INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VII, July 2026

Design and Implementation of a LoRa-Based Real-Time Tracking System for Outdoor Safety

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DOI: https://doi.org/10.51583/IJLTEMAS.2026.150700118

Received: 27 July 2026; Accepted: 01 August 2026; Published: 20 August 2026

ABSTRACT

The main objective of this research is to design and develop a reliable, low-cost tracking system that can operate real-time in an outdoor environment, where there is a possibility of no cellular or Internet connection. This system relies on LoRa communication since it is long-range, low-cost, and energy efficient. Therefore, it is possible to ensure the operation of the proposed tracking system in the absence of cellular or Internet connections. The design requires an ESP32 microcontroller, NEO-6M GPS module, SX1278 LoRa transceiver to acquire the position of the tracked object and transmit this information wirelessly for its remote monitoring and control purposes. The second objective is to design and develop a transmitter-receiver communication system, which is also capable of operating in real-time and can be used to relay the location and status of the tracked object from one device to another. The developed communication system will have an OLED display, which will show the received messages from the tracking device, and an SOS feature, which will send an emergency message in case of an emergency. The system will be used as a multipurpose outdoor tracking and safety device that can be utilized for human and animal tracking, trekking, camping, surveying, wildlife monitoring, and search and rescue operations. Finally, the third objective is to come up with a reliable, low-cost, portable, and energy-efficient prototype through step-by-step development and testing. The development process will involve testing individual components and the communication system because, at this stage, the rest of the system components will be integrated and tested as the development moves forward. In addition, the proposed architecture will be expanded in the future by adding other features, such as smartphone applications, cloud platform, geofencing, and other outdoor tracking and monitoring functionalities. This way, it will be possible to test and evaluate the performance of each component before building the final product.

Keywords— LoRa, ESP32, GPS, Outdoor Safety, Real Time Tracking, IoT, Long Range Communication, SX1278, NEO-6M, Emergency SOS

INTRODUCTION

The Internet of Things (IoT) has become an essential part of many fields of human activity from health care and emergency services to agriculture and bioengineering. Tracking the position of moving objects or person is one of the common use cases for IoT systems. In particular, the location of people is of serious importance for outdoor activities like trekker or field research. However, tracking systems are often used in places where cellular network and Internet networks are weak or not available. Most of such tracking systems use GPS and GSM modules to monitor the position of the tracked object or a person in real-time. In addition, GSM modules are huge power-hungry device.

Since GSM modules consume a lot of power, continuous use can cause the battery of a portable device to run out quickly.A possible solution to this problem is the use of alternative methods and hardware to transmit positioning data over long distances. One of the technology is LoRa, which can send small amounts of data over long distances while using less power.

The main goal of this project is to develop and test a low-cost, low-power prototype that can continuously track the location of the device in real time.. The prototype is based on the open-source ESP32 platform and utilizes a GPS module and LoRa radios. The designed system is able to operate outside of the cellular network and the

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Internet. Another important feature of the system is the possibility to send an SOS distress signal with the tracked coordinates. The overall idea is to allow for communication in the absence of traditional infrastructure. The system is mainly built up by the ESP32 microcontroller, GPS module, LoRa transmitter and receiver. The GPS module reads the position data of the user and sends it to the ESP32 microcontroller. The ESP32 sends the data to the receiver by LoRa. On the receiver side, it is displayed on an OLED display.

In addition to the described functionality, the system will also allow calling the emergency service. The user will be able to send an SOS message to the rescuers by pressing a special button. This function will be helpful in case when there is no access to cellular networks and Internet connection on the phone. The main criteria of the prototype include battery usage, coverage range, Packet Delivery Ratio (PDR), RSSI, SNR, packets loss, GPS accuracy, and latency. The experiment was carried out under various outdoor conditions in order to determine the system's efficiency and reliability.

The rest of the paper is structured as follows. Section II contains related works and compares the different approaches for tracking. The research objectives are formulated in Section III. Based on the objectives, the system design is presented in Section IV and the methodology is described in Section V. The components of the system are discussed in Section VI, while the development environment is described in Section VII. The results of the experiments are given in Section VIII, while they are analyzed and discussed in Section IX. The possible future improvements and modifications of the system are described in Section X, and the final conclusions are given in Section XI.

LITERATURE SURVEY

Introduction to the Survey

Outdoor tracking and communication are important in areas where cellular and Internet coverage is limited or unavailable. Many existing tracking systems combine GPS with communication technologies such as GSM, Bluetooth, Wi-Fi, and LoRa.

