Roboboat 2024: Technical Design Report

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Abstract:—In this paper, our team's Autonomous Surface Vehicle (ASV) strategy and research results are described for the completion of six missions in the International Roboboat Competition (IRC) in 2024. Our innovations span various aspects, such as object detection program algorithms, navigation systems, computer vision, new hull designs, and sensor systems. Experimentally, our team tested software simulation and ground testing. Based on the result of the simulations and experiments that have been carried out, Mandakini Hydra 2024 will able to complete the intended missions in the IRC 2024.

Keywords—ASV, Object Detection, Mandakini Hydra, Modified V Hull

I. COMPETITION GOALS

A. General Strategy

This year, the Mandakini Hydra 2024 boat is using a modularity system similar to last year's Mandakini Catra 2023 boat to facilitate mobility and transportation. The improvements this year generally focus on hull manufacturing, object detection algorithms, and electrical systems.

The hull manufacturing process reduces the number of layers of fiberglass composites to reduce the amount of weight on the boat in order to increase the boat's dimensions and increase displacement, but the hull is still able to retain strong, sturdy, and rigid. To improve performance when completing missions, the TensorRT object detection algorithm will be used in order to obtain better FPS and accuracy compared to last year's algorithm, namely Tensorflow-lite [1]. In addition, to improve the safety factor of the electrical system in ASV this year, the team have arranged the wiring components in a neater way, introduced air cooling to maintain the temperature of the components, used larger component boxes, and limited the holes for cables to pass through in the component boxes so that the components remain safe from water.

B. Course Task Strategy

In the International Roboboat Competition (IRC) of 2024, the Mandakini Hydra boat plans to carry out six missions, namely, Navigation Channel, Follow the Path, Docking, Duck Wash, Speed Challenge, and Return to Home, as displayed in Figure 1 [2].

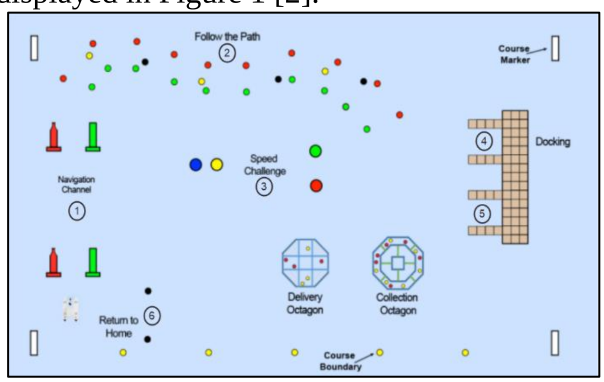


Figure 1. Autonomy Challenge Task

Before starting the course task, the sensors on the boat will be activated and integrated into a computer program system so that the input from the sensors can be processed according to the task at hand. The results of sensor inputs processing from the mini pc will be forwarded to the microcontroller to activate the supporting components needed to perform each mission.

Mandakini Hydra uses camera sensors to detect obstacles in the competition course and recognize specific objects in a particular task, such as detecting reference objects in the Docking and Duck Wash missions. In addition, to the camera sensor, Mandakini Hydra is equipped with ultrasonic sensors for boat optimization to avoid obstacles, and these are useful in the Navigation Channel and Follow the Path missions. The ultrasonic sensor works by calculating the distance between the boat and objects around the boat so that when the boat approaches an object, the sensor will send commands to move the boat's propulsion and maneuver the boat to avoid the object.

Mandakini Hydra starts tasks based on waypoints that have been set at the beginning of each mission, waypoints are also used to indicate that the boat has completed a mission. Figure 2 displays a diagram of the motion commands on the boat.

