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Development of A Surveillance and Remote Control System Based on ESP-Now for The ATSV Prototype (Autonomous Tourism Surface Vessel)

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Abstract – Indonesia, as an archipelagic country, has great potential in the marine tourism sector. One of the efforts to develop maritime technology is through the National Unmanned Fast Boat Contest (KKCTBN), which aims to encourage innovation in unmanned ship manufacturing. This research aims to design and implement a GPS surveillance system and remote steering control on the Autonomous Tourism Surface Vessel (ATSV) prototype by utilizing ESP-NOW wireless communication technology. The system uses an ESP32 microcontroller, a NEO-6M GPS sensor, and a joystick module as part of the hardware, as well as ESP-NOW as a communication protocol to overcome the limitations of internet connectivity in the ocean area. Ship position data is sent in real-time to Thingspeak servers for remote monitoring. The test results show that the system can transmit GPS data with good accuracy and control the ship's direction responsively at a distance of up to 50 meters using an external antenna. Tests also show that the system can function well in various communication conditions and is reliable in monitoring and controlling ATSV vessels in real-time. This system is expected to contribute to innovation in the maritime world, especially in the context of developing unmanned ships that compete in the KKCTBN.

Keywords: Autonomous Tourism Surface Vessel (ATSV), KKCTBN, ESP-NOW, GPS surveillance, steering control, Thingspeak, ESP32, NEO-6M GPS sensor

I. INTRODUCTION

Indonesia, as an archipelagic country, has great potential in the marine tourism sector thanks to its natural beauty. Based on the Travel and Tourism Competitiveness Index (TTCI), Indonesia's ranking increased from 44th in 2021 to 32nd in 2022 ("Indonesia's Global Tourism Index Increases" 2022). However, challenges in navigation safety are still a serious concern due to the high incidence of ship accidents (Ega Pratama Putra 2016). Technological innovation is needed to improve the efficiency, safety, and supervision of navigation, one of which is through the development of unmanned ships (Endriatno 2023).

One of the technologies that supports this innovation is the Autonomous Tourism Surface Vessel (ATSV), which is an electric-powered unmanned vessel designed as an innovation platform that can support marine tourism activities, such as visiting tourist sites and returning to the port independently (Andi Haris Muhammad, S.T., M.T. et al. 2023). In this case, the National Unmanned Fast Boat Contest (KKCTBN), held by the Indonesian Talent Development Center, is a strategic platform to advance digital maritime technology innovation, including the development of ATSV (Andi Haris Muhammad, S.T., M.T. et al. 2023).

The ATSV prototype required a reliable remote surveillance and control system to ensure efficient, safe, and accurate navigation. Obstacles such as limited internet connectivity in the sea area are one of the main challenges that must be overcome. Therefore, this research focuses on the development of a system that integrates GPS surveillance and remote control using the ESP-NOW protocol.

This ATSV system uses an ESP32 microcontroller with the ESP-NOW communication protocol, allowing the device to communicate wirelessly without the need for an internet connection (Espressif.com 2021). GPS sensors track the ship's position while managing waypoints for automatic navigation. The data from the ESP-master is sent to the ESP-slave, which is then forwarded to the Thingspeak server for real-time visualization and monitoring via the client application. The boat is also equipped with a joystick module to control direction and speed, so the system is designed to be reliable in dynamic conditions

II. METHODS

ESP-NOW

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ESP-NOW is a wireless communication protocol developed by Espressif and used in the ESP8266 microcontroller or ESP32, where data from the system is encapsulated in a packet called a special action frame. Using ESP-Now, these frames are then transferred directly between interconnected WiFi devices, without the need for an internet connection (Pasic, Kuzmanov, and Atanasovski 2021). This protocol is highly efficient for low-latency applications that require fast and stable communication in environments with limited internet connectivity.

RSSI (Receiver Signal Strength Indicator) is a parameter used to estimate the signal strength of the connection between devices in a certain network (Huda and Setiabudi, 2023). RSSI has a unit form (-x dBm), With this, a higher RSSI value indicates a stronger and stable connection, making it an important indicator in measuring network performance. The standardization of Signal Strength according to TIPHON is shown in Table 1.

