RoboBoat 2023: Technical Design Report

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***Abstract*—This report explains the team's strategy in completing the mission and competing in the International Roboboat Competition (IRC) 2023. Advancements from this year include object detection program algorithms, fully programmed navigation systems using MAVLink, and a new hull with modular systems. Testing on the ship is carried out with software simulation, ground testing, and on-water testing to ensure that the ship can carry out the mission properly and optimally. The evaluation and innovation of the system used by the team are conducted in order to achieve better performance than in the previous year.**

Keywords*— *Mandakini Catra, Autonomous Surface Vehicle, Object Detection, MAVLink, Modularity Hull.

I. Competition Strategy

A. General Preparation Strategy

In the previous year, the team used a relay (mechanical) system for multi-sensors. This year, however, the team has used a fully programmed system. The system is designed so that the ship navigation system with object detection can be optimally integrated. A navigation system based on a Global Positioning System (GPS) sensor will send commands to determine the ship's movement while carrying out the mission [1]. Then, in object detection, the team changed the image processing system from color detection to object detection to increase the precision of detections from obstacles that will be sent to the navigation system to complete each mission.

The concept used in ship prototypes is modularity. This can make it easier for the team to carry prototypes when traveling, because every part of the ship's prototype can be disassembled. Therefore, the prototype of the ship in 2023, called Mandakini Catra, is produced by improvising with the material used, to make it stronger when receiving outside forces when traveling.

B. Course Tasks Strategy

This year, the team plans to complete four missions, namely Navigate the Panama Canal, Magellan's Route, Northern Passage Challenge, and Ponce de Leon, which can be seen in Fig 1. Before performing the mission, waypoints are determined to reference the navigation of the ship placed at the starting point of each mission. The starting point is also the beginning of object detection.

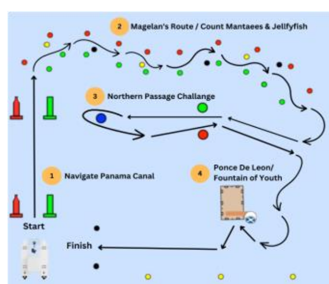

Fig. 1 Course Tasks Strategy Overview.

The first mission is Navigate the Panama Canal. When the ship is at the starting point, the ship will detect the mast object as the main parameter to determine the next movement of the ship. When the red and green poles in the camera detections are in a certain position, the movement of the ship will follow the algorithm that has been generated. After reaching the finishing point, the detection is completed and the ship moves on to the next mission. The second mission that the ship will complete is Magellan's Route. At the starting point of this mission, object detection will detect the nearest buoys as a reference to maneuver the ship to reach the midpoint between the detected buoys. Furthermore, the Northern Passage Challenge mission will determine several waypoints as the path that the ship will travel. Waypoints are set on the inlet buoy, some are arranged around the buoy so that the ship's maneuvers can move clockwise or counterclockwise, and the waypoints are set on the exit gate buoys.

The last mission to be performed is Ponce de Leon. Object detection will be used to detect the target. Then, the ship will go to the target until it reaches the dock. When target detection starts, the robotic arm will move, and it will move the water nozzle on the system that we are using. The movement of the nozzle will adjust the algorithm that has been created by the team. The water nozzle will target the shot to the center of the target and fill the water until the ball is lifted to the boundary line according to the handbook, and the ship can return to the launch point.

II. Design Creativity

A. Hull, Frame Design and Propulsion System

The mission presented in the International Roboboat Competition (IRC) 2023 requires good stability of the ship's prototype. The Mandakini Catra is a development of the Mandakini EVO prototype that has been used in IRC 2022 by prioritizing stability and reducing interference caused by water waves when facing dynamic amplitudes and wavelengths. Therefore, the symmetrical catamaran hull model is the most suitable type of hull to use, because the ship can return to the equilibrium point after receiving outside forces. However, the symmetric catamaran hull model has a greater resistance value compared to the asymmetric catamaran hull model [2]. By adjusting the ratio between the demihull of the ship (S) and the length of the ship (L) to be greater, it is possible to achieve the aim of minimizing resistance and improvising stability in the Mandakini Catra.

