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Design of the Bengawan Unmanned Vehicle (UV) Roboboat: Mandakini Neo

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Mandakini Neo is an autonomous vehicle designed and built by the students of the Universitas Sebelas Maret, which was included in the Bengawan Unmanned Vehicle (UV) Roboboat Team to compete in the annual international Roboboat competition of 2021. This competition requires participants to complete several missions; one of the primary missions is to move through two gates made from four poles using full automatic navigation to continue with the other missions. To complete the course, Pixhawk and GPS allow the ship to run automatically while minimizing the ship's movement tolerance. Mission Planner software for monitoring and color and shape image processing to help with the reading of objects, along with a sensor fitted on the ship, allowed the mission to be completed. Mandakini Neo was made with the ship's capacity, speed, and comfort in mind, as well as the ship's hydrodynamic performance, stability, volume, structural integrity, and construction cost. Therefore, the method used to determine the hydrostatic characteristics is through a simulation consisting of a resistance test, stability test, maneuver test, and seakeeping test. The simulation uses Maxsurf software with the Savitsky method, which is then processed by data. GPS and ultrasonic sensor tests were also conducted. Based on the simulation results, the stability of the Mandakini Neo ship has a GZ value of 0.1417 m with an angle of 30°, which follows the standards of the International Maritime Organization (IMO). In testing, the maneuvers obtained have met IMO standards based on tactical and advanced diameters. Based on the seakeeping test, when the speed is 5 knots, the heave movement has the same magnitude for all wave headings, 0.0096 m. while the most considerable rolling motion is in the wave direction of 135°, which is 0.36 m, and the most

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considerable pitch motion is in the direction of the 180° wave, which is 0.042 m. At a speed of 10 knots, the heave motion produced is the same as for all wave headings. The most considerable rolling motion in the wave direction of 135° is 0.36 m, and the most considerable pitch motion is in the 180° wave direction, which is 0.46 m. The resistance test results obtained are 14.57 N at a speed of 5 knots and 36.66 N at a speed of 10 knots. Based on sensor testing, it can be concluded that the more waypoints used, the more accurate the GPS is because the path is much clearer with more waypoints. Testing the ultrasonic sensor, parameters consisting of a turn angle of 30° and a trigger distance of 1 m are selected. The ship is more stable and safer when avoiding obstacles with these parameters.

1 Introduction

Mandakini Neo is an autonomous vehicle designed and built by the students of Universitas Sebelas Maret that was included in the Bengawan Unmanned Vehicle (UV) Roboboat Team to compete in the annual international Roboboat competition of 2021. This was the first international competition for the Bengawan UV Team, which had only been competing at the national level in Indonesia prior to this. This competition was expected to be a way to develop our team, requiring more advanced research on autonomous vehicles in order to complete the missions provided by the committee of the competition. Figures 1 and 2 follow the ship design and an image of the actual Mandakini Neo ship.

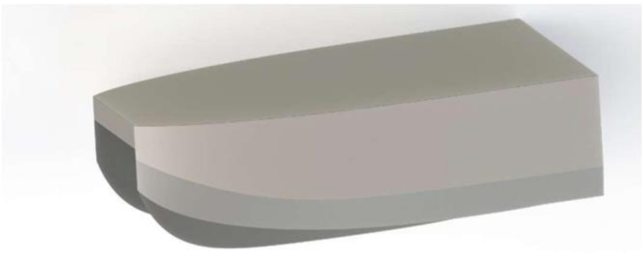

Figure 1. Design of the Mandakini Neo Ship.

Figure 2. The actual Mandakini Neo ship.

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In this year's Roboboat competition, the primary efforts are directed to maximize the completion of the main mission, which was mandatory, plus one additional mission—the speed gate mission. The first mission that must be carried out is mandatory, then proceed with the speed gate mission. Based on the flowchart shown in Figure 3, Mandakini Neo Ship must complete the mission in stages, starting from mandatory. After being obligated, Mandakini Neo Ship continues to complete an additional mission, namely the speed gate. If the ship cannot complete each mission, then the ship must restart from the starting point. However, if the speed gate mission is carried out correctly and according to the regulations, the ship will return to the starting point, and the entire mission will be considered complete.