Table 1 Signal Strength Standards by TIPHON

Category	***Signal Strength* (dBm)**
Very Good	> - 70 dBm
Good	-70 dBm s/d -85dBm
Keep	-86 dBm s/d -100 dBm
Signs	-100 dBm

Source : (Arnomo 2014)

Latency is the time it takes for data to move from the sender to the receiver. Latency testing on the ESP-NOW protocol is carried out by setting data transmission at certain intervals from one node to another, then recording the time of sending and receiving data. Furthermore, latency is calculated by subtracting the transmission time from the data receipt time. The equation used to determine the latency value is presented as follows.

$$\mathit{Latency(ms)}=(\mathit{Data\ Received\ time}-\mathit{Data\ sent\ time})-\mathit{delay} \quad (1)$$

Research Stages

This research was conducted with the aim of implementing a remote steering control system and ESP-NOW-based surveillance system on a prototype of an ATSV ship using a NEO6M GPS sensor and a Joystick module. This stage of research is carried out in a structured manner to ensure that the results are in accordance with the expected plan. The flow chart can be seen in figure 1 below.

In Figure 1 of this research design, there is a research flow diagram, namely starting, Literature Review, Problem Analysis, Hardware Design, Software Design, System Implementation, GPS-Tracker System Testing and Remote Steering System and conducting Data Analysis.

Hardware *Planning*

Based on the block diagram above, it can be seen that the system is powered by a power supply from a Li-po battery of 12V to supply a BTS7960 driver motor and a buck converter as a battery voltage converter from 12V to 5V as the supply voltage of the ESP32-Master microcontroller.

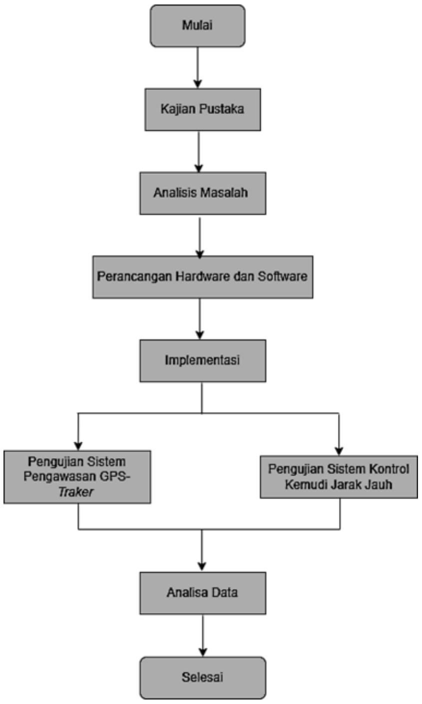


Figure 1. Research Design

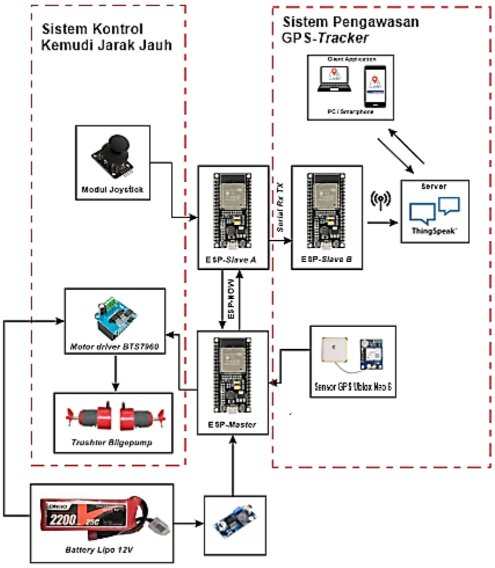


Figure 2. Hardware Design Block Diagram

The system uses the NEO-6 GPS sensor and joystick module as the main inputs. The data from the GPS sensor is processed by the ESP-Master and passed to ESP-Slave A via the ESP-NOW protocol. Furthermore, data in the form of latitude and longitude coordinates is transmitted from ESP-Slave A to ESP-Slave B through serial communication. ESP-Slave B then uploads the data to the Thingspeak server using an internet connection, allowing the data to be visualized in the form of a GPS-tracker map on an app on a smartphone or computer. Meanwhile, the joystick module generates data that is processed by ESP-Slave A and sent back to ESP-Master via ESP-NOW to control the speed and direction of the bilgepump thruster motor using BTS7960 motor driver.

