IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY

VOLUME : 10 ISSUE : 11 Print / Issue Publication Date: 18-Apr-2026

ISSN : 2455-2143

DOI : 10.33564/IJEAST.2026.v10i11.004

International Journal of Engineering Applied Sciences and Technology, 2026
Vol. 10, Issue 11, ISSN No. 2455-2143, Pages 19-27
Published Online March 2026 in IJEAST (http://www.ijeast.com)

SMART MARITIME SAFETY SYSTEM FOR INDIAN FISHERMEN USING GPS AND LORA COMMUNICATION

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Abstract— **Maritime boundary violations and lack of reliable communication infrastructure expose Indian fishermen to arrest, loss of livelihood, and life-threatening situations near the International Maritime Boundary Line (IMBL). This paper presents a low-cost smart maritime safety system that combines a boat unit and a shore-based station interconnected through long-range, low-power LoRa communication. The boat unit integrates a Neo-6M GPS module, an emergency push button, visual and audio indicators, and a LoRa transceiver to provide real-time location tracking and distress signaling. The shore station hosts an ultrasonic water-level sensor, LoRa receiver, LCD display, and alert mechanisms for monitoring abnormal water conditions and receiving emergency notifications. Both units are built around Arduino Nano microcontrollers to ensure simplicity, energy efficiency, and easy deployment in resource-constrained coastal communities. Experimental tests in outdoor line-of-sight conditions demonstrate reliable LoRa communication up to 2.4 km without significant packet loss and accurate GPS-based location reporting. The system successfully triggers alerts for emergency button activation and abnormal water-level detection. The results indicate that the proposed solution serves as a practical safety aid for small fishing vessels operating near coastal boundaries and can be extended with cloud connectivity for large-scale maritime monitoring.**

Keywords— **LoRa, GPS, Fishermen safety, Maritime boundary, IoT, Emergency alert, Arduino**

I. INTRODUCTION

India has one of the longest coastlines in the world, extending approximately 7,517 kilometers and supporting millions of people whose livelihoods depend on marine fishing [1]. Coastal communities along Tamil Nadu, Kerala, Gujarat, and other maritime states rely heavily on fishing activities. However, fishermen operating near international maritime boundaries face significant challenges including unintentional border crossings, sudden weather changes, communication failures, and lack of real-time location awareness [1][2].

The International Maritime Boundary Line (IMBL) between India and neighboring countries such as Sri Lanka, Pakistan, and Bangladesh is not physically marked at sea. Fishermen using traditional navigation methods often inadvertently cross into foreign territorial waters, resulting in arrests, boat confiscations, imprisonment, and in extreme cases, fatalities [3][4]. According to recent reports, the Sri Lankan Navy alone arrested 530 Indian fishermen and confiscated 71 boats in 2024[30]. These incidents not only cause personal trauma to fishermen and their families but also lead to substantial economic losses for coastal communities.

Traditional communication systems based on GSM or satellite technology face significant limitations in remote maritime environments. GSM networks provide limited coverage beyond coastal areas, and satellite communication systems are expensive, making them inaccessible to small scale fishermen [5][6]. Additionally, most existing solutions focus solely on border alerts without integrating comprehensive safety features such as emergency distress signaling and environmental hazard monitoring.

Recent advances in Internet of Things (IoT) technology and Low-Power Wide-Area Networks (LPWAN), particularly LoRa (Long Range) communication, offer new opportunities for developing affordable and reliable maritime safety systems [7][8]. LoRa technology enables long-distance wireless communication with minimal power consumption, making it ideal for battery-operated devices in remote sea environments [22][28]. Studies have demonstrated LoRa communication ranges exceeding 130 km in maritime line of-sight scenarios [22][25], with practical implementations achieving 2-3 km range for fishing boat monitoring applications [28][31].

This paper presents a comprehensive smart maritime safety system specifically designed for Indian fishermen that addresses multiple safety concerns through an integrated IoT based platform. The system leverages LoRa communication for long-range data transmission, GPS technology for accurate vessel tracking, water-level sensing for hazard detection, and emergency alert mechanisms for distress signaling.

