Bengawan UV Team: Mandakini EVO

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***Abstract* – A Mandakini EVO ship was developed the by Bengawan UV Team to compete in the 2022 International Roboboat Competition (IRC). For this year's IRC, the team attempted to enhance several aspects, including the stability, maneuverability, strength, sensors, and the system of the ship. The methodology for this research involved software simulation and on-water testing. The goal for this research is a ship capable of performing and completing 2022 Roboboat missions.**

Index Terms - Mandakini EVO; autonomous surface vehicle; Bengawan UV Roboboat Team; automated sensor

I. Competition Strategy

A. *Navigation Channel*

The navigation channel is a mandatory mission [1]. For this mission, waypoints are used as markers to regulate a ship's movement. The ships utilize a camera to read each gate and an avoidance sensor to avoid contact with obstacles.

B. *Avoid the Crowds*

Avoid the crowds is a similar mission to one already undertaken by the team in a national competition. For this mission, the ship utilizes a camera to scan colored buoys as markers for the mission's course. The reading from the camera helps the ship to maintain its course between green and red buoys, and also avoid the yellow buoy that serves as an obstacle. For this mission, the navigation system is used to mark the start and finish of the course, while the avoidance sensor is used to help the ship to avoid contact with the buoys.

C. *Snake Run*

For the snake run mission, the ship enters and exits the gate utilizing the navigation system and the camera; the camera becomes the ship's main sensor while avoiding the obstacle. It functions to scan the blue buoy so the ship can continue approaching the buoy, then later make a U-turn at the buoy. Subsequently, the ship proceeds back to the finish line, again utilizing the navigation system and the camera.

II. Design Creativity

For design creativity, the discussion is categorized into several subsystems, consisting of a navigation system, sensor system, and the hull and propulsion of the ship.

A. *Navigation System*

The navigation system is a system that guides the movement of the ship for every mission. The team used a Pixhawk PX4 and mission planner software to set the waypoint. Pixhawk is equipped with a GPS; thus, the ship can work within precise positions with tolerance of one meter (m). Other parameters can also be added so the ship can run accordingly to the set mission, e.g., servo turn radius and speed regulators. The output from Pixhawk is later sent to the relay to regulate the servo and motor.

B. Sensor System

The sensor system consists of a camera and an avoidance sensor. The ship's sensor system is activated automatically when triggered by a reading. Relays switch the input that originally comes from the Pixhawk (the navigation system) to the camera or avoidance sensor. Fig.1 shows the flowchart of the algorithm used for the sensor system.

1). Camera

The camera sensor system functioned to detect a gate or a buoy in the course of the mission. These two objects are read by shape and color, then classified to determine the ship's appropriate maneuver [2]. In order to determine the maneuver, the ship uses different algorithms according to the conditions of the mission. The camera replaces the Pixhawk and becomes the main sensor that regulates ship maneuvers while detecting an object (buoy or gate). This function is processed by a mini-PC, according to the algorithm. The results are then sent to the Arduino system to actuate the servo for the ship maneuver. The mini-PC that the team used for this was an Intel® NUC 11 PAHi3 [3] with an Intel® Core™ i3-1115G4 processor [4].

2). Avoidance

Avoidance sensors are utilized to avoid the possibility of the ship running into an obstacle. For this sensor, the team used an ultrasonic HC-SR04 device [5]. There are four ultrasonic sensors, placed 45° (from the forward direction of the ship) on both sides of the ship's bow. When an obstacle is within a 1 m radius of the ship, the input signal will switch to the ultrasonic sensor which then triggers the relay to actuate the servo. If there are not any obstacles within a 1 m radius, the input signal will switch back to the Pixhawk or the camera. Fig.2 shows the placement of the camera and avoidance sensor.