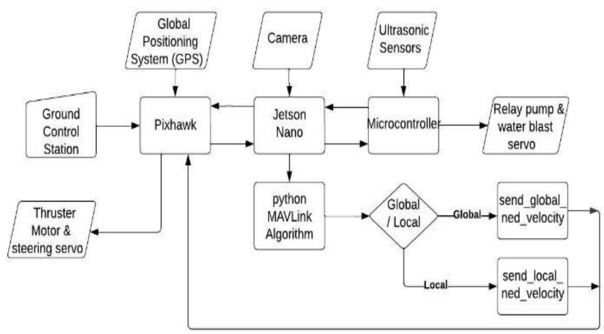


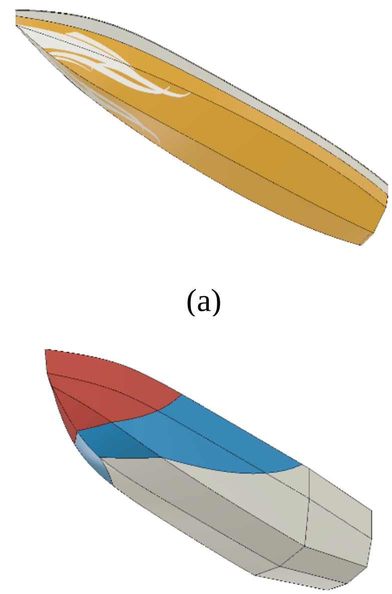
Figure 2. Flow Chart of Motion Delivery on the Mandakini Hydra

To ensure the boat can complete the competition course safely, Mandakini Hydra can change the mode to manual mode when the boat suffers a system failure or damage is made to the components so that the boat can be controlled remotely. The boat also has an emergency switch that can be pressed to turn off the entire system and cut off the electric current on the boat.

II. DESIGN STRATEGY

A. Hull and Frame Design

When completing various missions, ASVs that are flexible and ready for all conditions are required. Mandakini Hydra uses a type of hull called the Modified V hull. Modified V refers to a one-piece hull with a modified V-shape in the bow which transitions to a flatter V at the stern [3]. This design has a V-shape that tapers at the bow, equipping it with resistance, which is small, but retains the additional stability of a good rear stern. With this design, the boat can run quickly to complete the mission Speed Challenge, as well as have improved stability. This is unlike last year, where team used the concept of a symmetric V hull which only prioritizes the effect of stability [4]. Figure 3 compares last year's Mandakini Catra hull design and the Mandakini Hydra hull design.



(b)

Figure 3. CAD Hull Isometric View:
a) Mandakini Catra; b) Mandakini Hydra.

Our team has researched the material composition of the hull, which is lighter but has better strength. The hull is made of a mixture of polyester resin with aerosil, and we added three layers of fiberglass to strengthen the hull. This allows for a reduction in hull weight, which has the benefit of an increased thrust to weight ratio, as well as ease of transport. With such a composition, the weight of the obtained hull is lower than the weight of last year’s hull of the Mandakini Catra, and it has also allowed us to produce larger dimensions. Data comparing the hull weight to hull volume are outlined in Table 1.

Table 1. Hull Weight and Hull Volume Data

Type	Hull weight (kg)	Hull volume (m^3)
Mandakini Hydra	4.24	0.066
Mandakini Catra	5.46	0.042

Like last year, Mandakini Hydra uses a modular concept with an aluminum T-slot frame because this allows for flexibility when arranging the placement of components within the appropriate configuration so that it can work optimally. Mandakini Hydra has a greater ratio between the boat's demi-hull distance (S) and boat length (L) compared to the previous boat so that it is more stable when completing missions [5]. A comparison of the boat S/L ratios is shown in Table 2. The design of the boat is shown in Figure 4 and Appendix B.

Table 2. Comparison of boat S/L

Model Name	**S/L**
Mandakini Hydra	0.604
Mandakini Catra	0.523

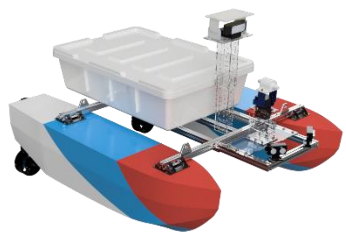
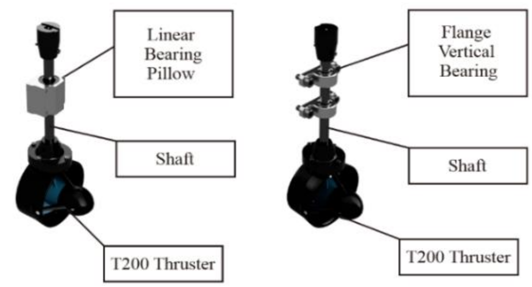


Figure 4. Mandakini Hydra Design

B. Navigation System and Propulsion System

The navigation controller device that the team used is called the Pixhawk cube, which functions to process commands from ground control from a computer and Pulse Width Modulation (PWM) signals to give commands to the propulsion system. On the Pixhawk cube, there is a Global Positioning System (GPS) that determines the direction and longitude and latitude coordinate points; the GPS is needed as a reference for the direction the boat is maneuvered in according to the trajectory [6]. The navigation system uses MAVLink serial communication to transmit various commands with the Python program language (pyMavlink). To make maneuvers more accurate, team also added control Proportional Integral Derivative (PID), Ground Speed, and Steering Rate to the Mission Planner software. In addition, the use of these controls can also help complete the Speed Challenge mission and make changing missions to the next one easier [7].