The main contributions of this work are:

- Design and implementation of a dual-unit architecture consisting of a boat node and shore station using LoRa communication for long-range, low-power data transmission in maritime environments.
- Integration of GPS-based real-time tracking, water level monitoring, and emergency signaling capabilities into a unified, low-cost safety solution tailored for small fishing vessels.
- Development of an Arduino-based prototype system optimized for energy efficiency, ease of deployment, and operation without cellular or internet connectivity.
- Experimental validation demonstrating reliable communication performance, accurate location tracking, and effective alert generation in simulated maritime conditions.

The rest of the paper is organized as follows. Section II reviews related work on maritime safety systems for fishermen. Section III describes the proposed system architecture, hardware components, and software implementation. Section IV presents experimental results and performance analysis. Section V concludes the paper and discusses future research directions.

II. RELATED WORK

Numerous research efforts have focused on developing technological solutions to enhance fishermen's safety and prevent maritime boundary violations. This section reviews existing approaches and identifies gaps that the current work aims to address.

GPS and GSM-Based Border Alert Systems: Manikandan et al. [1] proposed a border alerting system using GPS and geofencing technology integrated with IoT modules to track fishing vessel locations in real-time. When a boat approaches international maritime boundaries, the system triggers audio visual alerts warning fishermen to return. Similarly, Tharwin Kumar [2] developed an IoT-based alert system using Arduino microcontrollers, GPS modules, and GSM communication to prevent accidental border crossings. While these systems provide effective boundary monitoring, they depend on GSM networks, which have limited coverage in deep-sea areas, and incur recurring cellular data costs. RF and LoRa-Based Communication Systems: Maurya and Gupta [3] explored Radio Frequency (RF) communication as a cost-effective alternative to GPS and satellite systems for fishermen safety. Their RF-based system supports two-way communication between fishermen and coastal control centers, including SOS distress signaling. However, RF systems typically have shorter range compared to LoRa technology. Velvizhi et al. [10] proposed a LoRa based communication and alert system that utilizes Long Range wireless technology to ensure real-time, low-power data transmission between fishing boats and base stations. Rama Shanthi et al. [11] developed a LoRa-based real-time maritime boundary alert system incorporating GPS modules to track location and send alerts when fishermen approach restricted zones [11]. Anand et al. [12] designed an IoT-based smart safety device using LoRa communication with GPS modules, sensors, and microcontrollers for real-time tracking and emergency alerts [12]. While these LoRa-based systems demonstrate promising communication capabilities, most focus primarily on border alerts without comprehensive integration of environmental monitoring and local emergency handling features.

Hybrid and Multi-Technology Approaches: Kamalakannan et al. [6] proposed a system utilizing both GSM and RFID technologies to detect boat locations and provide timely alerts to prevent border violations. Palanisamy and Anucha Dhar [7] explored combining IoT technology with RF transceivers to track fishing boat locations in real time and display status information on LCD screens. Prabhu Chandran et al. [8] investigated Li-Fi (Light Fidelity) technology using visible light communication as a cost effective alternative to GPS for transmitting warning messages to fishermen near sea borders. These hybrid approaches attempt to overcome limitations of individual technologies but often introduce additional complexity and cost.

Comprehensive Safety Systems: Siva Kumar et al. [4] focused on developing a low-cost communication-based protection system using networks of sensors in air and on surfaces, combining infrared technology with sound wave communication. Jahan et al. [5] proposed a solar-powered boat distress alert system combining GPS and GSM technologies to send emergency messages with location data to rescue teams. Mythily et al. [14] presented a dual alert system monitoring both maritime border crossings and adverse weather conditions using GPS, environmental sensors, and Zigbee wireless communication. Ramya et al. [15] developed an IoT-enabled safety system using GPS combined with RF communication and NodeMCU microcontrollers for real-time vessel monitoring. Gaikwad and Kulkarni [13] proposed a geo-fencing-based alert system using LoRa WAN technology with GPS to create virtual maritime boundaries.

