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Real-Time Soldier Health Monitoring and Position Tracking Using LoRa-Based IoT System

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Abstract

Military capability is fundamentally determined by the effectiveness of its land, air, and naval forces. To enhance situational awareness and ensure the safety of personnel in real-time, this research proposes a compact, wearable soldier monitoring system. The proposed device, which can be easily mounted on a soldier gear, facilitates real-time tracking of physiological parameters and geolocation data. It integrates sensors to monitor heart rate, pulse, body temperature, and motion-key indicators for assessing a soldier's health and fatigue levels during active combat or field operations. The system leverages Long Range (LoRa) communication technology, enabling low-power, long-distance data transmission between the soldier and a central monitoring unit. LoRa's capability to maintain connectivity in remote and obstructed environments makes it highly suitable for military applications. This integration enhances command center awareness, enabling timely medical intervention and operational decisions. The proposed system not only improves troop survivability but also contributes to mission efficiency through robust, energy-efficient. The project achieved an accuracy exceeding 97%, indicating high reliability and performance.

Keywords: LoRa communication; Remote monitoring; Body temperature monitoring; Real-time location tracking; Heart rate sensor; Motion detection.

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1. Introduction

Modern military operations demand robust, real-time communication systems to ensure both mission success and the safety of personnel deployed in the field. Soldiers often operate in remote, high-risk environments where conventional communication infrastructure such as cellular or satellite networks may be unreliable or unavailable. In such scenarios, situational awareness including continuous updates on the health and location of soldiers is vital for timely command decisions and effective response strategies.[1] The rapid advancement of wearable and wireless technologies offers promising solutions for real-time monitoring of soldiers' biometric and positional data. These technologies enable military command centers to gain continuous insight into the physical status and location of personnel in active zones. Integrating such systems within existing military frameworks significantly enhances operational efficiency while reducing risks associated with delays in detecting injuries or miscommunication during combat operations.

This research proposes a LoRa-based health and position monitoring system tailored specifically for military personnel. LoRa (Long Range) technology is particularly suitable for military applications due to its low power consumption, long-range coverage, and ability to operate on unlicensed frequency bands.[2] These characteristics make it

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ideal for deployment in areas with limited infrastructure. The proposed system utilizes LoRa modules to transmit real-time health and geolocation data from wearable devices to a remote command unit, without depending on conventional cellular or Wi-Fi networks. To provide comprehensive monitoring, the system integrates biomedical sensors-including heart rate and body temperature sensors-with Global Positioning System (GPS) modules. These sensors have been selected for their critical relevance to detecting health emergencies in the field. For instance, a heart rate sensor can identify abnormal fluctuations caused by trauma or extreme stress, while a temperature sensor helps monitor physical strain or illness. Typical heart rate sensors used in such systems offer ±2 bpm accuracy, while temperature sensors can detect variations within ±0.2°C. These data points are transmitted in real time using LoRa communication, ensuring that critical health changes are promptly addressed.[3] The system architecture is centered around a low-power microcontroller, which acts as the processing hub. It collects sensor data, manages communication protocols, and ensures energy-efficient operation suitable for long-duration missions.[4] Commonly used microcontrollers such as the Arduino Nano 33 IoT or STM32 series offer built-in support for wireless modules and sensor interfacing, enabling compact and robust design. The microcontroller is responsible for encoding the data before transmitting it over LoRa and initiating alerts when parameters cross predefined thresholds.

A key feature of the system is the ability to automatically detect medical anomalies. If a soldier's heart rate exceeds or falls below a predefined threshold, or if body temperature deviates significantly from the normal range, the system triggers an alert. This alert includes both health metrics and GPS coordinates, allowing immediate action from the command center. In this research, the alert system is implemented using LoRa; however, for redundancy and comparative analysis, GSM modules are also referenced from existing solutions.[5] that offer SMS-based alerts though they require cellular coverage and consume more power. Unlike existing wireless solutions like Wi- Fi or Global System for Mobile Communications (GSM), which are limited in range and energy efficiency, LoRa allows data transmission across several kilometers while consuming significantly less power.[6] This is especially critical in military environments where resupply is limited, and continuous monitoring must be ensured over vast, rugged terrains. The system's independence from commercial infrastructure makes it particularly advantageous for covert or high-mobility operations in hostile regions. The integration of all system components including GPS, LoRa modules, biometric sensors, and the microcontroller results in a compact, wearable device that can be securely attached to the soldier's gear. The hardware is designed for minimal bulk, lightweight operation, and maximum battery efficiency.[5] Additionally, features such as automated data logging, fault tolerance in transmission, and configurable alert thresholds contribute to the system's overall reliability and adaptability for various mission profiles.[7] Modern military operations demand robust, real-time communication systems to ensure both mission success and the safety of personnel deployed in the field. Soldiers often operate in remote, high-risk environments where conventional communication infrastructure such as cellular or satellite networks may be unreliable or unavailable. In such scenarios, situational awareness-including continuous updates on the health and location of soldiers-is vital for timely command decisions and effective response strategies.[8]

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Table 1 indicates that Bluetooth Low Energy (BLE) is a wireless technology designed for short-range communication with very low energy consumption, typically operating in the

Table 1: Comparison of different communication techniques.

References	Communication Technique	Merits	Demerits
Gondalia *et al*.[2]	Bluetooth Low Energy (BLE)	Very low power consumption	Short communication range (~10–50 m)
Shalini *et al*.[4]	ZigBee Technolog y	Excellent for mesh networking	Slower data rate (~250 kbps)
Shinde *et al*.[6]	MQTT	Lightweight and scalable	Requires a broker (added complexity)
Annapoorani *et al*.[10]	LORAWA N	Long- range communication	Limited bandwidth and data rates
Meerabi *et al*.[11]	LPWAN	Ultra-low power and long- range	Low data rate and high latency

2.4 GHz ISM band. It is widely used in wearable health devices, smartwatches, and fitness trackers due to its compatibility with mobile phones and ability to run for months on small batteries. BLE supports various topologies, including mesh, broadcast, and point-to-point, with data rates up to 2 Mbps in BLE 5.0. It is ideal for intermittent communication, making it a common choice in health and personal monitoring systems.[2] BLE's short range, usually around 10–50 meters, limits its use in wider or outdoor environments. Its merits include extremely low power usage, high availability in consumer devices, and cost-effectiveness, while its demerits involve short communication range and lower data throughput compared to other technologies. ZigBee technology, based on IEEE 802.15.4, is a low- power, low-data-rate communication protocol ideal for home automation, industrial control, and sensor networks. Operating in the 2.4 GHz band, it allows communication over 10–100 meters and supports mesh networking, which increases reliability and coverage. ZigBee enables thousands of devices to connect within a network, making it highly scalable for large deployments. It includes AES-128 encryption for secure communication and is supported by the Connectivity Standards Alliance.[4] Its merits lie in efficient power consumption, robust mesh networking capability, and the ability to manage many nodes, while the demerits include lower data rates of about 250 kbps and limited integration with smartphones, tablets and Message Oriented Transport Technology (MQTT), is a communication method used primarily in Internet of Things (IoT) systems based on the publish-subscribe model. It allows devices to send and receive data asynchronously through brokers using protocols such as MQTT or AMQP. This model decouples the sender and receiver, promoting flexibility and scalability in the network. MQTT is ideal for scenarios where bandwidth is limited or latency is variable, and it supports lightweight data transmission, making it suitable for telemetry and remote monitoring. Its merits include minimal bandwidth usage, simple integration with IoT sensors, and high scalability, while its demerits involve dependency on a central broker, which adds complexity and reduces efficiency when handling large data volumes.[12]

Long Range Wide Area Network (LoRaWAN) is a low-power, wide-area communication protocol that uses LoRa modulation and operates in license-free frequency bands such as 868 MHz or 915 MHz. It is commonly used in smart agriculture, city infrastructure, and industrial IoT for sending small data packets over long distances up to 15 kilometres in rural areas. LoRaWAN networks typically follow a star topology with gateways that relay data between end devices and a central server. It is designed for battery- powered devices that transmit data infrequently and is supported by the LoRa Alliance. The merits of LoRaWAN include its long communication range, extremely low power usage, and unlicensed spectrum use, while its demerits include low data rates, high latency, and susceptibility to interference in crowded unlicensed bands.

