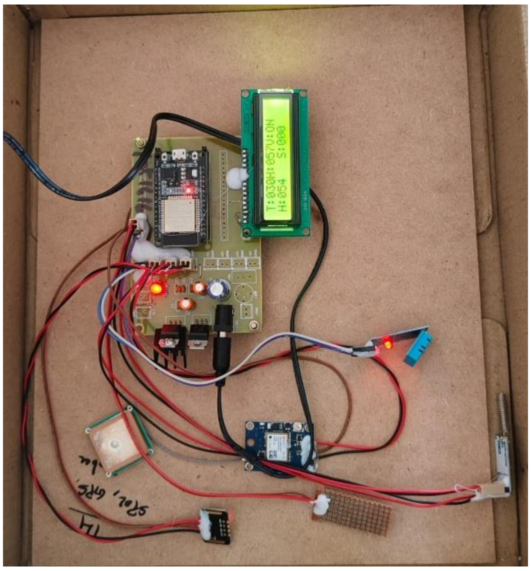

Figure 4. Zigbee Transmitter Module (Wearable Unit)

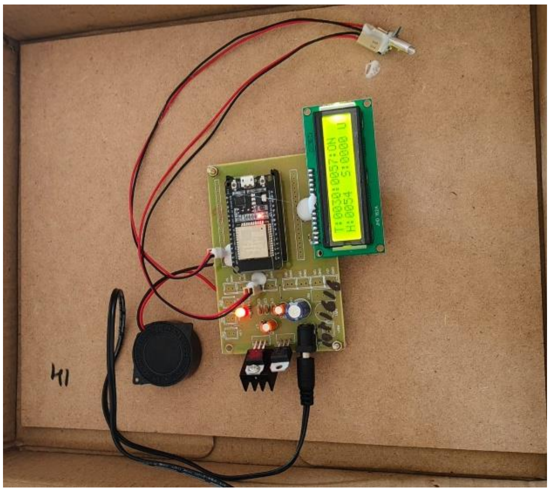

Figure 5. Zigbee Receiver Module.

S.No	Temperature	Humidity	Vib	Heart_Beat	SPO2	Location	Date	
1	29	50	ON	48	0	Location	Location	2026-03-02 13:42:36
2	29	50	ON	46	0	Location	Location	2026-03-02 13:42:26
3	29	50	ON	47	0	Location	Location	2026-03-02 13:42:15
4	29	51	ON	49	0	Location	Location	2026-03-02 13:42:10
5	29	50	ON	58	0	Location	Location	2026-03-02 13:41:42
6	29	50	ON	58	0	Location	Location	2026-03-02 13:41:34
7	295	295	ON	58	0	Location	Location	2026-03-02 13:41:23
8	29	50	ON	55	0	Location	Location	2026-03-02 13:41:10
9	29	50	ON	55	0	Location	Location	2026-03-02 13:40:50
10	29	50	ON	55	0	Location	Location	2026-03-02 13:40:40
11	29	50	ON	55	0	Location	Location	2026-03-02 13:40:29
12	29	50	ON	55	0	Location	Location	2026-03-02 13:40:18
13	29	50	ON	55	0	Location	Location	2026-03-02 13:40:08
14	29	50	ON	54	0	Location	Location	2026-03-02 13:39:57
15	29	50	ON	54	0	Location	Location	2026-03-02 13:39:47
16	29	50	ON	54	0	Location	Location	2026-03-02 13:39:36
17	29	50	ON	54	0	Location	Location	2026-03-02 13:39:25
18	29	50	ON	54	0	Location	Location	2026-03-02 13:39:14
19	29	50	ON	54	0	Location	Location	2026-03-02 13:39:03
20	29	50	ON	54	0	Location	Location	2026-03-02 13:38:53

Figure 6. IoT Web Server Monitoring Dashboard.

5. Conclusion

The proposed Zigbee Smart Safety Waist System provides a comprehensive and intelligent solution for enhancing worker safety in hazardous environments by integrating real-time health monitoring, environmental sensing, and wireless communication. By utilizing the ESP32 microcontroller along with DHT11, SpO_2, and vibration sensors, the system continuously tracks vital parameters such as temperature, humidity, oxygen levels, pulse rate, and fall detection, enabling early identification of critical conditions. The inclusion of GPS ensures accurate location tracking, while Zigbee communication facilitates reliable and low-power data transmission to a remote monitoring station. Immediate alerts through buzzer notifications and IoT-based remote monitoring allow quick response during emergencies, significantly reducing the risk to human life. This system overcomes the limitations of traditional safety methods by providing continuous, automated, and real-time monitoring. Finally, it improves safety standards, enhances operational efficiency, and offers a scalable and effective solution for protecting workers in industries such as mining, construction, and disaster management.

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