GSM and Internet-based technologies enable remote monitoring but depend on cellular or Internet connectivity. This limitation has encouraged research into low-power, long-range communication technologies such as LoRa. LoRa is well suited for outdoor applications because it provides long-range communication with relatively low power consumption and can operate without conventional cellular infrastructure.

Thematic Review of Existing Research

1. GPS/GSM-Based Tracking Systems

GPS and GSM are commonly combined for tracking applications. GPS determines the location, while GSM transmits the information to a remote monitoring user. These systems can also support emergency alerts and remote monitoring.

However, GSM-based systems require cellular network coverage and generally have higher power requirements, which can limit their use in remote areas and battery-powered devices.

2. Bluetooth- and Wi-Fi-Based Tracking Systems

Bluetooth-based tracking systems are relatively inexpensive and have low power requirements, but their short communication range limits their use in large outdoor environments. Wi-Fi-based systems can provide higher data rates but generally depend on Internet connectivity and network infrastructure, limiting their use in remote locations.

3. LoRa-Based Communication and Localization

LoRa provides a low-power alternative for long-range data transmission and is well suited for applications involving small amounts of data over large distances. Researchers have also investigated LoRa-based positioning

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using parameters such as signal strength and time difference of arrival. However, localization accuracy depends on the algorithms used and the deployment environment.

LoRa also differs from LoRaWAN in terms of infrastructure requirements. LoRa can support direct device-to-device communication without requiring a gateway, whereas LoRaWAN generally uses gateways as part of its network architecture. This makes direct LoRa communication suitable for applications where additional network infrastructure is unavailable.

4. GPS/GNSS and LoRa-Based Tracking

Several studies have combined GPS/GNSS with LoRa for outdoor tracking applications. GPS provides location information, while LoRa transmits the data over long distances. Such systems have been applied to applications including animal tracking and outdoor monitoring. However, they may require additional infrastructure such as gateways and Internet connectivity, depending on the system architecture.

C. Analysis and Synthesis of Existing Research

The reviewed research highlights the limitations of commonly used tracking and communication technologies. GSM-based systems provide remote access but depend on cellular coverage, while Bluetooth has limited range and Wi-Fi generally requires network infrastructure. LoRa provides a suitable alternative by offering long-range communication with relatively low power consumption.

Although several studies have demonstrated the use of LoRa for tracking and localization, many systems rely on gateways, cloud platforms, or other supporting infrastructure. The present work focuses on establishing a direct ESP32-to-ESP32 LoRa communication link using SX1278 transceivers, providing a low-cost and infrastructure-independent communication platform for future integration with GPS-based tracking and outdoor safety features.

Reference	**Technology**	**Advantages**	**Limitation**
GPS + GSM Tracking System	GPS, GSM	Real-time location tracking and SMS alerts	Requires cellular network, higher power consuption
Bluetooth Based Tracking	Bluetooth	Low cost, low power, easy implementati-on	Very limited communicati-on range
Wi-Fi/IoT Monitoring System	Wi-Fi Iot	Cloud monitoring and mobile application support	Requires internet and Wi-Fi infrastructur-e
LoRa-Based Tracking System	GPS, LoRa	Long-range communication and low power consumption	Limited focus on child-specific safety feature
Proposed System	ESP+LoRa+ GPS	Long-Range,Low power ,SOS Enable	Prototype Stage

LoRa Configuration of the Proposed Prototype

Parameter	**Configuration**
Operating frequency	433 MHz
Spreading Factor	SF9
Bandwidth	125 kHz
Coding Rate	4/7
Transmission power	17 dBm
Application payload	14 bytes

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Transmission interval	4 seconds per device
Antenna	433 MHz antenna

Objective

The aim of this work is to design and develop a reliable, inexpensive tracking and communication system that does not require cellular or Internet networks. The study uses LoRa communication to design and implement a prototype of a communication system that enables low-power long-range wireless communication.

The system achieves bi-directional message exchange between ESP32 modules with SX1278 LoRa transceivers. The current settings for SX1278 include a 433 MHz frequency, spreading factor 9, bandwidth – 125 kHz, coding rate 4/7, transmission power – 17 dBm, the length of the applied payload – 14-byte, and the set interval between two consecutive message transmissions – 4 sec. The designed system can operate in the following modes: trekking, camping, surveying, and rescue operations within forested areas, and other remote and outdoor locations.