Low Power Wide Area Network (LPWAN) is an umbrella term for technologies like LoRaWAN, Sigfox, NB-IoT, and others, optimized for long-range and low-power communication.[13] LPWANs operate in sub-GHz frequencies and are intended for devices that transmit small amounts of data occasionally over large distances, making them suitable for agriculture, utilities, and rural IoT applications. They can support millions of devices within a network and offer extended battery life up to 10 years. LPWANs generally use simple star topologies and offer coverage that reaches deep into buildings or remote areas. The merits of LPWAN include ultra-low power consumption, long- range capabilities, low operational costs, and large- scale deployment potential, while its demerits are mainly the low data throughput, higher latency, and unsuitability for applications requiring real-time or large-volume data communication.[14] The overall introduction of the research has been completed, and the proposed system section will be presented in the next section.

2. Materials and methods

Maintaining real-time awareness of soldiers' health and location is crucial in modern military operations. To achieve this, wireless RF modules transmit data collected from various sensors, such as GPS and biometric devices, to higher command levels. This setup allows control centers to continuously monitor troop positions and vital signs through a wireless body sensor network and RF receivers.

A key component in this system is the ESP8266 microcontroller, which is integrated into the control room's infrastructure. It consistently evaluates incoming data from multiple subsystems and triggers alerts if any readings deviate from established safety thresholds. By tracking soldiers' locations and health metrics, the system ensures prompt assistance is dispatched from either the control unit or the squad leader's node whenever anomalies are detected, thereby enhancing battlefield safety and responsiveness. Testing and prototyping are essential stages in the development process, enabling gradual improvements based on user feedback and validation research.[15] Accuracy, reliability, and efficient data transmission are achieved through the seamless integration and testing of hardware and software components within the jacket prototype. Following successful validation, the process advances to the production and deployment phase, which includes mass production, distribution, and continued maintenance and support. By adopting this systematic approach, wearable jackets have the potential to transform personal health and safety monitoring, empowering individuals to take proactive steps in managing their well-being in daily life. This research utilizes two nodes, designated as the transmitter and the receiver. Firstly, examine the soldier node in detail.[16]

2.1 Soldier node

The soldier node acts as a vital life-line system, integrating health monitoring with real-time tracking to enhance the safety of military personnel during missions. The GPS module not only tracks live location but also logs movement history, which is useful for mission analysis and post-operation reviews. In areas with low visibility or complex terrain, this GPS tracking becomes critical for team coordination and rescue operations. The soldier node is a compact system designed to monitor the soldier health and track their location in real time. It includes a GPS module for determining the soldier current position and movement, ensuring they can be located when needed. A temperature sensor keeps track of both body temperature and the surrounding environment, helping to detect potential health risks like heat exhaustion or hypothermia.[17]

The heart rate sensor continuously measures the soldier's pulse rate. Sudden spikes or drops in beats per minute (BPM), can indicate stress, injury, or medical distress. These vital signs are compared against predefined safe thresholds. If anomalies are detected, the system raises an alert signal to the command center. To ensure instant response, the system is capable of wireless data transmission using communication technologies such as LoRa WAN or BLE, making it suitable even in remote or battlefield areas with limited connectivity. Some models can also integrate fall detection sensors or accelerometers to detect injury due to sudden movement or impact. Additionally, a heart rate sensor measures the soldier pulse in BPM, ensuring their heart rate stays within a safe range. If any readings go beyond the set limits, the system identifies it as an emergency and can send alerts for quick action. This setup ensures better safety and real-time monitoring for soldiers in the field.[3]

Fig. 1 represents the block diagram of the transmitter node using the ESP8266 microcontroller as the central control unit. The ESP8266 is a powerful and efficient microcontroller with built-in Wi-Fi and Bluetooth capabilities, widely used in IoT applications. It acts as the core of the system, responsible for collecting, processing, and transmitting data received from multiple sensors. The temperature sensor used in this system is the DS18B20, which is a digital sensor known for its accuracy and wide operating voltage. It measures the body or ambient temperature and sends the data to the ESP8266 via the 1-Wire protocol. The heart rate sensor, which can be either MAX30100 or MAX30102, is used to monitor both heart rate and oxygen saturation (SpO_2). It works by using infrared and red LEDs to detect the changes in blood flow through the fingertip or earlobe.[18]

Another important module connected to the ESP8266 is the GPS module, which is used for position tracking. This module provides real-time latitude and longitude coordinates by receiving signals from GPS satellites, enabling the system to track the physical location of the user. The ESP8266 processes this data and can transmit it over long distances using the LoRa module. LoRa (Long Range) is a low-power wireless communication technology ideal for transmitting small packets of data over distances of several kilometres, especially in rural or remote areas where traditional networks may not be available. Additionally, the system includes an RF Rx block, which refers to a radio frequency receiver. This module is used to receive control signals or commands from a remote transmitter, allowing for basic remote control or configuration of the system.[19]

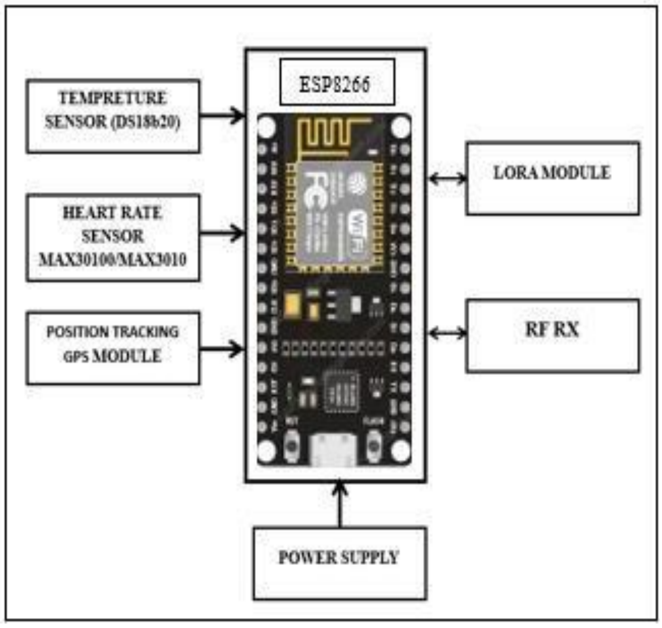


Fig. 1: Block diagram of transmitter (soldier) node.

Finally, the power supply block provides the necessary electrical power to all the components in the system. It ensures a stable and regulated voltage to the ESP8266, sensors, and communication modules, enabling continuous operation of the entire setup. The power supply could be sourced from a battery, solar panel, or a regulated adapter, depending on the application. This complete system is designed for real-time health monitoring and location tracking, suitable for soldier safety systems, emergency responders, or remote patient care. Following the analysis of the soldier node, the study now progresses to an examination of the control node.

