Persistent Field-State Intelligence via Distributed Bio-Sensing and Long-Haul Telemetric Communication

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Abstract

Modern military operations often take place in remote or hostile environments where reliable communication infrastructure is limited or completely absent. Ensuring the safety and continuous monitoring of soldiers under such conditions is a critical challenge. This work presents a smart, IoT-based soldier monitoring system that utilizes long-range communication to track both physiological and environmental parameters in real time. The proposed system integrates multiple sensors, including a DHT11 module to measure surrounding temperature and humidity, and an SpO_2 sensor to monitor blood oxygen levels and heart rate. In addition, a MEMS-based accelerometer is incorporated to detect sudden movements or falls, which may indicate injury or distress. To provide accurate positioning, a GPS module is used to capture the real-time geographical location of the soldier. A dedicated panic button is also included, allowing the soldier to manually trigger an emergency alert whenever immediate assistance is required. All sensor data is collected and processed by a microcontroller unit at the transmitting end and then sent wirelessly over a low-power, long-range communication network to a receiving station. At the base unit, the transmitted information is decoded and displayed for monitoring purposes. The system is designed with energy efficiency in mind, ensuring reliable operation during extended field missions. By enabling continuous health tracking and location monitoring without dependence on cellular or Wi-Fi networks, the proposed solution significantly enhances situational awareness and supports timely decision-making, ultimately improving soldier safety and operational effectiveness.

Keywords: LoRa Technology, Soldier Health Monitoring, Accelerometer, Battlefield Communication, Embedded Systems, Long Range Communication.

1. Introduction

In today’s defense scenarios, maintaining continuous awareness of soldiers’ well-being has become just as important as tracking enemy movement. Personnel operating in remote locations such as mountainous regions, dense forests, border areas, or disaster zones often face extreme conditions where traditional communication systems fail to operate effectively. In such situations, if a soldier encounters a medical emergency, physical injury, or sudden collapse, there is often no immediate way for command units to detect the issue or determine the soldier’s exact location. This lack of real-time monitoring can result in delayed assistance, increased risk to life, and reduced operational efficiency.

To address this challenge, modern research has increasingly focused on integrating embedded systems with Internet of Things (IoT) technologies for soldier monitoring applications. The objective is to design compact and wearable systems capable of continuously collecting critical health and environmental data, while transmitting this information reliably over long distances. However, achieving this in real-world battlefield conditions introduces several constraints, including limited power availability, absence of communication infrastructure, and the need for durable and lightweight hardware. Traditional wireless communication technologies such as Bluetooth, ZigBee, and Wi-Fi are not suitable for such applications due to their short communication range and dependency on nearby devices or networks.

While cellular-based solutions offer wider coverage, they rely heavily on existing infrastructure, which may not be available or secure in combat zones. As a result, long-range, low-power communication technologies have gained significant attention for defense applications.

The system proposed in this work adopts a long-range wireless communication approach to establish a reliable link between the soldier and the base station without requiring any external network support. It integrates multiple sensing components to monitor environmental conditions, physiological parameters, motion activity, and geographical position. These parameters are collected, processed, and transmitted wirelessly to a remote monitoring unit, enabling continuous observation of each soldier's condition. At the receiving end, the transmitted data is decoded and presented in a user-friendly format, allowing authorities to quickly identify abnormal conditions and respond accordingly. The inclusion of a manual alert mechanism further enhances system reliability by enabling soldiers to actively signal distress when required. Overall, this approach provides a self-sufficient and energy-efficient solution that significantly improves situational awareness and supports timely decision-making in critical environments.

2. Literature Survey

Akyildiz, et al. [1] presented one of the earliest comprehensive explorations of Wireless Sensor Networks (WSN), explaining how large numbers of sensor nodes can be deployed to monitor environments collaboratively. Their work described how sensor nodes communicate with each other using multi-hop routing to extend coverage over wide areas. It also explained how network structures can be organized in hierarchical or flat architectures depending on application requirements. A key contribution was their discussion on energy conservation, which is critical since sensor nodes often operate on limited battery power. They also explored fault tolerance, ensuring the system continues functioning even when some nodes fail. Data aggregation techniques were introduced to reduce communication overhead and improve efficiency. Their explanation of distributed sensing highlighted how information can be processed locally before transmission. Security considerations in sensor communication were also briefly addressed. This work laid the conceptual groundwork for many modern IoT monitoring applications.