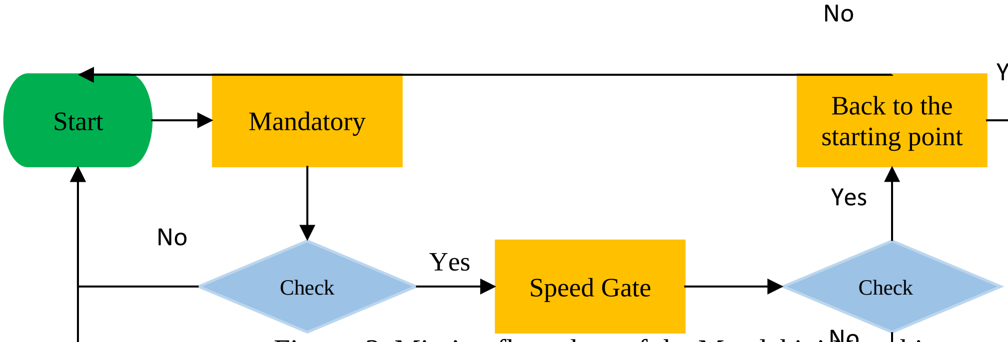

Figure. 3. Mission flow chart of the Mandakini Neo ship.

Mandatory is the first mission that must be completed to proceed to the speed gate mission. This mission consists of two gates consisting of four pillars. Each gate has two pillars of different colors, namely red and green. The distance between the two gates is 25 m, with 3 m between the pillars. Mandakini Neo Ship uses Pixhawk and GPS. The purpose of GPS is to determine the ship's direction in the form of coordinates. So the ship can run automatically based on the coordinates to the first and second gates. The software aims to monitor the ship's course so that the ship's direction is under the mission.

The second mission for the Mandakini Neo was the speed challenge. This mission utilizes logic and similar procedures to the mandatory autonomous navigation challenge. Several waypoints were determined for the course of the ship. When the ship moves near the poles, the output servo is controlled by image processing, and it circles the ball with a blue color. An ultrasonic sensor on the ship was fitted so the ship would not hit the balls with the blue color on the left side, allowing the ship to circle the balls smoothly.

An ideal design and a good series of sensors to complete the mission in the 2021 Roboboat competition are required. It starts from the selection of the hull that considers hydrostatic characteristics. The ship must have good maneuverability and ship stability. Apart from design, a sound sensor system and programming according to the mission are also required. Therefore, this study aims to determine the hull design of the Mandakini Neo Ship and a suitable sensor system to complete the mission in the 2021 Roboboat competition.

2 Experimental Methods

The method used is divided into two: hull design and sensor system. The ship hull design simulation tests stability, maneuver, seakeeping, and resistance which is then realized in Mandakini Neo Ship. Meanwhile, GPS and Ultrasonic sensor testing were carried out in sensor testing.

2.1. Hull design

Choosing the ship's hull does not require complicated calculations because the original shipbuilding process is made by experts or companies experienced in the maritime industry, so the possibility of defects is minimal [1]. The selection of the type of hull that will be used must be adjusted to the ship's function and the needs of the missions. This ship was required to maneuver well and have high ship stability. Several other aspects need to be considered when determining the hull shape and main design too; namely, the ship's capacity, speed, and comfort. Furthermore, several factors determined the main dimensions (LOA, depth, beam) of the ship's hull; the ship's hydrodynamic performance (resistance and propulsion, seakeeping, and maneuverability), stability, sufficient load volume, structural strength, and construction costs.