2.2 Control node

Node features an RYLR998 LoRa module, which enables it to receive data from other nodes in the network. Its primary role is tracking, storing, and analyzing the collected information. To facilitate internet connectivity, it integrates with the ThingSpeak web application. The node can be connected to the internet using a USB and a laptop, allowing real-time data transmission. Once online, sensor readings are sent to the ThingSpeak cloud and simultaneously displayed on a dedicated dashboard, ensuring smooth monitoring and interaction with the system.[3]

Fig. 2 represents the block diagram of receiver (control) node where data from the ESP8266 microcontroller is transmitted, received, and visualized through external systems. At the core is the ESP8266, which manages communication between the input sensors and output modules. In this stage of the system, the ESP8266 continues to communicate with both the LoRa module and the RF Rx module. The LoRa module is used to transmit data over long distances using low power, making it suitable for remote monitoring scenarios such as field deployments.[20]

The RF Rx module functions as a receiver that allows the ESP8266 to accept signals or commands wirelessly from a remote transmitter, which can be used to trigger certain actions or change system parameters.[21]

A crucial element in this diagram is the cloud component, which represents a remote server or storage system where the ESP8266 sends collected data via Wi- Fi or another network protocol. Once the data reaches the cloud, it is securely stored and can be accessed or analyzed further. Connected to the cloud is the dashboard, which is a graphical user interface (GUI) typically accessed through a web or mobile application. The dashboard presents real-time data such as temperature, allowing health professionals or supervisors to monitor the status of individuals remotely.[22]

The power supply unit is still responsible for providing stable voltage and current to the ESP8266 and its connected components, ensuring continuous operation. This setup allows for real-time monitoring and alerting by integrating wireless communication (LoRa and RF) with cloud-based services and user- friendly dashboards, making it highly suitable for smart health systems, remote surveillance, and military personnel tracking applications.[23] With both nodes thoroughly analyzed, the subsequent section delves into the hardware description.

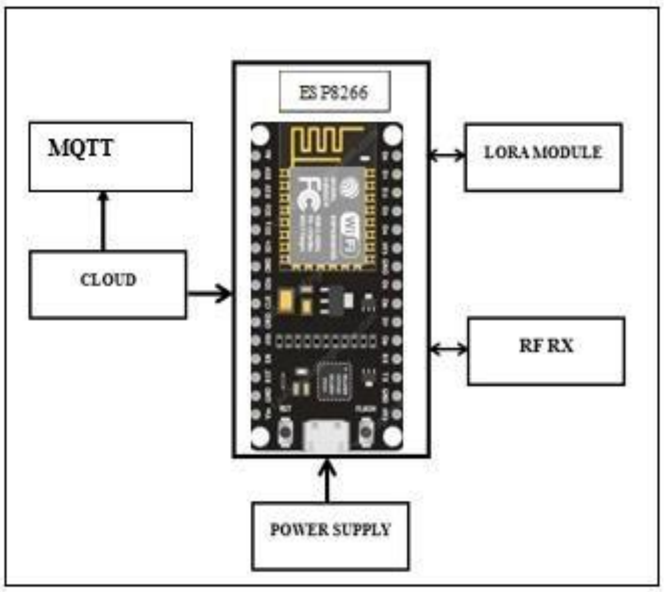


Fig. 2: Block diagram of receiver (control) node.

2.3 Hardware description

2.3.1 Microcontroller

The ESP8266 is an advanced microcontroller developed by Espressif Systems, succeeding the ESP8266. It's a cost-effective and compact System-on- Chip (SoC) that integrates Wi-Fi and Bluetooth capabilities, making it ideal for various Internet of Things (IoT) applications.[2]

2.3.2 Sensors

a) Temperature sensor: The core functionality of the DS18B20 is its direct-to-digital temperature sensor.[4]

b) Heart rate sensor: The MAX30102 is a compact sensor designed to monitor heart rate and blood oxygen levels. It operates by emitting red and infrared light onto areas like the fingertip or earlobe. These lights penetrate the skin, and a photodetector measures the amount of light that reflects. As blood pulses through the vessels with each heartbeat, the amount of reflected light changes.[6] The MAX30100 is a compact sensor module designed to measure both blood oxygen saturation and heart rate. It integrates red and infrared LEDs, a photodetector, specialized optics, and analog signal processing to accurately capture pulse oximetry and heart rate data.[11] This all-in-one design simplifies the process of monitoring vital signs in wearable health devices.

2.3.3 Position tracking

The NEO-M8N is a compact GPS module developed by u-blox, designed to provide accurate and reliable positioning. It supports simultaneous reception from multiple satellite systems, including GPS, Galileo, GLONASS, and BeiDou, enhancing location accuracy even in challenging environments.

2.3.4 LoRa Module

The Reyax RYLR998 is a compact transceiver module designed for long-range wireless communication using LoRa technology. It operates in the 868/915 MHz frequency bands and supports UART interface for easy integration. The module offers high sensitivity, low power consumption, and robust performance, making it suitable for various IoT applications. Following the comprehensive analysis of the hardware components, the focus now shifts to the software aspect of the system. This section outlines the software architecture, programming logic, and integration with the hardware modules. A detailed explanation of the implementation and functionality of the software is provided to ensure a clear understanding of the system's overall operation.[21]

2.4 Software description

MQTT is a lightweight messaging protocol designed for efficient communication between devices over the Internet. It operates on a publish- subscribe model, where devices can either send messages (publishers) or receive messages (subscribers) through a central broker.

With the software description thoroughly discussed, the next phase of the study focuses on the system's workflow. This section presents the flowchart, which visually represents the logical sequence and interaction between various components of the system. The flowchart serves as a blueprint for understanding the operational flow and decision-making processes within the proposed model.

A mathematical model is developed for LoRa communication to support system implementation. The model focuses strictly on the LoRa physical layer, emphasizing Chirp Spread Spectrum (CSS) modulation, while intentionally excluding higher- layer protocols such as LoRaWAN or LoRaPAN.[24]

$$x(t) = A \, . \cos[2\pi(f_o t + (B/2T)t^2)] \quad (1)$$

Equation (1) defines the LoRa up-chirp signal, where the frequency increases linearly over time. Here, A is the signal amplitude F_0 represents the starting frequency, b denotes the bandwidth, and t signifies the symbol duration.

$$T_s = 2\text{\textasciicircum}SF / B \quad (2)$$

The symbol duration Equation (2) T_s depends on the spreading factor (SF) and bandwidth (B). A higher spreading factor increases the duration, improving signal robustness and range at the cost of data rate. This is essential in low-data, high-reliability use cases like military health monitoring.

$$R = (SF \times BW / 2\text{\textasciicircum}SF) \times CR \quad (3)$$

Equation (3) calculates the data rate R, incorporating the spreading factor (SF), bandwidth (BW), and coding rate (CR). While a higher coding rate increases resilience to errors, a larger SF or smaller BW lowers the throughput. This balance is crucial when transmitting health and GPS data reliably without draining energy.

$$\text{Total Time} = \text{Number of Symbols} \times T_s \quad (4)$$

Equation (4) is computed by multiplying the number of symbols by the symbol duration T_s. This value helps in estimating the airtime required for each packet, informing decisions about latency and power budgeting in real-time systems.

