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LoRa-Based Long-Range Defence Sensor Network for Remote Perimeter Monitoring and Intrusion Detection

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Abstract - The increasing need for reliable, low-power, and long-range communication has encouraged the development of wireless sensor networks for remote surveillance and perimeter monitoring. Conventional wireless communication technologies may face limitations in terms of communication range, power consumption, and infrastructure requirements in geographically isolated locations. This review paper examines the application of Long Range (LoRa) communication technology in developing a low-cost defence sensor network for remote monitoring and intrusion detection. The proposed system integrates distributed sensor nodes, an Arduino or ESP32 microcontroller, LoRa transceiver modules, and a central monitoring station. Sensors such as passive infrared (PIR), magnetic contact sensors, vibration sensors, and environmental sensors can be deployed to detect predefined events and transmit status information to the monitoring station. LoRa's chirp spread spectrum modulation, low power consumption, and long communication range make it suitable for applications where small amounts of data must be transmitted over extended distances. The paper reviews the system architecture, communication principles, hardware and software requirements, potential applications, and major technical challenges, including interference, packet loss, security, scalability, and power management. It also discusses the importance of encryption, device authentication, and reliable alert mechanisms. The study concludes that LoRa-based sensor networks offer a promising solution for low-cost, non-weaponized perimeter monitoring, provided that communication reliability, cybersecurity, and regulatory requirements are addressed.

Key Words: LoRa, Defence Sensor Network, Wireless Sensor Network, Perimeter Monitoring, Intrusion Detection, Internet of Things (IoT).

1. INTRODUCTION

Wireless sensor networks have become an important technology for collecting and transmitting information from distributed locations. They are used in agriculture, industrial automation, environmental monitoring, disaster management, and remote security systems. In defence-related monitoring, sensor networks can support situational awareness by detecting predefined events and communicating alerts from remote or unattended locations to a central control station.

Traditional wireless technologies such as Wi-Fi and Bluetooth are generally designed for relatively short-range communication, while cellular networks depend on network coverage and infrastructure. These limitations can make deployment challenging in remote locations, where continuous power and communication facilities may not be available.

Long Range (LoRa) is a low-power wireless communication technology designed for transmitting small data packets over relatively long distances. It uses chirp spread spectrum modulation and can provide improved receiver sensitivity under suitable operating conditions. Actual range depends on terrain, antenna placement, transmission power, interference, and regional radio regulations.

A LoRa-based defence sensor network can consist of multiple remote sensor nodes communicating with a central receiver or gateway. Each node collects sensor readings, processes events through a microcontroller, and transmits relevant information using a LoRa transceiver. The central monitoring station receives these messages, identifies the reporting node, records event information, and displays alerts to an operator.

For a diploma-level Electronics and Telecommunication project, this concept can be implemented as a low-cost prototype using Arduino Uno or ESP32 boards, LoRa modules, sensors, and a local monitoring interface. The prototype can demonstrate remote perimeter monitoring without requiring expensive cellular connectivity. However, a prototype should not be considered a certified operational defence system; practical deployment would require extensive field testing, cybersecurity validation, and compliance with applicable radio regulations.

2. Body of Paper

2.1. System Overview

The proposed LoRa-Based Long-Range Defence Sensor Network is designed as a low-cost wireless monitoring system using two ESP32-S3 microcontrollers and two LoRa communication modules operating with compatible 433 MHz antennas. The system is intended for remote perimeter monitoring, motion-event detection, and wireless alert transmission between two sensor nodes.

The system consists of a transmitting sensor node and a receiving monitoring node. Each ESP32-S3 microcontroller processes the connected sensor inputs and controls the associated hardware. The PIR motion sensor detects movement within its sensing area, while the buzzer provides an audible indication of a detected event. LoRa modules provide long-range wireless communication between the two nodes, and an OLED display presents the received status and event information.

A battery-based power supply, supported by a Battery Management System (BMS) and appropriate step-up and step-down converters, provides regulated power to the electronic components. This arrangement makes the prototype suitable for studying embedded systems, wireless communication, low-power electronics, and distributed sensor networks.