The Mandakini Catra uses the modularity concept by adopting an aluminum T slotted profile, which connects the demihull and acts as a deck that aims to adjust the ratio between the demihull (S) and the length of the ship prototype (L), so that it can improvise the performance of the ship to improve it. This helps to position the components on the Mandakini Catra according to the appropriate configuration so that they can work optimally in completing the mission. With these considerations in mind, the Mandakini Catra is designed to fulfill all aspects needed in carrying out the mission. The design and details of the Mandakini Catra are shown in Fig. 2 and Table 1.

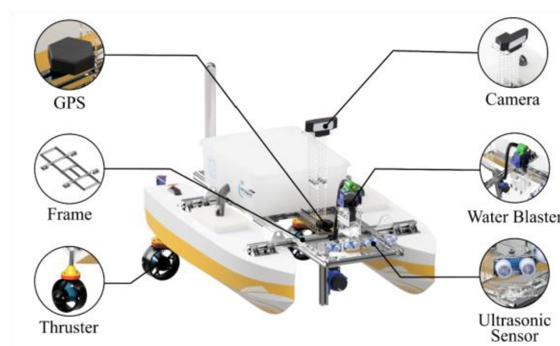

Fig. 2 Mandakini Catra Design.

Table 1. Mandakini Catra Principal Dimensions.

Measurement	Value	Unit
Length Over All	0.86	m
Breadth	0.62	m
Depth	0.17	m
Length Waterline	0.84	m

The hull on the Mandakini Catra is produced with a larger fiberglass layer and gelcoat layer compared to the Mandakini EVO (2022 prototype), so it is more rigid and does not require additional structures on the Mandakini Catra body. In addition, the thruster T200 [Blue Robotics. Torrance, USA] improves the performance of the Mandakini Catra compared to the Mandakini EVO, which uses an unbranded thruster, so that it is more successful in carrying out the mission. The propulsion system used is the same as in the previous year, using two azimuth thruster propulsion systems, because it is considered to provide better maneuverability at low speeds and is more stable in maneuvering compared to conventional rudder systems [3].

B. Navigation System

Pixhawk 2.4.8 is the main navigation controller device that functions to process the commands sent from ground control and process Pulse Width Modulation (PWM) signals to drive the propulsion system. GPS on the Pixhawk serves to determine the location and orientation of the maneuver's direction on the trajectory [4]. However, an improvement was implemented using MAVLink communication to send ship movement commands via the Python program [5].

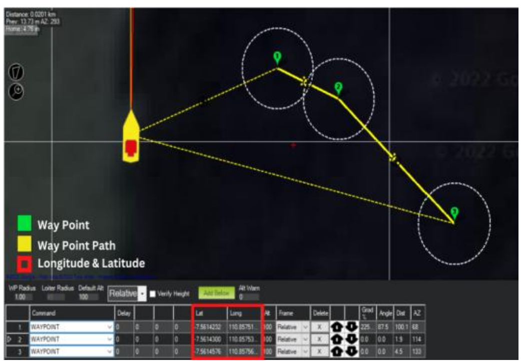

Fig. 3 Global Command Illustration with Latitude and Longitude References in the Red Square Area.

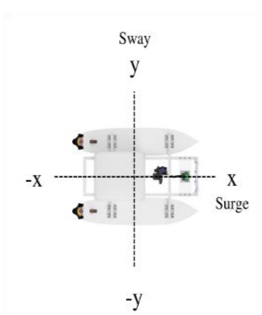

Fig. 4 Local Command Illustration (X Positive = Surge, Y Positive = Sway).

The command is divided into two, namely global maneuvering and local maneuvering. Global motion commands serve to give commands when a ship moves between missions and local motion commands serve to give commands when the ship is on a mission. The global command uses the longitude and latitude references of the Earth (see Fig. 3), whereas the local command uses velocity vectors on the x and y axes relative to the ship's headings (positive x is forward and positive y is left turn); see Fig. 4. Global motion commands are sent via a ground control device located at the home location that is transmitted using radio telemetry to Pixhawk. Then, these global commands are sent by Pixhawk and downloaded by the Raspberry Pi as the main computing device while performing a mission. Then, the Raspberry Pi will send a global motion command to Pixhawk, or, when camera detection starts, the Raspberry Pi will send a local command to Pixhawk. The local command will be sent to Pixhawk using the Python MAVLink protocol (pyMAVLink) to move the ship with digital signal input. A flow chart of the ship's motion commands is shown in Fig. 5.

