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Autopilot Unmanned Smart Boat Vehicle (AUSV) Communication with LoRa RFM95

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Abstract*— Autopilot is a system control application on moving vehicles such as airplanes, helicopters, or boat, which serves to stabilize the direction of motion in the desired time and the programmed path's direction. the autopilot control system is controlled by a series of microcontrollers and GPS that has the function to be able to determine and the desired object. This control system is designed with electrical system controls that utilize microcontrollers, sensor and GPS as control media. The development of autopilot prototypes is used for testing new control algorithms and the reliability of other electronic components such as sensors and microprocessors. A control system is needed to control the boat to its destination. The relatively accurate system dynamics model affects the steering performance of the autopilot system. The system in question can be considered a boat with an actuator rudder, which experiences external disturbances. this system is broadly divided into two parts: the control station part and the autonomous boat part. These two parts communicate with each other using LoRa device. The data sent from the control station to the autonomous boat is target latitude and longitude coordinates. The autonomous boat will send feedback in the form of boat latitude and longitude coordinates so that users can find out the current location of the boat. Autonomous Boat also provides feedback to the control station via LoRa in the form of boat coordinates so that users can find out the current location of the boat and whether the boat has reached the specified coordinates. The control station will send feedback from the boat to a database that can be monitored via the website to find out the boat's current condition on the website. Based on the results that have been obtained in the analysis and testing of the system. GPS sensor used in autonomous boat Ublox NEO-7m has an accuracy level with an average distance value of 3.22 meters with the lowest cold start time of 7 seconds. Compass sensor used in autonomous boat CMPS11 has an accuracy level with an average value of 3.041 degrees. Communication distance between autonomous boat and control station using LoRa with 5dBi antenna can reach 1,406.79 meters in condition without obstacle between nodes. Data delivery system can be successfully sent from user to autonomout boat and sending feedback back to user. Delay update of boat coordinate data on interface has the lowest average of 30.8 seconds. Based on turning circle test results, autonomous boat is able to create imperfect circles with a radius of 8.36 m.

***Keywords*— Autopilot Unmanned Smart Boat Vehicle; GPS; LoRA.**

I. Introduction

In this era of globalization, the development of technologies that apply electronic sciences and control systems, especially microcontrollers, is increasingly popular. A large number can know this of equipment that implements a mix of science and systems control, one of which is shipping [1]. In shipping, there is much work that has difficulty in terms of supervision and observation of the work. So it is necessary to system that can assist in the work of the company. One such system is an auto control system for pilots who can significantly assist with work on board to drive the boat. In such systems, the autopilot control system is controlled by a series of microcontrollers and GPS that has the function to be able to determine and the desired object. This control system is designed with electrical system controls that utilize microcontrollers, RSSI and GPS as control media [2][3][4][5][6]. With input data derived from GPS and the microcontroller will be sent to drivers and motors for the boat's propeller until it reaches the and if there is a barrier in front of the boat, the boat will stop automatically. This research will use small boats as testing media. The pilot's auto control system uses GPS to be tested directly in the water reservoir[7]. The data used in this GPS program is the data settings and real-time data, where data sets are data the destination of the boat stops and the real-time data is the actual position of the boat. With both data above, if the real-time data is the same as the data set, the boat will stop, and if real-time data is not the same as the data set, then the boat will continue to run and look for the location of the position of the data setting or destination [4].

Autopilot is a system control application on moving vehicles such as airplanes, helicopters, or boat, which serves to stabilize the direction of motion in the desired time and the programmed path's direction [8]. The development of autopilot prototypes is used for testing new control algorithms and the reliability of other electronic components such as sensors and microprocessors [9]. In rocket control, the control system is used to guide the rocket in the desired direction. The rocket's track can be read from the inertia sensor or additional from GPS data[10]. Changes in the motion of the rocket's path by changing the direction of the rocket motor's thrust or by rotating a few degrees of the tilt of the rocket's fins by utilizing the principle of aerodynamic forces[11]. To develop this system, using a rate gyroscope to calculate angles and a stable control actuator is an essential part of the system.

The autopilot system is a mechanical, electrical, or hydraulic system that guides a vehicle without human intervention [12] . Generally, the autopilot is associated with an airplane [13] . However, the autopilot is also used on boats with the same term. A navigation system and control system guide the movement of the boat in autopilot mode [4] . The boat navigation system on autopilot uses the waypoint method. The navigation system will guide the autopilot boat to move systematically following the waypoints that have been set at the ground control station. In the movement of an autopilot boat, external forces such as wind and waves and internal forces such as an imbalance in the rotation of the main propulsion speed will influence its movement. Therefore, a control system is needed to control the boat to its destination. The relatively accurate system dynamics model affects the steering performance of the autopilot system. The system in question can be considered a boat with an actuator rudder, which experiences external disturbances, as shown in Fig 1.