Software *Design*

The software design of this study is divided into a GPS-Tracker monitoring system and a two-way ESP-NOW-based ship steering control system with a software system flowchart design as below:

GPS-Tracker Surveillance System

Figure 3 shows the flowchart of the GPS-tracker system starting with initialization on the ESP-Master and ESP-Slave. On the ESP-Master, initialization includes the ESP-NOW declaration and the GPS sensor. ESP-Slave A initializes ESP-NOW and serial communication (Tx), while ESP-Slave B initializes the Thingspeak server and serial communication (Rx).

After the connection between the ESP-Master and ESP-Slave A is successful, the GPS data (latitude and longitude) is read, formatted, and sent to the ESP-Slave A by ESP-NOW communication. ESP-Slave A receives the data, extracts it, and then sends it to ESP-Slave B via serial (Tx-Rx). ESP-Slave B uploads data to the Thingspeak server using the API. The client app checks the connection with the server, and if successful, the GPS data is displayed in the form of a GPS-tracker**.**

Remote Steering Control System

Figure 4 shows the workflow of a remote steering control system. The process begins with the terminator symbol as the initial signal of the program on the ESP-Master and ESP-Slave A. After that, initialization is carried out on the ESP-Slave to manage the ESP-NOW communication and the joystick module, while the ESP-Master is set for the ESP-NOW communication and the BTS7690 driver motor module as the propulsion of the ship. Then it is to connect the ESP-Slave with the ESP-Master with the ESP-NOW connection. If the two devices are successfully connected, the ESP-slave starts reading the input from the joystick to determine the direction of movement, such as forward (Y-axis 127-254), backward (Y-axis 127-0), right (X-axis 127-254), and left (X-axis 127-0), with a specific PWM value appropriate to move the boat. The data from the joystick is formatted into an ESP-NOW packet and sent from the ESP-Slave to the ESP-Master. When the data is received by the ESP-Master, the packet is processed to retrieve the data from the joystick. This data is used to control the bilge pump motor, so that the boat can move according to the direction of the joystick input, i.e. forward, backward, right, or left.

III. RESULT AND DISCUSSION

Remote Steering System Test Results with ESP-NOW

The remote steering system test aims to determine the level of responsiveness and accuracy of ATSV ship control in receiving command signals from users. In this test, ESP-NOW was used as a communication protocol to control the steering direction (forward, reverse, left turn, and right turn). The test was carried out under two different conditions: using an external antenna and without an antenna, with the test distance varying between 10 to 50 meters. During the test, various parameters were tested, including: communication distance, Latency, RSSI, as well as testing the use of external antennas and build in by recording every 3 seconds. The test results are used to refine the system design, ensuring that the remote control works with high precision and remains stable, even in dynamic operational situations. The test result data is displayed in tables 2 to 5 as follows