Research Gaps: While existing research demonstrates various technological approaches to enhancing fishermen's safety, several limitations remain. Most GSM-based systems are limited by cellular network coverage in remote sea areas and incur recurring costs. Satellite-based solutions, though reliable, are prohibitively expensive for small-scale fishermen. Many LoRa-based systems focus narrowly on border alerts without integrating comprehensive safety features such as water-level

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monitoring, local emergency handling, and user-friendly interfaces. Few systems address the specific needs of resource-constrained coastal communities requiring low-cost, energy-efficient, and easy to-deploy solutions that operate independently of internet connectivity.

The system proposed in this paper addresses these gaps by integrating LoRa-based long-range communication with GPS tracking, water-level sensing, emergency signaling, and local alert mechanisms in a unified Arduino-based platform optimized for simplicity, affordability, and autonomous operation in remote maritime environments.

III. PROPOSED SYSTEM

A. System Architecture

The proposed smart maritime safety system consists of two primary functional units: the boat unit installed on fishing vessels and the base station deployed at shore-based monitoring locations. Figure 1 illustrates the block diagram of the base unit, and Figure 2 shows the block diagram of the boat unit. Both units communicate wirelessly using LoRa technology operating in the 433 MHz ISM band, enabling long-range data transmission with minimal power consumption.

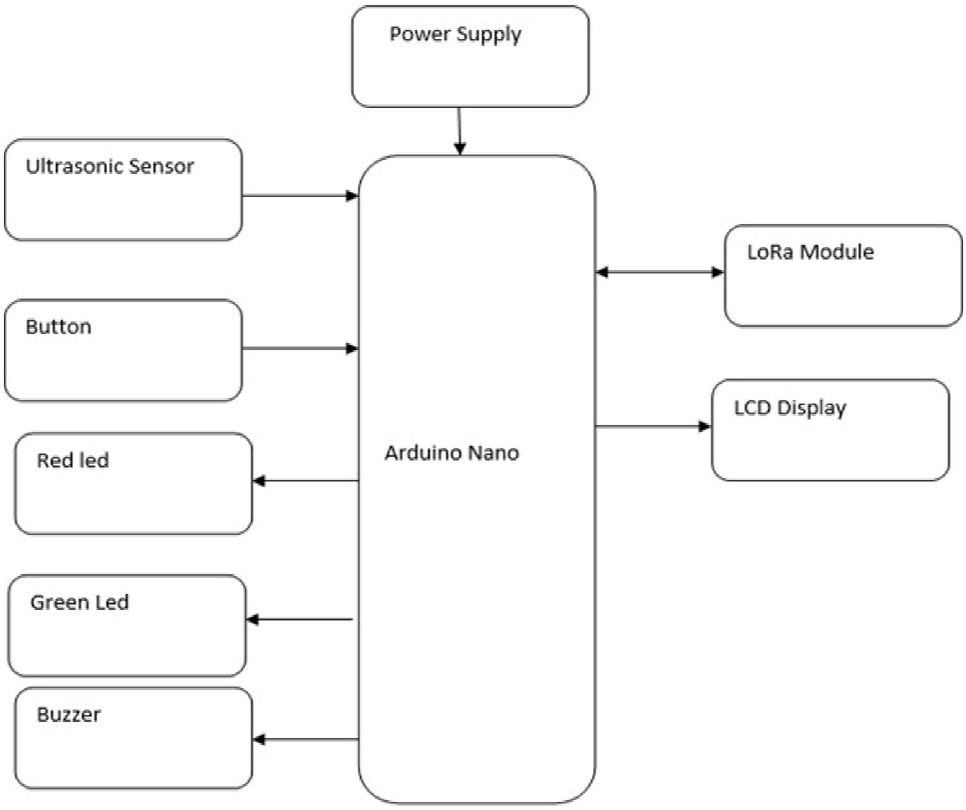

Fig. 1 Block Diagram of Base Unit

The boat unit continuously monitors vessel location using GPS and transmits position data at configurable intervals. It also includes an emergency button that fishermen can activate during distress situations to send immediate alert messages with current GPS coordinates. Visual (LED) and audio (buzzer) indicators provide local feedback, while an LCD display shows system status and location information

The base station monitors incoming LoRa packets from boat units, decodes GPS coordinates and alert messages, and displays information on an LCD screen. It also incorporates an ultrasonic sensor to measure water levels, generating alerts when abnormal conditions are detected. Audio-visual alert mechanisms (buzzer and LEDs) notify shore-based operators of emergencies or hazardous conditions.