$$SNR\_min = -20 \log_{10} (2\text{\textasciicircum}SF / B) \quad (5)$$

Equation (5) estimates the minimum signal-to-noise ratio (SNR) required to decode the signal successfully. A higher SF reduces the SNR requirement, improving communication reliability in noisy environments—a crucial feature for soldier tracking across rugged terrains.

$$T_s = 2\text{\textasciicircum}10 / 125000 = 8.192 \text{ ms} \quad (6)$$

Equation (6) indicates that each symbol requires approximately 8.192 milliseconds for transmission. This timing is used to determine the duration of data packets and optimize the trade-off between energy consumption and communication latency for soldier health monitoring.

$$BW = f\_high - f\_low \quad (7)$$

Equation (7) defines the bandwidth (BW) of the signal as the difference between the highest and lowest frequency components. In LoRa, typical bandwidth values are 125 kHz, 250 kHz, or 500 kHz. Selecting an appropriate bandwidth is essential for determining the resolution and the communication range of the system.

$$N = Payload\_bits / (SF \times CR) \quad (8)$$

Equation (8) calculates the number of symbols (N) needed to transmit a given payload. It is derived by dividing the total number of payload bits by the effective number of bits each LoRa symbol can carry. This helps in estimating transmission time and energy requirements for data packets.

$$BER \approx 0.5 \cdot \text{erfc}(\sqrt{(SNR)}) \quad (9)$$

The Bit Error Rate (BER) can be approximated using the complementary error function (erfc). Equation (9) provides a way to evaluate how reliably data can be transmitted over a noisy channel, with lower BER indicating higher fidelity in signal reception, essential for critical health data in soldier monitoring.

$$E\_tx = P\_tx \times T\_tx \quad (10)$$

The transmission energy (E_tx) is calculated as the product of the power consumed during transmission (P_tx) and the time taken to transmit (T_tx). Equation (10) evaluates the battery life of wearable health sensors and optimizes transmission schedules.

$$ToA = T\_preamble + T\_payload \quad (11)$$

In Equation (11), The Time on Air (ToA) of a LoRa packet includes the time spent transmitting the preamble and the actual payload. This metric is critical in duty-cycled networks and helps estimate latency and compliance with regional regulations.

$$T\_preamble = (n\_preamble + 4.25) \times T\_s \quad (12)$$

Equation (12) calculates the duration of the LoRa preamble, which helps the receiver synchronize with the incoming signal. The 4.25 factor accounts for the fixed symbols appended after the preamble. Accurate preamble timing ensures proper decoding.

3. Proposed system

Ensuring the safety and well-being of soldiers in the field is a critical aspect of modern military operations. Soldiers are often exposed to extreme conditions, high- risk environments, and unpredictable situations that can impact their health and security. To address these challenges, a real-time monitoring system is essential for tracking a soldier's vital signs and location, allowing the base station to respond quickly to emergencies. This system, as illustrated in the flowchart, integrates various sensors, the ESP8266 microcontroller, and wireless communication to provide continuous monitoring and data transmission.[22]

The flow chart initiates by powering on and verifying the functionality of all integrated components, including the heart rate sensor, temperature sensor, GPS module, and LoRa

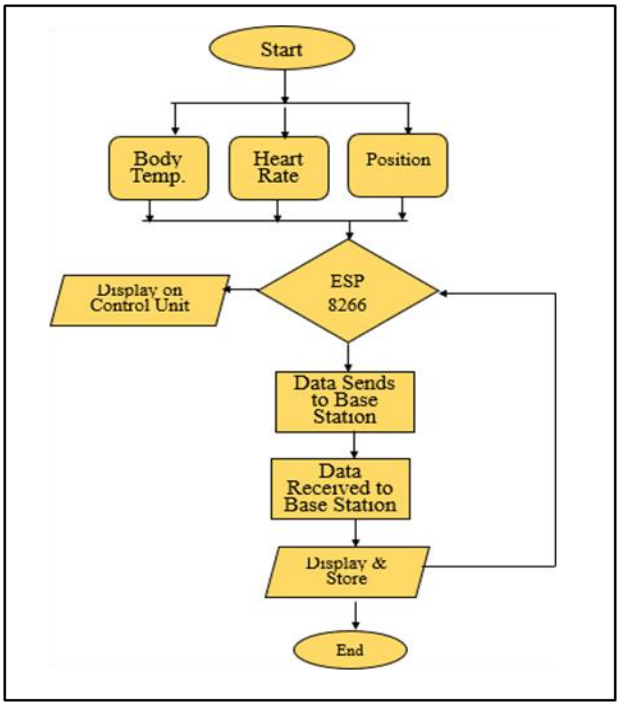


Fig. 3: Soldier monitoring system workflow.

transceiver. Once operational, the wearable sensors continuously monitor the soldier's vital signs, such as heart rate and body temperature. Simultaneously, the GPS module tracks the soldier's real-time location. This collected data is processed by a microcontroller, like the ESP8266, which formats it for transmission. A decision-making algorithm then evaluates the data to detect any abnormalities or emergency conditions, such as lack of movement or irregular vital signs. If such conditions are identified, the system triggers an alert to inform the command center for immediate action. The LoRa module transmits it to a central base station. The receiving system decodes the information and displays the health parameters and current location on a user interface or control dashboard. If data indicates a medical emergency or an out-of-bounds location, the system triggers an alert to the concerned authorities. real-time health and position monitoring. The flowchart outlines the process of collecting, processing, and transmitting data related to a soldier's body temperature, heart rate, and location. The data is displayed on the soldier unit and transmitted to the base station via an ESP8266 module, which ensures efficient wireless communication. The received data is then displayed and stored at the base station for further analysis and prompt decision-making.[25]

Fig. 3 shows the flow chart of the proposed system which begins with an initialization phase, where all components are powered on and ready for operation.[26] At this stage, various critical parameters such as the soldier's body temperature, heart rate, geographic location, and a secret code for security verification are collected. These parameters are vital for monitoring the soldier's health and safety in real-time during missions or in remote environments.

The wearable jacket is equipped with sensors that continuously track vital health parameters, such as body temperature and heart rate. Additionally, a GPS module determines the soldier precise location in real- time. To ensure secure access to the system, an authentication mechanism using a secret code is implemented. Data Processing with ESP8266. Once the data is collected, it is transmitted to the ESP8266 microcontroller, which acts as the central processing unit. The ESP8266 evaluates the information, ensures that the data is valid, and prepares it for communication. At this stage, the data can also be displayed on a soldier unit, providing real-time feedback about their health and location status.

The base station receives the SMS from the soldier unit and decodes the information.[27] The received data is then displayed on a monitoring system and stored for further analysis or future reference. This step is crucial for real time monitoring and historical health tracking enabling commanders or medical personnel to make informed decisions. Conclusion and Continuous Monitoring. The process concludes the moment data is displayed and stored at the base station, but the system remains in a continuous monitoring loop. The flow repeats itself periodically or when triggered by specific events, ensuring the soldier health and safety are always under supervision. This structured and automated process improves response times and enhances situational awareness in defense operations.[28] The system starts by collecting essential data from the soldier, including body temperature, heart rate, location, and a secret code. These parameters are continuously monitored to ensure the soldier well- being and provide real-time updates to the base station. The collected data is displayed on the soldier unit, allowing them to be aware of their health status and position.