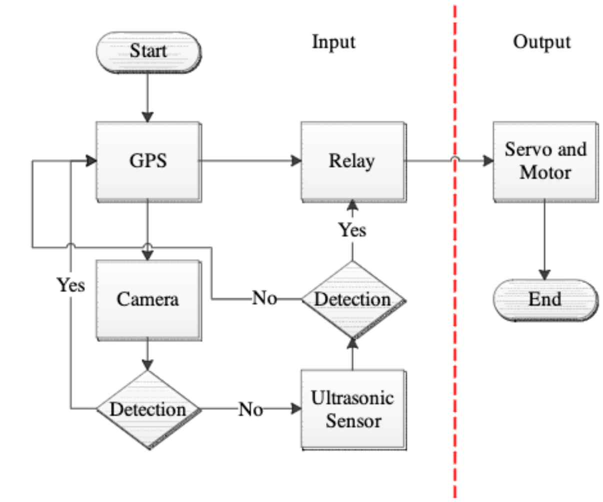

Fig. 1 Flowchart of the sensor system algorithm.

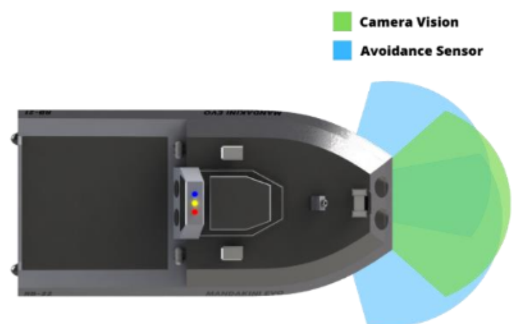

Fig. 2. Sensor placement illustration.

C. Hull and Propulsion

For the 2022 IRC, the team still use the same hull type as that used in the 2021 IRC, which is an asymmetric flat-inside catamaran hull. This particular hull has properties such as low resistance, suitable for the kind of missions in the 2022 Roboboat IRC [6]. The Mandakini EVO is a development from the previous ship the Mandakini NEO used in the 2021 IRC. For the Mandakini EVO, the hull was made wider and lower at the same time. This ensures the better stability of the ship. The team used the SOLIDWORKS software to design the Mandakini EVO [7]. Fig.3 shows the design of the ship. The Mandakini EVO has an overall length of 1 m, height (hull only) of 0.25 m, height (total) of 0.46 m, and breadth of 0.52 m. The characteristics of the Mandakini EVO are shown in Table 1.

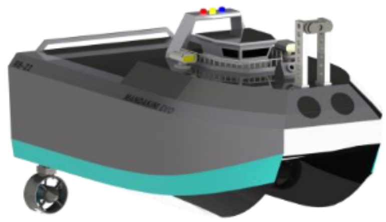

Fig. 3 Design of the Mandakini EVO.

TABLE 1. CHARACTERISTIC VALUES OF THE MANDAKINI EVO SHIP.

Draft	Displacement	Coefficient Block	Coefficient Prismatic
0.084 m	15 kg	0.769	0.0257

When building the Mandakini EVO, the team considered several aspects of strength, efficiency, and cost. Regarding those aspects, the team chose to use gelcoat and fiberglass for the ship's hull. The gelcoat composite in the Mandakini EVO design is for strength and flexibility, reducing the aerosil and adding more resin to the composition. Three more layers of fiber were also added to achieve high strength. For the propulsion system, the ship used two azimuth thrusters. This achieved greater maneuverability at low speed in comparison with a conventional rudder system [8].

III. Experimental Result

A. Navigation system

To test the navigation system of the ship, five waypoints were placed at five different coordinates. The use of five waypoints represented the number of waypoints necessary to complete the entire mission. The test was conducted at three different speeds: 0.5 m/s, 1 m/s, and 1.5 m/s. Fig. 4 shows the data results from the navigation system test.

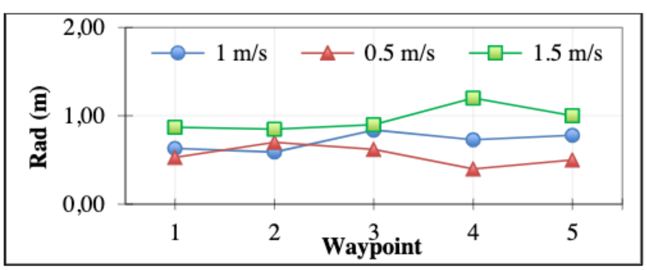

Fig. 4 Radius testing results of the system navigation.

The data shown in Fig.4 are an average from the five tests which were performed. The data show that the best distance average from the waypoint to the ship's actual position was 0.55 m, at 0.5 m/s speed. From that, the team could conclude that the ship's navigation system was working properly.