The work will examine the characteristics of the LoRa communication system, namely the range, packet delivery ratio, packet loss, received signal strength indication (RSSI), signal-to-noise ratio (SNR), transmission time, and power. The system will be equipped with GPS tracking via the NEO-6M module, an OLED display, and an SOS alarm function in the future. In addition, the communication system will be expanded by implementing applications for mobile devices, cloud-based solutions, geotesting, and other wilderness safety systems.

PROPOSED SYSTEM

The offered system under review is considered appropriate for the implementation of long-range and low-power wireless communication processes in order to ensure the stable functioning of wireless communication devices outside the zones of cellular networks coverage and the Internet. The developed prototype uses two ESP32 microcontroller modules with integrated SX1278 LoRa Transceiver for the realization of peer-to-peer communication. The selected modules operate at a frequency of 433 MHz, spreading factor of SF9, bandwidth of 125 kHz, coding rate of 4/7, a transmission power of 17 dBm, 14-byte application payload, and 4-second interval between the data packets.

The described prototype implies that the ESP32 development board is connected to the SX1278 LoRa module for establishing wireless communication links, which allows transmitting and receiving data without the involvement of GSM, WiFi, or Internet access. In this way, the offered system can be implemented in order to provide long-range and low-power communication outside the zones of cellular networks coverage and the Internet.

The current model of the prototype is primarily aimed at establishing LoRa communication between the two nodes, while the metrics of the prototype are analyzed in order to evaluate its performance, reliability, and stability. Thus, the communication range, packet delivery ratio, packet loss ratio, signal strength, signal-to-noise ratio, transmission delay, and power consumption are analyzed.

The described system can be applied in trekking, hiking, camping, surveying, bicycling, wildlife exploring, rescuing and other outdoor activities. The system can also be expanded by involving the use of such structures as a NEO-6M GPS module for tracking location data, an OLED display for displaying information about the system, and an SOS button for calling for help. At that, the addition of the described structures would not require significant changes to the presented prototype. In addition, there is an opportunity to add such functions as smartphone applications, cloud connectivity, and geofencing.

System Architecture

The overall architecture of the proposed system is illustrated in:

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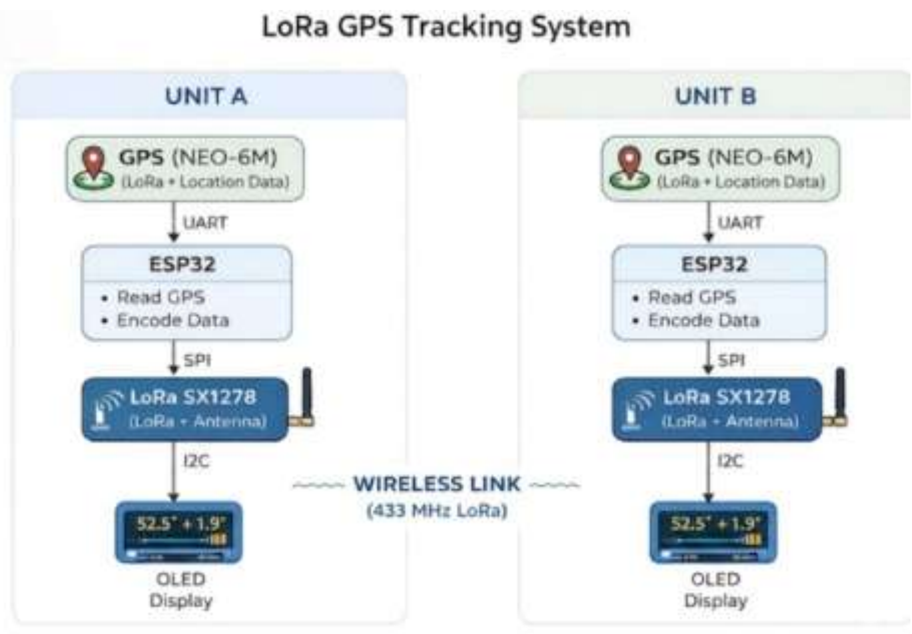
Figure 1:Block Diagram



The proposed system consists of two ESP32-based nodes, with each node interfaced with an SX1278 LoRa transceiver. The nodes communicate bidirectionally through the LoRa wireless link, enabling long-range data transmission without relying on cellular or Internet connectivity. The system is configured to operate at 433 MHz with SF9, 125 kHz bandwidth, coding rate 4/7, transmission power of 17 dBm, a 14-byte application payload, and a transmission interval of 4 seconds per device.