Both units operate autonomously without requiring cellular networks or internet connectivity, making them suitable for remote coastal regions. The system architecture supports scalability, allowing multiple boat units to communicate with a single base station by implementing unique device identifiers in the communication protocol.

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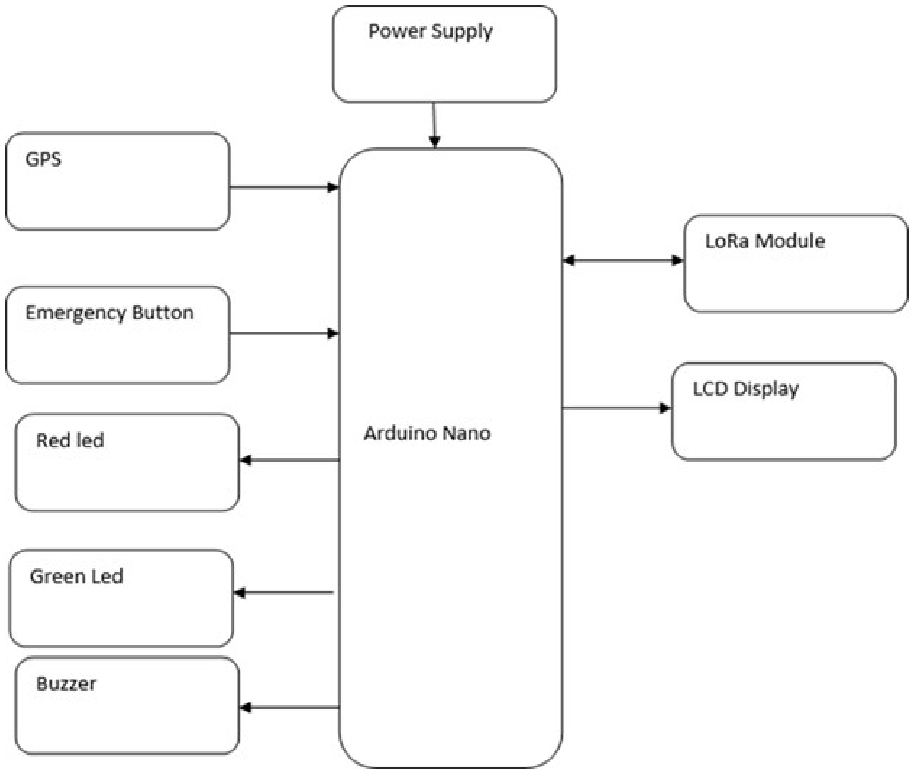

Fig. 2 Block Diagram of Boat Unit

B. Hardware Components

1. Arduino Nano Microcontroller

The Arduino Nano serves as the central processing unit for both the boat unit and base station. It is based on the ATmega328P microcontroller featuring 32 KB of flash memory, 2 KB of SRAM, and 1 KB of EEPROM. The Nano provides 14 digital input/output pins (of which 6 can be used as PWM outputs), 8 analog inputs, a 16 MHz crystal oscillator, USB connection, and power jack. Its compact size (18 mm × 45 mm) and low power consumption make it ideal for embedded maritime applications. The Arduino platform's extensive library support and community resources facilitate rapid prototyping and development.