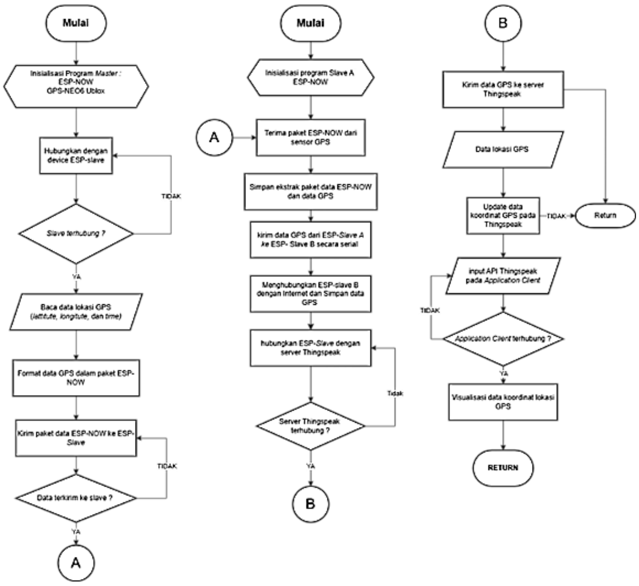


Figure 3. Flowchart GPS-Tracker Surveillance System

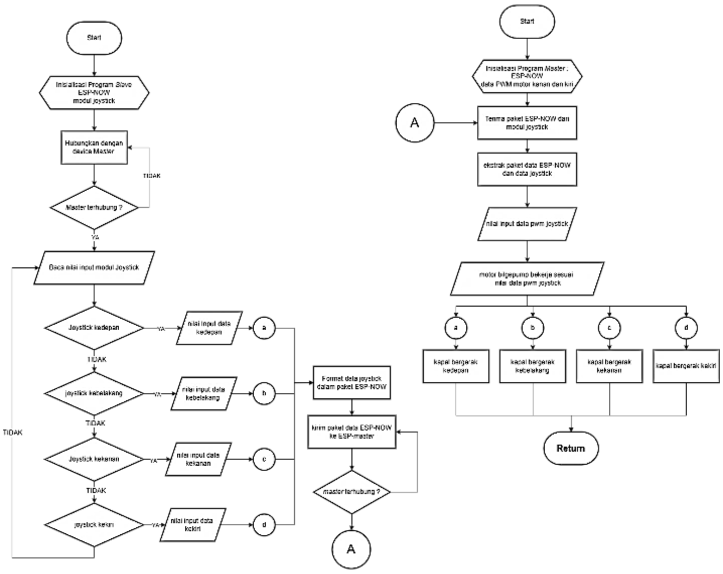
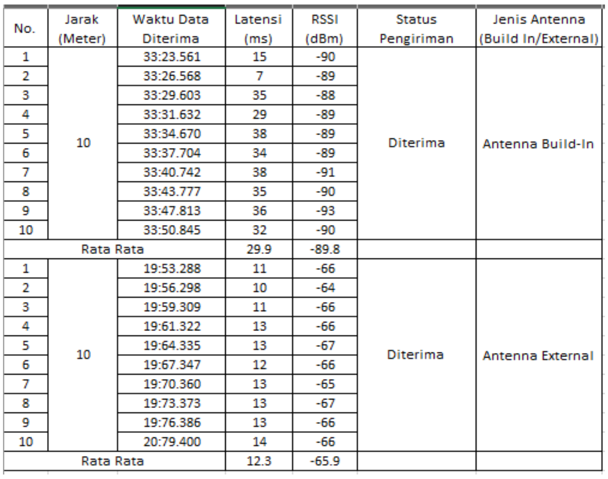


Figure 4. Remote Steering System Flowchart

In the 10-meter distance test, the data was taken 10 times. For the Build-In antenna, the average data transmission time is

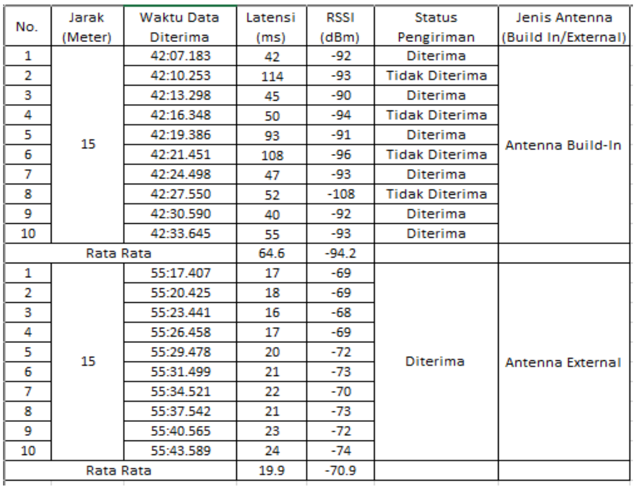
29.9 ms, with the fastest speed of 7 ms and the longest 38 ms, as well as an average signal strength of -89.8 dBm, which indicates quite good reception. Meanwhile, the External antenna has an average latency of 12.3 ms, with a range of 10 to 14 ms, and an average signal strength of -65.9 dBm, showing better performance with excellent transmission.

