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Prototype Design of a Fishing Boat Safety Monitoring System Using LoRa and Microsensor Devices

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Abstract

This paper reports a prototype of a low-cost tracking and monitoring system to address the challenges faced by Indonesian fishermen. The lack of safety equipment in their boats exposes them to high risks of work-related accidents and illnesses. Data from the National Basarnas Center reveals a staggering 24,000 annual fatalities among fishermen during their activities. These issues stem from a combination of factors: poorly designed boats, low prioritization of safety, and the lack of readily available preventive measures. Moreover, the development of telecommunications infrastructure in aquatic areas presents its unique obstacles. In response, this study proposes a prototype design for a "Fishing Boat Safety Monitoring System" utilizing LoRa and Microsensors for proactive and preventive measurement by tracking the boat position and sending the data via a long-distance wireless transmission with Low-Power Wide Area Network (LPWAN) scheme based on frequency-spread spectrum technology. This LPWAN serves as the substitution for cellular network which is usually not available in the ocean. The tracking system uses a low-cost TTGO T-Beam LoRa32 V1.1 Microcontroller Unit (MCU) board that has an embedded SX1276 LoRa module and Neo-6M GPS module. The system also uses a GY-25 gyroscope microsensor. The system implemented a 923 MHz LoRa signal for point-to-point communication between the transmitter to receiver. This research has successfully yielded a developed device capable of tracking the location of boats up to 2 km from the shoreline with -113 dBm received signal strength indicator (RSSI) and around 60% of data quality of service (QoS). Further research will explore the use of high-gain antennas and signal amplifiers integration with embedded LoRa on the MCU board to expand the coverage area of the LoRa signal.

Keywords: Boat; GPS; LoRa; MCU; Tracking.

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1. Introduction

Indonesia is an archipelagic country consisting of more than 17,000 islands. It has a sea area of 3.25 million km^2 and an Exclusive Economic Zone of 2.55 million km^2.[1]. With these geographical conditions, most of the Indonesian people work in the fishing industry. According to data from the National Basarnas Center, approximately 24,000 fishermen die at sea each year during fishing activities. This is predominantly due to poor boat design, low concern for safety, and non-availability of preventive mitigation measures.

Boat safety can be enhanced through the addition of a device that tracks a boat's location while at sea. Such a feature is already present in boats equipped with advanced technology, but it is lacking in conventional fishing boats. Therefore, this research centers on the development of a prototype for a low-cost boat monitoring device that can be implemented on traditional fishing vessels. Previous research has utilized a GSM cellular network for transmitting GPS data to a database [2]. In another similar study [3], GSM networks were used for communication. In this study, fishermen's smartphones were used as the main tool for tracking their location while at sea. The system was also supported by a standalone server to manage data received from each smartphone used using Raspberry Pi. However, this method suffers from limitations. Firstly, as the boat travels far from the island, the GSM signal may become unreachable

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to the smartphone [4]. Secondly, the GSM module cannot receive cellular signals if the device's IMEI is not registered with Bea Cukai Indonesia, as per Indonesian cellular network laws. LoRa networks were used as the data communication media in this study to overcome the limitations of GSM networks. LoRa's ability to provide coverage of up to 15 kilometers or even more [5], combined with its minimal power usage [6]. LoRa is enabled for operation on unlicensed frequency bands, with specific options like 433MHz, 868MHz, or 915MHz, dictated by the geographic region and its regulations [7]. Furthermore, LoRa's openness has made it easier for a variety of IoT deployments to adopt it, which has led to its widespread use in both practical and research applications. [8].

Several other studies used LoRa in a variety of contexts. In Ref [9], a LoRa network was implemented to communicate between surface and underwater nodes at 868 MHz. The underwater node transmitted water temperature data to the surface gateway. This was achieved by modifying the shape of the LoRa antenna with a specific design and adding a buffer of oil-impregnated paper to improve the performance of the LoRa signal. This modification successfully extended the range of the LoRa signal emitted by the underwater node at a depth of 6 m to communicate with the surface gateway from a maximum of 80 m distance to 160 m.

