WanderWatch: LoRaWAN-Based Monitoring System for Wandering Risk Patients

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***Abstract*—Caregivers and families of wandering risk patients (e.g., Alzheimer's and dementia) face the critical issue of tracking those individuals' movements to ensure their safety. Several monitoring tools are available today, including GPS trackers, RFID systems, Bluetooth-based trackers, smartwatches, home security systems with cameras and sensors, and community alert programs. However, these systems often rely on cellular networks, which can be unreliable or nonexistent in remote locations, making them unsuitable for tracking over large distances or outdoor areas. One way to address this challenge is to use Long-range Wide Area Networks (LoRaWAN) networks that do not require internet connectivity while operating independently. This paper presents WanderWatch, a LoRaWAN-based monitoring system for wandering risk patients. WanderWatch is a robust monitoring and geofencing solution that leverages advanced LoRaWAN technology, which provides reliable and long-distance communication even in areas with poor cellular coverage, ensuring continuous monitoring of patients. It combines wearable IoT devices with an advanced geofencing system to track patients in real-time and alert caregivers if they wander outside designated safe zones. Our system utilized LoRa hardware supported by an optimized Echo protocol in a zero-control mesh network to efficiently detect boundary breaches of the monitored subjects, such as patients with Alzheimer's disease, robots mounted with IoT devices and sensors, etc. WanderWatch is evaluated with a real-world testbed using various performance metrics.**

***Index Terms*—WanderWatch; LoRa; Mesh Communication; Monitoring System; Wandering Risk Patients.**

I. Introduction

Alzheimer's disease (AD) cases, the most generic form of dementia worldwide, are expected to reach 131 million by 2050, which will critically burden economies and health systems in the following decades [1]. One of the most distressing and potentially dangerous manifestations of dementia and Alzheimer's is wandering behavior. Wandering is characterized by aimless and disoriented movement, where affected individuals often find themselves far from familiar and safe surroundings. This behavior poses severe safety risks, include drowning and car accidents [2].

These situations can be highly stressful and unpredictable, highlighting the need for a tracking system to monitor them 24/7. Traditional methods of monitoring wandering Risk patients often depend on cellular networks to track their movements and send alerts if they leave designated safe areas. However, these methods have their drawbacks. Cellular networks can be unreliable, especially in remote or rural areas where coverage is inconsistent or nonexistent [3]. This unreliability can result in delayed alerts or no alerts at all, putting patients in danger.

LoRaWAN technology is a pivotal advancement in low-power wireless communication, particularly in the IoT domain [4], [5], [6], [7]. LoRa's architecture enables long-range communication with minimal power consumption, making it ideal for applications in healthcare, smart cities, agriculture, and environmental monitoring [8]. The critical characteristics of LoRaWAN include its ability to operate over long distances, robustness to interference, and low data rate transmission, which are essential for battery-operated IoT devices.

This paper presents WanderWatch, a LoRaWAN-based geolocation and geofencing alert system for wandering risk patients. WanderWatch is tailored to overcome the limitations of cellular coverage in remote areas and dense urban communities. Our system utilized low-power LoRa hardware to create a real-time monitoring system to track patients' movements and ensure they stay within predefined safe zones. WanderWatch sends instant alerts to caregivers if a patient crosses the geofenced boundaries, allowing for quick intervention and reducing the risk of harm.

We developed a user-friendly GUI supported by Google Maps that enables caregivers to create patient safe zones by drawing multiple geofencing areas in the shape of circles and polygons. Caregivers can precisely monitor their patients' locations on the map in real-time. A set of real-world experiments is conducted using LoRa hardware to assess WanderWatch's efficiency using various network configurations.

II. Related Work

The lack of reliable monitoring systems for wandering risk patients not only puts those patients at significant risk but also causes constant worry and stress for their caregivers, who need to provide continuous supervision and care [9], [2], [10]. Numerous technological solutions have been developed to address these issues, including GPS-enabled gadgets [4]. While GPS-based tracking gadgets perform well in cities with good cellular coverage, they have limitations. They typically require cellular connectivity, necessitating ongoing subscription fees and regular recharging [3]. Wearable gadgets must be recharged periodically due to their power-intensive nature, making continuous monitoring unfeasible for more extended periods [11]. Also, the high data usage and subscription fees can make cellular-based systems unaffordable as sustainable monitoring solutions.