2.2. Working Principle of the Proposed System

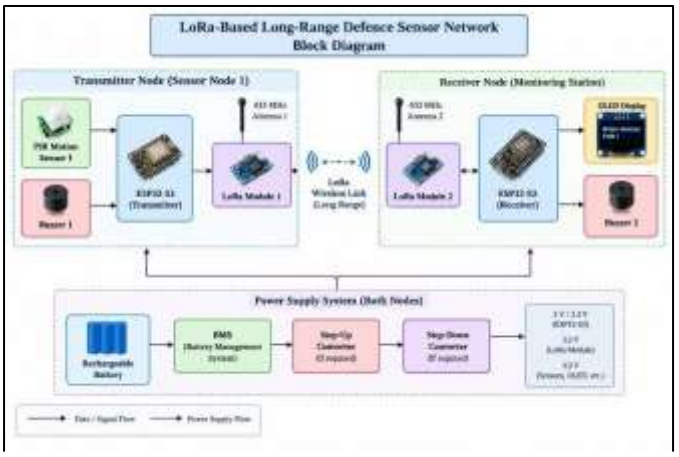

Fig: Block Diagram

The system operates through two interconnected wireless nodes.

2.2.1Transmitter Node

The transmitter node consists of one ESP32-S3 development board, one LoRa module, one 433 MHz antenna, one PIR motion sensor, one buzzer, and a regulated battery-based power supply.

The PIR sensor monitors the surrounding area for movement. When motion is detected, the sensor generates a digital output signal that is read by the ESP32-S3. The microcontroller processes this input and prepares a data packet containing the node identification, event status, and sequence number. The packet is transmitted through the LoRa module to the receiver node.

The transmitter can also send periodic status messages to indicate that the sensor node is operating. Appropriate software filtering can reduce repeated alerts caused by sensor fluctuations or continuous motion detection.

2.2.2 Receiver Node

The receiver node consists of the second ESP32-S3, a LoRa module, a compatible 433 MHz antenna, a buzzer, an OLED display, and a regulated power supply.

The LoRa module receives wireless packets from the transmitter and forwards their contents to the ESP32-S3. The microcontroller validates the message format and checks the event status. When a valid motion-event notification is received, the OLED displays the event information and the buzzer generates an audible alert.

The receiver can also display the node ID, communication status, and received message sequence number. This enables the operator to identify incoming events and observe the basic communication status of the prototype.

2.3. Hardware Description

1. ESP32-S3 Development Board

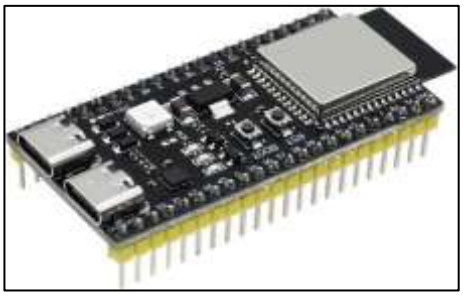

Fig: ESP32-S3 Development Board

The ESP32-S3 development board is the main processing and control unit of the proposed system. Two ESP32-S3 boards are used, one for the transmitting node and another for the receiving node. The transmitter reads the PIR sensor output, processes the detected event, and sends the corresponding data to the LoRa module. The receiver processes incoming wireless messages and controls the OLED display and buzzer. The ESP32-S3 provides GPIO, SPI, I²C, and other interfaces required for connecting the peripheral components.

2. LoRa Communication Module

Fig: LoRa Communication Module

Two LoRa communication modules are used to establish wireless communication between the transmitter and receiver nodes. The transmitter module converts the digital data supplied by the ESP32-S3 into a radio signal, while the receiver module recovers the transmitted data and passes it to the receiving microcontroller. LoRa technology uses chirp spread spectrum modulation to support long-range communication with low data rates and relatively low power consumption. Both modules must use compatible frequency settings and communication parameters.

3. 433 MHz LoRa Antenna

Fig: 433 MHz LoRa Antenna

Two antennas designed for the 433 MHz frequency band are used, with one antenna connected to each LoRa module. The antenna enables the transmission and reception of radio-frequency signals between the two nodes. Suitable antenna selection and installation are important for achieving reliable communication. The antenna should be compatible with the selected LoRa module, correctly matched to the operating frequency, and installed away from significant sources of interference. The operating frequency and transmission parameters must comply with applicable radio regulations.