In the other study [10], a LoRa network was implemented on a life jacket to track the location of people wearing it, making it easier to find them in the event of a marine accident. The system used a Raspberry Pi as a controller to ally all the components, including the LoRa mDot module, pulse sensor, water sensor, and GPS sensor. All LoRa modules use MultiTech’s LoRa device for both transmitter and receiver. The study found that the device could communicate up to 4 km using LoRa. The data transmission time from transmitter to receiver was 1.9 ms, with the receiver placed in a helicopter. The pulse sensor accuracy for measuring beats per minute (BPM) was 98%, and the GPS sensor location error margin of 7 m.

In Ref [11], a LoRa network was applied to support the activities of marine biologists on offshore expeditions. The system achieved a maximum range of 83.6 km using three shore-based nodes and one node on a ship. The location error was within a radius of 3.4 km, or about 4% of the maximum distance. This is achieved by using a LoPy MCU board with 868 MHz LoRa frequency, 14 dBm transmit power, 125 kHz bandwidth, and a spreading factor of 7.

Other studies [12] have compared the networks of the NRF24 module and the LoRa module for communication systems in robots. LoRa was set to a frequency of 433 MHz and its performance was compared to NRF24. The results showed that the NRF24 module had faster transmission times and lower power consumption compared to the LoRa module. However, for signal range in obstructed or non-line-of-sight conditions, LoRa was able to communicate up to 411 meters, while the NRF24 network could only reach 80 meters.

In this study, the TTGO T-Beam LoRa32 V1.1 MCU board, which already has the LoRa SX1276 and GPS Neo-6M modules on its PCB, was used. A GY-25 MPU6050 gyroscope microsensor was also added as a complement to display the orientation of the ship. No modifications were made to the LoRa or GPS modules and both antennas on the MCU board to keep it low-cost and to see how far the capabilities of this MCU board are to be used as a prototype for monitoring fishing boats. LoRa operates at the 923 MHz frequency with point-to-point communication between transmitter and receiver. This low-cost prototype was able to track the boat position up to 2 km from the shoreline where the receiver antenna was placed. The system has a -113 dBm received signal strength indicator (RSSI) and around 60% of data quality of service (QoS).

2. Research Methodology: Developing the Boat Safety Monitoring Prototype

2.1. Developing Process

The development process, covering both hardware and software, begins with a literature review focusing on existing research and experiments, particularly those related to LoRa communication. Following this, the process involves selecting essential components like the microcontroller board, sensors, and the LoRa module. Subsequently, block diagrams are created for both the transmitter and receiver sections, which serve as a blueprint before the final assembly of all components. All the processes in this research are depicted in Fig. 1.

2.2. Block Diagram

Fig. 2 illustrates the relationship between the components on the transmitter side, with the red line indicating the power line and the blue line indicating the data line. The gyroscope sensor measures the orientation angle of the fishing boat from the x, y, and z axes (pitch, roll, yaw). A GPS module was added to show the coordinates of the fishing boat. Both data are sent by the LoRa module with point-to-point communication to the receiver side.

The transmitted signal contains all 5 parameters such as pitch, roll, yaw, latitude, and longitude which are combined into one string data type.

Fig. 3 depicts the receiver side components. The receiver will be placed on the shoreline to capture the