B. Sensor System

The test for the sensor systems was carried out separately between the camera and the avoidance sensor. The camera was tested to ascertain its ability to direct the ship into the center between two poles of a gate. The gate was the same one as in the mandatory mission. This is because the mandatory mission was used as the base logic for the camera's algorithm on the other missions. The test was performed at three different speeds, 0.5 m/s, 1 m/s, and 1.5 m/s, with three different starting positions, as shown in Appendix F. Fig.5 shows the data results for the camera sensor test.

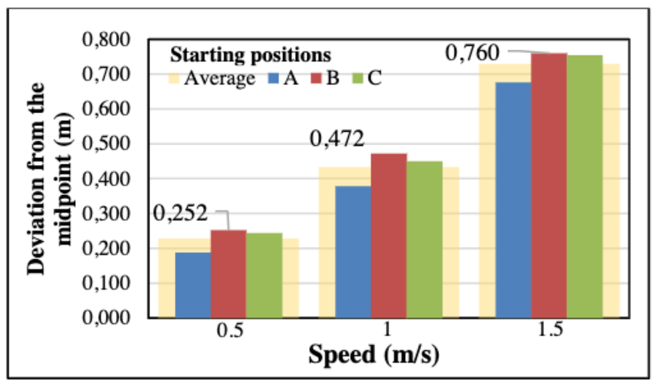

Fig. 5 Camera sensor testing results.

From the test results, the team could say that the camera detection was working successfully. This was because the camera could direct the ship into the center of the two poles with the smallest deviation of 0.252 m at 0.5 m/s speed. This result shows that, at the speed of 0.5 m/s, the mini-PC had more time for calculations with the algorithm, and could minimize the turning radius of the ship due to the difference in the thrust motor.

For the avoidance sensor, the test was performed by trying multiple trigger distance values to avoid obstacles: 1 m, 0.75 m and 0.5 m. The ultrasonic sensor test was performed on water by directing the ship into an area of obstacles then observing the ship's response while approaching an obstacle [9]. That test was carried out at two different speeds: 0.5 m/s and 1 m/s. Data results from this test are shown in Fig .6. The ideal trigger distance of 1 m was obtained at 0.5 m/s speed, yielding an actual average distance to the obstacle of 0.83 m.

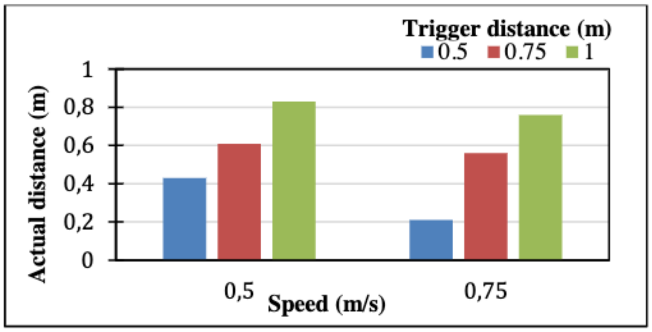

Fig. 6 Avoidance sensor test results.

C. Hull and Propulsion

The tests on hull and propulsion were performed by combining software simulation and on-water testing. The simulations were performed with Maxsurf [10] and ANSYS [11] software. When performing the resistance analysis simulations, the team compared the data results of the Mandakini EVO (IRC 2022) with the previous ship, the Mandakini NEO (IRC 2021), using *Maxsurf Resistance* software. The data results are shown in Fig.7. The comparison showed that there was a decrease in resistance by 11%.

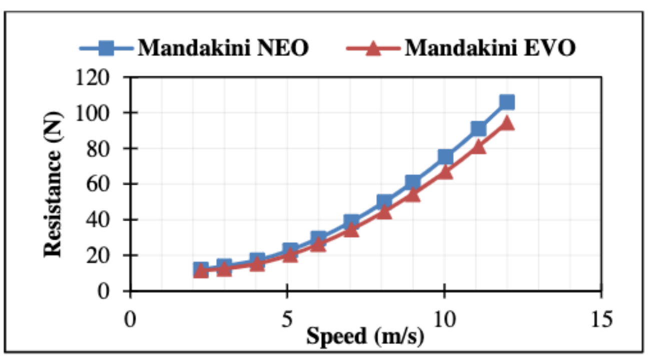

Fig. 7 Comparison data results from Maxsurf Resistance on the Mandakini EVO with the Mandakini NEO.

