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LoRa-Based IoT Soldier Monitoring System Using ESP32 for Long-Range Health Tracking and Alerts

Koppula Manasa[1*], Kadaboina Karthik[2], Thakkalapelli Vamshi[2], Maloth Ganesh Naik[2], N. Harikeerthana[2]

[1]Assistant Professor, [2]UG Student, [1,2]Department of Electronics & Communication Engineering

[1,2]Vaagdevi Engineering College, Bollikunta, Warangal, 506005, Telangana, India.

*Correspondence: Koppula Manasa (manasa436@gmail.com)

Abstract

The growing need for advanced soldier safety systems in modern defense operations has intensified due to increasing battlefield risks, with global defense expenditures exceeding 2 trillion USD annually and real-time monitoring technologies in defense growing at over 14% per year. Additionally, delayed communication and lack of continuous health monitoring contribute significantly to casualties in remote and hostile environments, highlighting the importance of reliable long-range communication systems. Traditional soldier monitoring systems rely on short-range communication or manual reporting, which may fail in critical situations due to network limitations, delayed response, or lack of real-time data transmission. Furthermore, conventional systems lack integrated IoT monitoring, centralized data access, and automated alert mechanisms, reducing their effectiveness in ensuring soldier safety. To address these challenges, the proposed LoRa-based soldier security system integrated with IoT utilizes transmitter side for sensor data acquisition and the ESP32 on the receiver side for IoT communication. The system integrates SpO2 and heartbeat sensors to continuously monitor vital health parameters, along with an emergency keypad button for manual alerts. Data is transmitted over long distances using LoRa communication, ensuring reliable connectivity even in remote areas. Upon detecting abnormal conditions or emergency signals, alerts are generated through buzzers and LCD displays on both transmitter and receiver units, while IoT integration enables real-time notifications to command centers. This intelligent system enhances soldier safety, ensures timely emergency response, improves situational awareness, and provides a scalable and energy-efficient solution for modern military operations.

Keywords: Monitoring, Internet of Things, LoRa Communication, Military Technology, Real-Time Monitoring, Soldier Safety System, SpO2 Sensor, Wireless Communication

1. Introduction

The growing need for advanced soldier safety systems in modern defense operations has intensified due to increasing battlefield risks and complex mission environments [1]. Global defense expenditures have exceeded 2 trillion USD annually, reflecting significant investments in technologies that enhance operational efficiency and personnel safety. At the same time, real-time monitoring technologies in defense are growing at over 14% annually, driven by the demand for intelligent and connected systems [2]. In critical scenarios such as border surveillance, combat zones, rescue missions, and remote military operations, there is a strong requirement for solutions that provide continuous health monitoring, instant alert generation, and reliable long-range communication to ensure soldier safety and mission success [3].

Traditional soldier monitoring systems rely primarily on manual reporting or short-range communication technologies such as RF or

Bluetooth [4]. These approaches are often unreliable in remote or hostile environments where network connectivity is limited or unavailable. As a result, critical health data may not reach command centers in time, delaying emergency response [5].

Additionally, conventional systems lack integration with IoT platforms, centralized monitoring, and automated alert mechanisms, making it difficult to track multiple soldiers simultaneously [6]. The absence of real-time data transmission and long-range communication further reduces the effectiveness of these systems in dynamic battlefield conditions.

In real-time scenarios, these limitations lead to several critical challenges that can compromise soldier safety and operational efficiency. Sudden changes in vital parameters such as heart rate or oxygen levels may go undetected without continuous monitoring systems. Delayed communication in remote areas can prevent timely medical assistance, increasing the risk of fatalities. Furthermore, the lack of reliable long-range communication can disrupt coordination between soldiers and command centers [7]. The absence of automated alert systems also delays response during emergencies. These challenges highlight the need for an intelligent, IoT-enabled soldier monitoring system that integrates long-range communication technologies like LoRa [8], real-time health tracking, and instant alert mechanisms, ensuring enhanced safety, improved situational awareness, and efficient military operations in challenging environments.

2. Literature Survey

Aoun et al. [9] proposed a review of Industry 4.0 characteristics and challenges, highlighting automation, connectivity, and data-driven processes, with improvements using blockchain technology. Khan et al. [10] proposed a framework integrating blockchain, Artificial Intelligence (AI), and Industrial Internet of Things (IIoT) for digitalization of small and medium-sized enterprises. Reghunadhan [11] proposed an analysis of ethical considerations in blockchain-based systems within war zone environments using a case study approach. The study evaluated risks and ethical challenges in critical applications.