Table 2. 10 Meter Long Range Steering System Testing



No.	Jarak (Meter)	Waktu Data Diterima	Latensi (ms)	RSSI (dBm)	Status Pengiriman	Jenis Antenna (Build In/External)
1	10	33:23.561	15	-90	Diterima	Antenna Build-In
2		33:26.568	7	-89		
3		33:29.603	35	-88		
4		33:31.632	29	-89		
5		33:34.670	38	-89		
6		33:37.704	34	-89		
7		33:40.742	38	-91		
8		33:43.777	35	-90		
9		33:47.813	36	-93		
10		33:50.845	32	-90		
Rata Rata			29.9	-89.8		
1	10	19:53.288	11	-66	Diterima	Antenna External
2		19:56.298	10	-64		
3		19:59.309	11	-66		
4		19:61.322	13	-66		
5		19:64.335	13	-67		
6		19:67.347	12	-66		
7		19:70.360	13	-65		
8		19:73.373	13	-67		
9		19:76.386	13	-66		
10		20:79.400	14	-66		
Rata Rata			12.3	-65.9		

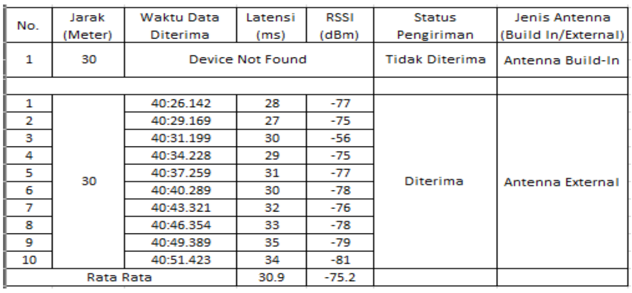
Table 3. 15 Meter Long Range Steering System Testing



No.	Jarak (Meter)	Waktu Data Diterima	Latensi (ms)	RSSI (dBm)	Status Pengiriman	Jenis Antenna (Build In/External)
1	15	42:07.183	42	-92	Diterima	Antenna Build-In
2		42:10.253	114	-93	Tidak Diterima	
3		42:13.298	45	-90	Diterima	
4		42:16.348	50	-94	Tidak Diterima	
5		42:19.386	93	-91	Diterima	
6		42:21.451	108	-96	Tidak Diterima	
7		42:24.498	47	-93	Diterima	
8		42:27.550	52	-108	Tidak Diterima	
9		42:30.590	40	-92	Diterima	
10		42:33.645	55	-93	Diterima	
Rata Rata			64.6	-94.2		
1	15	55:17.407	17	-69	Diterima	Antenna External
2		55:20.425	18	-69		
3		55:23.441	16	-68		
4		55:26.458	17	-69		
5		55:29.478	20	-72		
6		55:31.499	21	-73		
7		55:34.521	22	-70		
8		55:37.542	21	-73		
9		55:40.565	23	-72		
10		55:43.589	24	-74		
Rata Rata			19.9	-70.9		

At a distance test of 15 meters, the Build-In antenna took an average of 64.6 ms to transmit data, with the fastest speed of 40 ms and the longest 108 ms, as well as an average signal strength of -94.2 dBm, which indicates poor reception as the data was not received. In contrast, the External antenna has an average latency of 19.9 ms, with a range of 17 to 24 ms, and an average signal strength of -70.9 dBm, indicating better performance with excellent reception.

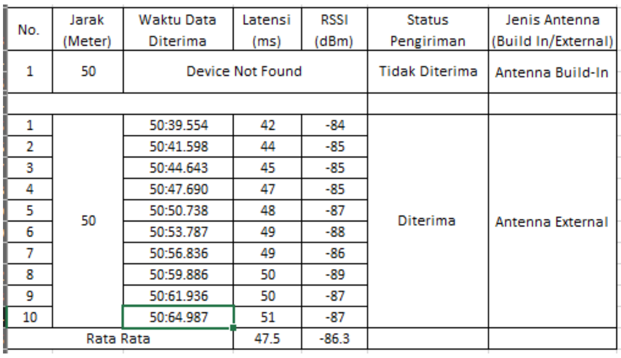
Table 4. 20 Meter Long Range Steering System Testing



No.	Jarak (Meter)	Waktu Data Diterima	Latensi (ms)	RSSI (dBm)	Status Pengiriman	Jenis Antenna (Build In/External)
1	30	Device Not Found			Tidak Diterima	Antenna Build-In
1	30	40:26.142	28	-77	Diterima	Antenna External
2		40:29.169	27	-75		
3		40:31.199	30	-56		
4		40:34.228	29	-75		
5		40:37.259	31	-77		
6		40:40.289	30	-78		
7		40:43.321	32	-76		
8		40:46.354	33	-78		
9		40:49.389	35	-79		
10		40:51.423	34	-81		
Rata Rata			30.9	-75.2		