Fig. 11 shows the test data results from Maxsurf Stability software used by the team. From the data results, it can be seen that the maximum turning degree of the Mandakini EVO was 22.7°, with the maximum GZ value of 0.017 m, whereas the maximum turning degree of the Mandakini NEO was 21.8°, with a maximum GZ value of 0.014 m. These data prove that the new ship has better stability, which makes it safer for on-board electrical components [12].

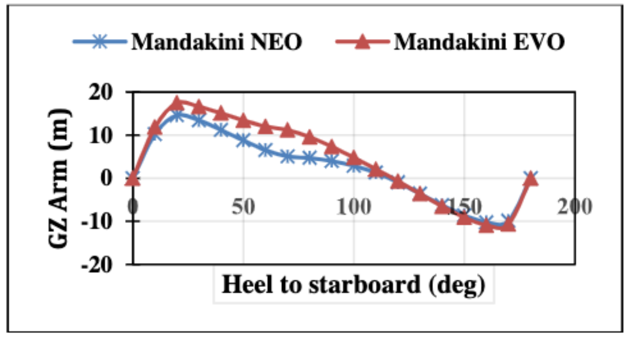

Fig. 8 Maxsurf Stability test data results.

For the next test, which was seakeeping, the team used two software packages: ANSYS Water Diffraction and Maxsurf Motion. The test results for the seakeeping are shown in Fig. 9. The test was performed within the ship parameters of 4 m/s speed, 180^0 (Head Seas) wave axis direction, and 0.02 m wave amplitude. Those parameters were set in order to obtain the heave value of the ship. Table 2 shows the seakeeping data test results.

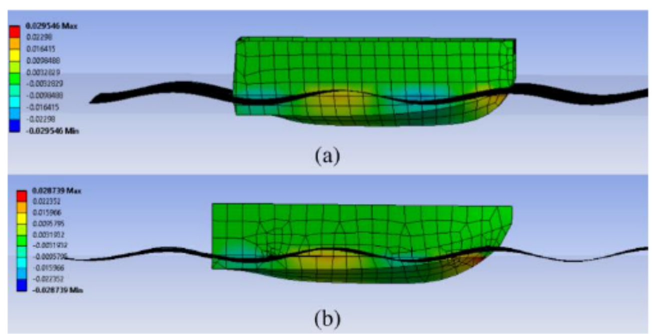

Fig. 9 Seakeeping test results: (a) Mandakini NEO and (b) Mandakini EVO.

TABLE 2. SEAKEEPING TEST RESULTS AT A SPEED OF 4 M/S.

Model	Item	Wave Heading	Motion	Velocity
Mandakini NEO (IRC 2021)	Heave	90°	0.0295 m	0.0385 m/s
		180°	0.032 m	0.0410 m/s
Mandakini EVO (IRC 2022)	Heave	90°	0.0287 m	0.0231 m/s
		180°	0.029 m	0.0372 m/s

The team chose to use heave values in seakeeping tests. This was to determine the vertical movement value of the ship, because on the lake that was used for the test, the ships rarely encountered high wave amplitudes. From Fig. 9 and Table. 2, it can be seen that the wave amplitude value and velocity of the Mandakini EVO were 0.0287 and 0.0231 m/s, respectively, whereas the Mandakini Neo exhibited values of 0.0295 m and 0.0385 m/s, respectively. The data show that the Mandakini EVO experienced less vibration, which meant that unwanted vibration of ship components was avoided, and at the same time made camera reading and detection an object easier.

For the on-water testing, the first test was the thruster test. The team used an unbranded thruster that was also employed for our previous national competition. Throughout its lifetime, this thruster had been very reliable. One of the main reasons for choosing this thruster was its relatively low price, which considerably helped in reducing the overall cost of the ship. This test was performed by setting both the thrusters to maximum thrust while the ship was attached to a digital scale. From five tests, the maximum thrust of the ship was demonstrated to be at 7.8 kg. Appendix D presents the test documentation and more comprehensive data results.