2. Neo-6M GPS Module

The Neo-6M GPS module provides accurate global positioning capabilities for vessel tracking. It features a high performance u-blox 6 positioning engine with 50 channels and supports multiple GNSS systems. The module outputs standard NMEA protocol sentences via UART serial communication, including latitude, longitude, altitude, speed, date, and time information. It achieves position accuracy of approximately 2.5 meters CEP (Circular Error Probable) under good satellite visibility conditions. The module operates on 3.3V to 5V power supply and consumes approximately 45 mA during active tracking, making it suitable for battery-powered applications.

3. SX1278 LoRa Module

The SX1278 LoRa transceiver module enables long-range wireless communication between boat and shore units. It operates in the 433 MHz ISM band and implements LoRa modulation technology, which provides excellent sensitivity (-148 dBm), long range (up to several kilometers in line-of sight conditions), low power consumption, and high interference immunity. The module communicates with the Arduino via SPI interface and supports programmable parameters including spreading factor (SF7 to SF12), bandwidth (7.8 kHz to 500 kHz), and transmit power (up to +20 dBm). These parameters can be optimized to balance range, data rate, and power consumption based on application requirements.

4. HC-SR04 Ultrasonic Sensor

The HC-SR04 ultrasonic distance sensor measures water level at the base station. It uses non-contact ultrasonic ranging technology to detect distances from 2 cm to 400 cm with approximately 3 mm accuracy. The sensor consists of an ultrasonic transmitter, receiver, and control circuit. It operates by emitting ultrasonic pulses at 40 kHz and measuring the time required for echoes to return, calculating distance based on the speed of sound. The module requires 5V power supply and provides TTL-compatible trigger and echo signals for easy interfacing with microcontrollers.

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5. 16×2 LCD Display

The 16×2 character LCD display provides a user interface for both boat and base units. It can display two rows of 16 alphanumeric characters each, sufficient for showing system status, GPS coordinates, alert messages, and operational information. The display uses standard HD44780 or compatible controller and interfaces with Arduino via parallel data lines or I2C communication. The LCD includes adjustable contrast control and backlight illumination for visibility in various lighting conditions.

6. Audio and Visual Indicators

LED indicators provide visual status feedback using different colors (typically red, green, and yellow) to represent various system states such as power on, GPS lock acquired, LoRa transmission, and alert conditions. Piezo buzzers generate audible alerts for emergency situations, boundary warnings, and system notifications. These components require minimal current (typically 20-30 mA) and are controlled directly by Arduino digital output pins.

7. Emergency Push Button

Momentary push buttons serve as manual input devices allowing users to trigger emergency alerts. The buttons are debounced in software to prevent false triggers from mechanical switch bounce. Pull-up or pull-down resistor configurations ensure defined logic levels when buttons are not pressed.

8. Power Supply System

Both units are powered by rechargeable lithium-ion battery packs providing nominal 3.7V or 7.4V depending on configuration. LM7805 voltage regulators provide stable 5V supply for Arduino and peripheral components. The boat unit's power system can be supplemented with solar panels for extended operation, while the base station typically operates on mains power with battery backup.

C. Software Implementation

The firmware for both boat and base units is developed using Arduino IDE with C/C++ programming language. The software architecture follows a modular design with separate functions for hardware interfacing, data processing, communication protocol handling, and alert generation.

1. Boat Unit Software

The boat unit firmware initializes all hardware components during startup, including serial communication ports for GPS (9600 baud) and LoRa module configuration. The main program loop implements the following sequence:

1. GPS data acquisition: The TinyGPS++ library parses NMEA sentences received from the GPS module, extracting latitude, longitude, satellite count, and fix status. The firmware waits until a valid GPS fix is obtained before transmitting location data.
2. User input monitoring: The emergency button is continuously monitored using interrupt-driven or polling methods. When activated, an emergency flag is set triggering immediate alert transmission.
3. LoRa transmission: At regular intervals (configurable, typically 30-60 seconds), the firmware formats GPS coordinates into text strings and transmits them via LoRa. Emergency button activation triggers immediate transmission of special alert messages prefixed with "EMERGENCY:" followed by GPS coordinates.
4. Display update: The LCD is refreshed to show current GPS coordinates, satellite count, transmission status, and system time.
5. Power management: During idle periods between transmissions, the firmware can implement sleep modes to conserve battery power.