Gousteris et al. [12] proposed a secure distributed cloud storage system based on blockchain and smart contracts for data protection and integrity. Krichen et al. [13] proposed a survey of blockchain applications in modern systems, analyzing architectures, protocols, and use cases across domains. Kassen [14] proposed the use of blockchain in e-government systems to automate public information processes and improve transparency.

Abdulrahman et al. [15] proposed a survey on the synergy between AI and blockchain in aerospace engineering, focusing on operational efficiency and technological challenges. Khoshavi et al. [16] proposed a survey of blockchain applications in transportation systems to improve operational efficiency and security. The study analyzed system architectures and use cases. The work lacked real-time implementation. Lee et al. [17] proposed blockchain as a cyber defense mechanism, analyzing its applications in enhancing security and resilience in digital systems.

Jain et al. [18] proposed a blockchain-based Internet of Things (IoT) architecture for drone networks, enabling secure communication and coordination. Kendall et al. [19] proposed the use of Hyperledger Fabric blockchain to improve information assurance in IoT devices for Artificial Intelligence model development. Aljohani et al. [20] proposed a study on autonomous strike unmanned aerial vehicles for homeland security missions, focusing on

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operational challenges and preliminary solutions.

3. Proposed System

Figure 1 illustrates the soldier unit (transmitter module) of the GPS-based soldier tracking and health monitoring system built around the ESP32. This unit is deployed with the soldier and is responsible for collecting real-time physiological and location data. It integrates sensors such as DHT11 for temperature and humidity, SPO2 sensor for pulse rate and oxygen level monitoring, a fall detection sensor for emergency situations, and a keypad for manual input. A GPS module provides real-time location tracking. The ESP32 processes all sensor data and transmits it wirelessly through a LoRa transmitter (Tx) to the base station. An LCD is used for local display of information.

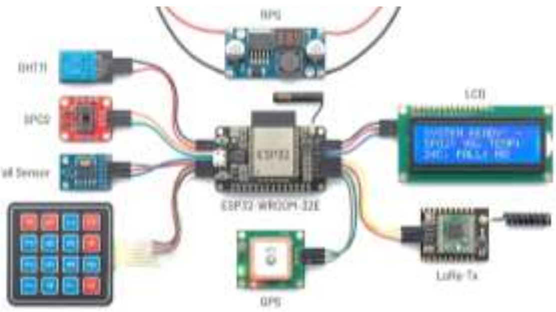

Figure 1. Soldier Unit (Transmitter) – GPS-Based Health Monitoring System.

Figure 2 illustrates the base station (receiver module) of the soldier monitoring system. The ESP32 acts as the central controller, receiving data from the soldier unit via a LoRa receiver (Rx). The received data includes health parameters and GPS location. The ESP32 processes this information, displays it on an LCD, and activates a buzzer alert in case of abnormal conditions such as low oxygen levels, high temperature, or fall detection. This module ensures centralized monitoring and rapid response for soldier safety.

Step 1: Power Supply Initialization (RPS): The regulated power supply provides stable voltage to the ESP32 and receiver components.

Step 2: Data Reception via LoRa: The LoRa receiver (Rx) collects transmitted data from the soldier unit over long distances.

Step 3: Data Processing using ESP32: The ESP32 processes received data, including health parameters and GPS location.

Step 4: LCD Display for Monitoring: The LCD displays real-time data such as temperature, SPO2 levels, and soldier location coordinates.

Step 5: Buzzer Alert System: If abnormal conditions are detected (e.g., fall detection, abnormal vitals), the buzzer is activated to alert monitoring personnel.

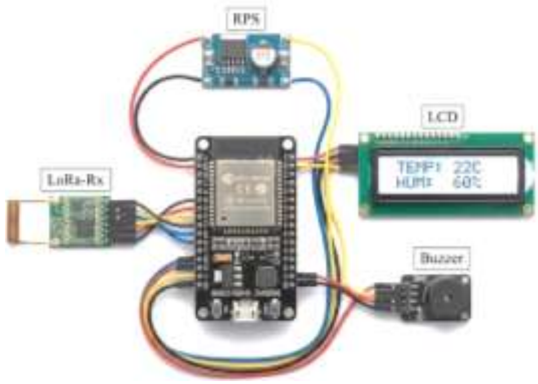

Figure 2. Base Station Unit (Receiver) – Monitoring and Alert System.