The final test for the ship was a maneuverability test. This test was based on standard testing, referring to IMO (*International Maritime Organization)* MSC 173 76 Resolution from the year 2002 [13]. This test was performed by circling a buoy while the motor was at 85% speed. From five consecutive tests, the average results for the turning radius were 0.35 m (clockwise) and 0.38 m (counterclockwise). These data are proof that the ship would be able to complete an IRC 2022 mission requiring great agility for maneuvering. The test documentation and more extensive data research are presented in Appendix D.

IV. Conclusions

This Technical Design Report was written to present more information regarding the Mandakini EVO, show the team's strategy for the 2022 IRC, and also share the team's development from last year. The developments consisted of an updated hull design, a novel hull material, and sensor optimization. These upgrades were performed in the hope that the ship would be able to finish the mission in 2022 IRC. The tests conducted by the team on the ship were mainly performed to present the possibility of completing all the missions. Our team hopes that this report will serve as a learning and developing opportunity for Bengawan UV for future competitions. We also hope that everyone who reads this report can benefit.

V. Acknowledgment

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4. Sponsors of Bengawan UV Team that supported the team's finances.
5. All the team members of Bengawan UV that gave their best effort and hard work for the research of 2022 International Roboboat Competition.

VI. References

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APPENDIX A : COMPONENT SPESIFICATION

Component	Vendor	Model/Type	Specs	Cost (USD)	Status
ASV Hull form/platform	Handmade, with *Fiberglass* material	Catamaran Flat Side Inside	Length Overall = 1 m Depth = 0.3 m Beam = 0.52 m	200	New
Propulsion	No Brand	12V Underwater Thruster Brushless Motor Driving Engine 80mm Propeller	Voltage = 12 V KV Value = 460 KV Speed = 5300 rpm	106	Old
CPU	Intel	Intel® NUC 11 PAHi3	Intel Core i3-1115G 4 GB DDR4 240 GB SSD Intel Iris Graphics	500	New
Teleoperation	TP-Link	CPE-510	15 km range, 100 mbps, 27 dBm, 5 GHz	75	Old
Compass	Radiolink	SE100 M8N	Receiver type 72-channel u-blox M8 engine GPS/QZSS L1 C/A, GLONASS L10F, BeiDou B1 SBAS L1 C/A: WAAS, EGNOS, MSAS Galileo-ready E1B/C (NEO-M8N)	20	New
Camera(s)	Logitech	C920	HD 1080 30 FPS	97	New
Motor controls	Ardupilot	Pixhawk 2.4.8	32-bit ARM Cortex M4 core with FPU	100	Old
Autopilot Algorithms	Ardupilot	Pixhawk 2.4.8	32-bit ARM Cortex M4 core with FPU	100	Old
Vision	Logitech	C920	HD 1080 30 FPS	97	New
Localization and mapping	Ardupilot	Pixhawk 2.4.8	32-bit ARM Cortex M4 core with FPU	100	Old

Autonomy Team Size (number of people)	N/A	N/A	N/A	N/A	13
Expertise ratio (hardware vs. software)	N/A	N/A	N/A	N/A	4 vs 3
Testing time: simulation	N/A	N/A	N/A	N/A	2 months
Testing time: in-water	N/A	N/A	N/A	N/A	2 months
Programming Language(s)	Python Software Foundation	N/A	N/A	N/A	C/C++, Python