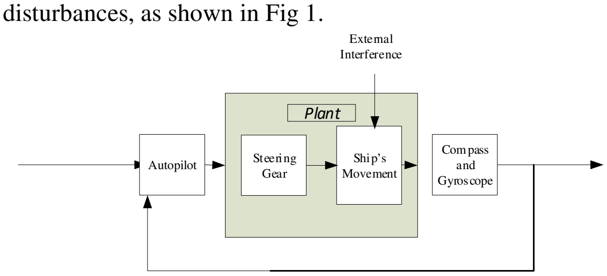


Fig 1. Autopilot System Diagram Blocks[4]

LoRa module is a device with a wireless frequency or radiofrequency with a long-distance using low power consumption. LoRa module can be used to control and monitor something with radiofrequency. Such as monitoring mountain activities, drones, electricity, agriculture, and others. LoRa (Long Range) is a unique and extraordinary modulation format created by Semtech. The resulting modulation uses FM modulation. LoRa is a digital wireless data communication technology patented and developed by Cyclo from Grenoble, France, and acquired by Semtech in 2012. LoRa is a long-range wireless communication protocol that can compete with other Low-Power Wide-Area Network (LPWAN) such as Narrowband IoT (NB IoT) or LTE Cat M1. Compared to this technology, LoRa has a very long-range, which exceeds 10 km, but the resulting data rate is low. The SX1276 / 77/78/79 transceiver is a LoRa® long-range wireless transceiver module that provides Ultra-long spread spectrum communication with a high degree of resistance to low power consumption interventions. Using the LoRa modulation technique patented by Semtech, the module can run with a sensitivity up to -148 dBm and function at a low cost. This LoRa module has advantages, such as selectivity and blocking capabilities, which are much better than conventional modulation systems, making this module one of the transceiver devices superior in range, resistance to intervention, and power consumption. However, the disadvantage of LoRa itself is that the data speed is below 50 kbps and because LoRa has a duty cycle and other weaknesses, in practice, this technology is suitable for applications where the delay in sending data is not taken into account. RFM95 is a LoRa type widely circulating in the market and uses the LoRa SX1276 chip with a frequency of 915 MHz [14] .The specifications and forms of the Arduino LoRa module are shown in Table 1.

TABLE 1.
LORA RFM95 915MHZ SPECIFICATIONS [15]

Parameter	Specification
Frequency	915 MHz
Chips	SX 1278
Supply Voltage	1.8 - 3.3 V
Data Transfer Speed	1.2 – 300 kbps
Data	SPI data Interface
Sensitivity	-139 dBm
Parameter	Specification
Modulation	LoRa

II. METHOD

A. The System Design

In this stage, the system design consists of designing the complete autonomous boat that has been done to produce an autonomous boat that suits the initial needs and objectives. An overview of the autonomous boat work system is shown in fig 2.

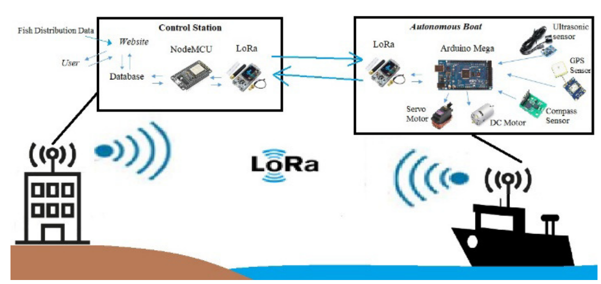


Fig 2. LoRA communication in Autopilot Unmanned Smart Boat Vehicle

Figure 2 shows that this system is broadly divided into two parts: the control station part and the autonomous boat part. These two parts communicate with each other using LoRa device. The data sent from the control station to the autonomous boat is target latitude and longitude coordinates. The autonomous boat will send feedback in the form of boat latitude and longitude coordinates so that users can find out the current location of the boat. The workflow for sending coordinates by the control station can be seen in the block diagram of the system workflow in fig 3.