LoRaWAN technology can be considered a sustainable and affordable alternative to conventional cellular-based monitoring systems [12], [9]. In particular, the energy efficiency of LoRaWAN surpasses that of GSM or cellular systems, enhancing its practicality for continuous patient monitoring. Also, LoRaWAN offers a budget-friendly, user-centric, and proactive avenue for patient care, especially pertinent in cognitive disorders [2].

Geofencing technology, often implemented through smartphone apps, has gained popularity to define virtual boundaries and trigger alerts when individuals cross them [3], [11]. Caregivers can set up geofences around specific areas, such as the home or a healthcare facility, and receive notifications when the individual enters or leaves these areas. Smartphone apps offer easy use and accessibility, as many caregivers possess the necessary hardware [13].

Smart-Monitor [12] is a patient monitoring system for IoT-based healthcare systems using deep learning for e-healthcare. The developed method can monitor the surveyed patients' physiological signals. Trigo et al. [10] proposed a patient tracking system in a multi-building and tunnel-connected hospital complex. The proposed system leverages LoRaWAN and Near Field Communication (NFC) to track the locations of the patient's nodes within the hospital complex–however, this system is designed for indoor environments.

Varadharajan et al. [2] proposed a secure monitoring system for patients with wandering behavior in hospital environments. The proposed system utilized Software Defined Networking (SDN), Wireless LAN (WLAN), and wearable devices to track patients in indoor environments. The authors developed a security method using SDN for secure monitoring of dementia patients and raising the alarm to the hospital staff when the patient's location violates security and privacy policies.

III. System Design

Figure 1 shows the system architecture of WanderWatch, which is divided into three layers. Layer 1 shows the remote monitoring side, including a LoRa mesh multi-hop zero-control network suitable for dynamic scenarios where patients are represented by mobile LoRa nodes. An IoT gateway provides internet connectivity to our mesh network using WiFi technology. Layer 2 describes the cloud side, including the LoRa central server and the remote monitoring system utilizing the SQLite version 3.46 database engine.

A gatekeeper is used to communicate messages securely between the remote monitoring and cloud sides, where various security and encryption mechanisms are implemented. Layer 3 shows the GUI user interface, which allows end-users (e.g., healthcare providers) to use the proposed monitoring system using web-based tools and mobile apps from their computing devices, such as PCs and Smartphones.

Figure 2 illustrates the data flow between the remote monitoring and cloud sides, where the LoRa End Device