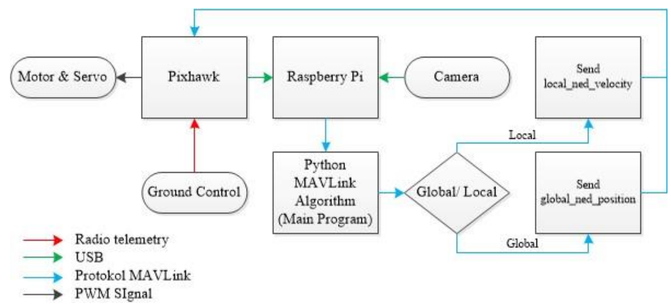

Fig. 5 Flow Chart of Motion Delivery on the Mandakini Catra ship.

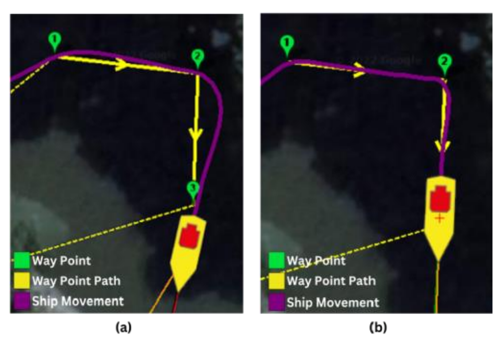

Fig. 6 Turning Testing:
(Left) Before PID Control; and (Right) After PID Control.

The navigation system used in the Mandakini Catra uses Proportional Integral Derivative (PID) control, which serves to increase the effectiveness and provide better control in the original conditions. Some of the parameters that can be controlled by the PID are the steering rate and speed throttle, which function so that the level of maneuver precision increases significantly when accelerating and maneuvering (see Fig. 6). The following effect is shown in the Mission Planner application when the PID control variable is activated.

C. Object Detection

The team developed an object detection system on the Mandakini ship using an object detection algorithm with Tensorflow Lite [6]. The algorithm is selected by adjusting the component device that the team uses. The team decided to use an object detection algorithm because, from the results of detection using the color detection method, the detection program could not distinguish different obstacles with the same color for example, in the Navigate the Panama Canal and Magellan's Route, where the detection was less accurate, as shown in Fig. 7.

Fig. 7 Object Detection on Magellan's Route Task.

The object detection algorithm method is used to solve the problem because it uses more parameters for more accurate detection results [7]. Object detection is able to detect more specific objects with a high degree of accuracy. The team uses detection objects to complete missions, so as to be more optimal and accurate.

D. Water Blaster System

The mechanism that the team used was a 2-axis robotic arm. The link of the robotic arm uses a servo that will be controlled by the Raspberry Pi. The water blaster is placed on the front of the hull with a nozzle height of 0.18 m. Then, the water pump will be placed below the water level, which aims to ensure that the water supply can be fulfilled continuously. Fig. 8 shows the prototype of the water blaster.

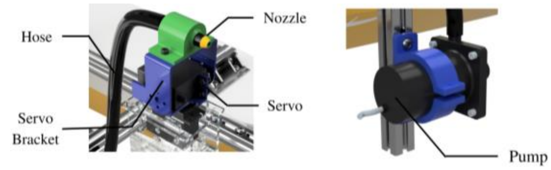

Fig. 8 Water Blaster System.

E. Emergency Switch

The emergency switch on the Mandakini Catra consists of a manual system controlled by a switch and a tele-operating system controlled by a remote control. The emergency switch will cut off all electricity in the computing and propulsion systems. In the emergency switch system, the remote will send a signal to the Arduino; when the remote or switch is pressed, the four relays will be activated so that they can cut off the electric current from the battery to all electronic components. The emergency switch diagram is shown in Fig. 9.