Stability affects the ship's balance, wherein the ship's ability to return to its original position (ship's equilibrium point) after tilt occurs due to external forces. This ship required good stability, meeting the prescribed standards because stability will affect the ship's performance in the water when exposed to external forces when completing the missions. Stability was also needed to support the ship in maneuvering and maintaining the balance of the components inside the ship. Based on the IS Code 2008, the maximum righting lever GZ shall occur at an angle of the heel not less than 25°. The formula is given in Eq. 1 [2].

$$\frac{dGZ}{d\varphi}(\varphi \geq 25°) = 0 \tag{1}$$

The model of ship maneuvering motion can be utilized as a control model or a state observer when designing a control algorithm of ship motion [3]. Maneuverability affects the ship's ability to maintain its position under the control of the ship operator. Maneuverability testing helps determine the level of safety in ship maneuvering due to various factors, such as the magnitude of water flow waves and ship shipping in narrow areas like rivers, lakes, and ports. Ships with good maneuvering can avoid accidents or collisions with objects around them. Six types of floating body movements are included in the six degrees of freedom: heaving, pitching, rolling, swaying, surging, and yawing. Only three types of motion are affected by acceleration and deceleration, known as added mass: heaving, pitching and rolling. Swaying, surging, and yawing movements can occur if the acceleration is close to zero, however, for this analysis, the ship is under acceleration.

The seakeeping characteristics of ships specifically show the impact of ship length *L*, ratios of *D*/*Lpp* and *B*/*Lpp*, and the coefficient of forwarding water field area [4]. Assuming the oscillatory motion is linear and hormonal, the equation based on six degrees of freedom is shown in Eq. 2.

$$\sum_{n=1}^{6} \quad [(Mjk + Ajk)\zeta k + Bjk\zeta k + Kjk\zeta k] = Fje^{iwt}; j, k = 1, \dots, 6 \tag{2}$$

Where *Mjk* is the mass matrix and moment of inertia of the marine building (there is a matrix of hydrodynamic added mass coefficients and the number of hydrodynamic damping coefficients); *Kjk* is the matrix of strength coefficients or hydrostatic force and moment; F_j is the matrix of the excitation force (F_1, F_2, F_3) and the moment of excitation (F_4, F_5, F_6) in the complex function (expressed by e^{iwt}); F_1 is the excitation force which causes the motion surge; F_2 is the excitation force causing the sway motion; F_3 is the excitation force causing the heave motion; F_4 is the moment of excitation which causes the roll motion; F_5 is a moment of excitation causing pitch motion, and F_6 is a moment of excitation causing yaw motion [1].

Vessel resistance is one crucial factor that must be taken into account when wanting to build a hull. When the hull operates in the water, there will be resistance (resistance) from the fluid that passes through. These obstacles will be the primary influence on the performance of the ship [5]. The Savitsky method is used to estimate the resistance of the hull when planning speed conditions. The planning condition is when the speed of the ship is 30 knots, and the Froude number is more than 1.5, making it a fast ship. The Savitsky method considers the resistance at the trim angle with speed, whereas the Holtrop method does not consider this resistance. Therefore, to measure the resistance of fast boats, it is better to use the Savitsky method. This research used the Savitsky method to calculate the value of ship resistance through Eq. 3. (6).

$$RT = \Delta \tan \tan \tau + \frac{\frac{1}{2}\rho V^2 \lambda b^2 Cf}{cos\tau} \tag{3}$$

Maxsurf software is used as a simulation tool. Resistance testing uses Maxsurf Resistance, while stability testing uses Maxsurf Stability. Seakeeping testing using Maxsurf Motion software. Mandakini Neo Ship maneuvers were carried out by direct observation on the water. The results of the maneuver test are based on standard rules from the International Maritime Organization (IMO) [7].

2.2. System and Sensor

The Global Positioning System (GPS) is a global coordinate system that can determine the coordinates of objects. The output of a GPS receiver is latitude, longitude, and height in the World Geodetic System 1984 (WGS84) coordinate frame [8]. GPS is a fully operational coordinate system; the system provides accurate, continuous, worldwide, three-dimensional position and velocity information to users with the appropriate receiving equipment. GPS also disseminates a form of Coordinated Universal Time (UTC). The satellite constellation nominally consists of 24 satellites arranged in six orbital planes, with four satellites per plane [9]. The problem is that the number of satellites received by the GPS sensor constantly changes, depending on the weather and satellite factors. Given the changeable conditions, in this study, testing and implementation were needed to determine the effect on the GPS of the number of satellites available due to the vehicle's position when carrying out autonomous navigation. By creating a navigation system that could read the values received by the GPS and then compare them with the intended location, the navigation system could be applied to the ship.