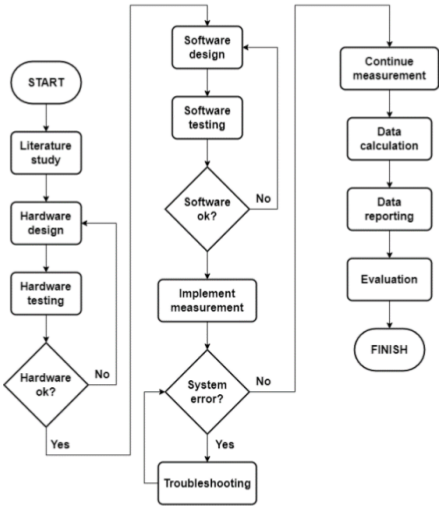

Fig. 1. Research Process Flowchart

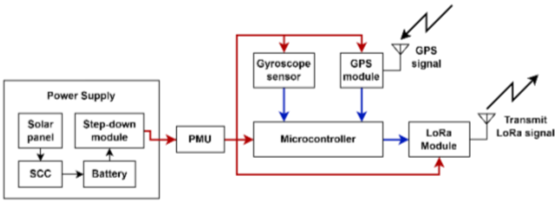

Fig. 2. Transmitter Block Diagram

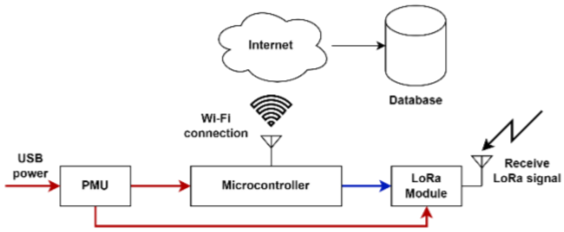

Fig. 3. Receiver Block Diagram

LoRa signal transmitted from the transmitter side. Received data is then sent to the Firebase database for storage via the internet with a Wi-Fi connection.

2.3. Main Components

The transmitter side has five primary components: an MCU board, a gyroscope sensor, a GPS module, a LoRa module, and a battery for power. On the receiver side the same MCU board and LoRa module with a power source from a dedicated micro-USB port. The component's relation in both transmitter and receiver can be seen in Fig. 2 and 3.

Table 1. General Specifications of TTGO T-Beam LoRa32 V1.1 MCU Board

Module	Type/Model
MCU	ESP32
LoRa	SX1276
GPS	NEO-6M
Power source	On board micro-USB port, 18650 lithium battery, 5V or 3.3V power pin

Fig. 4. SX1276 LoRa Module on MCU Board

1. MCU Board

The MCU board that is used in this application is TTGO T-Beam LoRa32 V1.1 with ESP32 as MCU, GPS module, and LoRa module that is already soldered in the PCB. The AXP192 IC power management unit (PMU) regulates all power resources for these components. This IC has several functions, including a USB-compatible charger, 3 buck DC-DC converters, 4 linear low dropout regulators, a voltage/current/temperature monitor, and a multichannel 12-bit ADC [13]. The advantage of using this board is its ease of usage. In addition, this board can be powered in various ways, as detailed in Table 1.

2. LoRa Module

According to Indonesian regulations, LoRa must be operated within the 920-923 MHz frequency range. Any other frequency usage is unauthorized. The SX1276 LoRa module offers a wide frequency range of 137-1020 MHz and a sensitivity of -111 to -148 dBm [14], ensuring native support for permissible LoRa frequencies in Indonesia. This module interfaces with the MCU using the Serial Peripheral Interface (SPI).

3. GPS Module

The MCU board incorporates a Neo-6M GPS module equipped with a dedicated ceramic antenna. This module interfaces with the MCU via UART at a baud rate of 9600. According to the datasheet [15], coordinate measurement commences 1-27 seconds after power-up, depending on ambient conditions. The TTGO MCU board's dedicated GPS antenna uses a smaller footprint (16 x 7 mm) compared to the NEO-6M's original (25 x 25 mm). The performance in terms of signal reception might be affected.

4. Gyroscope Module

This application utilizes the GY-25 MPU6050 gyroscope sensor. The MPU6050 is a micro-electro-mechanical system (MEMS) sensor that combines an

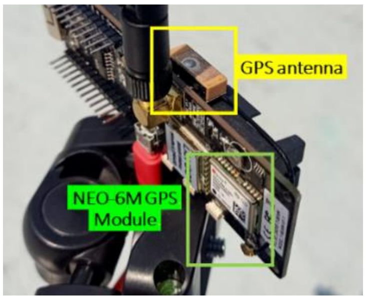

Fig. 5. NEO-6M GPS Module on MCU board

accelerometer and a gyroscope to record movement or changes in position and acceleration [16]. This sensor communicates with the MCU via UART.

5. Power Source Option

A 12V 7Ah battery, a 20Wp solar panel, and a Solar Charge Controller with a 12V 10A max output power the transmitter. This power is then regulated by an MP1584 step-down module to provide a fixed 5V voltage at up to 3A current. The receiver is powered directly from a power bank connected to the micro-USB port on the MCU board. The option was chosen not only to ensure sufficient power supply but also to serve as a power source for other devices such as lights.