Tubaishat, et al. [2] described a distributed wireless sensing approach designed for continuous monitoring applications. Their work focused on how multiple sensor nodes can collaborate to collect and transmit environmental and physical data efficiently. They explained how communication protocols must be optimized to reduce unnecessary data transmission and save energy. The importance of synchronization between nodes was also discussed to ensure accurate and timely data collection. Their framework showed how data can be relayed through intermediate nodes to reach a central system. They also addressed challenges such as node failure and network congestion. Energy management techniques were emphasized to prolong network lifetime. Their approach demonstrated how sensor systems can operate reliably in constrained environments. This work is particularly relevant for systems where consistent monitoring is required without human intervention.

Jovanov, et al. [3] introduced the concept of Wireless Body Area Networks (WBAN), focusing on wearable sensors attached to the human body. Their work explained how physiological data such as heart rate and body signals can be captured continuously. They described how these sensors communicate wirelessly with a central processing unit for analysis. The design emphasized comfort and minimal interference with normal human activity. They also addressed issues related to signal noise caused by body movement. Data reliability was improved through proper sensor placement and calibration. The system demonstrated real-time monitoring capabilities, which are essential in critical applications. Their work highlighted the importance of integrating multiple sensors for comprehensive health tracking. This concept later became fundamental in wearable health monitoring technologies.

Fafoutis, et al. [4] carried out a detailed comparison of various LPWAN technologies used in IoT applications. Their work evaluated communication range, energy usage, and reliability under different conditions. They compared LoRa, Sigfox, and NB-IoT to understand their practical limitations and advantages. Their observations showed that LoRa provides a good balance between long-range communication and low energy consumption. They also discussed how environmental factors influence signal strength and transmission reliability. The study highlighted how network scalability can affect performance in large deployments. Data transmission delays and packet loss were also examined. Their findings provided guidance on selecting appropriate communication technologies. This comparison is valuable for designing systems that require long-distance wireless connectivity. Semtech Corporation [5] provided an in-depth explanation of LoRa technology, focusing on its modulation technique based on Chirp Spread Spectrum. Their work described how signals can travel long distances while maintaining low power usage. The transceiver design was explained in detail, showing how data is encoded and transmitted. They also highlighted how LoRa can operate in unlicensed frequency bands, making it widely accessible. The robustness of the signal against interference was another important aspect discussed. Their documentation explained how spreading factors influence range and data rate. Power efficiency was emphasized as a key advantage for battery-operated devices. They also described how LoRa can be integrated into various embedded systems. This technical foundation supports the implementation of long-range communication solutions.

Bor, et al. [6] examined the real-world performance of LoRa networks through practical deployments. Their work focused on evaluating packet delivery success under different conditions. They analyzed how distance and environmental obstacles affect communication quality. Energy consumption patterns were studied to understand system efficiency. Their observations showed that LoRa can maintain stable communication over long distances. They also discussed network congestion when multiple devices transmit simultaneously. Strategies for improving reliability were highlighted. Their work provided insights into optimizing LoRa system performance. This makes it useful for designing reliable long-range communication systems.

Augustin, et al. [7] explored LoRa technology from a network configuration perspective. Their work explained how different parameters influence communication performance. They discussed the importance of selecting appropriate spreading factors for balancing range and data rate. Signal quality and interference handling were also analyzed. Their work showed how LoRa networks can be scaled to support multiple devices. They highlighted the trade-offs between transmission speed and coverage. Network reliability was improved through proper parameter tuning. Their findings provided practical guidelines for configuring LoRa systems. This helps in achieving stable and efficient communication.