This research used the Ublox Neo M8N GPS sensor module on the Mandakini Neo ship. The Mission Planner software controlled this sensor using the Pixhawks PX4 Set. Mission Planner was used to maintain the propulsion systems to travel to the location determined by the GPS. To minimize problems from using the GPS sensor, we tested the GPS sensor on the vehicle directly. The test was carried out automatically to give the accuracy of the GPS so that the best test data could be obtained as a reference for its use on the mission.

In GPS testing, there is a tolerance for the accuracy of the location to be addressed. For this reason, image processing using a webcam was applied to the vehicle to determine the direction/destination. This was based on an object in the form of an obstacle that was adjusted for the mission. Identifying existing obstacles was based on three parameters: color, shape, and area. The color parameter was used as the existing obstacle had been given a striking color that differed according to its function. The color detection system was based on the Hue Saturation Value (HSV) color code. The HSV color space was used because it corresponds closely to human color perception [10]. It has proven more accurate in distinguishing shadows than the RGB space. Color detection is done in the open and real-time, so additional parameters, precise contrast, and brightness facilitate color detection. The area parameter was based on the extent of the area where the color was detected by the color parameter entered. Shape parameters were used to improve the systematics of object detection, improving the precision. Object detection systematics were based on the angle of the detected object. Furthermore, the object was classified based on the three parameters. After the object had been classified, the program provided the direction of the vehicle's destination, according to the mission and the detected object.

Because GPS sensors and webcams were insufficient on their own, an ultrasonic sensor (HC-SR04) was added as an object avoidance system. This sensor functioned so that the ship could avoid obstacles such as buoys and other obstacles that could interfere with the ship's process of completing the mission. This ultrasonic sensor was controlled using an Arduino with a servo motor angle output. This system also utilized a relay as a servo PWM input switch when the ultrasonic read an object at a certain distance. When the object was too close, the Arduino triggered the relay, and the servo signal input came from the Arduino. When no nearby objects were detected, the Arduino did not trigger the relay, and the servo signal input came from the Pixhawk (GPS).

At the 2021 International Roboboat Competition, simple electronic components with proper specifications were used to match with a funding allocation to undertake research. This research used HC-SR04 and Ublox Neo M8N (GPS) components for the primary sensor, assisted by image processing via the Logitech C922 webcam. The main electrical components used were the Arduino Due microcontroller, Servo, Pixhawk PX4, and a thruster for ship propulsion. This research used a USB cable to connect the Arduino and Pixhawk microcontrollers, allowing commands from the Personal Computer (PC) to drive the thruster and servo. Pixhawk was used to determine the starting point to the end point of the ship's movement in carrying out missions, with data from the GPS, using the Mission Planner software via the PC. Once processed via a PC and HC- SR04, the webcam output data were further processed by a microcontroller to drive the servo, with the help of a relay module to convert the input from Pixhawk into commands from the microcontroller.

For more powerful image processing, it was using a PC as a motherboard, an ACER SF314 with an Nvidia MX250 GPU, which was able to process color detectors, shapes, and sizes of bodies. This also meant that lightness did not overload the ship, minimizing the low thrust of the thruster. Tenda AC6 is the primary network system to connect the vehicle and the team base with the Team Viewer software. The circuit system is shown in the appendix.