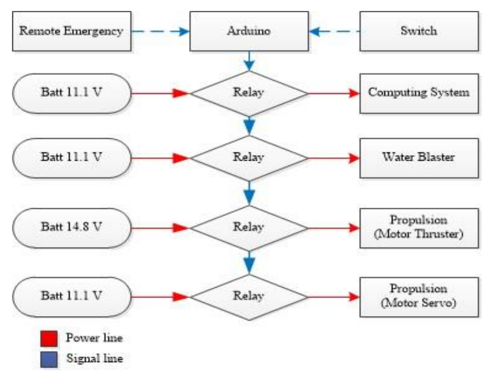

Fig. 9 Diagram of Cut-Off Emergency Switch.

The Mandakini Catra uses an emergency switch that is custom-made, because it is more cost-effective and more flexible to be applied to ships according to needs.

III. Experimental Result

A. Hull, Frame Design and Propulsion System

Analysis of the performance on the Mandakini Catra was conducted by combining several software programs, as well as live testing on water. Mandakini Catra hull testing was performed using ANSYS AQWA [8] and Maxsurf Stability [9] software. The Mandakini Catra's hull testing prioritizes stability and the Response Amplitude

Operator (RAO), which aims to analyze the ship's ability to return to its equilibrium point, as well as the ship's motion response to the dynamic water waves. The Mandakini Catra stability simulation is shown in Fig. 10.

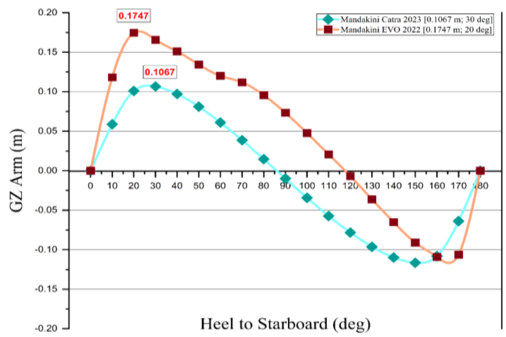

Fig. 10 Stability Simulation Result.

Based on the results of the stability analysis, it can be concluded that the Mandakini Catra has better stability, with a turning degree of 30° and a maximum GZ value of 0.1067 m, compared to the Mandakini EVO, with a turning degree value of 20° and a maximum GZ value of 0.1747 m under the same simulation conditions [10]. Analyzing the Response Amplitude Operation (RAO) serves to determine the value of the effect of the amplitude of water waves on the movement of the ship [11]. The data from the RAO simulation on the Mandakini Catra are shown in Table 2.

Table 2. RAO Simulation Result.

Name	Parameter	Frequency (Hz)	RAO Position
Mandakini Catra (2023)	Pitching	5.491	3.415
	Heave	5.491	2.636
Mandakini EVO (2022)	Pitching	5.491	4.052
	Heave	5.491	3.091

Based on the simulation data, the Mandakini Catra has a lower RAO position value, with a value of 3.415 in pitching conditions and 2.636 in heave conditions, compared to the Mandakini EVO, with a value of 4.052 in pitching conditions and 3.091 in heave conditions with the same frequency conditions; the RAO heave and pitch graphs are displayed in Appendix G. This explains the nature of the Mandakini Catra's motion movement better in dealing with the amplitude of water waves so that it can optimize the program reading on the ship by the camera vision.

Then, the team simulated static stress on the Mandakini Catra's frame using Autodesk Fusion 360 [12] software. The Mandakini Catra's frames are designed to fulfil the safety factor value or construction safety requirement. In the simulation, frames were given a load of 11.9 kg. The safety factor value obtained must be greater than 4.0 for safety to be guaranteed [13]. The results of the static stress simulation obtained a minimum safety factor value of 4.77, as shown in Fig. 11. and Appendix H.

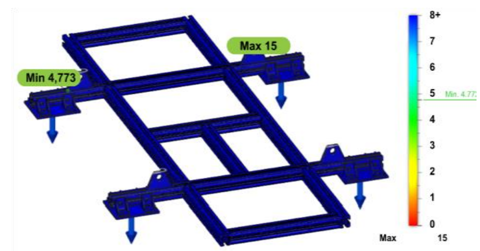

Fig. 11 Safety Factor for Frame of Mandakini Catra.