3.1 Working Procedure

The soldier unit continuously monitors health parameters and location as shown in Figure 3, processes the data using ESP32, and transmits it via LoRa to the base station. The base station receives and displays this data while generating alerts for emergencies. This system ensures real-time tracking, health monitoring, and improved safety for soldiers in critical environments.

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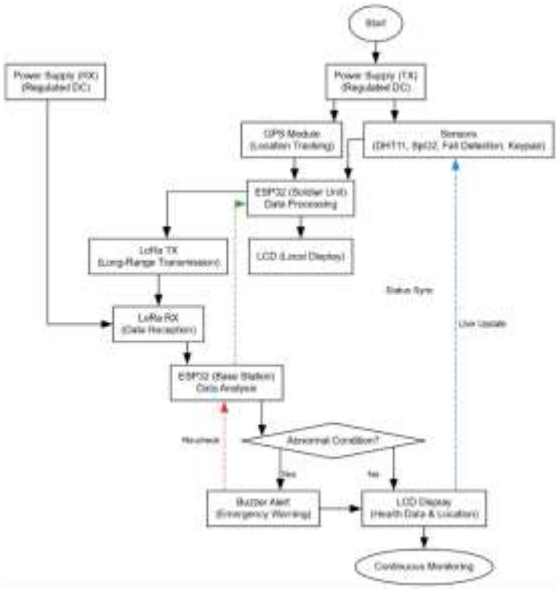

Figure 3. Proposed Flowchart.

Figure 4 illustrates the transmitter unit of a LoRa-based soldier tracking and health monitoring system designed for real-time surveillance of soldiers in remote or battlefield environments. The system is powered by a regulated power supply unit consisting of a step-down transformer, bridge rectifier, filter capacitors, and a 7805-voltage regulator to provide a stable +5V output. The ESP32 microcontroller acts as the central processing unit, interfacing with a GPS module for real-time location tracking, a SpO2 sensor for monitoring oxygen levels, a DHT11 sensor for temperature and humidity monitoring, and a vibration sensor for detecting abnormal movement or injury. A keypad is included for manual input or emergency signaling. The collected data is transmitted wirelessly using a LoRa transmitter module, while a 16×2 LCD displays real-time status. This system ensures continuous health monitoring and location tracking of soldiers in critical conditions.

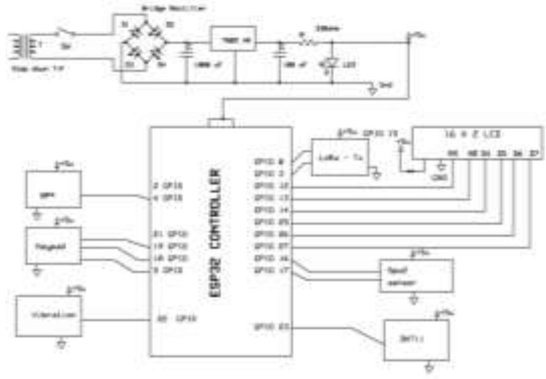

Figure 4. Transmitter Circuit Diagram.

Figure 5 presents the receiver unit of the LoRa-based soldier tracking and health monitoring system, responsible for receiving and displaying data from the transmitter. The system uses a regulated power supply like the transmitter unit. The ESP32 microcontroller receives transmitted data via a LoRa receiver module and processes it for monitoring and alert generation. An IoT module enables remote monitoring and cloud-based data access. A 16×2 LCD displays received health parameters and location information, while a buzzer provides audible alerts during emergency or abnormal conditions. This receiver system enables centralized monitoring, improving response time and ensuring the safety of soldiers in mission-critical environments.

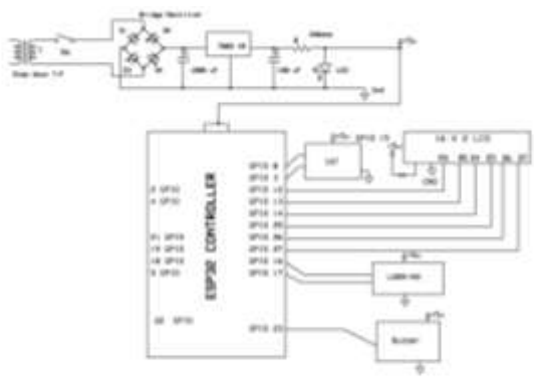

Figure 5. Receiver Unit Circuit Diagram.