APPENDIX B : ELECTRICAL DIAGRAM

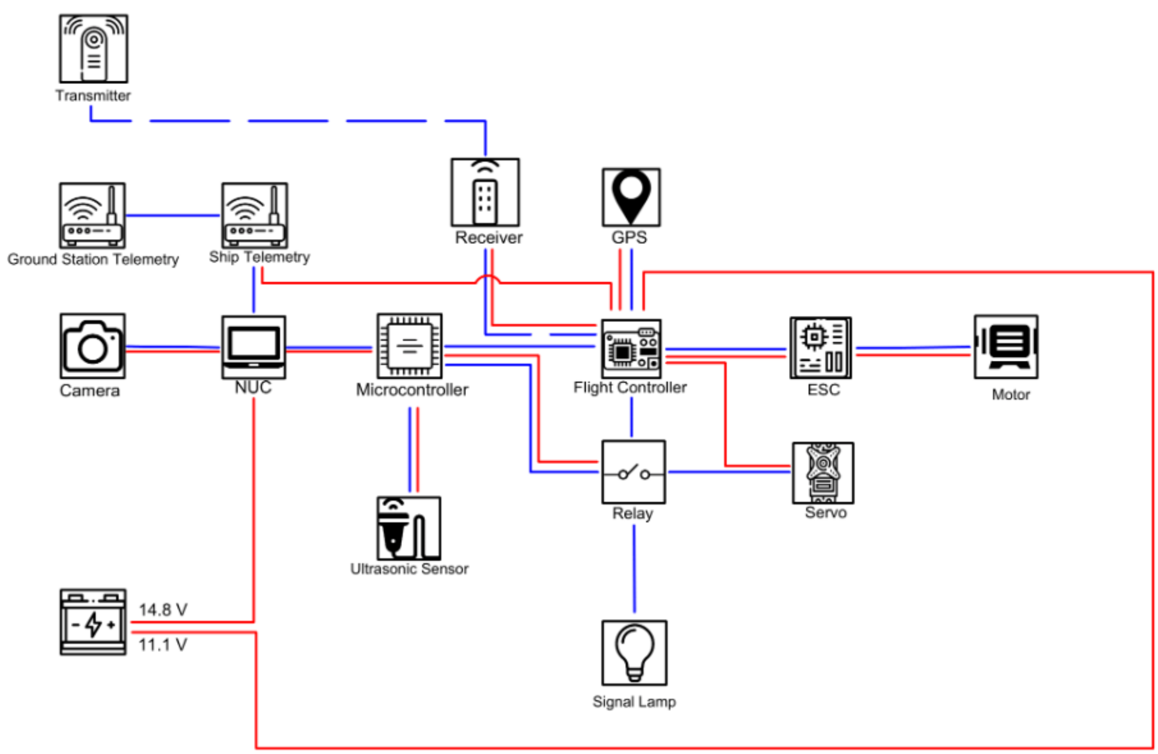

Fig B. Mandakini EVO electrical diagram.

APPENDIX C : TESTING DOCUMENTATION

1. Navigation Test

Fig C-1 Navigation Testing.

2. Camera Test

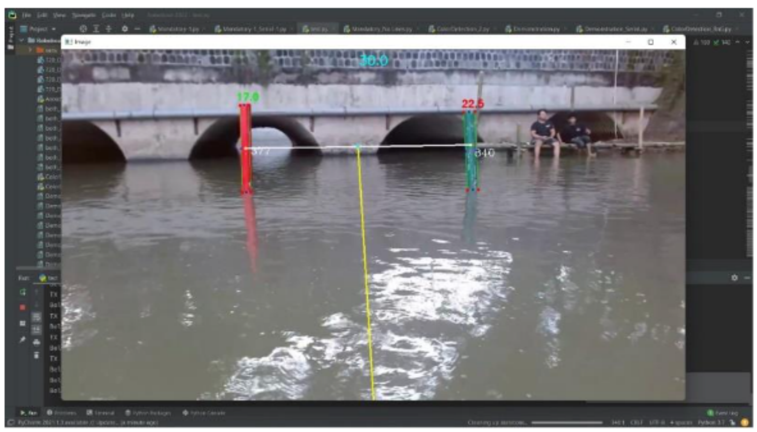

Fig C-2 Camera Testing.

3. Avoidance Test

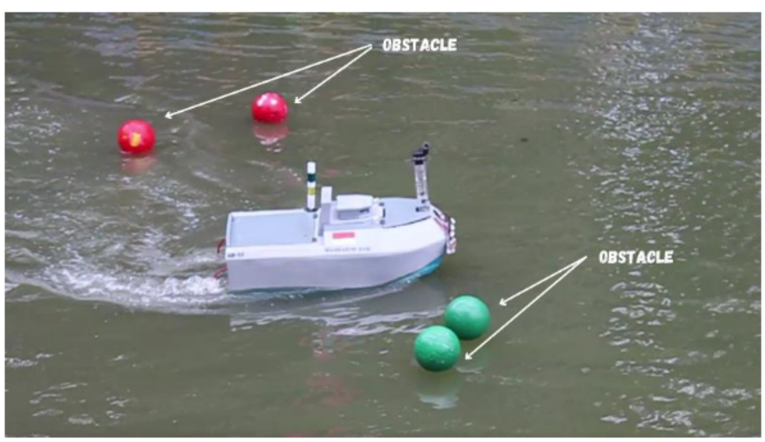

Fig C-3 Avoidence Testing.