Each ESP32 generates and processes the application data before transmitting it through the SX1278 LoRa transceiver. At the receiving node, the SX1278 receives the transmitted packet and forwards the data to the ESP32 for processing. The received information can then be monitored through the serial interface, while communication parameters such as RSSI and SNR can be obtained for evaluating link performance.

B. Working Principle

The system operates through a bidirectional LoRa communication process. Initially, both ESP32 nodes configure their respective SX1278 modules with the predefined LoRa parameters. Each node periodically generates a 14-byte application payload and transmits it through the LoRa communication link at an interval of 4 seconds.

When a packet is transmitted by one node, the SX1278 module at the other node receives the signal and forwards the received data to its ESP32 controller. The ESP32 processes the packet and records the relevant communication information. The same process is performed in the reverse direction, allowing both nodes to transmit and receive data.

The current implementation focuses on evaluating the LoRa communication link in terms of range, packet delivery ratio, packet loss, RSSI, SNR, latency, and power consumption. Integration of the NEO-6M GPS module, OLED display, and SOS push button is planned as a future enhancement to provide location tracking, local information display, and emergency alert functionality.

C. Communication Parameters

The communication parameters adopted for the implemented prototype are summarized in the below table:

Parameter	Value
Microcontroller	ESP32
LoRa Module	SX1278
Operating Frequency	433 MHz

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Spreading Factor	SF9
Bandwidth	125 kHz
Coding Rate	4/7
Transmission Power	17 dBm
Application Payload	14 bytes
Transmission Interval	4 seconds per node
Communication Interface	SPI
Wireless Technology	LoRa
Antenna	433 MHz antenna
Communication Architecture	Bidirectional Peer-to-Peer

The selected hardware and communication parameters provide a suitable balance between communication range, power consumption, implementation cost, and portability, making the prototype suitable for outdoor safety applications in remote environments. The NEO-6M GPS module, OLED display, and SOS functionality can be integrated in future implementations to enhance the tracking and emergency communication capabilities of the system.

Data Packet Structure

Field	**Description**
Device ID	Unique identifier of the transmitter
Latitude	GPS Latitude coordinate
Longitude	GPS Longitude coordinate
SOS Status	Indicates whether the emergency button is pressed
Packet Number	Sequential packet identifier
Checksum	Error detection value

This packet structure minimizes communication overhead while ensuring reliable transmission of essential information.

METHODOLOGY

The system consists of two ESP32-based LoRa nodes that provide bidirectional long-range communication without depending on cellular networks or Internet connectivity. Each node consists of an ESP32 microcontroller interfaced with an SX1278 LoRa transceiver. The ESP32 controls the communication process, while the SX1278 handles wireless data transmission and reception.

The two nodes communicate using the configured LoRa parameters: 433 MHz frequency, SF9, 125 kHz bandwidth, coding rate 4/7, transmission power of 17 dBm, and a 14-byte application payload. Each node transmits data at an interval of 4 seconds, allowing continuous exchange of information between the nodes. The received packets are processed by the ESP32, and parameters such as RSSI and SNR are recorded for evaluating communication performance.

Flow Chart

The operation of the implemented system can be summarized through the following sequence:

Step 1: The system is powered on and the ESP32 starts the initialization process.

Step 2: The ESP32 initializes the connected SX1278 LoRa transceiver and configures the required LoRa

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parameters.

Step 3: The LoRa communication interface is established between the two ESP32-based nodes.

Step 4: Each ESP32 prepares a 14-byte application payload for transmission.

Step 5: The payload is transmitted through the SX1278 LoRa module at a 4-second interval per node.

Step 6: The SX1278 module at the other node receives the transmitted packet and forwards it to the ESP32.