3. Result and Discussion

3.1. Hull design

Stability was also needed to support the ship in maneuvering and maintaining the balance of the components inside the ship. On the Mandakini Neo, the best stability was obtained with a righting lever (GZ) value of 0.1417 m and an angle of vanishing stability of 30°, which already met IMO standards [2]. Hence, the ship was safe to use for missions. Before carrying out the maneuvering test, it is necessary to know the ship's characteristics because the level of maneuverability of the ship is also influenced by the shape of the hull, according to the International Maritime Organization (IMO) [11]. The characteristic values of the Mandakini Neo prototype are presented in Table 1. Figures 4 and 5 present the rotary motion trajectory images to clarify further the five outputs in the maneuvering test.

Table 1. Ship characteristic values.

LWL (m)	B (m)	TF (m)	Cb	LCG (m)
0.941	0.50	0.08	0.262	0.39

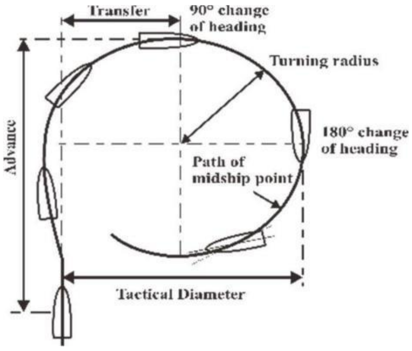

Figure 4. Rotary motion trajectory.

Figure 5. The rotary motion of the Mandakini Neo.

In the maneuvering test, the ability of the Mandakini Neo prototype ship at each steering angle (10°, 15°, 20°, 25°, 30°, and 35°) was predicted. This test was intended to determine the characteristics of the ship prototype from the rotation at each steering angle. Table 2 and Figures 6 to 9 present the data and graphical images of the Mandakini Neo prototype maneuvering test results.

Table 2. Test result data on the maneuvering of the prototype Mandakini neo ship.

Data Output	Turning Angle					
	10°	15°	20°	25°	30°	35°
Steady Turning Diameter (m)	1.0	0.9	0.8	0.8	0.7	0.7
Tactical Diameter (m)	1.3	1.0	1.0	0.9	0.8	0.8
Advance (m)	1.2	1.1	0.9	0.7	0.7	0.6
Transfer (m)	0.7	0.7	0.6	0.5	0.4	0.4
Steady Speed in Turn (m/s)	2.1	1.9	1.8	1.6	1.4	1.2

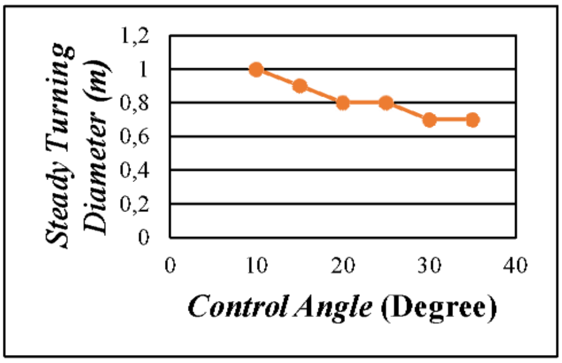

Figure 6. Steady turning diameter.

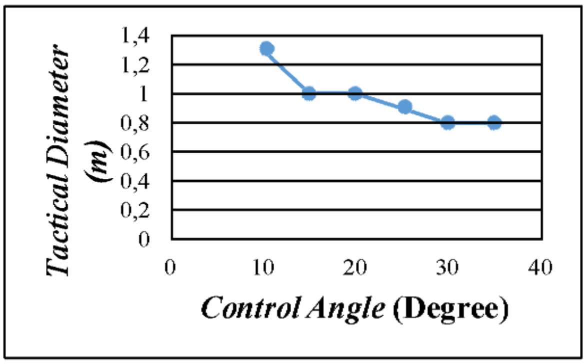

Figure 7. Tactical diameter.