3. Result and Discussion

3.1. GPS Module Test

The GPS test method in this application involves comparing manually added placemarks in Google Earth with output coordinates from the GPS module. The test location depicted in Fig. 6 is on the rooftop of the School of Electrical Engineering (FTE), Telkom Universit. Fig. 7 depicts the manual placemark (blue) and the GPS output data (yellow). The test results are presented in Table 2. The error distance was calculated using the ruler menu on Google Earth.

Fig. 6. Rooftop of FTE Telkom University

Fig. 7. Manually Added Placemarks (blue) vs. GPS Module Output Placemarks (yellow)

Table 2. Placemark Error Between Manual Added and GPS Data Output

Manual Added	GPS Data Output	Error (m)
1_Manual	1.0	11.25
2_Manual	2.0	9.52
3_Manual	3.0	4.89
4_Manual	4.0	5.53
5_Manual	5.0	5.68

The horizontal coordinate error of the NEO-6M module ranged from 4-11 m, with an average of 7.374 m. This accuracy compares favorably to the iPhone 6, which exhibited a 7-13 m horizontal accuracy in similar research [17]. The larger original antenna size of the NEO-6M compared to the included MCU board suggests that increasing the antenna size could further improve accuracy.

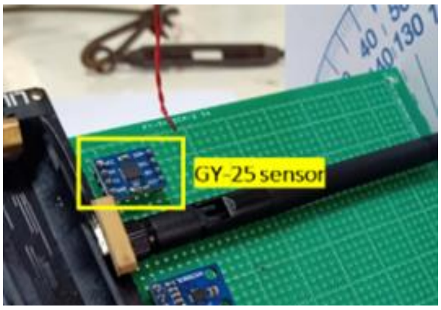

Fig. 8. Gyroscope Sensor with MCU Board on PCB

Table 3. Gyroscope Sensor Value Compared to the Protractor Angle

Protractor Angle	Pitch Value	Roll Value	Yaw Value
0	6,87	0,87	-1,63
30	-22,55	27,43	33,55
45	-37,59	44,2	43,59
60	-51,8	57,1	61,8
90	-83,3	89,3	90,3

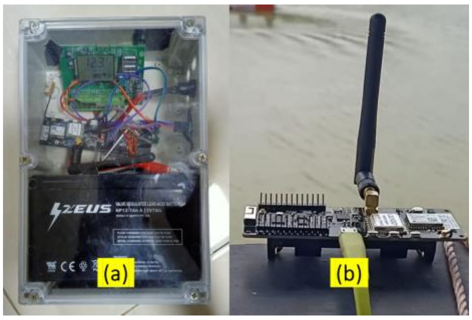

Fig. 9. Transmitter (a) and Receiver (b)

3.2. Gyroscope Sensor Calibration

The gyroscope sensor's pitch axis was calibrated using a protractor printed on paper. Fig.8 shows the sensor connected to the MCU board via a PCB. From the results displayed in Table 3, linear regression calculations were performed as a correction factor for the obtained pitch, roll, and yaw values directly on the microcontroller.

3.3. LoRa and Gyroscope Sensor Test

LoRa testing was conducted after all components were assembled into a single system. This test was conducted twice: the first at Ciburuy Lake, Padalarang, Indonesia, and the second at Jayanti Beach, Cianjur, Indonesia. Fig. 9 shows the transmitter section (a) placed on a boat and the receiver section (b) placed on the shoreline.

The LoRa frequency was set to 923 MHz, and a point-to-point communication test was conducted between the transmitter to receiver in an endless loop until the transmitter powered off. Another setting is set to default, based LoRa 0.8.0 version library by Sandeep Mistry in Arduino IDE, such as spreading factor value 7, 125 kHz bandwidth, and 0 dB transmit power. Theoretically, this LoRa network configuration can send data at 5496 bps bitrate [18]. Fig. 10 presents the algorithms in the flowchart of the transmitter section (a) and the receiver section (b). The data received from the transmitter was sent to the Firebase Realtime Database by the receiver for storage.

1. First Test Result

The first test was carried out by carrying the transmitter around Ciburuy Lake for 27 minutes and 56 seconds. The data from the transmitter was sent to the receiver at intervals of 5 seconds. The placemark of the boat's coordinates in Google Earth is shown in Fig. 10 with the receiver side marked with a house icon.