At a distance of 30 meters, the Build-In Antenna is not able to guarantee communication because all data transmission fails or the transmitted signal network is not detected by the transmitting device. In contrast, the External Antenna provides excellent performance, with an average latency value of 30.9 ms and the lowest latency time ranging from 28 ms to 35 ms and RSSI in the range of -75 dBm to -81 dBm, indicating that the External antenna has a stable connection with good reception status

Table 5. 50 Meter Long Range Steering System Testing



No.	Jarak (Meter)	Waktu Data Diterima	Latensi (ms)	RSSI (dBm)	Status Pengiriman	Jenis Antenna (Build In/External)
1	50	Device Not Found			Tidak Diterima	Antenna Build-In
1	50	50:39.554	42	-84	Diterima	Antenna External
2		50:41.598	44	-85		
3		50:44.643	45	-85		
4		50:47.690	47	-85		
5		50:50.738	48	-87		
6		50:53.787	49	-88		
7		50:56.836	49	-86		
8		50:59.886	50	-89		
9		50:61.936	50	-87		
10		50:64.987	51	-87		
Rata Rata			47.5	-86.3		

At a distance of 50 meters, the Build-In Antenna is not feasible because all data transmission fails. On the other hand, the External Antenna provides quite good performance up to a distance of 50 meters, with an average latency value of 47.5 ms and the lowest latency time ranging from 42 ms to 51 ms and RSSI in the range of -84 dBm to -89 dBm, this shows that the External antenna has a stable connection with a fairly good reception status

Based on the results of tests conducted at various distances using Build-In and External antennas, significant performance differences can be seen. Build-In antennas show limitations in receiving data at longer distances (±15 meters and above), and are not even able to receive data at all at distances of 30 and 50 meters. In contrast, External antennas exhibit more stable and superior performance with lower average latency and better signal strength (RSSI). At distances of 10, 15, 30, and 50 meters, the External antenna is able to maintain communication with an average latency of about 44–76.5 ms and an average RSSI in the range of -62.5 dBm to -86.3 dBm, while the Build-In antenna is likely to experience data transmission failures or exhibit worse RSSI.

Overall, the External antenna is more reliable for long-distance communication than the Build-In antenna, which is more suitable for short distances.

NEO-6M GPS Sensor Test Results

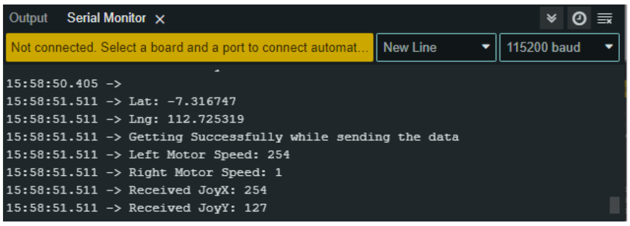
The NEO-6M GPS sensor test aims to assess the accuracy and accuracy of the GPS sensor in reading location data precisely. The GPS sensor test was carried out in the A9 Robotics Lab of Unesa by recording sensor data in the form of lattitude and longitude in a time range every 1 second in static conditions and calculating the error value between coordinate points, with the Haversine formula as follows:

$$d = 2r * \arcsin\left(\sqrt{sin^2 \frac{\Delta\emptyset}{2} + \cos(\emptyset_1) \, . \cos(\emptyset_2) \, . \, sin^2 \left(\frac{\Delta\lambda}{2}\right)}\right) \qquad (2)$$

Where:

1. r : The radius of the Earth, average (or 6371000 meters).$r = 6371km$
2. $\emptyset_1, \emptyset_2$: Latitude in Radians
3. λ_1, λ_2 : Longitude in the Radian
4. $\Delta\emptyset = \emptyset_2 - \emptyset_1$: The Lattitude Difference
5. $\Delta\lambda = \lambda_2 - \lambda_1$: Longitude Difference