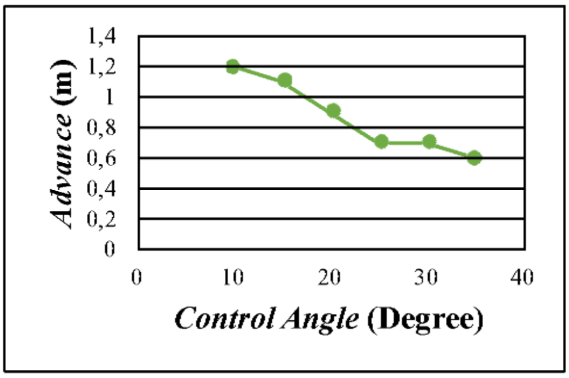

Figure 8. Advance

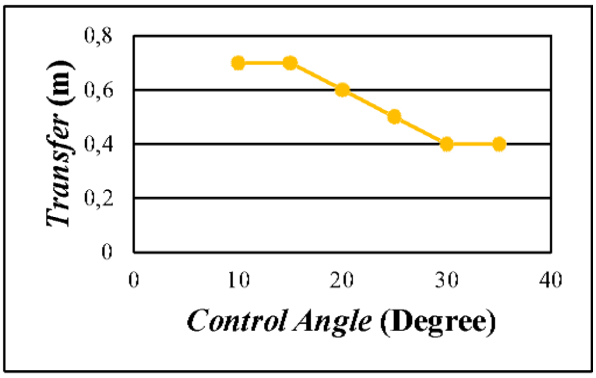

Figure 9. Transfer

From the results of the turning cycle of the prototype Mandakini Neo ship, a standard check was able to be carried out to evaluate the maneuverability, according to the International Maritime Organization (IMO), which applies to all ships [7]. This states that the advanced trajectory length rotating capability should not be more than 4.5 times the ship length, and the tactical diameter should not be more than five times the ship's length. Below is the calculation for the advanced track length and tactical diameter.

- The length of ship (LOA) = 0.97 m
- Advance trajectory length at a steering angle of 35° = 0.6 m
- The length of the tactical diameter at a steering angle of 35° = 0.8 m
- The advance length, according to IMO, is 4.5 x ship length = 0.5 m
- The length of the tactical diameter, according to IMO, is 5 x the length of the ship = 0.7 m

In the experiment, the rotating capability of the Mandakini Neo ship prototype, according to the International Maritime Organization (IMO), meets the standards for both advance and diameter tactical maneuvers so that it is safe when maneuvering.

In the seakeeping test, this ship is required to have the ability to maintain its stability in choppy water conditions. This test is conducted to meet IMO standards that limit ships' movement due to waves, which can cause motion sickness. This test aims to maintain the position of the components attached to the ship, such as sensors, GPS, cameras, and other electrical components so that there is no position movement which could lead to malfunctions in the prototype system and derail the mission trajectory due to the waves on the water surface. In this research, a seakeeping test was carried out at a speed of 5 knots and 10 knots. Tables 3 and 4 present the data on the Mandakini Neo prototype maneuvering test results.

Table 3. Seakeeping performance at 5 knots.

Item	Wave Heading	Motion	Velocity
Heave	90°	0.0096 m	0.0077 m/s
	135°	0.0096 m	0.0092 m/s
	180°	0.0096 m	0.0098 m/s
Roll	90°	0.24°	0.02245 rad/s
	135°	0.36°	0.06312 rad/s
	180°	0°	0 rad/s
Pitch	90°	0.039°	0.00073 rad/s
	135°	0.030°	0.00182 rad/s
	180°	0.042°	0.0028 rad/s

After conducting several tests on the Mandakini Neo ship design, it was found that this ship design has a reasonably small resistance value. The advantage of ships with small values is that they can move forward and have good maneuverability. This makes it easier to complete missions. Obstacles are not only caused by external factors such as fluid and air but also various other factors, such as the designer's ability to select and create a model to produce the slightest possible resistance.

Table 4. Seakeeping performance at 10 knots.