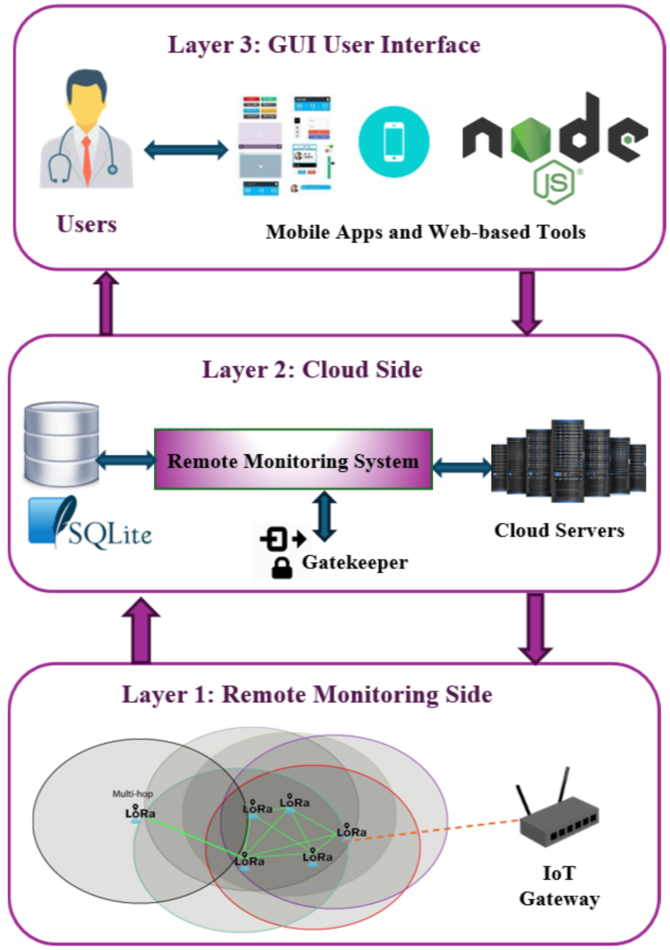


Fig. 1. System Architecture

(ED) generates its current location (i.e., longitude and latitude values) by a NEO-6m GPS module. An ESP32 microcontroller processes the GPS data and then transmits it to the central node via the LoRaWAN mesh network using a LoRa HopeRF 95w transmitter. The central node, equipped with an ESP32 microcontroller attached to a LoRa LoRa HopeRF 95w transceiver, gathers the GPS data from multiple LoRa EDs and forwards it to the LoRa central server for aggregation and visualization.

The LoRa central node establishes a communication channel with the cloud server, facilitated by the MQTT protocol over WiFi connectivity. This central node is the data processing and distribution hub within our geofencing system. The LoRa server is responsible for implementing the geofencing algorithm, aggregating the GPS data received from the LoRa EDs, and storing it in the database. The processed data is visualized on a map dashboard in real-time, which enables users to track and monitor the movement and location of the patients effectively to provide geofencing capabilities.

We used an optimized version of the ECHO protocol [14] for LoRaWAN mesh networks. We tried to minimize the collision rate of packets transmitted simultaneously by LoRa EDs. In the original ECHO protocol, each node sends packets

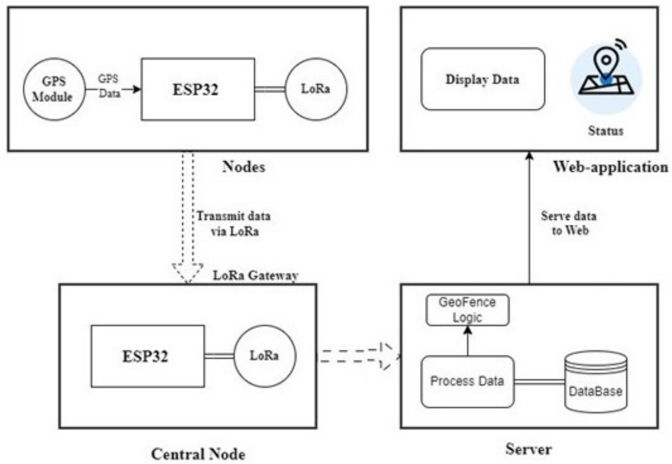


Fig. 2. Data Flow between the Remote Monitoring and Cloud Sides

whenever GPS data are available and the duty cycle restrictions are met. As a result, some packets are lost due to collisions. In the optimized ECHO version, we aim to minimize the collision rate and increase the packet delivery rate.

We assume that all nodes in the mesh network transmit the same number of data packets β, and the average data collection time is then equal to β/τ, where τ is the transmission rate of packets. The Spreading Factor (SF) in LoRa technology adjusts the packet transmission rate, influencing the transmission range of EDs [15]. The higher value of SF increases the range and robustness of interference at the cost of a reduced data rate. For instance, if a node at a distance x from the IoT gateway sends a packet with SF α, the packet will be delivered successfully if there is no overlap with any other packets in the network using the same α within the transmission time $T \times \alpha$.

We model the potential number of interfering nodes, N_α, that may increase the packet collision rate, as follows.

$$N_\alpha = \frac{(min(x\lambda, \sigma))^2}{\sigma^2} \tag{1}$$

where λ is the distance array of the potential interfering nodes from the gateway and σ is the range of the deployment for the given α.

Our goal is to increase the probability of successful packet delivery, $P_\alpha(x)$, within a dual transmission period, $2T_\alpha$, which is represented as:

$$P_\alpha(x) = e^{-2T_\alpha \phi N_\alpha} \tag{2}$$

where ϕ is the packet transmission rate.

IV. Implementation

WanderWatch has been prototyped using a real-world testbed implementing a mesh LoRaWAN in IoT settings.