4. Results and Discussion

Figure 6 shows the complete hardware implementation of the LoRa-based Soldier Security System consisting of both transmitter

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(Tx) and receiver (Rx) modules. The system integrates sensors, ESP32/Arduino controllers, LoRa communication modules, LCD displays, and buzzer units for monitoring soldier health parameters and transmitting alerts wirelessly.

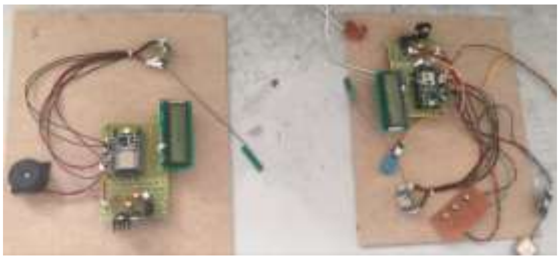

Figure 6. Hardware Setup of LoRa Based Soldier Security System (Transmitter and Receiver Units)

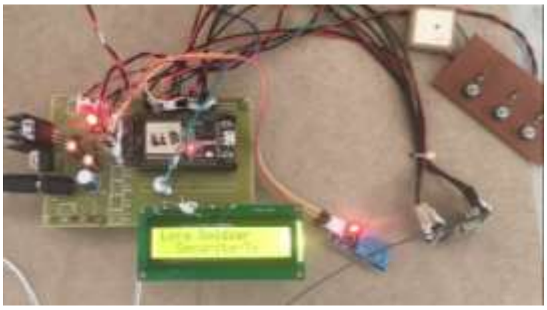

Figure 7. Transmitter (Tx) Module of LoRa Soldier Security System

Figure 7 shows the transmitter unit carried by the soldier. It includes sensors such as SpO_2, heartbeat sensor, vibration sensor, emergency button keypad, LoRa transmitter module, LCD display, and buzzer used to collect health data and transmit alerts to the receiver unit.

Figure 8 shows the receiver unit that receives transmitted data from the soldier's transmitter module using LoRa communication. The received information is displayed on the LCD and alerts are generated using a buzzer for monitoring at the control station.

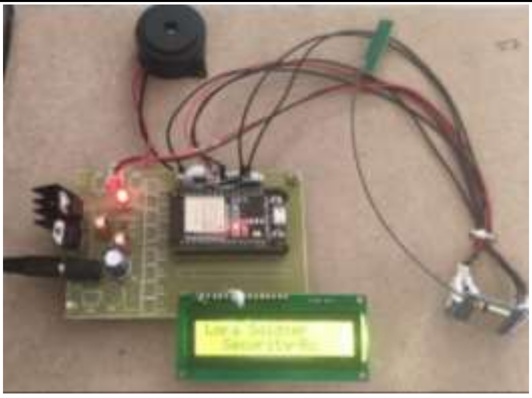

Figure 8. Receiver (Rx) Module of LoRa Soldier Security System

Figure 9 shows the IoT web server dashboard used for remote monitoring of soldier health parameters. It displays information such as temperature, humidity, vibration status, heart rate, SpO_2 level, system status, and location along with timestamped records.

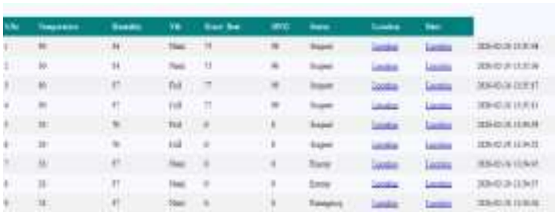

Figure 9. IoT Server Monitoring Interface.

5. Conclusion

The proposed LoRa-based Soldier Security System integrated with IoT offers a robust and intelligent solution for enhancing soldier safety in modern battlefield environments by enabling long-range communication, real-time health monitoring, and automated alert mechanisms. By incorporating SpO_2 and heartbeat sensors, the system continuously tracks vital parameters, allowing early detection of critical health conditions. The use of LoRa communication ensures reliable, low-power, and long-distance data transmission even in remote or hostile areas where conventional networks may fail. The inclusion of an emergency keypad provides manual alert capability, while buzzer and LCD notifications enable immediate local awareness. Additionally, IoT integration facilitates real-time data transmission to command centers, improving situational awareness and enabling rapid decision-making. This system effectively overcomes the limitations of traditional monitoring approaches by providing continuous, automated, and reliable communication.

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