Thrust testing was carried out directly in the water by hooking the frame onto the Mandakini Catra with a digital scale. Then, the thruster was given a maximum speed on the motor in five attempts. Based on these tests, the maximum thrust value on the ship was obtained at 10.46 kg. Thrust test results are displayed in Appendix E.

The next test was a maneuver test on the ship. This test was carried out by performing a turn on the buoy and providing 100% throttle at 30% maximum thruster speed. After conducting five experiments, the team obtained data with an average turning radius of 0.39 m for clockwise, and an average radius of 0.37 m for counterclockwise. Maneuver testing and test result data can be seen in Appendix E. This was carried out following the International Maritime Organization (IMO) standard MSC.173(76) Resolution from the year 2002 [14].

B. Navigation System

Navigation testing was carried out directly on the water by providing 5 waypoints at varying speeds. This test method is also used in IRC 2022 but the addition of a control PID is used to make the movement of the ship when navigating easier to control. The PID control values change in each test because each speed variable leads to different acceleration and maneuver results. The test was carried out 5 times with 3 speed variations of 0.5 m/s, 1 m/s and 1.5 m/s. Fig. 12 presents the average results of testing at each waypoint before and after adding a PID control to the Mandakini Catra, compared to the Mandakini EVO.

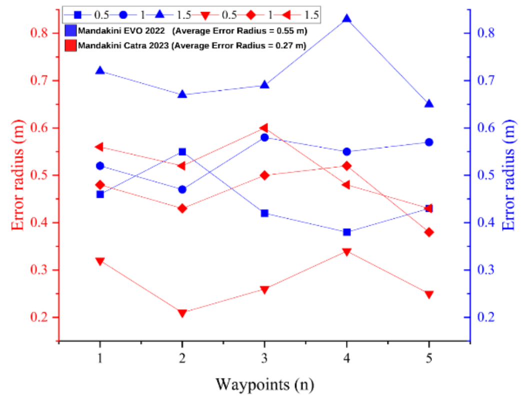

Fig. 12 Accuracy of the Navigation System during Testing on Water.

Based on the test results, a speed of 1 m/s was chosen with a PID value (P=1.7, I=0.5, D=0.3) as the standard speed of the Mandakini Catra to carry out the mission, because it had the lowest radius error value.

C. Object Detection

In the Tensorflow Lite framework, there are five architectural models that can be used to train custom models. Before conducting training, it is necessary to collect a sample of objects divided into 2, i.e., 85% for training models and 15% for data validation [15]. The architecture model was tested using the Raspberry Pi 4.

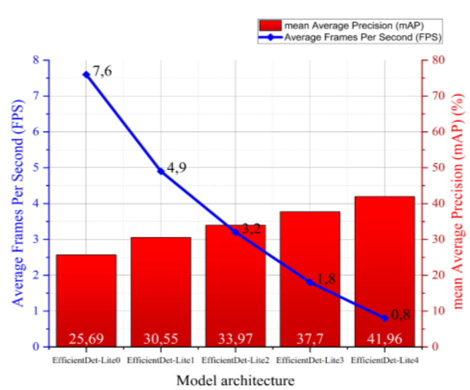

Fig. 13 Test Results of Five Tensorflow Lite Architecture Models.

The results obtained on the sample data and the number of step trains tested were in the form of average frames per second (FPS) and mean average precision (mAP), as presented in Fig. 13. From the test data obtained by the team, it was decided to use the EffidentLite0 architecture model because it had an average FPS result of 7.6 and 25.69% mAP, so that the Raspberry Pi 4 device can perform optimal object detection when carrying out missions.

D. Water Blaster

Water blaster testing is carried out on land directly. The water blaster is placed at a distance of 1 m from the target. The water blaster nozzle can shoot water as far as 3.2 m at an angle of 38° from the surface of the water. Then, water was shot at the target hole. The average time required to fill the water blast tank was 20.93 seconds.