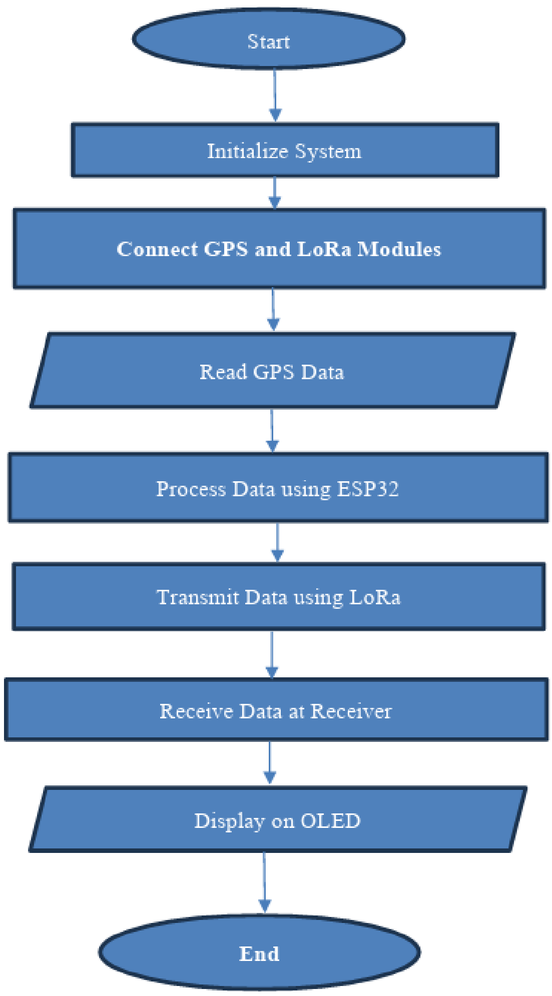
Step 7: The receiving ESP32 decodes and processes the received data.

Step 8: Communication parameters such as RSSI and SNR are obtained from the received packet for performance evaluation.

Step 9: The same process is performed in the reverse direction, enabling bidirectional communication between the two nodes.

Step 10: The process continues periodically to maintain continuous data exchange between the nodes.

GPS-based location tracking using the NEO-6M module, OLED-based monitoring, and SOS functionality are planned as future integrations of the system.



B. Algorithm

1. Start the system.

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2. Initialize the ESP32 microcontroller.
3. Initialize and configure the SX1278 LoRa transceiver.
4. Establish the LoRa communication link between the two nodes.
5. Prepare the 14-byte application data packet.
6. Transmit the packet through the SX1278 LoRa module.
7. Receive the transmitted packet at the other LoRa node.
8. Decode and process the received data using the ESP32.
9. Record communication parameters such as RSSI and SNR for performance evaluation.
10. Repeat the transmission and reception process at a 4-second interval for continuous bidirectional communication.

Hardware

The proposed prototype uses low-cost and reliable hardware components that are suitable for long-range outdoor communication. The prototype's hardware consists of an ESP32 and SX1278 LoRa transceiver at each station. The ESP32 microcontroller is used to run the program and manage the communication process, while the SX1278 module handles radio frequency (RF) communication.

The SX1278 operates at 433 MHz frequency with Spreading Factor (SF) 9, 125 kHz bandwidth, coding rate 4/7, and transmission power (Pt) of 17 dB. The prototype uses a 433 MHz antenna for RF communication. The developed prototype is small in size and portable, making it appropriate for hikers, campers, and field surveyors who usually operate in remote places without mobile network coverage.

The prototype can be enhanced in the future by adding a NEO-6M GPS module, OLED display, and SOS push-button to enable location tracking, local display, and emergency messaging features, respectively.

Component	Specification	Purpose
ESP32	Dual-core 240 MHz Microcontroller	Data processing and system control
SX1278 LoRa	433 MHz LoRa Transceiver	Long-range wireless communication
NEO-6M GPS	Accuracy +-2.5m	Real-time location acquisition
OLED Display	0.96-inch, 128*64, I^2C	Display GPS coordinates and system status
SOS Push Button	Digital Input	Emergency alert generation
Li-ion Battery	3.7 V Rechargeable	Portable power supply

Software Specifications

This communication system was designed using the Arduino IDE, which was used for programming the main ESP32 microcontrollers. The default libraries were used for programming the ESP32 microcontrollers and LoRa communication. Indeed, according to the information provided and discussed above, the SX1278 LoRa transceiver module uses the SPI protocol to communicate with the ESP32 microcontroller in order to ensure long-range radio transmission of information. The application data is then periodically generated, the LoRa