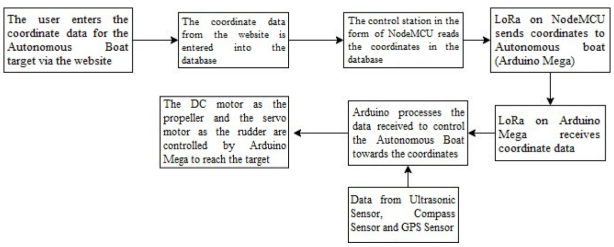


Fig 3. Workflow diagram of coordinate ransmit by control station

The first step of sending coordinates in the form of latitude and longitude by the control station is that the user accesses the website to determine the autonomous boat's coordinates. The website obtains a reference point for fishing coordinates from the website of the Marine Research and Observation Center of the Ministry of Marine Affairs and Fisheries [16]. After the user determines coordinates to a destination via the website, then coordinates and orders to run the boat will be sent to the database. The control station in the form of NodeMCU will read the coordinates and command to run the boat in the database and send orders to the boat through the LoRa intermediary. After Arduino Mega on an autonomous boat receives coordinates and data from the installed ultrasonic sensor, compass, and GPS, Arduino Mega is processed to move actuators in DC motors and Servo motors so that the autonomous boat can go to the predetermined coordinates. The block control diagram of the autonomous boat can be seen in Figure 4.

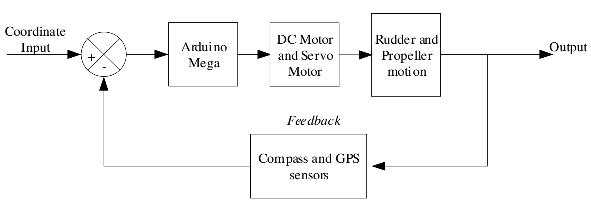


Fig 4. Technical Obstacle Avoidance

Autonomous Boat also provides feedback to the control station via LoRa in the form of boat coordinates so that users can find out the current location of the boat and whether the boat has reached the specified coordinates. The control station will send feedback from the boat to a database that can be monitored via the website to find out the boat's current condition on the website.

B. Data Communication Method

A unique pattern makes ways to prevent foreign LoRa data from interfering with communication between the control station and the autonomous boat, so LoRa on the autonomous boat and the control station only reads from each other's LoRa. Each node will be programmed to ignore the data received if the data does not match the pattern that has been created. Each node is also programmed to send data with a predetermined pattern. A technical picture of data reception between an autonomous boat and a control station can be seen in Figure 5.

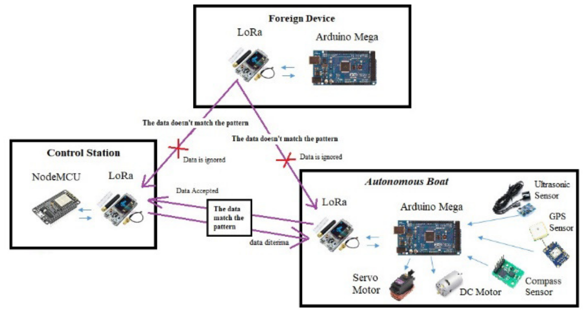


Figure 5. Data Communication Method

C. Obstacle Avoidance Technique

No more than 3 levels of headings should be used. All The technical illustration of avoiding obstruction on an autonomous boat is shown in Figure 6.

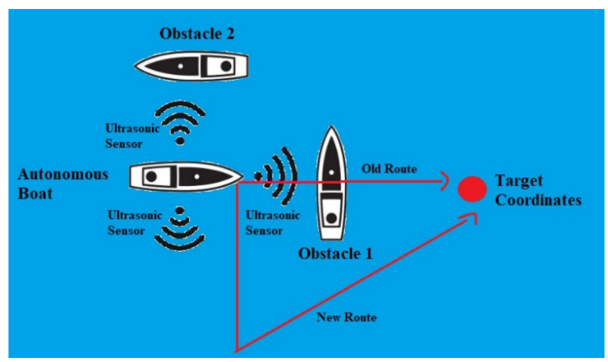


Fig 6. Obstacle Avoidance Technique

There are three ultrasonic sensors: on the front, right, and left sides of the autonomous boat. The ultrasonic sensor is used to detect obstacles on the front, right, and left of the autonomous boat. When there is an obstacle on the front, the microcontroller will read the ultrasonic sensors on the right and left to determine which route has no obstruction and go to that route. After avoiding the obstacle, the autonomous boat can return to the target coordinates. Meanwhile, when there are obstacles on the front, right and left, the autonomous boat will back off and then check the right and left sides to find a way to avoid obstacles. Figure 7 shows a block diagram of control to avoid obstacles.