A. Physical Implementation

For the remote monitoring side, we deployed three LoRa EDs (shown in Figure 3) equipped with an ESP-WROOM-32 microcontroller, HopeRF RFM95W LoRa module, NEO-6M TTL GPS module with an antenna, and a 3.7V Li-Po battery for power supply. The three LoRa EDs are positioned to establish a mesh LoRa network that effectively covers a radius of up to 6 miles.

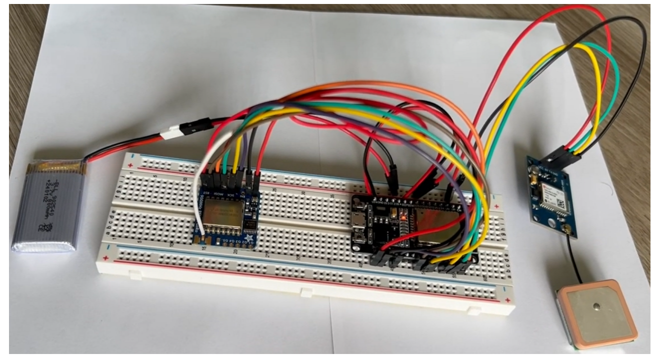


Fig. 3. The Hardware Design of a LoRa End Device.

The ESP32 microcontroller enables both WiFi and Bluetooth connectivity with a low-power consumption. Its dual-core CPU enables real-time data processing at the network edge. The HopeRF RFM95W LoRa module operates at 915MHz, which requires a 7.8 cm (3 inches) wire soldered directly to the transceiver's ANA pin as an antenna, as shown in Figure 3. The NEO-6M GPS module can provide precise real-time location data for tracking patients from 22 GPS satellites. Patients inside geofenced zones can be reliably and accurately tracked with its integrated antenna, which improves signal reception. It also has a UART TTL connector and an integrated 25x25mm active GPS antenna, providing extra information on the LoRa node's heading, speed, and time.

For the cloud side, as shown in Figure 4, we deployed a central LoRa node equipped with an ESP32 microcontroller and a LoRa HopeRF 95w transceiver attached to a laptop server. Using the MQTT protocol, the central node enables reliable connectivity with the cloud server, which processes the incoming data from the deployed EDs and visualizes it on the map dashboard.

B. GUI User Interface

The GUI user interface is developed as a web-based application with an interactive map powered by Google Maps API, ensuring accurate and up-to-date mapping services. We built the web application using Node.JS, HTML5, CSS3, JavaScript, and JSON. We set up a WebSocket using `Socket.IO` for enabling real-time communication between the LoRa EDs and the central node. Each ED represented as an MQTT client subscribes to publish/subscribe topic, `wanderwatch/gpsdata`, where the server checks the incoming messages to update the geofence status of nodes, which contain the latitude and longitude values, and node ID.

The homepage of the map-based web application is shown in Figure 5, which provides users with a visualization panel for drawing geofence areas in the shape of circles and polygons.