4. PIR Motion Sensor

Fig: PIR Motion Sensor

Two Passive Infrared (PIR) motion sensors are used to detect movement in the monitored areas. A PIR sensor detects changes in infrared radiation caused by moving objects, such as people or animals, within its detection field. When motion is detected, the sensor generates a digital output signal that can be read by the ESP32-S3. This signal is processed to identify a motion event and initiate the transmission of an alert message. Using two sensors allows separate monitoring points to be demonstrated in the prototype.

5. Buzzer

Fig: Buzzer

Two buzzers are used to provide audible notifications. One buzzer can indicate local motion detection at the transmitting node, while the second buzzer can alert the operator at the receiving node when a valid motion-event message is received. The ESP32-S3 controls the buzzer according to the programmed event logic. If the buzzer requires more current than the microcontroller GPIO can safely supply, a suitable transistor driver should be used.

6. OLED Display

Fig: OLED Display

One OLED display is used at the receiving station to present event information and the operational status of the network. It can display the source node ID, motion detection status, received message information, and communication status. An OLED display offers good readability and compact size, making it suitable for an embedded monitoring system. If an I²C OLED module is selected, it can be connected to the ESP32-S3 through the configured SDA and SCL pins.

7. Rechargeable Battery

Fig: Rechargeable Battery

Rechargeable batteries provide portable electrical power to the sensor nodes. Battery operation reduces the need for a continuous external power supply and allows the prototype to be tested at different locations. Battery voltage, capacity, discharge rating, and current capability must be selected according to the power requirements of the ESP32-S3, LoRa module, sensors, and other connected components. Battery life depends on the average current consumption, transmission frequency, converter efficiency, and operating mode.

8. Battery Management System (BMS)

Fig: Battery Management System (BMS)

The Battery Management System is used to manage and protect the rechargeable battery. Depending on its design, a BMS may provide protection against overcharging, excessive discharge,

and overcurrent. It may also support battery voltage monitoring and cell balancing for compatible multi-cell battery packs. The BMS must be selected according to the battery chemistry, number of cells, charging requirements, and maximum current. It should not be treated as a replacement for a compatible battery charger.

9. Step-Up Converter

Fig: Step-Up Converter

A step-up converter, also known as a boost converter, increases a lower input DC voltage to a higher output voltage when required by the selected hardware. It can be used where the battery voltage is lower than the required regulated supply voltage. The output voltage must be adjusted and verified before connecting the electronic components. The converter should have adequate current capacity and efficiency to support the connected load without excessive voltage fluctuations.

10. Step-Down Converter

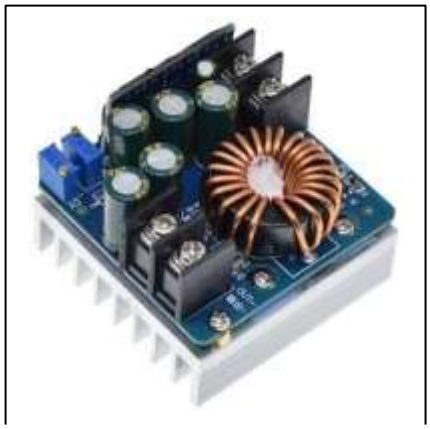

Fig: Step-Down Converter

A step-down converter, also known as a buck converter, reduces a higher input DC voltage to a lower regulated output voltage. It can be used to provide the appropriate supply voltage to the ESP32-S3 development board and other peripherals, depending on their individual requirements. The output voltage must remain within the recommended operating range of the connected devices. Proper voltage regulation helps prevent malfunction and protects sensitive electronic components from overvoltage.

11. Connecting Wires and Enclosure

Connecting wires are used to establish electrical connections between the ESP32-S3 boards, LoRa modules, PIR sensors, buzzers, OLED display, and power-supply circuits. Correct wiring and a common ground reference, where required, are essential for reliable operation. The enclosure protects the electronic components from dust, accidental contact, and minor physical damage. It should also allow suitable antenna placement and avoid unnecessarily obstructing radio-frequency transmission.