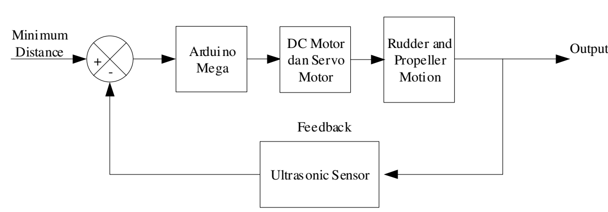


Fig 7. Block Diagram of Obstacle Avoidance Control

D. Autopilot System Algorithm

The workflow of the autopilot system program is shown in Figure 8. Autopilot starts working after the user enters all the target waypoints to be addressed. After the target coordinates have been received, the first target waypoint will be set, and the microcontroller will update the current position coordinate data from the GPS sensor and the compass sensor heading. After the target data and position data are obtained, calculations are carried out to get the distance between the position coordinates, the target coordinates, and the target coordinates' bearing angle. The haversine formula method is used to find out the distance between coordinates. The bearing calculation results will generate a value ranging from -180 to 180. The obtained bearing angle is used to calculate the relative bearing value. The relative bearing value is used to determine the direction of the rudder's movement. If the bearing's relative value is positive, the rudder movement will move to the right. Also, in the opposite direction, if the bearing's relative value is negative. The rudder will go straight if the relative bearing is 0 with a tolerance value of ± 10. Since the semicircular angle is 180 degrees, if the relative bearing value is more than 180 degrees, then:

$$\text{Relative bearing} = \text{relative bearing} - 360 \quad (1)$$

Moreover, if the relative heading value is less than -180 degrees, then:

$$\text{Relative bearing} = \text{relative bearing} + 360 \quad (2)$$

Visualiation of headings, bearings, and relative bearings is shown n Figure 10.

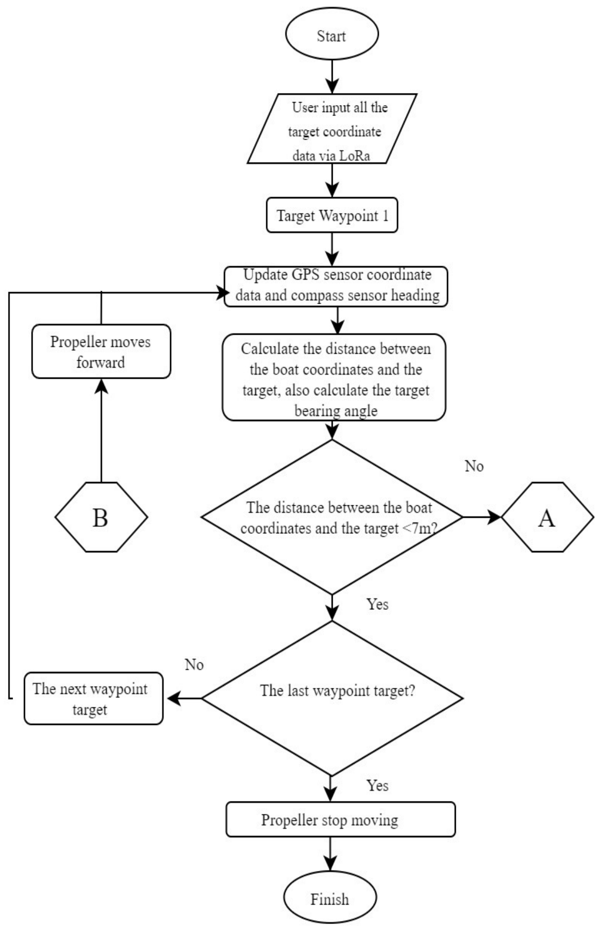


Fig 8. Autopilot System Program Flowchart (1)

The autonomous boat will move towards the target until the coordinates' distance is less than 7 meters. If any target coordinate distance is less than 7 meters, the target coordinates will change to the next-point coordinates. If there is no other target waypoint, the autonomous boat will stop.