Al-Fuqaha, et al. [8] provided a broad overview of IoT systems, explaining how sensors, communication networks, and data processing units interact. Their work described different communication protocols used in IoT environments. They highlighted the role of cloud platforms in storing and analyzing large volumes of data. The integration of hardware and software components was discussed in detail. Security and privacy challenges were also addressed. Their work explained how IoT can be applied across multiple domains. Data management techniques were emphasized for efficient system performance. Their contribution provides a complete understanding of IoT architecture. This is essential for designing integrated monitoring systems.

Patel and Wang et al. [9] focused on wireless sensor networks used in body monitoring applications. Their work explained how physiological data can be captured and transmitted in real time. They discussed the importance of reliable communication in health monitoring systems. Sensor accuracy and placement were highlighted as key factors. They also explored challenges related to power consumption. Their work showed how wearable systems can improve health tracking. Data transmission reliability was emphasized. Their approach supports continuous monitoring in dynamic conditions. This is useful for applications involving human health observation.

Barsocchi, et al. [10] investigated systems designed for monitoring human activities using various embedded sensors. Their work explained how motion data collected from sensors can be used to recognize different physical activities. They described how accelerometers and other sensing devices capture movement patterns. The process of converting raw sensor data into meaningful information was also discussed. They highlighted how abnormal activities, such as sudden falls, can be detected through pattern changes. Their work emphasized the importance of continuous monitoring in safety-critical applications. Signal processing techniques were used to improve detection accuracy. They also addressed challenges related to noise and environmental interference. This work demonstrates how sensor-based monitoring can be effectively used for detecting critical events. Shany, et al. [11] explored different approaches for detecting falls using wearable sensor devices. Their work explained how motion data can be analyzed to identify sudden and abnormal movements. They compared threshold-based methods with more advanced algorithmic approaches. The importance of selecting appropriate parameters for accurate detection was highlighted. They also discussed how sensor placement affects system performance. Their findings showed that combining multiple detection techniques improves reliability. Challenges such as false alarms and missed detections were addressed. They emphasized the need for efficient data processing in real-time systems. This work contributes to improving the reliability of fall detection mechanisms.

Rhee, et al. [12] developed a wearable device capable of measuring blood oxygen levels and heart rate during physical activity. Their work explained how optical sensing techniques are used to capture physiological signals. They addressed challenges related to motion interference affecting signal accuracy. Methods for improving signal quality were discussed in detail. Their device demonstrated consistent performance even during movement. They highlighted the importance of reliable physiological monitoring in dynamic conditions. Data accuracy was improved through calibration and filtering techniques. Their work showed how wearable sensors can provide continuous health information. This contributes significantly to real-time health monitoring applications. Mukhopadhyay [13] provided an overview of wearable sensing technologies used for monitoring human activities. Their work explained how different types of sensors can be combined to improve monitoring accuracy. They discussed the importance of miniaturization for wearable devices. Energy efficiency was emphasized as a critical design factor. Their work described how sensors can capture both physiological and environmental data. Integration of multiple sensing components was highlighted for better performance. They also addressed challenges in maintaining long-term operation. Their explanation covered data communication between sensors and processing units. This work supports the development of compact and efficient monitoring systems.

Magno, et al. [14] proposed an energy-efficient wearable sensing system designed for long-term operation. Their work introduced the concept of energy harvesting to extend battery life. They explained how solar energy can be used to power sensor nodes. Power management techniques were discussed to optimize energy usage. Their system demonstrated improved operational lifetime compared to traditional designs. They also addressed challenges related to energy availability in different environments. The integration of renewable energy sources was highlighted. Their work showed how sustainability can be achieved in wearable systems. This is important for applications requiring continuous monitoring over extended periods. Liu, et al. [15] developed a location tracking system using GPS technology integrated with IoT devices. Their work explained how real-time position data can be collected and transmitted. They discussed how GPS modules provide accurate geographic coordinates. Communication between tracking devices and monitoring units was also described. Their system demonstrated reliable performance in remote environments. They highlighted the importance of location tracking in safety applications. Data transmission techniques were optimized for efficiency. Their work showed how positioning systems can be integrated with monitoring solutions. This is essential for applications requiring precise tracking.