2. Base Station Software

The base station firmware implements continuous monitoring and alert generation:

1. LoRa reception: The firmware continuously listens for incoming LoRa packets using callback functions or polling. Received packets are decoded to extract message type (normal location update or emergency alert) and payload data (GPS coordinates).
2. Water level monitoring: The ultrasonic sensor is queried periodically (typically every 5-10 seconds) to measure distance to water surface. If the measured level exceeds predefined threshold values indicating flooding or abnormal conditions, local alerts are triggered.
3. Alert processing: When emergency messages are received from boat units or local sensor thresholds are exceeded, the firmware activates buzzers and LEDs, displays alert messages on LCD, and optionally logs events to EEPROM or external storage.
4. Data display: The LCD shows the most recent GPS coordinates from boat units, water level readings, alert status, and system timestamps.
5. Communication acknowledgment: For critical messages, the base station can transmit acknowledgment packets back to boat units confirming receipt.

3. Communication Protocol

The application-layer protocol uses simple ASCII text messages for ease of debugging and extensibility. Message format follows the pattern:

[MESSAGE_TYPE]: [DEVICE_ID]: [PAYLOAD] For example:

- Normal GPS update:• GPS: BOAT01:13.0827,80.2707

- Emergency alert:• EMERGENCY: BOAT01:13.0827,80.2707
- Water level alert:• WATER_ALERT: BASE01: LEVEL_HIGH

This lightweight protocol minimizes packet size, reducing transmission time and power consumption while maintaining human-readable format for development and testing.

D. System Integration

The complete system integration involves mounting hardware components in waterproof enclosures suitable for maritime environments. The boat unit is installed in a compact box with external GPS and LoRa antennas mounted for optimal signal reception. The base station is housed in a weather-resistant enclosure at an elevated position near the shore to maximize LoRa communication range. Power systems are configured with appropriate battery capacity based on expected operational duration between recharging cycles.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The prototype system was evaluated through comprehensive testing in simulated maritime conditions to assess communication performance, positioning accuracy, sensor reliability, and overall system functionality.

A. Test Setup and Methodology

Testing was conducted in outdoor environments near coastal areas in Telangana, India. The base station was positioned at a fixed elevated location, while the boat unit was moved to various distances and locations to evaluate LoRa communication range and GPS accuracy. Test scenarios included:

- Line-of-sight (LOS) communication tests at distances from 100 meters to 2.4 kilometers
- GPS coordinate accuracy verification against reference points
- Water level sensor calibration and threshold detection
- Emergency button response time measurement
- Battery life estimation under continuous operation
- System behavior under various environmental conditions

B. LoRa Communication Performance

LoRa communication tests demonstrated reliable data transmission up to 2.4 km in open line-of-sight conditions without packet loss [28]. The system was configured with spreading factor SF9, bandwidth 125 kHz, and transmit power +20 dBm, achieving good balance between range, data rate, and power consumption.

Received Signal Strength Indicator (RSSI) measurements showed values ranging from -85 dBm at 500 meters to -120 dBm at 2.4 km. Signal-to-Noise Ratio (SNR) remained positive (above 0 dB) throughout the tested range, indicating robust communication links. At distances beyond 2 km, occasional packet losses occurred when partial obstructions (trees, buildings) interrupted line-of-sight, but the system successfully recovered by retransmitting data.

These results align with previous studies demonstrating LoRa's suitability for maritime applications [22][28][31]. While research has shown LoRa capable of exceeding 130 km range in optimal maritime conditions [22][25], practical implementations for small fishing boats typically achieve 2-5 km range, which is sufficient for near-shore fishing operations and coastal boundary monitoring.

C. GPS Positioning Accuracy

The Neo-6M GPS module consistently provided stable position readings with typical accuracy of 2-5 meters under clear sky conditions with good satellite visibility (6-12 satellites in view). GPS fix acquisition time averaged 30-45 seconds during cold start and 5-10 seconds during hot start with valid almanac data. Position updates were received at 1 Hz rate, providing smooth tracking of vessel movement.