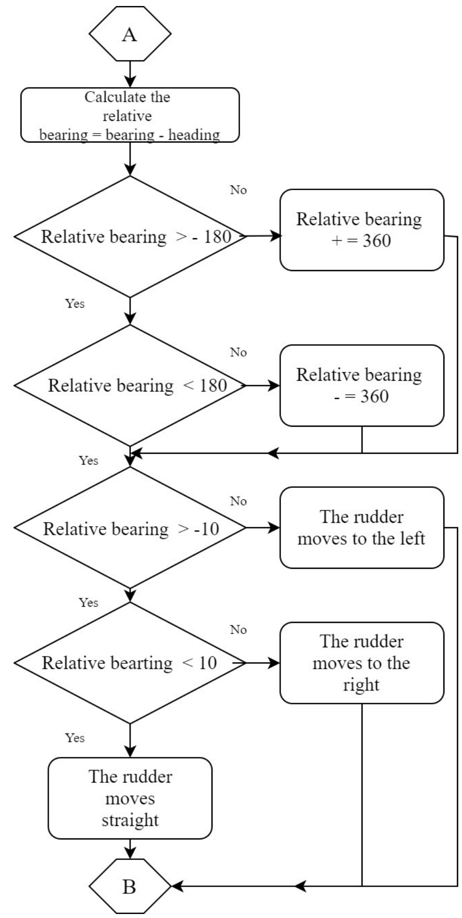


Fig 9. Autopilot System Program Flowchart (2)

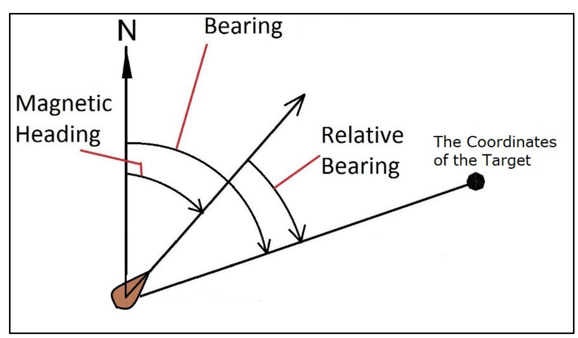


Fig 10. Heading, Bearing, and Relative Bearing Visualization

III. Result & Discussion

A. Testing of Communication LoRa

In this test, data was sent ten times with a different character arrangement for each delivery. Testing is also carried out where there are no objects or obstacles between the sender and receiver. This experiment was carried out using an antenna with a 5dBi amplifier. The results of the LoRa test shown in Table 2.

TABLE II
LORA TESTING RESULTS

No.	Distance (m)	Data Number :										RSSI Average (dBm)
		1	2	3	4	5	6	7	8	9	10	
1	10.6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-55.7
2	20.47	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-62.6
3	25.22	✓	✓	✓	-	✓	✓	-	✓	-	✓	-63.4
4	30.30	✓	✓	✓	-	✓	-	✓	✓	✓	✓	-72.8
5	40.48	✓	✓	✓	✓	✓	✓	-	-	-	✓	-67.3
6	49.60	✓	✓	✓	✓	-	✓	✓	✓	✓	-	-70.3
7	60.82	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	-75.2
8	69.94	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	-77.2
9	74.5	✓		✓	-	-	✓	-	✓	✓	✓	-66.9
10	80.84	-	✓	✓	-	✓	✓	✓	-	✓	-	-77.2
11	89.60	✓	✓	-	✓	-	✓	✓	✓	✓	✓	-91.0
12	101.27	✓	✓	✓	-	✓	-	✓	✓	✓	-	-85.9
13	120.29	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	-86.0
14	125.53	✓	✓	✓	✓	✓	-	✓	-	✓	✓	-91.5
15	140.74	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-94.3
16	150.4	✓	✓	✓	✓	-	-	✓	✓	✓	✓	-91.1
17	159.07	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-93.9
18	175.43	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-89.5
19	180.56	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	-89.8
20	201.29	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	-92.7
21	250.84	✓	✓	✓	✓	✓	✓	✓	✓	✓		-90.8
22	300.05	✓	-	✓	✓	✓	-	-	✓	✓	✓	-88.0
23	351.20	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-87.2
24	400.69	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	-88.3
25	450.94	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-89.9
26	500.26	-	✓	✓	-	✓	✓	✓	✓	✓	-	-89.9
27	550.55	-	✓	✓	-	-	-	✓	✓	✓	-	-95.0
28	602.62	-	✓	✓	✓	✓	-	-	✓	✓	✓	-98.1
29	711.85	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-100.5
30	801	-	✓	✓	✓	✓	✓	✓	-	✓	✓	-92.8
31	910.92	-	-	-	✓	✓	✓	✓	-	-	-	-109.3
32	1011.49	✓	✓	✓	-	✓	✓	✓	-	✓	✓	-109.1
33	1217.1	✓	✓	✓	✓	✓	-	✓	✓	✓	-	-109.0
34	1309.25	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	-114.2
35	1352.18	-	✓	-	✓	✓	✓	-	✓	✓	✓	-115.1
36	1406.79	-	✓	✓	-	✓*	✓	✓	-	✓*	-	-112.6
37	1454.11	✓	-	✓	✓	✓	✓	✓	-	✓	✓	-99.5
38	1466.07	✓*	-	✓	✓	-	✓	✓	-	-	-	-112.4
39	1507.29	-	-	-	✓	-	-	✓	-	-	-	-113.5
40	1512.58	-	-	-	-	-	-	-	-	-	-	-