IV. Acknowledgement

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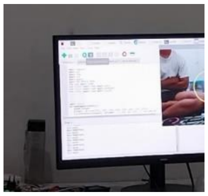
Appendix A: Component List

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of Purchased
ASV Hull Form/Platform	Handmade, with Fiberglass material	Catamaran Symmetric	LOA = 0.86 m Depth = 0.17 m Breadth = 0.62 m	Custom	$200	2023
Propulsion	Blue Robotics	T200	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Awarded	N/A	2022
Power System	Wild Scorpion	Li-Po	5500 mAh 50c 14.8V	Purchased	$80	2022
Motor Controls	Blue Robotics	Basic ESC	https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Awarded	N/A	2022
CPU	Raspberry Pi	Raspberry Pi 4 Model B	https://datasheets.raspberrypi.com/rpi4/raspberry-pi-4-datasheet.pdf	Purchased	$245	2022
Teleoperation	3DR Robotics	3DR Radio Telemetry	433-434.79MHz	Purchased	$32	2022
Compass	RadioLink	SE100	https://www.radiolink.com/se100_specifications	Purchased	$40	2022
Inertial Measurement Unit (IMU)	3DR	Pixhawk 1	https://docs.px4.io/v1.9.0/en/flight_controller/pixhawk.html	Purchased	$64	2022
Doppler Velocity Logger (DVL)	-	-	---	-	-	-

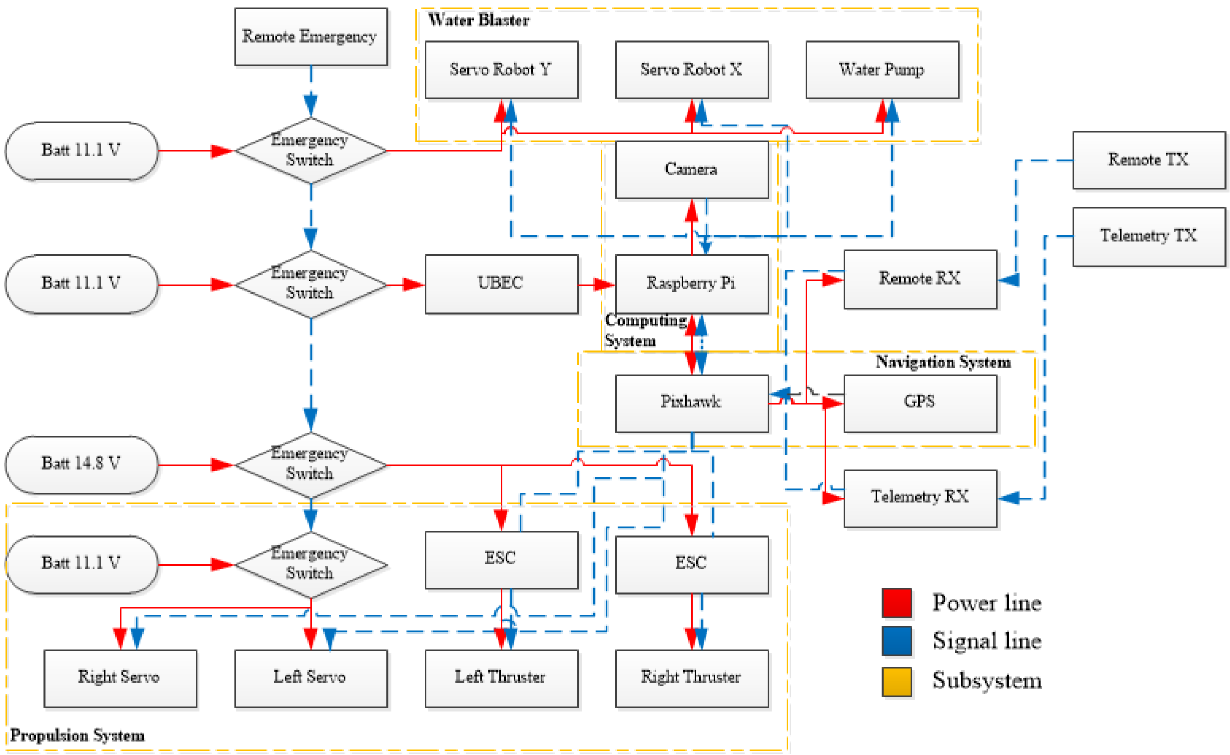
Camera(s)	Logitech	C920	https://support.logi.com/hc/en-hk/articles/360023307294-C920-Technical-Specifications	Purchased	$83	2022
Hydrophones	-	-	---	-	-	-
Algorithims	Tensorflow	Tensorflow Lite	Tensorflow Lite 0	Open Source	N/A	N/A
Vision	Object Detection	-	-	Custom	N/A	N/A
Localization and Mapping	MAVLink.io	MAVLink Protocol	MAVLink 1	---	-	-
Autonomy	Team Research	-	-	---	-	-
USB Accelerator	Coral AI	Coral	https://coral.ai/docs/accelerator/datasheet/	Purchased	$234	2023
Servo(s)	TowerPro	MG995	Tor (**τ**): 9.4kg/cm	Purchased	$12	2021
Engineering Simulation and Design Software	Dassault Systèmes	SolidWorks 2021	N/A	Commercial Faculty License	N/A	N/A
Engineering Simulation Software	ANSYS Inc	ANSYS AQWA	N/A	Commercial Faculty License	N/A	N/A
Engineering Simulation and Design Software	Maxsurf	Maxsurf Stability	N/A	Commercial BRIN License	N/A	N/A
Engineering Simulation and Design Software	Autodesk	Autodesk Fusion 360	N/A	Free Student License	N/A	N/A