To improve Mandakini Hydra's performance in terms of maneuvering boats when moving through the passage and avoiding obstacles, Mandakini Hydra uses a T200 thruster mounted azimuth on the stern of the boat. Each T200 thruster is mounted on a hollow aluminum shaft with a diameter of 15 mm inserted into two pieces, bearing a flange vertical universal so that the height of the shaft can be adjusted to the surface of the water. The propulsion system is more rigid in terms of resisting water waves, stronger in terms of resisting vibrations from the rotation of the T200 thruster, and corrosion-resistant compared to last year's propulsion mechanism, which used linear bearings and steel shafts. Each shaft is connected to a servo to rotate the shaft according to the direction of the movement of the boat arranged by the Pixhawk cube. The design of the propulsion system is shown in Figure 5.



(a) (b)

Figure 5. CAD Design Thruster Assembly
a) Mandakini Catra; b) Mandakini Hydra.

C. Object Detection

Mandakini Hydra uses the algorithms object detection algorithm deep framework TensorRT to recognize objects on each course task. TensorRT is an object detection algorithm developed by Nvidia that is suitable for use on Nvidia Jetson Nano devices [8]. The use of TensorRT on Jetson Nano provides better results in terms of object detection speed and detection accuracy than object detection at Framework Tensorflow-Lite, whereas team used the Raspberry Pi 4 device on the Mandakini Catra boat last year [9]. Object detection using TensorRT is shown in Figure 6.

Figure 6. TensorRT Object detection

Detection speed is one of the most important parameters because it can affect the maneuver response of the boat, while the accuracy of the detection relates to the ability of the boat to avoid hitting objects when the boat maneuvers, for example, when the boat completes the Navigation Channel and Follow the Path missions. The accuracy of the detections is also useful for improving the accuracy of the aiming boats when performing the Docking and Duck Wash missions; the boat will be able to perform the Docking mission in the appropriate place and shoot water precisely at the target.

D. Electrical System

The electrical system on the Mandakini Hydra boat includes power sources provided by three types of batteries to be distributed to all the components on the Mandakini Hydra boat. The diagram of the electrical system is shown in Figure 7.

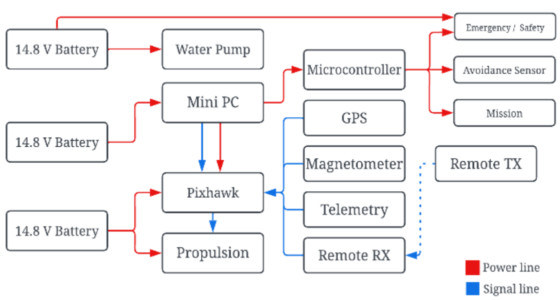


Figure 7. Electrical System Diagram

Then, for the emergency system, it is necessary to cut off all the current components that function as security features if things out of our control occur. The emergency system diagram is shown in Figure 8.

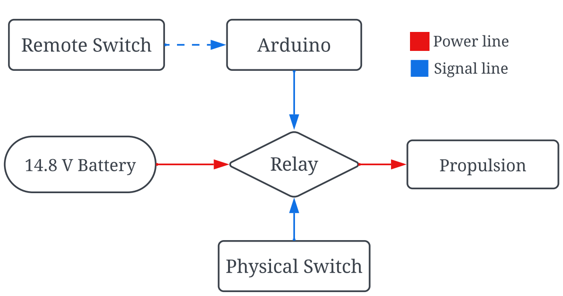


Figure 8. Diagram of Emergency Switch System

The Mandakini Hydra boat uses a custom-made emergency system that adjusts to the needs of all systems on the boat to obtain the most effective, flexible, and functional system.

III. TESTING STRATEGY

A. Hull Analysis and Simulation Method

Analysis and simulation testing of the boat's hull is carried out so that the boat is able to produce a better performance compared to the previous boat. Analysis is outlined as follows, and the simulation test carried out.

1. RAO Simulation:

   The simulation method carried out on the Mandakini Hydra hull prioritizes the location Center of Gravity (CoG) in the x, y, and z axes and the location Center of Buoyancy (CoB). CoG is a point on the boat's body where gravity can work, while CoB is the center of gravity to the volume of water displaced by the hull. These two parameters are very important to consider because they will affect the stability of the boat when sailing [10].