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MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
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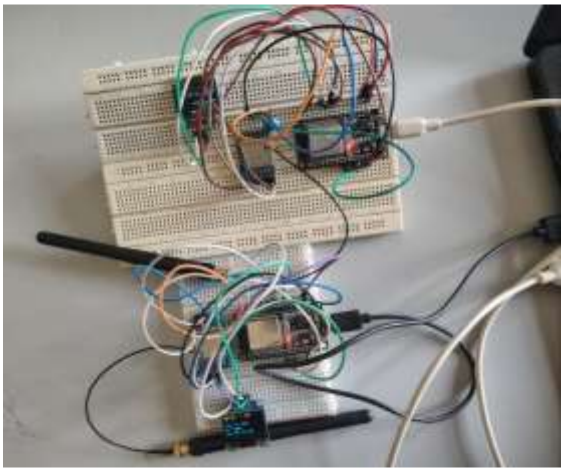
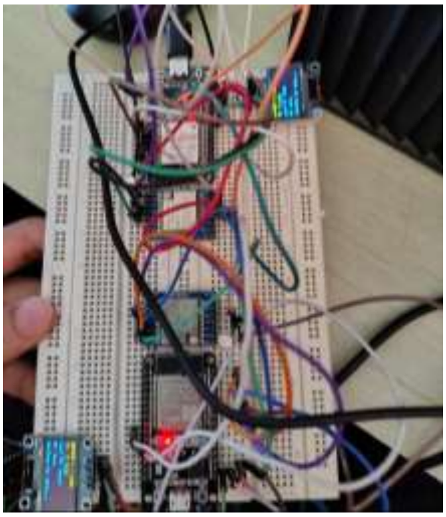
parameters are configured, and the processed information is transmitted from one node to the other. The received data can then be decoded by the receiver node's ESP32 microcontroller while the communication parameters (RSSI, SNR, etc.) are logged to ensure reliable and continuous bi-directional data exchange.

Software Parameter	**Description**
Development Environment	Arduino IDE
Programming Language	Embedded C/C++
GPS Library	TinyGPS++
LoRa Library	LoRa Library(SX1278)
OLED Library	Adafruit SSD1306/U8g2
Communication Protocol	UART(GPS),SPI(LoRa),I^2C(OLED)
LoRa Frequency	433 MHz

RESULT

The proposed system was successfully implemented to verify communication between two SX1278 LoRa transceiver modules using ESP32 microcontrollers. During testing, stable bidirectional wireless communication was established between the two nodes, and the transmitted data packets were successfully received and processed as expected. These results demonstrate that the implemented LoRa communication link is functional and provides a suitable foundation for low-power, long-range data transmission in outdoor applications. The current prototype establishes the basic feasibility of the proposed approach. In the next phase, the system will be extended by integrating the NEO-6M GPS module for real-time location tracking, along with OLED-based visualization, SOS functionality, and comprehensive field testing to evaluate the overall system performance.





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DISCUSSION

The successful implementation of LoRa communication between the two ESP32-based nodes confirms the feasibility of the proposed system for long-range, low-power wireless communication. The prototype demonstrates that the ESP32 and SX1278 LoRa modules can exchange data reliably without depending on GSM or Internet connectivity, making the system suitable for remote outdoor environments where network coverage is limited or unavailable. This initial implementation provides a solid foundation for the complete tracking system. In the next phase, the NEO-6M GPS module will be integrated to enable real-time location tracking, along with OLED-based location display and SOS functionality. Detailed field testing will also be conducted to evaluate communication range, GPS accuracy, power consumption, and overall system performance.

Future Scope

The next step in development is to integrate the system with the NEO-6M GPS module in order to provide precise positioning and location tracking in real-time. The system can be upgraded by including an OLED display and SOS emergency signal function, which will improve the overall safety. The parameters to consider during the prototype testing will include communication range, GPS accuracy, power consumption, and the system's overall reliability. The system can further be improved by incorporating an application programming interface, cloud storage, geofencing, and notification service for better performance and flexibility in meeting the diverse demands of the outdoor safety market.

CONCLUSION

This paper described in detail the designed and implemented LoRa communication system that can be used for the purpose of outdoor safety. The developed prototype aims to provide far-distance data transmission for people who do not have access to cellular networks or the Internet. The proposed solution was constructed with the use of ESP32 modules and SX1278 LoRa transceivers. The results of the test experiments have shown that the prototype enables successful information exchange between the two devices. The created communication system can be used in remote areas to ensure safety and provide help when needed. It is portable, affordable, and easy to use, thus, being suitable for such outdoors activities as trekking, hiking, camping, field studies, and many others. Moreover, additional features such as GPS, OLED display, and SOS function can be added to create a highly efficient tracking device.

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