An ESP8266 microcontroller processes the data and plays a crucial role in transmitting it to the base station. The ESP8266 module ensures efficient wireless communication, sending critical information in the form of an SMS. The message is transmitted to the base station, where it is received, displayed, and stored for further analysis. This allows military personnel to monitor the soldier condition and location in real time ensuring prompt action in case of emergency.[29]

By integrating this system, military operations can enhance the safety of soldiers in the field. The use of biomedical sensors and GPS tracking helps in continuously monitoring vital health parameters and positioning. If a soldier faces a health emergency or an unknown threat, the base station can immediately respond with necessary assistance.[30] This system ensures efficient monitoring, rapid decision-making, and improved security for military personnel.

The flowchart illustrates the operational workflow of the proposed soldier health monitoring and position tracking system. It begins with the collection of key parameters such as body temperature, heart rate, and position. These inputs are processed by the ESP8266 microcontroller, which then transmits the data to the base station via LoRa communication. Simultaneously, the information is displayed on the control unit for immediate monitoring. Upon successful transmission, the data is received at the base station, where it is displayed and stored for further analysis. With the system flow clearly defined, the next section presents the experimental results and analysis.[31]

4. Results and discussion

System is quick, accurate, and secure. It's user- friendly, making it easy to check soldiers' health and locate them precisely. This system for monitoring soldier health and tracking their position uses several pieces of technology. Wearable sensors track key health indicators like heart rate, body temperature, and blood pressure continuously. Additionally, a GPS module records the soldier's real-time location. Both the health data and location information are handled by a microcontroller, such as the ESP8266, ensuring everything is up-to-date and transmitted correctly. Utilizing LoRa communication, the system transmits the processed data to a centralized cloud platform. This platform enables military personnel to monitor soldiers' health and location remotely, providing timely alerts and facilitating quick decision-making. To ensure uninterrupted operation, the system incorporates solar panels that charge the battery, offering a sustainable power solution.

The soldiers' real-time health conditions and their precise geographical location were constantly tracked using IOT technology combined with lora communication. Parameters like body temperature, heart rate, and location were monitored using appropriate sensors, and this information was sent over long distances with minimal power usage through the lora protocol.

The main objective of the implementation was to create a small, wearable device for soldiers that could function effectively in real-time situations. Through the implementation of lora technology, long-distance and energy-efficient communication was successfully established, making it well-suited for military operations in challenging terrains. This arrangement not only improved the capability to find soldiers in urgent situations but also offered valuable health information to aid in prompt medical assistance. This project's outcome plays a crucial role in enhancing the defense system's efficiency and security by incorporating advanced communication and health monitoring technologies.

These values were processed by the ESP8266 microcontroller, and relevant information was transmitted to the base station using the LoRa module. The data was also displayed locally on the soldier unit for immediate feedback. The system demonstrated high accuracy in capturing physiological and positional data under various conditions, including indoors and outdoors. In terms of communication, the LoRa module enabled long-range, low-power data transmission, making it ideal for military operations in remote areas where cellular networks may be unavailable. Field testing under different environmental conditions—such as urban settings, forested regions, and mild elevation changes—demonstrated the resilience and adaptability of the system. In urban areas, the communication range decreased slightly due to interference and obstacles, averaging effective transmission up to 3 kilometres. However, data integrity remained high with error correction mechanisms enabled via LoRa's Chirp Spread Spectrum (CSS) modulation. Signal strength (RSSI) and Signal-to-Noise Ratio (SNR) values were monitored in real time and showed stable readings that affirmed consistent connectivity between nodes and the control unit.

The system was created to operate efficiently in regions where conventional communication networks are either absent or inconsistent. By utilizing lora's extended range and low-power capabilities, data could be sent over several kilometers without relying on cellular networks. The health data was regularly updated and transmitted to a central monitoring station for comprehensive tracking. This ensured that any unusual health conditions or distress signals from soldiers could be detected immediately.

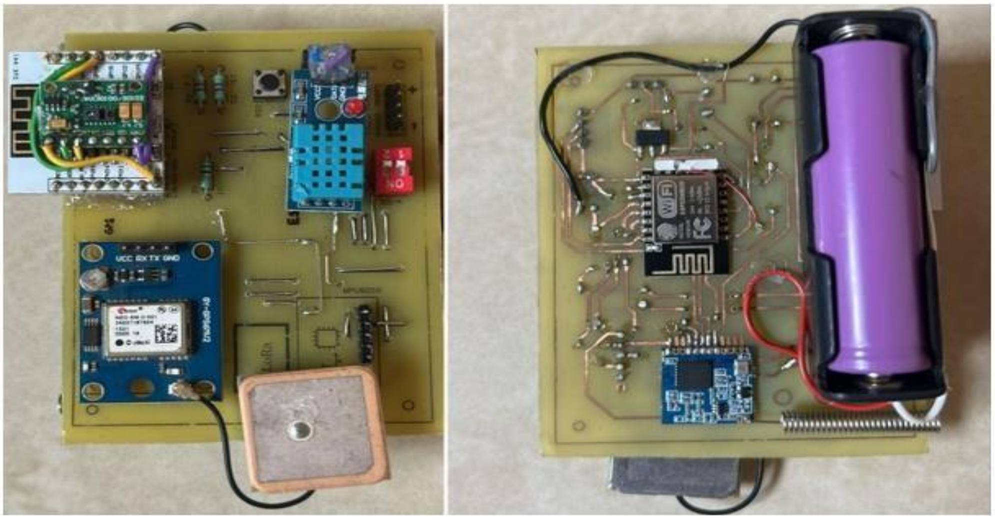
The system successfully monitored and displayed real-time physiological and environmental parameters, including temperature, humidity, oxygen level, and heart rate. The temperature remained stable around 33°C, indicating consistent sensor performance. Humidity levels initially held steady at approximately 52% before showing a sharp drop, possibly due to a sudden environmental change or sensor reset. Oxygen and heart rate readings remained at baseline levels, suggesting either a lack of significant variation during the test or potential calibration needs. Overall, the system demonstrated effective data acquisition and graphical representation, validating its capability to track vital signs and environmental conditions for soldier monitoring in real time. The proposed system was tested for its ability to monitor and transmit vital health and environmental parameters, specifically temperature, humidity, heart rate, and oxygen levels. The temperature readings, as shown in the top-left graph, consistently hovered around 33°C, indicating that the temperature sensor operated reliably without significant fluctuations during the observation period. The humidity data, depicted in the top-right graph, remained stable at approximately 52% initially but showed a sharp decline after the 705-second mark. This sudden drop may be attributed to a sudden environmental change, sensor disconnection, or signal noise, warranting further investigation or signal filtering. The suggested soldier health monitoring and position tracking system provides a solid basis for enhancing the safety and situational awareness of military personnel. Future improvements can involve incorporating additional biosensors to monitor parameters like blood pressure, electrocardiogram (ECG), and stress levels, allowing for a more comprehensive evaluation of a soldier's health. Integrating GPS modules can enhance location precision, especially in intricate or isolated landscapes. The system's analytical capabilities can be enhanced by utilizing machine learning algorithms for real-time anomaly detection and predictive health diagnostics.