4. Thrust Test

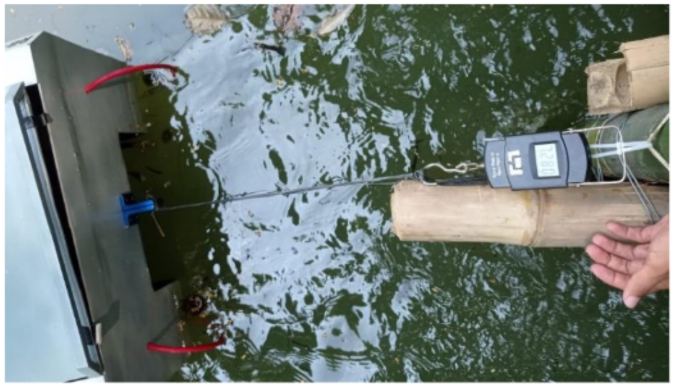

Fig C-4 Thrust Testing

5 Maneuver Test

Fig C-5 Manuever Testing Clockwise and Counterclokwise

APPENDIX D : TESTING RESULT

1. Thrust Test

Table D-1 Thrust Testing Result.

Test	Result (kg)
1	7.28
2	7.22
3	7.20
4	7.84
5	7.62
Maximal	7.84

2. Maneuver Test

Table D-2 Maneuver Testing Result.

Test	Clockwise Result (m)	Counterclockwise result (m)
1	0.40	0.42
2	0.38	0.40
3	0.35	0.38
4	0.33	0.36
5	0.31	0.34
Average	0.35	0.38

3. Camera Sensor Test

Table D-3 Camera Sensor Testing Result.

	Starting Point	**Speed (m/s)**		
		0.5	**1**	**1.5**
Deviation from the Midpoint (m)	**A**	0.12	0.36	0.66
		0.09	0.42	0.64
		0.14	0.33	0.71
		0.12	0.41	0.75
		0.16	0.37	0.62
	B	0.29	0.52	0.78
		0.22	0.44	0.73
		0.27	0.47	0.72
		0.26	0.43	0.81
		0.22	0.50	0.76
	C	0.19	0.51	0.72
		0.22	0.43	0.70
		0.23	0.46	0.75
		0.26	0.41	0.84
		0.32	0.44	0.76

APPENDIX E : TESTING SETUP

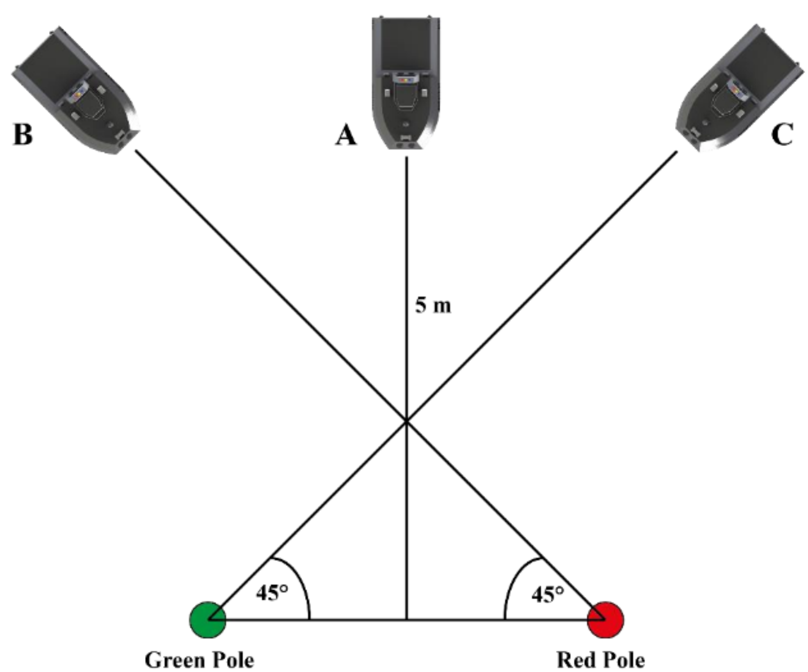

Fig E-1 Camera Vision Setup.