The LoRa signal was not received by the receiver in the marked area due to tall buildings obstructing the line of sight from the transmitter. The following graph of the LoRa signal RSSI from the closest (0 m) to the farthest distance (900 m) from the transmitter to the receiver is shown in Fig. 12.

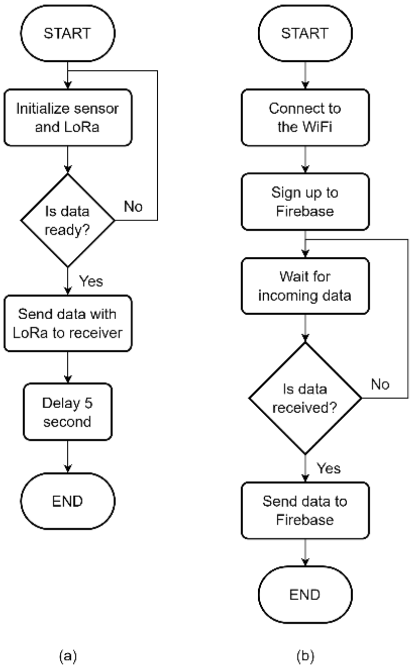

Fig. 10. Transmitter Algorithm (a) and Receiver Algorithm (b) Flowchart

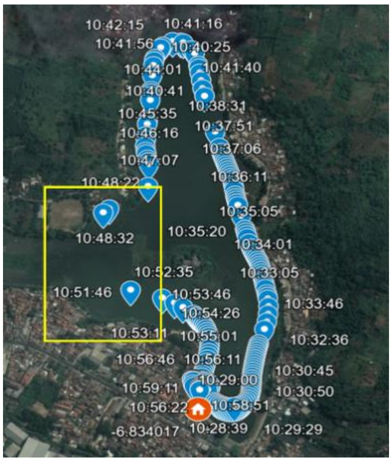

Fig. 11. Placemark of the Boat's Coordinates on Ciburuy Lake

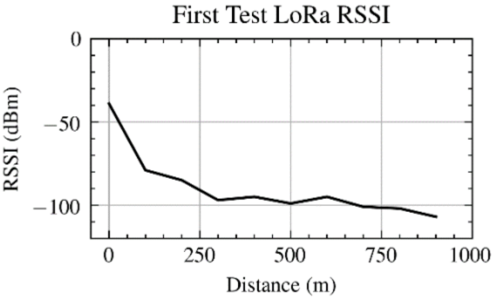

Fig. 12. RSSI of LoRa signal on the First Test

Table 4. Amount of Data from the First Test

Data	Amount
Received data	209
Valid data	186
Invalid data	23
Expected data	335

$$QoS = \frac{Amount\ of\ valid\ data}{Amount\ of\ expected\ data} \times 100\% \qquad (2)$$

Quality of Service (QoS) was calculated using equation (2) with the data from Table 4, and the result was about 55%. This low QoS result was caused by buildings blocking the line of sight between both devices, resulting in a lot of data loss during the test [19]. Additionally, some data was not captured perfectly by the receiver due to the presence of noise from other devices that mixed with the signal from the transmitter.

Fig. 13 shows how the boat's orientation is measured by the gyroscope sensor for pitch, roll, and yaw. The data from the sensor is shown in Fig. 14. The water in Lake Ciburuy has calm waves, so there is minimal shaking of the boat. This is also indicated by the minimum standard deviation values for pitch and roll, which are around 1 degree and 7.3 degrees, respectively. Yaw data can be used to determine the boat's facing direction, but it needs to be adjusted to set 0 degrees as the north angle of the Earth