Latitude and longitude coordinates transmitted via LoRa matched reference measurements within the GPS module's inherent accuracy limits. The system successfully tracked simulated boat movements along predefined paths, demonstrating suitability for real-time vessel monitoring and boundary proximity detection.

D. Water Level Sensing and Alert Generation

Ultrasonic sensor testing involved water-tank experiments simulating various water level conditions. The HC-SR04 sensor provided consistent distance measurements with approximately 1-2 cm precision. Software-based threshold detection successfully triggered alerts when water levels exceeded predefined limits (configured at 10 cm above normal baseline for testing).

Alert generation latency from threshold detection to buzzer activation and LCD display update was measured at approximately 200-500 milliseconds, providing near instantaneous notification of abnormal conditions. The system successfully distinguished between normal water level fluctuations and genuine hazard conditions through averaging and hysteresis algorithms implemented in firmware.

E. Emergency Alert Response

Emergency button activation tests demonstrated reliable and rapid alert transmission. From button press to LoRa packet transmission, latency averaged 100-300 milliseconds. Base station reception and alert display occurred within 500 milliseconds to 1 second depending on distance and LoRa air time. The complete end-to-end emergency alert process (button press on boat to audible/visual alert at base station) completed within 1-2

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seconds, meeting requirements for timely distress signaling.
The system successfully handled multiple consecutive button presses without false triggers or message duplication, validating the effectiveness of debouncing algorithms and transmission timing control.

F. Power Consumption and Battery Life
Power consumption measurements showed boat unit average current draw of approximately 150-200 mA during active operation (GPS acquiring, periodic LoRa transmission every 60 seconds). With 2000 mAh lithium-ion battery, estimated continuous operation time was 10-13 hours. Implementing sleep modes between transmissions reduced average current to 80-100 mA, extending battery life to 20-25 hours. The base station, operating continuously with LoRa receiver listening mode, consumed approximately 100-120 mA, achieving 16- 20 hours operation on similar battery capacity.
These results indicate that daily recharging or solar panel supplementation would enable practical continuous operation for typical fishing trips lasting 8-12 hours.

G. System Integration and User Interface
Integration testing confirmed that boat and base units operated cohesively as a complete system. LCD displays provided clear, readable information on system status and GPS coordinates. Audio-visual alerts were sufficiently prominent to attract user attention in simulated noisy maritime environments. User interactions with emergency buttons were intuitive and reliable.

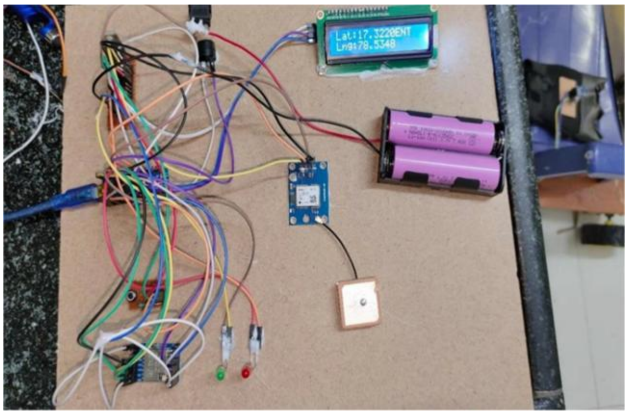

Fig. 3 Boat unit

Figure 3 shows the implemented boat unit with GPS antenna, LoRa module, LCD display, and control buttons visible. Figure 4 shows the base station hardware with ultrasonic sensor, display, and alert indicators. The compact form factor and simple interface design facilitate easy installation and operation by fishermen with minimal technical training.