Item	Wave Heading	Motion	Velocity
Heave	90°	0.0096 m	0.0077 m/s
	135°	0.0096 m	0.0108 m/s
	180°	0.0096 m	0.0122 m/s
Roll	90°	0.24°	0.02245 rad/s
	135°	0.36°	0.06251 rad/s
	180°	0°	0 rad/s
Pitch	90°	0.021°	0.00040 rad/s
	135°	0.028°	0.00263 rad/s
	180°	0.46°	0.0048 rad/s

The resistance test results were 14.57 N at a speed of 5 knots and 36.66 N at a speed of 10 knots. In selecting the ship materials, attention must be paid to the ship's structural strength. Therefore, carbon fiber was selected to manufacture the ship. This choice of material for the Mandakini Neo ship changed from when the Bengawan UV Team participated in national competitions, which still used composites in the form of fiberglass. Therefore, the choice of carbon fiber could be compared to this earlier material, resulting in carbon fiber being better than fiberglass. To prove this, several tests were carried out.

3.2. System and sensor

GPS M8N was considered in this research, and image processing and an ultrasonic sensor were considered. The focus of the research was on the primary function of the sensor and also image processing. For the GPS sensor test, we set three parameters that could be regulated: the number of waypoints, waypoint radius, and speed. The waypoints were determined by placing the ship at the desired point. A buoy then marked that point, so later, the ship could be directed to the Buoy. When the ship stopped at the Buoy, the Mission Planner marked that location. After the software marked the point, the ship could run automatically following the previously marked points. The next step involved changing and combining the three test parameters to achieve the best result in terms of the ship's distance and the determined waypoint. The results of the GPS M8N sensor test are listed in Table 5.

Table 5. GPS M8n Sensor Testing.

WP Para meter	Speed (throttle)	WP Radius (m)	Distance from the Buoy (m)					
			1st Test	2nd Test	3rd Test	4th Test	5th Test	Average
1 WP	50%	0	1.23	1.43	1.35	1.54	1.5	1.41
		1	2.06	2.38	2.5	2.14	2.29	2.274
	70%	0	1.52	1.72	1.37	1.48	1.6	1.538
		1	2.39	2.52	1.98	2.28	2.6	2.354
2 WP	50%	0	0.98	1.32	1.68	1.21	0.89	1.216
		1	1.89	2.55	2.17	2.01	2.18	2.16
	70%	0	1.01	1.45	1.22	1.63	1.12	1.286
		1	2.12	2.77	1.98	2.27	2.43	2.314

The GPS sensor test compared the use of parameter combinations to run the ship automatically. The best average after running the test was obtained using the parameter 2 waypoint, with a 50% speed throttle and a 0 m waypoint radius, and 1.216 m for the determined waypoint range. The worst result was obtained using the parameter 1 waypoint, with 70% speed throttle and a 1 m waypoint radius. From the earlier result, it can be concluded that the more waypoints used, the more accurate the GPS is because the course is much clearer with more waypoints. Additionally, the lower the speed and the smaller the waypoint radius, the greater the accuracy of the GPS because a larger waypoint radius means a more extensive range that the GPS can reach, so the waypoint distance determined by the ship will be greater. The best result from this test was applied to the missions.

The ultrasonic sensor HC-SR04 was tested using two ultrasonic sensors fitted at a 30° angle from the front of the ship. Two ultrasonic sensors were used because the mission objectives could be met using only two sensors for object avoidance. The test compared two parameters: the turn angle of the servo and the trigger distance carried out manually to move the ship towards the object. When the determined parameter was fulfilled, the ship could run while avoiding the object. The data from the ultrasonic sensor HC-SR04 test of Mandakini Neo are presented in Table 6.

Table 6. Ultrasonic Sensor Testing Hc-Sr04.