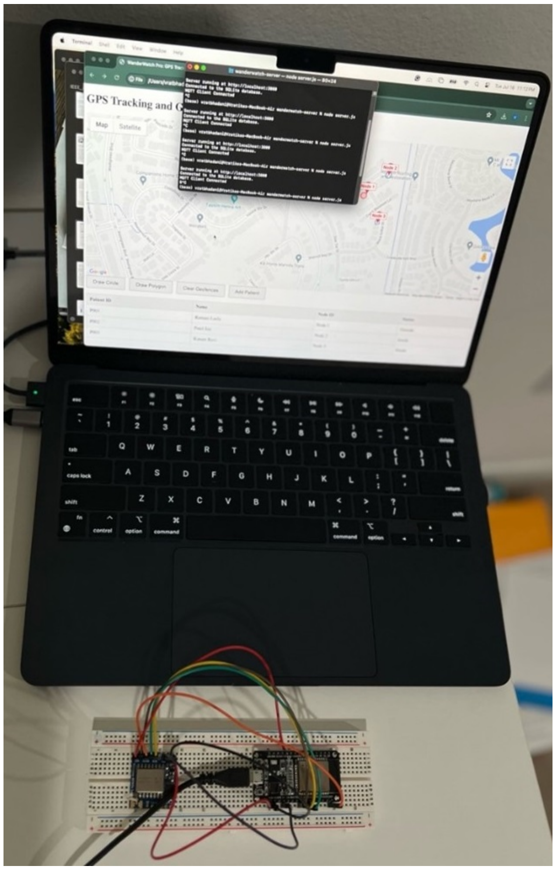
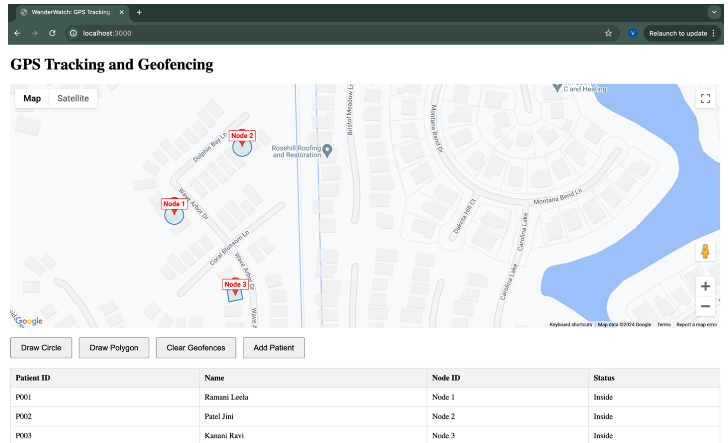
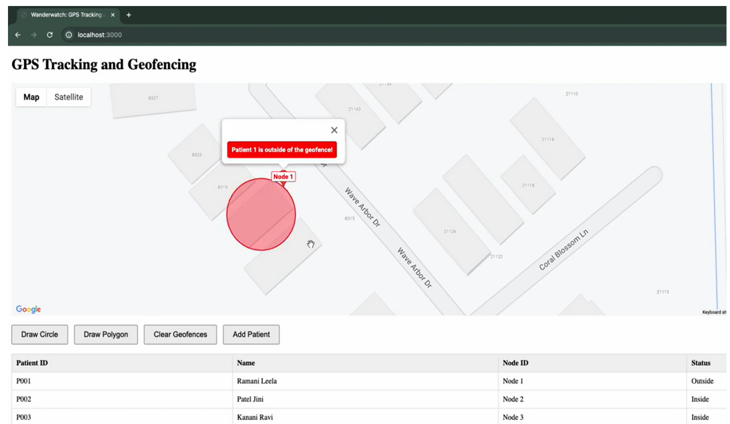


Fig. 4. The Hardware Design of the Central LoRa Server.



(a) The Web Application Dashboard



(b) Patient #1 Moved Outside the Monitoring Zone Triggering an Alert

Fig. 5. Screenshots of the Map-Enabled Web Application

Healthcare providers can pin LoRa EDs on the map, which is represented by a red marker along with its nodeID. Figure 5(a) shows three geofencing zones created around three patients' EDs. The initial status of these patients is 'inside' the geofence zone. Figure 5(b) shows an example scenario of Patient #1 moving outside the geofence zone, which triggers an alert to the healthcare provider and changes the status to 'outside.'

We developed an algorithm that precisely calculates the distance between two geographic points on a map and determines the bearing (i.e., direction) between them using their longitude and latitude values. By identifying the midpoint between these two designated geographic coordinates, we can conduct a proximity check to determine whether a point is within the boundary of a circle or polygon.

V. Experimental Evaluation

We conducted real-world experiments conducted close to the Greater Houston Area to evaluate WanderWatch in terms of its performance and accuracy. The experimental parameters of the testbed are shown in Table I. Three LoRa EDs, each with a coverage area of 2 miles, were moving at different speeds up to 6 miles/hr, which creates a mesh LoRa network with a radius of up to 6 miles during the 60 minutes of experiment duration. We set the data rate, packet size, and packet interval to 5 Kbps, 40 Bytes, and 10–60 seconds, respectively.