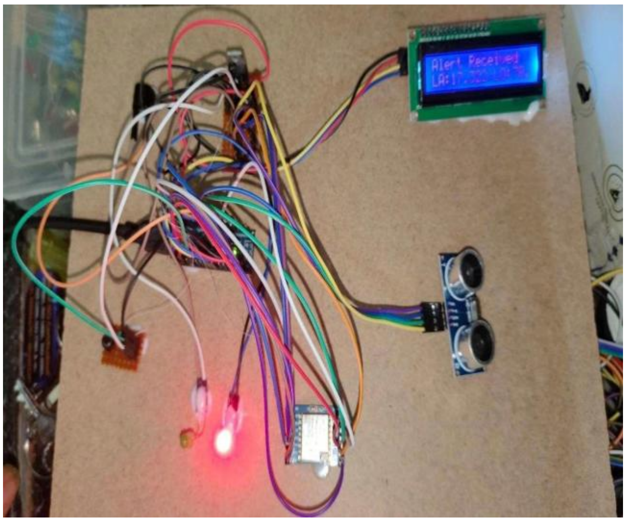

Fig. 4 Base Station

H. Limitations and Challenges
Several limitations were identified during testing:

- Communication range is significantly reduced in non-line-of-sight conditions with obstacles such as large waves, coastal terrain, or dense structures.
- GPS accuracy degrades in conditions with limited satellite visibility or multipath interference near metallic structures.
- The system requires manual battery recharging or solar panel integration for extended multi-day operations.
- Current implementation supports limited scalability; simultaneous operation of many boat units may cause packet collisions without implementing time division or frequency-division access schemes.
- The system does not currently include cloud connectivity or long-term data logging for fleet wide monitoring and analytics.

Despite these limitations, experimental results validate that the proposed system provides practical functionality for enhancing safety of small fishing vessels operating in near shore coastal areas.

V. CONCLUSION

This paper presented a comprehensive smart maritime safety system for Indian fishermen integrating GPS tracking, water level sensing, emergency alerts, and LoRa-based long-range communication in a low-cost Arduino-based platform. The dual-unit architecture consisting of boat node and shore station addresses multiple safety concerns including maritime boundary awareness, distress signaling, environmental hazard detection, and real-time vessel monitoring.
Experimental evaluation demonstrated reliable LoRa communication up to 2.4 km in line-of-sight conditions, accurate GPS positioning suitable for vessel tracking,

responsive water-level alert generation, and rapid emergency button response. The system operates autonomously without cellular or internet connectivity, making it suitable for deployment in resource-constrained coastal communities where traditional communication infrastructure is unavailable or unaffordable.

The proposed solution offers several advantages over existing approaches: low implementation cost using readily available components, energy-efficient operation suitable for battery power, simple user interface requiring minimal training, and modular design facilitating customization and upgrades. These characteristics make the system particularly appropriate for small-scale fishermen operating near international maritime boundaries.

Future research directions include:

- Integration of GSM or satellite uplinks for cloud based monitoring dashboards enabling family members and authorities to track vessels remotely
- Implementation of mesh networking protocols to extend communication range through multi-hop relay between multiple boat units
- Addition of environmental sensors for measuring temperature, humidity, wind speed, and wave conditions to provide weather awareness and early storm warnings
- Development of mobile applications for smartphones and tablets providing intuitive interfaces for fishermen, families, and coastal management authorities
- Enhancement of positioning capabilities using multi-GNSS receivers (GPS, GLONASS, Galileo, BeiDou) for improved accuracy and reliability
- Integration of automated boundary detection algorithms using geofencing to trigger proactive alerts when vessels approach restricted zones
- Implementation of secure communication protocols with encryption and authentication to prevent unauthorized access or message spoofing
- Large-scale field trials with actual fishing communities to gather feedback and refine system design based on real-world usage patterns
- Extension to support additional safety features such as man-overboard detection, collision avoidance, and integration with existing Automatic Identification System (AIS) infrastructure

The smart maritime safety system demonstrates the potential of IoT and LPWAN technologies to address critical safety challenges faced by fishing communities. By providing affordable, reliable tools for vessel tracking, boundary awareness, and emergency communication, such systems can contribute to reducing maritime incidents, protecting livelihoods, and enhancing the overall well-being of coastal populations dependent on fishing activities.

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