The results of this test are the basis for evaluating system performance and making optimizations, so that location data communication remains reliable and accurate in supporting ATSV ship surveillance. Pictures and GPS sensor test tables can be seen below:



```
15:58:50.405 ->
15:58:51.511 -> Lat: -7.316747
15:58:51.511 -> Lng: 112.725319
15:58:51.511 -> Getting Successfully while sending the data
15:58:51.511 -> Left Motor Speed: 254
15:58:51.511 -> Right Motor Speed: 1
15:58:51.511 -> Received JoyX: 254
15:58:51.511 -> Received JoyY: 127
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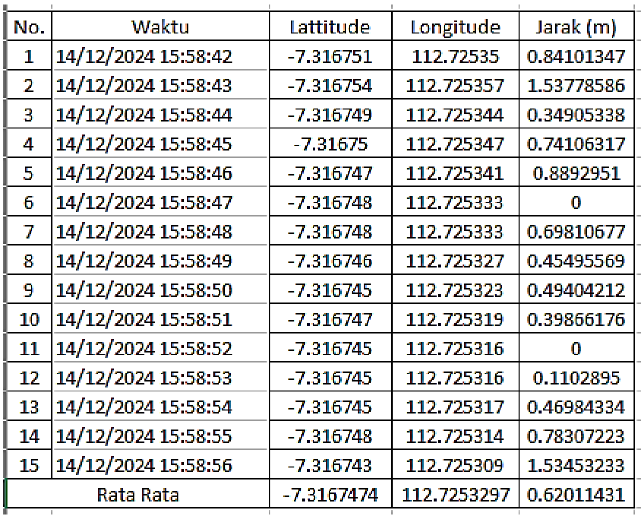
Figure 5. Serial Monitor Testing of GPS sensors

Table 6. GPS Sensor Test Results



No.	Waktu	Lattitude	Longitude	Jarak (m)
1	14/12/2024 15:58:42	-7.316751	112.72535	0.84101347
2	14/12/2024 15:58:43	-7.316754	112.725357	1.53778586
3	14/12/2024 15:58:44	-7.316749	112.725344	0.34905338
4	14/12/2024 15:58:45	-7.31675	112.725347	0.74106317
5	14/12/2024 15:58:46	-7.316747	112.725341	0.8892951
6	14/12/2024 15:58:47	-7.316748	112.725333	0
7	14/12/2024 15:58:48	-7.316748	112.725333	0.69810677
8	14/12/2024 15:58:49	-7.316746	112.725327	0.45495569
9	14/12/2024 15:58:50	-7.316745	112.725323	0.49404212
10	14/12/2024 15:58:51	-7.316747	112.725319	0.39866176
11	14/12/2024 15:58:52	-7.316745	112.725316	0
12	14/12/2024 15:58:53	-7.316745	112.725316	0.1102895
13	14/12/2024 15:58:54	-7.316745	112.725317	0.46984334
14	14/12/2024 15:58:55	-7.316748	112.725314	0.78307223
15	14/12/2024 15:58:56	-7.316743	112.725309	1.53453233
Rata Rata		-7.3167474	112.7253297	0.62011431

The results of the GPS sensor test show that the coordinates of Lattitude and Longitude tend to be stable around the mean values, which are -7.3167474 for Lattitude and 112.7253297 for Longitude. Meanwhile, the largest error distance value is up to 1.5378 meters, with an average error of 0.62 meters. From this error value, the Neo 6m GPS sensor is able to provide an accuracy of less than 1.53453233 m, indicating that the GPS sensor has good enough accuracy for use in GPS-Tracker surveillance systems.

Pengujian Server ThingSpeak dan Visualisasi GPS-Tracker

In this test, it was carried out by circling the area on the banks of Lake UNESA Ketintang to collect GPS data in real time. This test aims to evaluate the system's ability to transmit GPS data in real-time from the ATSV ship prototype to a cloud platform in the form of Thingspeak as a monitoring or surveillance system. The data taken are lattitude and longitude data on the GPS-NEO6M sensor obtained from the results of the integration of the GPS sensor system on the master board which will be connected to the thingspeak server via ESP-slave board and can visualize it in the form of an interactive map in the form of a GPS-tracker.