TABLE I
Testbed Experimental Parameters

Parameter	Value
Number of ED Nodes	3
Average Area Coverage	2 miles
Speed of ED Nodes	up to 6 miles/hr
Data Rate	5 Kbps
Packet Size	40 Bytes (payload and overhead)
Packet Interval	10–60 seconds
Simulation Time	60 minutes

Figure 6 shows the impact of the patient moving speed on the detection accuracy of the geofence alerts. We evaluated different moving activities, starting from slow walking (1 meter/second) to running (6 meter/second). It is found that WanderWatch achieved a high detection accuracy of 97% at the walking speed and drops to an average accuracy of 91% for patients moving at a speed of 3 meters/second, which is the the average human walking pace. At the running speed, the detection accuracy decreased to 85%, which is acceptable given the scaracy scenario of an elderly patient running.

Figure 7 shows the impact of varying the LoRa SF and transmission intervals on the collision rate of packets in the

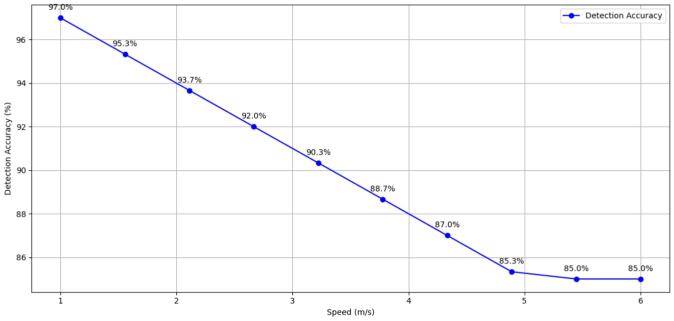


Fig. 6. The Impact of the Node Moving Speed on the Detection Accuracy of the Geofence Alerts.

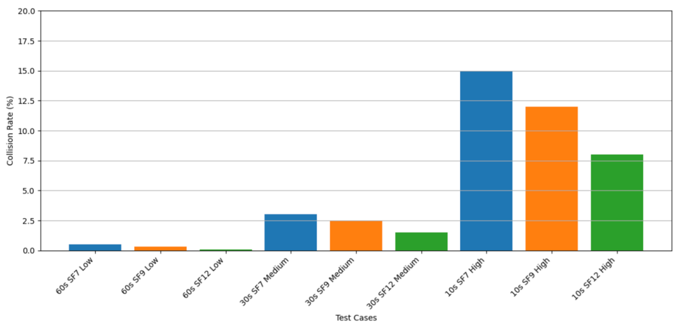


Fig. 7. The Impact of Varying the LoRa Spreading Factor and Transmission Intervals on Collision Rate.

mesh network while fixing all other parameters. As shown in the chart, the experimental results indicated that using higher transmission intervals and lower SFs leads to a higher collision rate. For instance, the test case 10s-SF7-High (i.e., the transmission interval is 10 seconds using SP7) had the highest collision rate of 15%, while 60s-SF7-Low had a 0.5% collision rate. We found that network administrators can optimize signal robustness by adjusting the spreading factor and selecting appropriate transmission frequencies, ensuring that communications are reliable in challenging networking conditions. Also, our experiments showed that the lower transmission frequencies and higher SFs can reduce battery consumption by decreasing the duty cycle and extending the on-air time.

VI. Conclusions

This paper presented WanderWatch, a monitoring and geofencing system for wandering risk patients using LoRaWAN technology. WanderWatch addresses the challenge of cellular-based geofencing systems, which require reliable connectivity in remote and densely populated areas, ongoing subscription fees, and regular recharging to its on-body devices. WanderWatch used a subscription-free model, making it an affordable and accessible monitoring solution for caregivers and healthcare facilities. A real-world testbed is implemented and evaluated using physical LoRa hardware, including ESP32 microcontrollers, NEO-6m GPS modules, and LoRa HopeRF 95w transmitters. The conducted experiments closely mimic actual deployment scenarios, providing direct insights into how a monitoring system performs in real-world environments. The evaluation results showed that WanderWatch achieved a high detection accuracy at the average walking speed and acceptable accuracy at the running speed. Also, this paper showed the impact of varying the LoRa network parameters on the packet collision rate. Most notably, we found that using higher SFs and lower transmission frequencies can significantly lower the collision rate and consequently improve the network performance. In ongoing work, we are looking into opportunities for generalizing our approach by assessing its scalability by deploying a large number of LoRa EDs on the ground and utilizing Machine Learning (ML) to predict the behavior of patients based on their movement patterns.

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