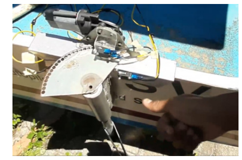
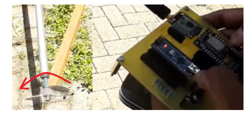
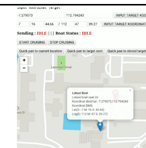
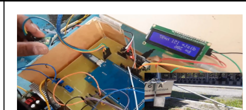
✓ = data received
- = data not received
* = data received does not match the data sent

Based on the test results above, it can be seen that the farther the distance between the nodes, the farther the RSSI value is from the 0 value, which indicates the weakened signal. Significant differences at 1406.79 meter, there is data received does not match the data sent. At 1507.29 meters, the data received only 2 out of 10 data sent, the receiver can no longer receive data. During the test, found in the data transmitted, there was no significant delay in sending the data due to a time of less than 1 second for the data received by the recipient from the target despite the increasing distance. However, LoRa module also has its limit, which is that the farther the distance between nodes, the more often the data fails to be sent or is not appropriate. It can be concluded from the tests carried out that the LoRA module can exchange data effectively up to 1406.79 meters during obstacles between nodes.

B. Testing the Autopilot System

From testing the Autopilot system, it can be concluded that the system and communication from the user to the autonomous boat and feedback to the user can function correctly. The results of the experiments are listed in Table 3.

TABLE III
AUTOPILOT SYSTEM TESTING RESULTS

No.	Description	Test Result Image
1.	The rudder manages to move to the right and left during remote mode when the right direction button is pressed, and then the left direction button is pressed.	
2.	The propeller manages to move forward and backward during remote mode when the forward button is pressed then the back button is pressed.	
3.	The website display has successfully displayed the autonomous boat's location and has successfully sent the target coordinates.	
8.	The target coordinates have been successfully sent to the autonomous boat and displayed on the LCD	
9.	Send commands to go to the target coordinates via the website display	
11.	Test the rudder motion in autopilot mode and success in showing all degrees.	
14.	The ultrasonic sensor can read the state. If there is an obstacle, the propeller will move backward.	

C. Testing of Turning Circle Boat's Movement

This test is conducted to determine the boat's maneuverability in facing a turn by controlling the boat manually, and then the boat is controlled to turn to form a circle. The turning circle test results are shown in Fig. 11

Fig 11. Mapping of the autopilot boat's turning circle testing

Based on the results of turning circle testing, it is known that the resulting circle made by the boat during a full turn does not form a perfect circle due to external influences such as wind, which can affect the boat's motion. Besides, the coordinate data from the GPS sensor, which is used as a reference for mapping the path that the boat passes during the turning circle test, also have errors. The surface area was obtained after being mapped on google maps with an area of 219.79 m^2. So if the shape of the area is considered as a perfect circle, a radius of turning circle is obtained by using a formula of circle area of 8,364 m

IV. Conclusions

Based on the results that have been obtained in the analysis and testing of the system that has been made, it can be concluded that:

1. GPS sensor used in autonomous boat Ublox NEO-7m has an accuracy level with an average distance value of 3.22 meters with the lowest cold start time of 7 seconds.
2. Compass sensor used in autonomous boat CMPS11 has an accuracy level with an average value of 3.04 degrees.
3. Communication distance between autonomous boat and control station using LoRa with 5dBi antenna can reach 1,406.79 meters in condition without obstruction between nodes.
4. Data delivery system can be successfully sent from user to autonomout boat and sending feedback back to user.
5. Delay update of boat coordinate data on interface has the lowest average of 30.8 seconds.
6. Based on turning circle test results, autonomous boat is able to create imperfect circles with a radius of 8.36 m.

Acknowledgment

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