Fig. 4(a) represents the soldier node, while Fig. 4(b) illustrate the control node of the system. The soldier node integrates multiple sensors and communication modules for real-time health and location tracking. The soldier node includes components such as the GPS module, DHT11 sensor for temperature and humidity, and an MPU6050 sensor for motion detection, all interfaced with a microcontroller. It is responsible for acquiring health and positional data. Fig. 4(a) shows the power management and communication setup, featuring the ESP8266 Wi-Fimodule for data transmission and a rechargeable lithium-ion battery for portable operation. On the other hand, Fig. 4(b) illustrate the control node architecture. The control node house the ESP8266 module connected to a power regulation circuit, designed to receive data sent from the soldier node. It supports the control unit with power via a 9V battery and contains the LoRa module for long- range communication. The control node, shown in Fig. 4(b), is configured to receive, decode, and display the incoming data for further processing or emergency response. The inclusion of LoRa modules in both nodes enables long-distance, low-power data transmission, making the system ideal for military or remote deployment scenarios. This robust interconnection between the nodes ensures seamless communication, efficient data acquisition, and real- time monitoring, which are critical for enhancing situational awareness and soldier safety. The circuit boards are custom-designed to accommodate all necessary components compactly and efficiently. The soldier node is equipped with sensors that continuously monitor body temperature, heart rate, humidity, and motion, ensuring comprehensive health tracking. Overall, the hardware implementation ensures portability, stability, and effective communication between the transmitter (soldier node) and receiver (control node).

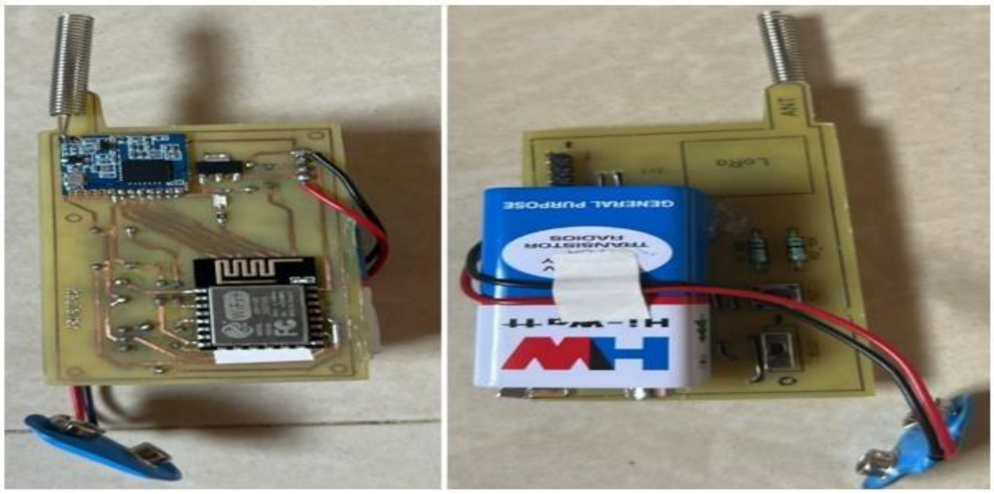
Fig. 5(a) shows the implemented system monitors vital health parameters, body temperature, heart rate, oxygen saturation, and position data of the soldier in real time. The collected figures are transmitted via the ESP8266 microcontroller over LoRa communication to a centralized base station. The flow of information is represented in the project's flowchart, showing smooth interfacing between sensors, the control unit, and the communication module. The real-time values from sensors such as temperature (~33°C), humidity (~52%), and heart rate (~75–110 bpm) confirm that the hardware-software integration is stable and reliable for on-field monitoring.

Fig. 5(b) illustrates the graphical representation of the data provides insights into individual health parameters. The bar charts of oxygen saturation levels remained consistent around 96–99% for most individuals, indicating proper functioning of the pulse oximeter. Heart rate measurements displayed expected variation among individuals, ranging from 75 to 110 bpm, while temperature and humidity values were also within normal environmental and physiological ranges. Additionally, a horizontal bar graph ranks key system attributes like sensor accuracy, data integrity, and transmission range, with most achieving scores above 8/10. Overall, the results validate the practical applicability of the system has been developed to continuously monitor the health and whereabouts of soldiers at all times. This system uses LoRa technology, which allows for communication over long distances while using very less battery power. While the ESP8266 module facilitates reliable data processing and transmission. The combination of multiple sensor inputs and efficient wireless data relay provides a scalable and low-cost solution for military personnel health tracking, making the prototype suitable for further development and field deployment. The performance evaluation of the system also highlights its efficiency across several parameters crucial for real- world deployment. Parameters such as data integrity, security, and packet delivery ratio received high accuracy ratings, suggesting stable and secure communication throughout operation. This responsiveness is vital during combat or rescue missions, where real-time health feedback can be the difference between life and death. Moreover, the hardware modules exhibited good battery efficiency, which is essential for prolonged field operations without frequent charging or replacement. Also, the Fig. 5(a) and Fig. 5(b) indicates the actual result of the research. The Fig. 5(a) indicates the actual image of the dashboard. Fig. 5(b) indicates the result.

Table 2 displays a new system that leverages IoT technology to monitor soldiers' health and locations live. It gives crucial information shown in a result table. This system



(a)



(b)

Fig. 4: a) Soldier node architecture, b) control node architecture.

Table 2: Comprehensive research finding.

Person	Temp.	Humidity	Oxygen	Heartrate	State	Latitude	Longitude
1	40	55.5	98	75	Normal	18.7301977N	73.4257434E
2	38	54.6	96	77	Normal	18.7360163N	73.4264805E
3	38	55.7	98	110	Fine	18.7408836N	73.4255947E
4	34	58.4	90	102	Fine	18.7305181N	73.4305189E
5	36	51.3	88	89	Fine	18.7356022N	73.4189360E

uses affordable Arduino boards for data processing. It also features various biomedical sensors that track key health metrics such as heart rate, body temperature, and environmental conditions around the soldiers.

The collected information is sent to the control centre, allowing military personnel to continuously monitor soldiers' well-being and location. One of the major benefits of this system is its ability to accurately locate missing soldiers, especially those in critical situations, reducing the risk of losing personnel in action. Additionally, it improves communication between soldiers, particularly in emergencies, and provides reliable navigation support to the command centre. This technology serves as a life-saving tool for soldiers, enhancing their safety and improving military operations. In the future, a more advanced, portable handheld device with additional sensors can be developed to provide even better assistance to soldiers in the field.

The soldier health and position tracking system significantly enhance military operations by providing real-time information on the whereabouts and condition of troops. The system uses GPS technology to find locations and wearable sensors to check health. This helps you understand everything happening around you. You should think about how long the battery will last, how quickly data is sent, and