Appendix B: Test Plan & Result

Date	Documentation	Target	Result	Environment	Member Presence
12/1/2022		1. On-ground camera detection testing. 2. FPS and mAP checking of object detection.	1. Object detection is not accurate, Re-sampling is carried out. 2. Low FPS, due to object samples that are still too heavy, Try out another model architecture.	Bengawan UV Workshop	All Member
12/8/2022		1. Straight motion testing. 2. Maneuver testing. 3. Buoyancy testing.	1. The ship is stable in a straight moving state. 2. Optimal maneuver, no obstacles found. 3. No leakage detected.	Universitas Sebelas Maret Lake Facilities	All Member
12/10/2022		Testing of water blaster mechanism.	It is optimal to spray water into the target.	Universitas Sebelas Maret Lake Facilities	All Member
12/13/2022		1. Navigation system testing. 2. Testing the effect of adding PID.	1. The accuracy of the navigation system is sufficient to carry out the mission. 2. The addition of PID variables adds precision to the navigation system.	Universitas Sebelas Maret Lake Facilities	All Member
12/20/2022		Simulation of running 4 missions selected in the Mission Planner application.	Good enough to carry out the mission of both object detection and navigation systems in real time.	Bengawan UV Workshop	All Member
12/27/2022		Mission testing of the Navigate the Panama Canal and Magellan's Route.	Detection from pole still needs to be improvised, but the ball buoy is accurate enough.	Universitas Sebelas Maret Lake Facilities	All Member
1/10/2023		Testing the Northern Passage Challenge and Ponce de Leon Missions.	1. The navigation system on the Northern Passage Challenge is accurate. 2. Ponce De Leon object detection needs to be improvised.	Universitas Sebelas Maret Lake Facilities	All Member

1/24/2023		Full Mission Testing	It is necessary to improvise the obstacle detection and PID variables so that the mission can run optimally	Universitas Sebelas Maret Lake Facilities	All Member

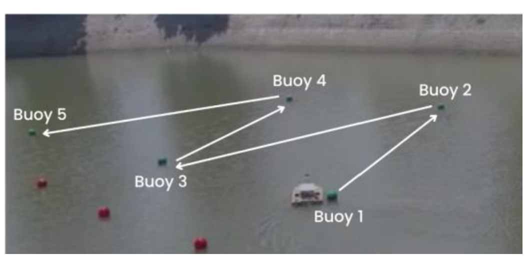
Appendix C: Electrical Diagram



Batt : Battery
ESC : Electronic Speed Control
GPS : Global Positioning System
RX : Receiver
TX : Transmitter
UBEC : Universal Battery Elimination Circuit