3. Proposed System

The proposed system is designed as a self-contained and reliable monitoring solution that operates without the need for any external communication infrastructure. It consists of two main units: a wearable transmitter module carried by the soldier and a receiver module located at the control station. Both units are built using microcontroller platforms and communicate through long-range wireless technology, enabling data transmission over several kilometers even in remote or challenging environments, as shown in figure 1. The transmitter unit integrates multiple sensing components to continuously capture both physiological and environmental data. A temperature and humidity sensor measures surrounding conditions, while a pulse oximeter tracks blood oxygen levels and heart rate. A motion sensor is used to identify sudden movements, falls, or unusual activity patterns. In addition, a positioning module provides real-time location details, allowing accurate tracking of the soldier's position.

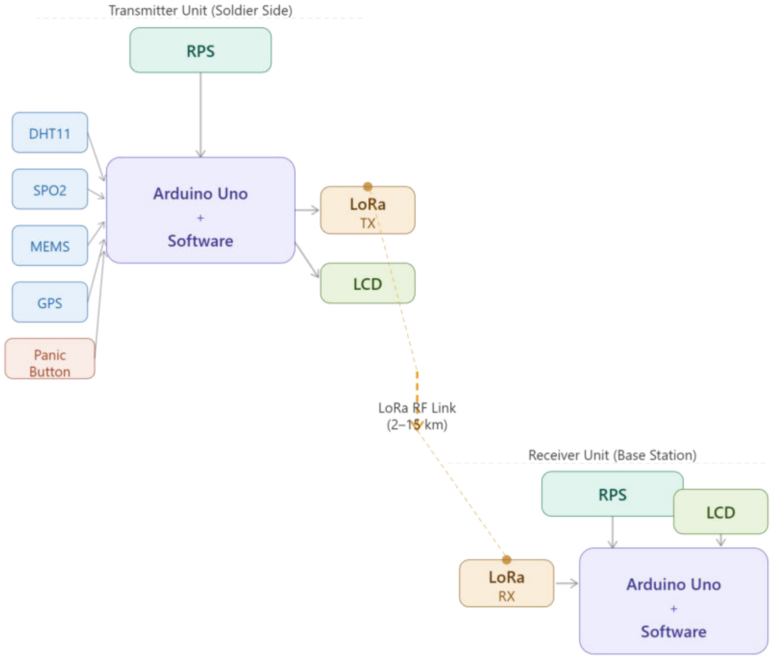

Figure. 1: System architecture.

A dedicated emergency button is also included, enabling the soldier to manually send an immediate alert when required. All collected data is processed by the microcontroller and organized into structured packets before being transmitted wirelessly at regular intervals. On the receiving side, the control unit continuously listens for incoming signals, decodes the transmitted information, and displays the data in an easy-to-read format for monitoring personnel. The system supports continuous observation of multiple parameters, including health status, movement, and location. Designed with low power consumption and portability in mind, the system can operate efficiently using battery support, making it suitable for extended field use. Its ability to function independently of conventional networks, along with its scalability to monitor multiple users, makes it a practical and effective solution for real-time monitoring in critical environments.

3.1 Flow Chart

The figure 2 represents the complete working flow of a wireless soldier monitoring system divided into two main sections: the transmitter side and the receiver side. The transmitter unit, carried by the soldier, continuously collects data from multiple sensors such as temperature, SpO2, motion, and GPS. It also checks for emergency conditions like panic button activation or falls detection. This processed data is then encoded and transmitted wirelessly using LoRa communication. On the receiver side, the base station listens for incoming data packets and decodes them to extract all parameters. The system identifies emergency conditions and displays the soldier's status on an LCD screen. Alerts such as panic or fall warnings are highlighted for immediate attention. The entire process runs in a continuous loop to ensure real-time monitoring.