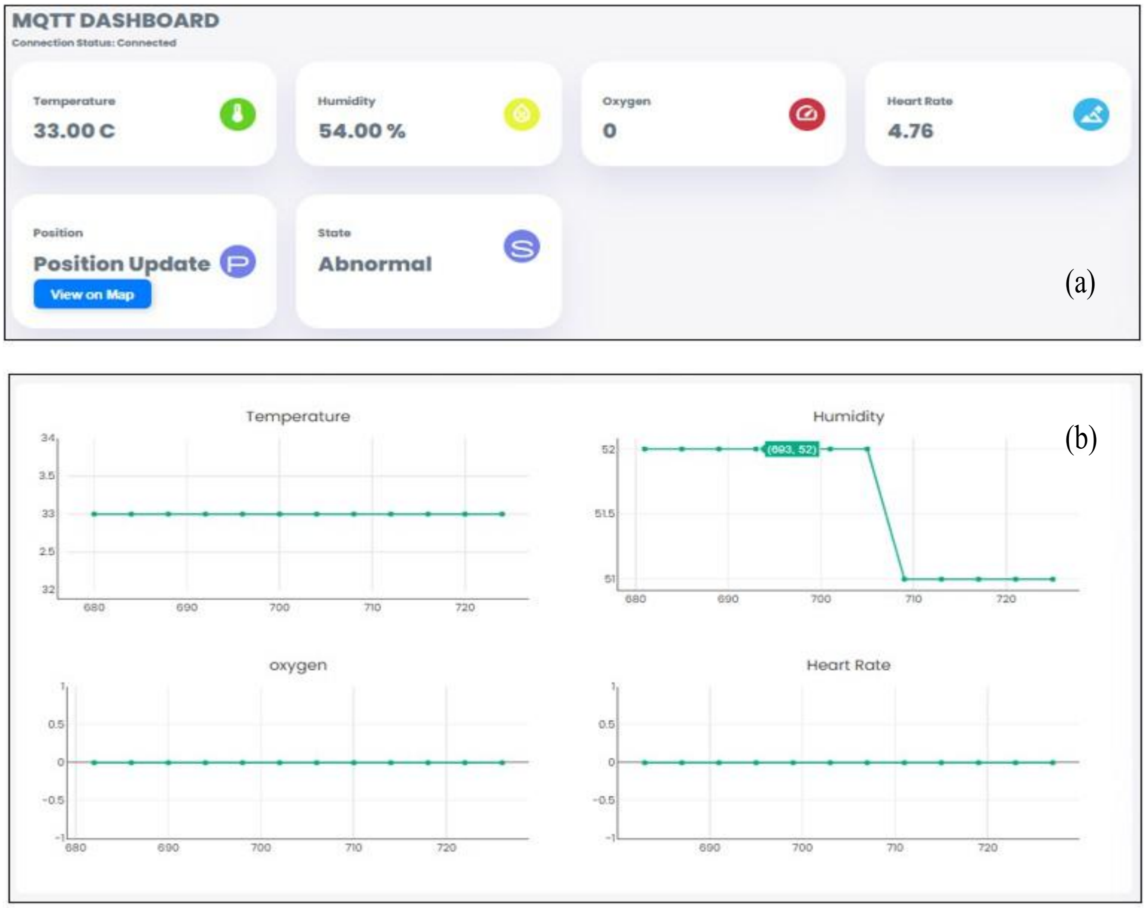


Fig. 5: a) Dashboard display, b) results.

how simple the system is to use when you're out and about.

Continuous operation of sensors and data transmission can rapidly deplete battery resources, especially in remote or prolonged missions. Implementing energy-efficient components and exploring alternative power sources, such as solar panels, can help address this challenge. Reliable and secure communication channels are essential for transmitting health and location data. Utilizing low-power communication protocols and ensuring data encryption can enhance system reliability and security.

The analysis of the results has been completed, and the focus now shifts towards evaluating the performance parameters. This next phase will provide deeper insight into the system's efficiency, reliability, and overall effectiveness based on various technical metrics.

The Fig. 6(c) represents the performance evaluation of an IoT-based soldier health and location monitoring system using a range of critical parameters such as transmission range, data rate, latency, battery life, GPS accuracy, and security. Each parameter is scored on a scale of 0 to 10 based on its effectiveness and relevance to real-time monitoring applications, particularly in military scenarios. The curve is plotted using cubic spline interpolation, which provides a smooth transition between data points and highlights trends in system performance. From the standard curve, it is evident that the system excels in areas like transmission range, packet delivery ratio (PDR), reliability, and security, which are crucial for ensuring consistent data transmission in remote environment. However, certain parameters like data

Table 3: Performance parameter of LoRa communication technology.

Parameter	Accuracy (%)
Transmission Range	98
Data Rate	22
Spreading Factor (SF)	83
Packet Delivery Ratio	92
Latency	34
Bit Error Rate (BER)	19
Sensor Accuracy	87
Sampling Rate	78
Response Time	87
Data Integrity	95
Battery Life	76
Power Consumption	66
Sleep Mode Efficiency	93
Location Accuracy	98
Update Rate	89
Time to First Fix (TTFF)	78
Reliability	97
Scalability	82
Robustness	81
Security	96

rate and latency show relatively lower scores, which aligns with the inherent trade-offs in LoRa-based communication systems that prioritize range and power efficiency over high-speed data transfer. Overall, the graph provides a clear and insightful visualization of the system's strengths and areas for improvement.

Table 3 delves into key aspects such as accuracy, latency, power efficiency, data integrity, and communication reliability. Evaluating these parameters is essential to understanding how well the system operates under different conditions and to identifying potential areas for optimization. The next section shows the graphs of temperature and humidity, as well as oxygen level and heart rate for each person.

The Fig. 6(a) representing temperature and humidity per person offers insights into the environmental conditions each individual is exposed to. The temperature values range between 34°C and 38°C, showing only slight variation across the five individuals. In contrast, humidity levels show a slightly wider range, peaking at 55% for Person 4 and dipping slightly below 50% for Person 5. These consistent readings suggest a controlled environment or similar external conditions for all individuals. Such data is particularly useful in health monitoring scenarios where environmental factors could influence physiological parameters.

Figure 6(b) indicates the graphical representation of oxygen and heartrate parameters. It compares vital health metrics for five individuals. Oxygen saturation is relatively high across all participants, with values above 80%, indicating good respiratory function. Meanwhile, heart rate values vary more noticeably, ranging from around 75 bpm to nearly 100 bpm. Person 3 and Person 5 exhibit higher heart rates compared to others, which could point to physical activity or stress. Together, these parameters provide a snapshot of individual health, helping in the early detection of anomalies when integrated into real-time monitoring systems. The next section shows the graph of the accuracy of performance parameters.

Figure 6(c) presents a bar chart that visually summarizes the accuracy levels of different performance parameters evaluated in the proposed system. Each parameter, namely data integrity, reliability, update rate, transmission range, and location accuracy, is measured on a scale from 0 to 100 percent. The chart plays a crucial role in showcasing how well the system performs in critical areas that determine its real-world applicability and robustness. From Figure 6(c), it is evident that the parameters such as transmission range and location accuracy achieve the highest levels of accuracy, both peaking at 98%. This indicates that the system has a strong capability in maintaining communication over long distances and accurately determining the position of the subject or device. These two attributes are essential, especially in applications like soldier tracking and health monitoring where consistent and precise location data is critical. The next highest-performing parameter is Reliability, which records an accuracy of 97%. This high level of reliability reflects the system's consistent behaviour under various conditions and suggests minimal data loss or communication failures. A reliable system is fundamental in safety-critical applications, and Figure 6(c) successfully highlights that the designed model performs well in this regard. Data integrity follows closely with a 95% accuracy, as shown in the chart. This suggests that the data collected and transmitted remains intact without significant corruption or modification. Maintaining data integrity ensures that the information processed by the system reflects true and accurate conditions, which is crucial for decision-making and real-time response in dynamic environments. One of the key observations from Figure 6(c) is the relatively lower accuracy of the Update Rate, which stands at 89%. While this value is still within an acceptable range, it does point to an area that could benefit from further optimization. The update rate directly affects how frequently new data is available, and in time-sensitive scenarios, a higher update rate can significantly improve system responsiveness and performance. Figure 6(c) provides a clear and concise representation of the system's strengths and areas for improvement. Most of the parameters have achieved near-optimal accuracy, suggesting that the overall system design is both effective and efficient. The slightly lower performance in the update rate could be addressed through hardware or firmware enhancements. Overall, the graphical analysis in Figure 6(c) supports the conclusion that the proposed system is well-suited for its intended application, combining high accuracy with robust performance.