Fig: Connecting Wires and Enclosure

2.4. LoRa Communication Technology

LoRa is a low-power wireless communication technology that uses chirp spread spectrum modulation. It is designed for applications that require relatively long-range communication with low data rates and limited energy consumption.

In the proposed system, the LoRa transmitter sends small data packets representing motion events and node status. The receiving module demodulates the transmitted signal and passes the recovered data to the ESP32-S3 for processing.

The communication range depends on several factors, including antenna characteristics, antenna height, transmission power, receiver sensitivity, terrain, obstacles, interference, and the selected radio configuration. Therefore, the actual operating distance must be determined through practical testing rather than assuming a fixed range.

The two LoRa modules must use compatible frequency settings, modulation parameters, and packet configurations. The 433 MHz antennas must also be suitable for the selected modules and installation conditions. Operation must comply with the applicable Indian frequency-allocation and radio-equipment requirements.

2.5. Sensor Integration and Event Detection

The PIR motion sensors are used to detect changes in infrared radiation associated with movement in their sensing areas. Each sensor supplies a digital signal to its corresponding ESP32-S3 controller.

When the sensor output indicates motion, the microcontroller registers an event and prepares a corresponding message. A simple event record may contain:

- Node identification number.
- Event type, such as motion detected.
- Sequence number.
- Sensor status.
- Optional timestamp or elapsed-time information.

The use of a sequence number helps the receiver identify repeated packets. A configurable delay or software filtering mechanism can prevent excessive alert repetition while the sensor remains active.

The two PIR sensors can be installed at separate test locations to demonstrate distributed sensing. Their outputs can be monitored independently, allowing the system to distinguish between events reported by different nodes when the corresponding node identification is included in the transmitted message.

2.6. Embedded Software Design

The embedded software is developed using the Arduino IDE or a compatible ESP32-S3 development environment. The program is divided into initialization, sensor monitoring, packet transmission, packet reception, event notification, and power-management functions.

6.1 Transmitter software

The transmitter program initializes the ESP32-S3 pins, PIR sensor, buzzer, and LoRa module. It continuously monitors the sensor output and detects changes indicating motion. When a valid event is identified, the controller constructs and transmits the event packet.

The program may also send periodic heartbeat messages to indicate that the node is operational. Transmission status and sensor activity can be recorded for later testing.

6.2 Receiver software

The receiver program initializes the LoRa module, OLED display, and buzzer. It continuously checks for incoming packets. After receiving a packet, it validates the message structure and processes the event information.

If a valid motion alert is received, the receiver updates the OLED display and activates the buzzer according to the programmed alert duration. If the received message is invalid or incomplete, the software should reject it rather than generating an unverified alert.

6.3 Communication reliability

Communication reliability can be improved through sequence numbers, message validation, periodic heartbeat packets, and controlled retransmission where appropriate. Packet delivery ratio and message latency should be measured during experiments to evaluate actual system performance.

LoRa transmission alone does not guarantee confidentiality or authenticity. If the prototype is extended beyond a classroom demonstration, appropriate authentication, message-integrity protection, and encryption should be incorporated.

2.7. Power Supply and Battery Management

The proposed system uses rechargeable batteries supported by a Battery Management System and voltage-conversion circuits. Because the ESP32-S3 and LoRa modules may have different input-voltage requirements, regulated power rails must be designed for the

3. CONCLUSIONS

The LoRa-Based Long-Range Defence Sensor Network demonstrates how ESP32-S3 microcontrollers, LoRa communication modules, PIR motion sensors, buzzers, an OLED display, and a battery-management system can be integrated into a distributed wireless monitoring prototype. The transmitting node detects motion and communicates event information to the receiving node, where the event is displayed and an audible notification is generated.

The proposed architecture provides a foundation for investigating long-range communication, embedded sensor integration, portable power supplies, and wireless network performance. Its practical effectiveness must be established through measured communication range, packet delivery ratio, latency, false-alert rate, and battery operating duration. With suitable improvements in reliability and security, the design can serve as a useful academic project for Electronics and Telecommunication engineering students.

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