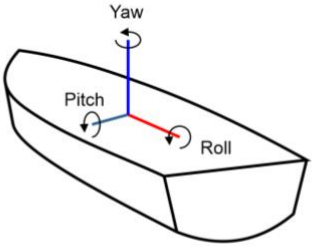

Fig. 13. Placemark of the Boat's Coordinates on Ciburuy Lake

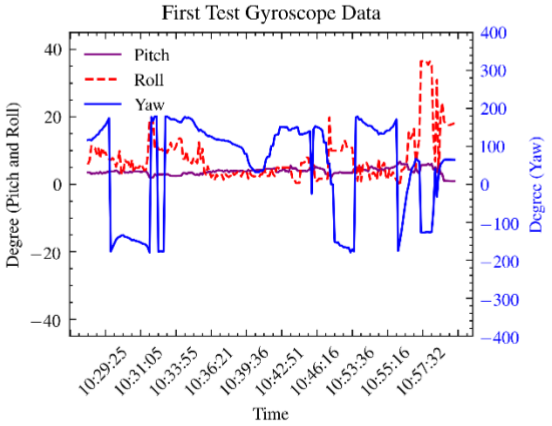

Fig. 14. Gyroscope Sensor Data on Ciburuy Lake

Fig. 15. Placemark of the Boat's Coordinates on Jayanti Beach

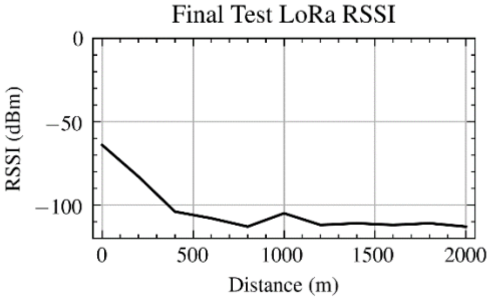

Fig. 16. RSSI of LoRa signal on the Final Test

Table 5. Amount of Data from Final Test

Data	Amount
Received data	65
Valid data	65
Invalid data	0
Expected data	109

2. Final Test Result

In the final test, the transmitter was placed in the middle of the Jayanti Sea, and measurements were taken upon the boat's return from the sea, covering approximately 2 km to the shoreline in 9 minutes and 7 seconds. Fig. 15 shows the boat's placemark when it returned to the harbor, and the RSSI is shown in Fig. 16.

Using equation (2) and data from Table 5, the QoS value is about 60%. The absence of objects blocking the line-of-sight and less noise on LoRa caused the QoS value in the final test to be 4.11% higher. The RSSI at the 2 km distance was -113 dBm. However, in this test, the transmitter was not placed properly on the boat, so there were moments when large waves hit the boat during the transmission, causing the signal to be lost.

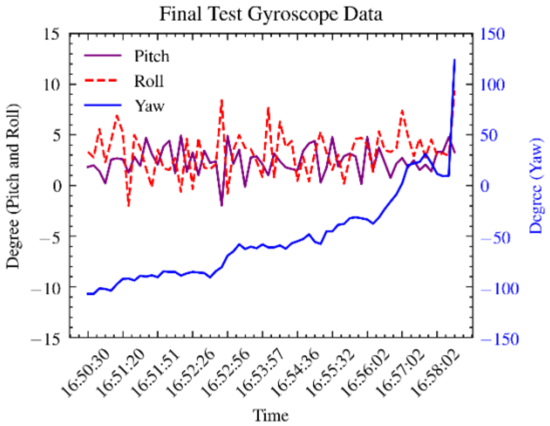

Fig. 17. Gyroscope Sensor Data on Jayanti Beach

Despite the large waves at Jayanti Beach, the data from the gyroscope sensor, as shown in Fig. 17, indicates smaller values compared to the data collected during the test at Lake Ciburuy. The standard deviation of pitch and roll for the data is around 1.3 degrees and 2.2 degrees. This is likely because the LoRa signal was not received by the receiver during periods of significant shaking, resulting in only the gyroscope data being received when shaking was minimal.

4. Conclusions

This research successfully developed a prototype for tracking and monitoring fishing boats utilizing the TTGO T-Beam V1.1 MCU board. The Neo-6M GPS module with the MCU board's built-in antenna received a position error with a range of 4-11 m. For LoRa testing at a frequency of 923 MHz by default without any additional amplifiers or high-gain antennas, it was able to communicate up to 2 km with an RSSI of -113 dBm. However, the QoS obtained was still in the range of 50-60%. This was caused by the placement of the antenna from the transmitter on the boat, which could sometimes be blocked by the boat's hull during large waves, resulting in a non-line-of-sight condition. To overcome this issue, an external antenna can be added and placed higher than the objects inside the boat. This ensures that the transmitter antenna can maintain a line-of-sight condition with the receiver antenna at all times.

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Additional Information