The results of the monitoring are displayed on the Thingspeak platform and for map visualization, the GPS-Tracker can be displayed on the Thingspeak GPS tracker application by integrating the channel ID code and the write API on the thingspeak server shown in the following figure:

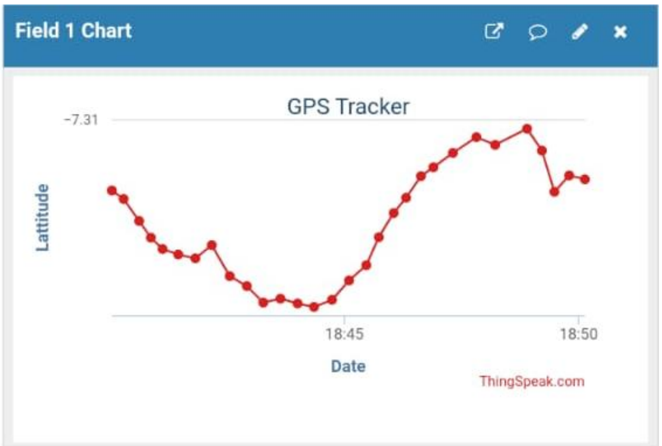


Figure 6. Interface Thigspeak Data Lattitude

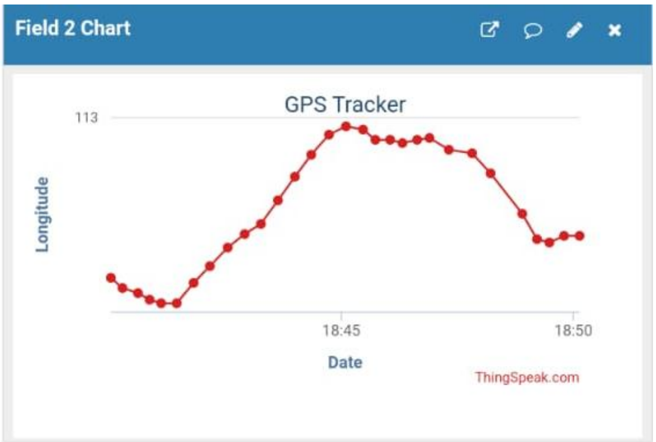


Figure 7. Interface Thigspeak Data Longitude

Figure 7. Interface Thigspeak GPS Tracking

Figure 6. System Implementation on ATSV Ship Prototype

After testing the system on the ATSV ship, it is known that the performance of the system in sending and collecting data on the Thingspeak server until the GPS data visualization process tends to be stable with a range of data updated every 20 seconds on the Thingspeak server

IV. CONCLUSION

Based on the results of the test and the data obtained, the following conclusions are obtained:

1. The design of the ATSV ship monitoring and control system was successfully carried out by utilizing the ESP-NOW Two-Way protocol. In the surveillance system, the ESP-Master sends GPS data to the ESP-Slave, which then sends the data to the Thingspeak server to be visualized in the form of a GPS tracker map in real-time. Meanwhile, the remote control system uses a joystick module connected to the ESP-Slave to read the ship's direction and speed values. The joystick data is sent to the ESP-Master, which converts it into values to set the direction and speed of the ship's movement.
2. The GPS-Tracker Surveillance System shows good performance with high GPS accuracy, with an average error of 0.62 meters and a highest error of 1.54 meters. The system can send GPS data in real-time and display the ship's location on the Thingspeak platform with good accuracy. The Remote Steering Control System is also stable in a variety of distance tests. Testing with an external antenna showed lower latency (12.3 ms to 47.5 ms) and stronger signal (RSSI between -62.5 dBm to -89.3 dBm). The system can operate optimally with an External antenna up to a distance of 50 meters with stable responsiveness in dynamic conditions.

ACKNOWLEDGMENT

There are several things that the author recommends to support further research to be better:

1. Using ship movement control system methods such as PID, Fuzzy or other methods so that the steering control system is more flexible and reduces the noise received to be more accurate
2. Adding other devices, such as Compass sensors, ultrasonics, or cameras as supporting devices in the surveillance system to make it more reliable and accurate.Uses a lift with a better level of stability and accuracy than the NEO 6M GPS sensor as well as more effective communication protocols at long distances such as LoRa

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