Speed (throttle)	Turning Angle (°)	Trigger Distance (m)	Result					Percent tage of Success
			1st Test	2nd Test	3rd Test	4th Test	5th Test	
70%	30	0.8	Succeed	Failed	Failed	Failed	Failed	40%
		1	Succeed	Succeed	Succeed	Succeed	Failed	80%
	45	0.8	Failed	Failed	Succeed	Succeed	Succeed	60%
		1	Succeed	Failed	Succeed	Succeed	Succeed	80%

First, the ship's performance was compared without ultrasonic sensors and then with ultrasonic sensors. When using the ultrasonic sensors, the ship could avoid the object, and there was no collision. However, optimizing the ultrasonic sensor to maximize the avoidance system performance was necessary. This test's success parameter was whether the ship could avoid an obstacle without touching or bumping into it. The test was conducted with 70% speed from the maximum throttle. The first test used a 30° turn angle and trigger distance of 0.8 m. A 30° turn angle and 1 m trigger distance were used for the second test. In the third test, a turn angle of 45° and trigger distance of 0.8 m were used. For the fourth, a 45° turn angle and trigger distance of 1 m was used. Based on the tests, two-parameter settings had a success rate of 80%. The authors selected to use the parameters consisting of a 30° turn angle and trigger distance of 1 m because the ship was more stable and more secure when avoiding obstacles with these parameters in place.

The test of the digital algorithm of image processing compared the use of a combination of shape and space as detection parameters, using a pole as the object. The test was conducted by comparing three programs: 1) A color detection program with a space parameter; 2) a color detection program with a space parameter and the shape of four corner points, and 3) a color detection program with a space parameter and the shape of 4 to 6 corner points. The program detected too many objects in the first test, meaning the wrong signal was sent to the ship. For the second test, under several conditions, the color parameter was not entirely detected, and the pole's shadow was also legible. This meant the object could not be detected as having four corner points and categorized as a rectangle, as it should have been. For the second test, an object that was accidentally read could be dismissed under several conditions. The pole was still read as an object even though the result from the color parameter was not perfect. In this research, an intensive trial was carried out on the mandatory navigation mission, because it needed to be completed successfully in order to continue to the other mission. This intensive trial was directed to optimize the combination of the functions of the three sensors. More research can be directed to propulsion/turbine and hull material concepts, which these work [12-17] can be viable references in future works.

4. Conclusion

Based on the results of the hull design test, it is found that:

a. The stability of the Mandakini Neo Ship based on the righting lever curve has a GZ of 0.1417 m with an angle of vanishing of 30°. This follows the International Maritime Organization (IMO) standard that the righting lever should not be less than 25°.
b. In the experiment, the rotating capability of the Mandakini Neo ship prototype, according to the International Maritime Organization (IMO), meets the standards for both advance and diameter tactical maneuvers so that it is safe when maneuvering.
c. Based on the seakeeping test at a speed of 5 knots, the heave motion has the same magnitude for all wave headings, which is 0.0096 m. while the most significant roll motion (heading 135°), which is 0.36 m, and the most considerable pitch motion (heading 180°), which is 0.042 m. At a speed of 10 knots, the heave motion produced is the same as for all wave headings. The most considerable roll motion is at wave heading 135°, which is 0.36 m and the most prominent pitch motion is at wave heading 180°, which is 0.46 m. The resistance test results were 14.57 N at a speed of 5 knots and 36.66 N at a speed of 10 knots.
d. Based on sensor testing, it can be concluded that the more waypoints used, the more accurate the GPS is because the course is much clearer with more waypoints. Additionally, the lower the speed and the smaller the waypoint radius, the greater the accuracy of the GPS. A larger waypoint radius means a more extensive range that the GPS can reach, so the waypoint distance determined by the ship will be greater. The best result from this test was applied to the missions.
e. Based on ultrasonic sensor testing, the success parameter of this test was if the ship could avoid an obstacle without touching or bumping into it. The test was conducted with 70% speed from the maximum throttle. The first test used a 30° turn angle and trigger distance of 0.8 m. A 30° turn angle and 1 m trigger distance were used for the second test. In the third test, a turn angle of 45° and trigger distance of 0.8 m were used. For the fourth, a 45° turn angle and trigger distance of 1 m was used. Based on the tests, two-parameter settings had a success rate of 80%. The parameters consisting of a 30° turn angle and trigger distance of 1 m were selected because the ship was more stable and more secure when avoiding obstacles with these parameters in place.

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