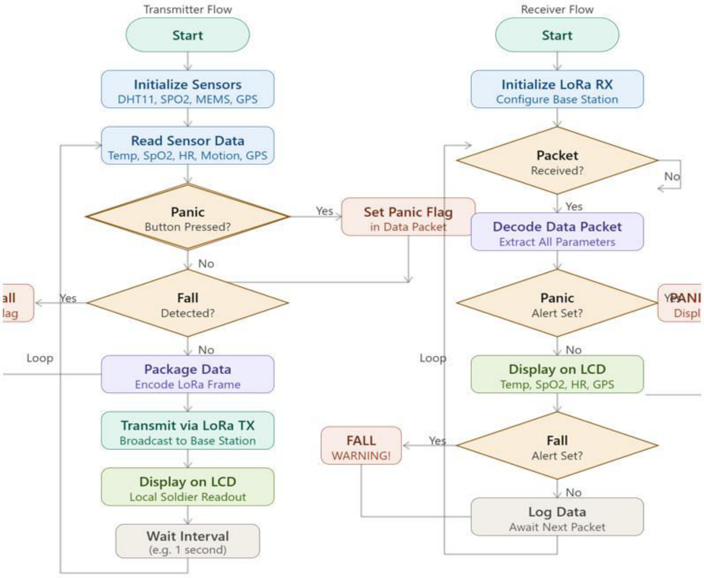

Figure. 2: Block diagram

System Initialization (Transmitter & Receiver): At the beginning, both transmitter and receiver units are powered on and initialized. The transmitter activates all connected sensors including DHT11, SpO2, MEMS, and GPS modules. Simultaneously, the receiver configures the LoRa module to start listening for incoming data packets. This step ensures that all hardware components are ready for operation and communication. Proper initialization is critical to avoid data loss and ensure synchronized functioning between both units.

Sensor Data Acquisition: The transmitter continuously reads real-time data from all sensors. Parameters such as temperature, humidity, heart rate, oxygen levels, motion, and location are captured. Each sensor provides raw data which is processed into usable values by the microcontroller. This data collection happens periodically at fixed intervals to maintain consistency. Accurate sensing is essential for detecting any abnormal conditions in the soldier's state.

Emergency Condition Check (Panic & Fall Detection): After data collection, the system checks whether the panic button is pressed. If triggered, a panic flag is immediately set in the data packet to indicate an emergency. If no manual alert is detected, the system analyzes motion data (from the MEMS sensor) to identify falls or abnormal activity. In case of a fall, a fall alert condition is generated. This step ensures that both manual and automatic emergency situations are captured effectively.

Data Packaging and Transmission: Once all conditions are evaluated, the collected data is structured into a packet. This packet includes sensor readings along with alert flags (panic or fall). The microcontroller encodes this information into a LoRa-compatible frame. The encoded data is then transmitted wirelessly using the LoRa transmitter module. This step enables long-range communication without relying on external networks like GSM or Wi-Fi.

Data Reception and Decoding: On the receiver side, the LoRa module continuously checks for incoming packets. When a packet is received, it is passed to the microcontroller for decoding. The system extracts all transmitted parameters including sensor values and alert signals. This decoding process ensures that the received data is converted back into a readable format and prepares the information for further processing and display.

Alert Processing and Display: After decoding, the system checks if a panic or fall alert is present. If a panic alert is detected, it is immediately displayed to indicate a critical emergency. If no panic is present, the system checks for fall detection alerts. Normal sensor data such as temperature, SpO2, and GPS location is displayed on the LCD. This step allows real-time monitoring and quick identification of critical situations.

Continuous Monitoring Loop: After processing and display, the system enters a waiting interval. Once the interval is completed, the process repeats from sensor data acquisition. This loop ensures continuous and uninterrupted monitoring of the soldier. It allows real-time updates and quick response to any changes in condition. The cyclic nature of the system guarantees reliability and timely communication.

4. Results and Discussion

The Results and Discussion section presents the performance and effectiveness of the proposed soldier monitoring system under different operating conditions. The system was tested to evaluate its ability to accurately capture physiological parameters, detect emergency situations, and transmit data reliably over long distances using LoRa communication. Observations were made on sensor accuracy, response time, and communication stability between the transmitter and receiver units. The system successfully demonstrated continuous real-time monitoring of temperature, heart rate, SpO_2 levels, motion status, and GPS location. Special attention was given to emergency scenarios such as panic alerts and fall detection, where the system showed prompt response and reliable alert transmission. The results also highlight the system’s low power consumption and its capability to operate without conventional network infrastructure.