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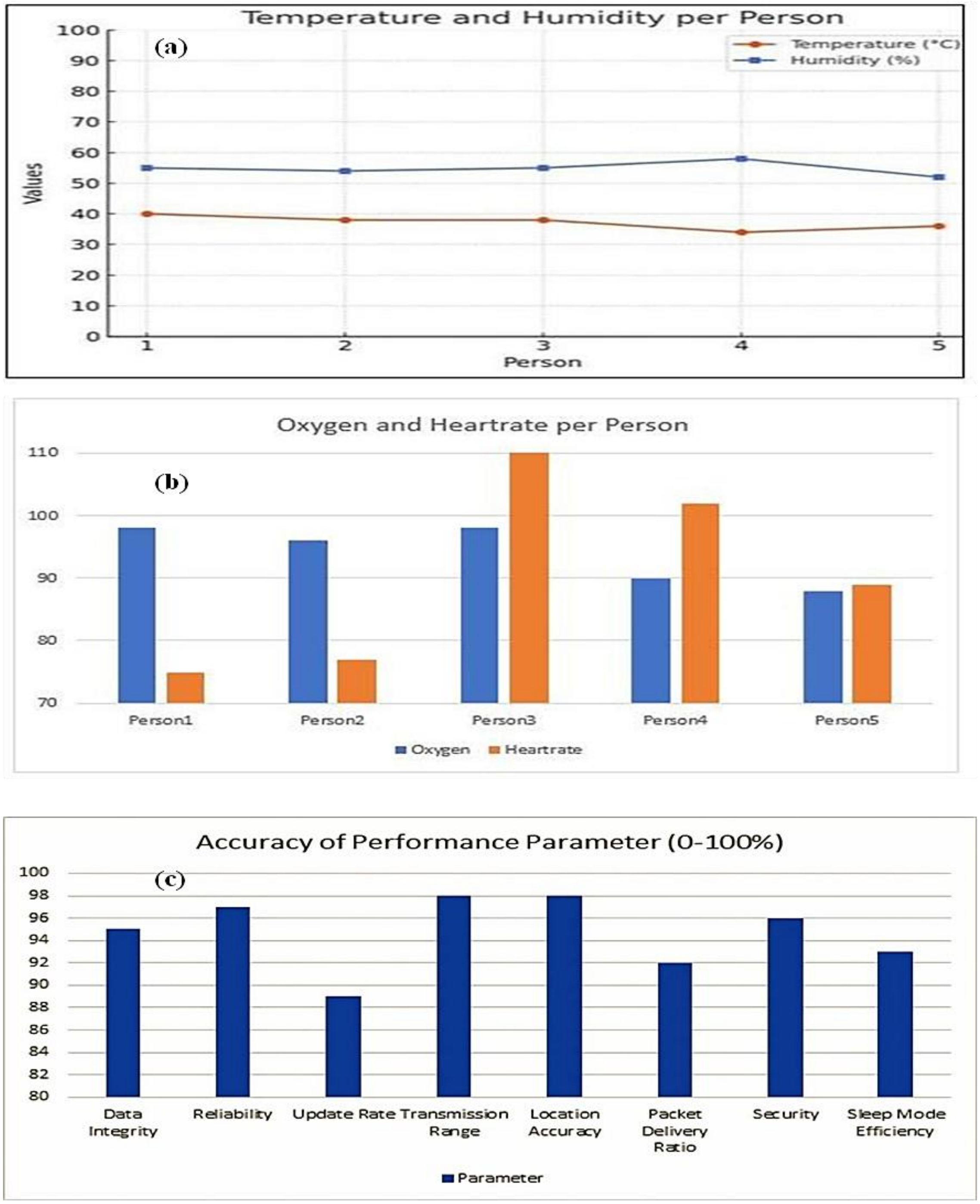

Fig. 6: a) Graphical representation of the results based on temperature and humidity, b) graphical representation of the results based on oxygen and heart rate, c) the accuracy levels of different performance parameters.

5. Conclusion and future scope

This research presents a comprehensive health monitoring and location tracking system for soldiers, utilizing LoRa technology to enhance operational safety and situational awareness in remote and challenging environments. The system is designed to monitor key biometric parameters-body temperature, blood pressure, oxygen saturation (SpO_2), and heart rate-and transmit real-time geolocation data during emergencies. These capabilities allow military personnel to maintain oversight of soldier well-being, particularly during rest periods or in high-risk operational settings. By detecting anomalies in health indicators and localizing personnel quickly, the system improves the efficiency and effectiveness of rescue and medical response efforts.

A significant strength of this system is its independence from conventional communication infrastructure, making it highly applicable in terrain- constrained or signal-deprived environments. This feature ensures communication continuity and safety monitoring without reliance on cellular networks, which are often unavailable in combat zones.

During the early development stages, the project encountered several design constraints, particularly regarding the initial concept of a wrist- mounted unit. Limitations such as the large size and weight of the battery pack (comprising 16 individual cells), along with manual soldering inaccuracies, hindered miniaturization and ergonomic integration. These challenges were addressed by opting for a more robust external module configuration, prioritizing functionality and data reliability over compact form factor. This adaptation allowed for stable performance and accurate data collection in real-world test scenarios.

The system did not achieve full optimization in terms of energy efficiency or component integration; however, it demonstrated a notable reduction in sensor output variability, particularly in heart rate and oxygen level readings, across repeated trials. This improved consistency is critical for applications where false readings or erratic data could lead to misinformed decisions in life-critical situations.

While absolute efficiency was not attained, the system achieved high operational reliability, delivering consistent data communication over long distances with minimal packet loss. The evaluation of performance metrics highlighted the system's potential to be integrated into broader military communication and health-monitoring platforms. Furthermore, this project fostered meaningful collaboration, as the team contributed to peer groups in areas such as firmware development and circuit debugging, reinforcing a cooperative research environment.

Future scope

- Integration with AI and Machine Learning: Incorporating AI/ML algorithms can enable predictive analysis of health trends, identifying patterns associated with stress, fatigue, or early-onset health issues. This would transform the system from a reactive to a proactive tool for soldier safety.
- Adoption of Edge Computing and IoT Interoperability: By embedding edge processing capabilities, the system can analyze and respond to critical biometric data in real time, reducing reliance on centralized servers. This will also enable interfacing with other IoT-based devices on the battlefield for enhanced data fusion and mission planning.
- Network Scalability and Coverage Expansion: Enhancing the range and capacity of the LoRa network is essential for deployment across larger operational regions, especially in mountainous or forested terrain. This entails addressing technical limitations related to signal attenuation, antenna optimization, and interference management.
- Advanced Sensor Integration: Future versions may incorporate sensors capable of detecting hydration levels, muscle fatigue, EEG activity, or cognitive alertness, providing a multidimensional health profile. However, integrating these sensors while maintaining low power consumption remains a key challenge.
- Miniaturization and Power Management: Developing compact, energy-efficient hardware remains a critical objective. This includes transitioning to surface-mount devices (SMD), using flexible printed circuits (FPCs), and implement in high-density rechargeable power solutions such as Li-Po batteries with advanced battery management systems (BMS).
- Cybersecurity and Data Integrity: Ensuring secure communication protocols, including end-to-end encryption and authentication mechanisms, will be necessary to protect sensitive soldier health and location data from interception or tampering.
- Environmental and Tactical Robustness: Future iterations must meet military-grade durability standards, offering resistance to water, dust, shock, and electromagnetic interference (EMI), without compromising performance or increasing device weight significantly.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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