Appendix D: Testing Documentation

1. Navigation Test



D-1 Navigation Test

2. Maneuver Test

D-2 Maneuver Test

3. Thrust Test

D-3 Thrust Test

Appendix E: Testing Result

1. Thrust Test

Table E-1 Thrust Test

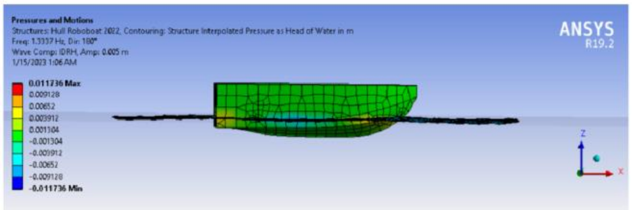
Test	Result (kg)
1	7.55
2	7.55
3	8.17
4	9.94
5	10.46
Maximal	10.86

2. Maneuver Test

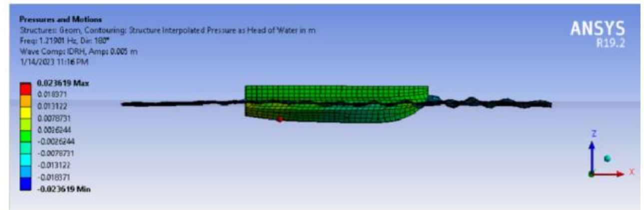
Table E-2 Maneuver Testing Result

Test	Clockwise Result (m)	Counter Clockwise Result (m)
1	0.35	0.36
2	0.44	0.35
3	0.4	0.41
4	0.37	0.4
5	0.42	0.36
Average	0.39	0.37

Appendix F: CFD Hull Simulation by ANSYS AQWA

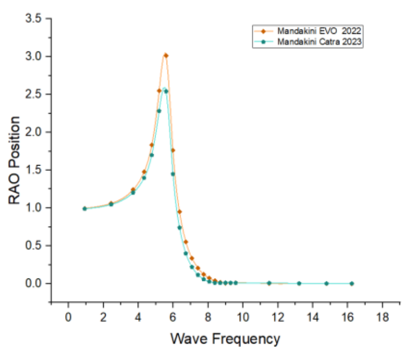


Mandakini EVO (2022)

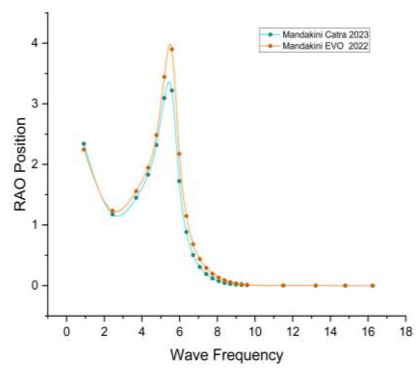


Mandakini Catra (2023)

Appendix G: RAO Graph Result

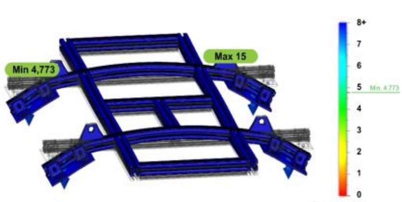


RAO Heave Motion

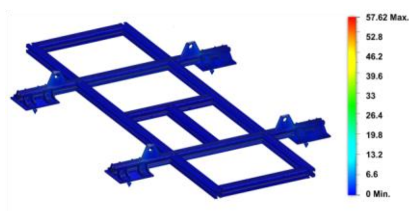


RAO Pitch Motion

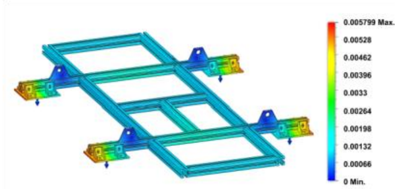
Appendix H: Testing Result of Static Analysis by Autodesk Fusion 360



Adjusted Deformation Scale 1x



Von Mises Stress Result



Total Displacement Result