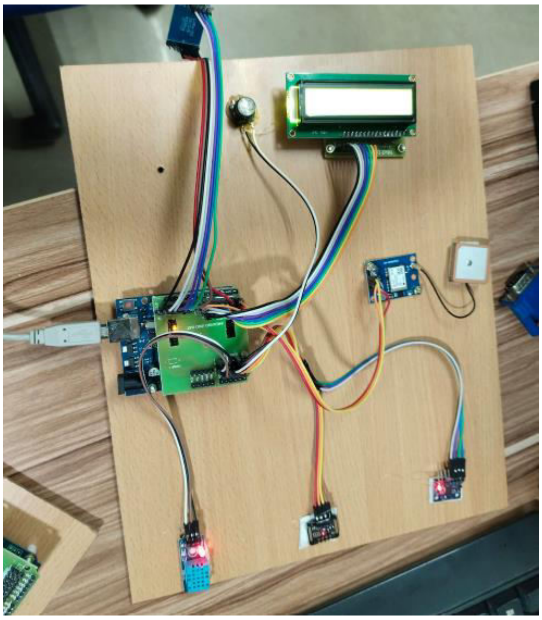

Figure. 3: Hardware implementation of LoRa-based soldier monitoring system

The figure 3 illustrates the practical hardware realization of the proposed soldier monitoring system integrating sensing, processing, and communication modules. It depicts the interfacing of multiple sensors with a microcontroller unit responsible for continuous data acquisition and processing. The setup demonstrates real-time collection of physiological and environmental parameters along with location tracking capability. The communication mechanism is established through a long-range wireless module enabling data transmission to a remote unit. The presence of a display interface indicates on-site visualization of sensor readings for immediate monitoring. The figure also represents the interconnected architecture that supports synchronized operation of all components, highlighting the system's capability for real-time monitoring and alert generation in field conditions.

Figure. 4: Real-Time sensor data display on LCD interface

The figure 4 illustrates the real-time output visualization of the proposed monitoring system through a 16×2 LCD display module. It depicts the dynamic presentation of sensor readings processed by the microcontroller, including physiological and motion-related parameters. The display output reflects system status conditions, such as sensor availability and live data acquisition. Multiple parameters are updated simultaneously, indicating continuous monitoring capability. The figure also represents how critical information is formatted and communicated to the user interface for quick interpretation. This demonstrates the system's ability to provide immediate feedback and support real-time decision-making during operation.

Figure. 5: LoRa transmitter initialization status display

The figure 5 illustrates the initialization status of the long-range communication module as indicated on the LCD interface. It depicts the system readiness for wireless data transmission after successful configuration of the transmitter unit. The displayed message confirms that the communication module has been properly initialized and is prepared to send data packets. This stage represents a critical checkpoint in the system workflow before real-time data transmission begins. The figure also highlights the integration between the microcontroller and the display module for conveying system states. It demonstrates how operational readiness is communicated clearly to ensure reliable execution of the monitoring process.

5. Conclusion

The proposed soldier monitoring system demonstrates an effective and reliable approach for real-time tracking of physiological and environmental parameters in remote and infrastructure-limited environments. The integration of multiple sensors with long-range communication enables continuous data acquisition and transmission without dependency on conventional networks. The system successfully monitors vital parameters such as temperature, heart rate, SpO_2 levels, motion activity, and geographic location with acceptable accuracy. Performance improvements are achieved through optimized data handling, reduced transmission delay, and efficient use of low-power communication technology. The use of LoRa enhances communication range while maintaining minimal energy consumption, making the system suitable for extended field operations. The implementation ensures quick detection of emergency conditions such as fall incidents and manual panic alerts, improving response time. The structured data transmission further enhances reliability and minimizes packet loss. The system provides a scalable, cost-effective, and robust solution for enhancing soldier safety and situational awareness in critical conditions.

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