   Stability occurs when CoG and CoB are located in one vertical line. In addition, data can also be obtained Response Amplitude Operator (RAO) in orientation Six Degrees of Freedom (surge, sway, heave, roll, pitch, and Yaw.) It aims to determine the response of boat motion to dynamic water waves.

2. Stability Analysis:

   The results of the analysis we carried out are outlined here in terms of the Righting Lever (GZ cm) of the boat and the boat's motion. Both parameters are highly prioritized because they can have a major impact on boat performance [12]. The GZ arm aims to determine the ability of the boat to be able to return to its equilibrium point when experiencing a slope. The team simulated stability on the Mandakini Hydra hull using Ansys software. Stability simulation was conducted to evaluate and ensure that the boat has adequate stability under various conditions when completing the missions, especially the Duck Wash mission [13]. The simulation results are in the form of curves shown in Figure 9.

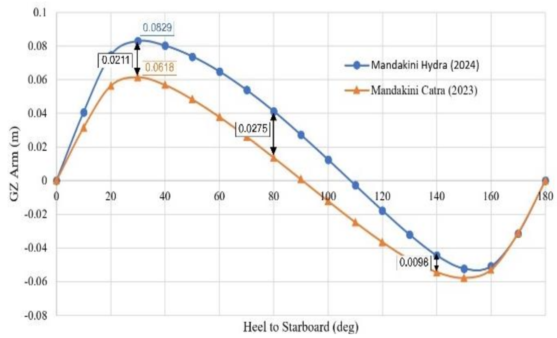


Figure 9. Boat Stability Simulation Results Curve

Based on the stability simulations, the maximum GZ arm data of Mandakini Hydra are 0.0829 m with an angle of 30 degrees, while the Mandakini Catra GZ arm has a maximum of 0.0618 m with an angle of 28.2 degrees. The maximum GZ arm difference is 2.11 cm, while at an angle of 80 degrees, it has a difference of 0.0275 m, and at an angle of 140 degrees it has a difference of 0.098 m. Mandakini Hydra has a larger average GZ arm than Mandakini Catra, so it can be concluded that Mandakini Hydra has better stability compared to Mandakini Catra.

RAO simulations explain the boat performance under various operational conditions, such as responding to water waves [14]. A comparison of the stability simulation and RAO of the Mandakini Catra with the Mandakini Hydra is shown in Table 4.

Table 4. RAO Simulation Results

Type	Parameters	Frequency (rad/s)	RAO Position
Mandakini Hydra	Pitch	5.491	0.987
	Heave	5.491	1.014
Mandakini Catra	Pitch	5.491	3.415
	Heave	5.491	2.636

B. Navigation System

Navigation testing is carried out directly by moving the ASV on water. This test was carried out by providing five waypoint coordinates with varying PID speeds and controls. This testing method is also performed on the Mandakini Catra. The PID control value is obtained by testing five times with three speed variations, namely 0.5 m/s, 1 m/s, and 1.5 m/s. Figure 7 presents the average results of each waypoint test. The data from the navigation system test results are shown in Figure 10.

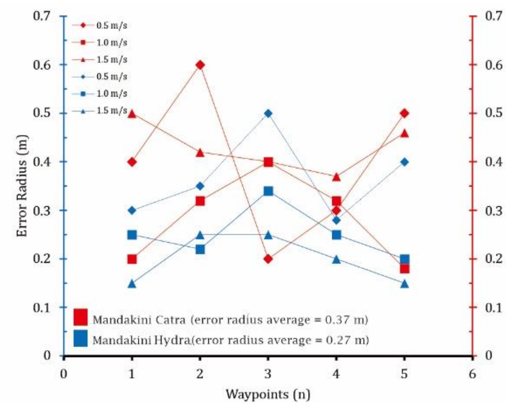


Figure 10. Navigation System Accuracy Testing

Based on the test results, a speed of 1.5 m/s with PID values (P = 0.18, I = 0.18, D = 0.0, IMAX = 1.0, and FF = 3.0) was chosen as the standard speed of Mandakini Hydra for carrying out missions because it has the lowest radius error value compared to other parameters.

C. Sensor Avoidance System

Sensor testing is carried out directly by testing the accuracy of the ultrasonic sensor by comparing the value of the ultrasonic with the actual distance. This test was carried out five times using ten variations at actual distance, 10 cm–100 cm, with intervals of 10 cm. Figure 11 presents the results of the ultrasonic sensor accuracy testing.

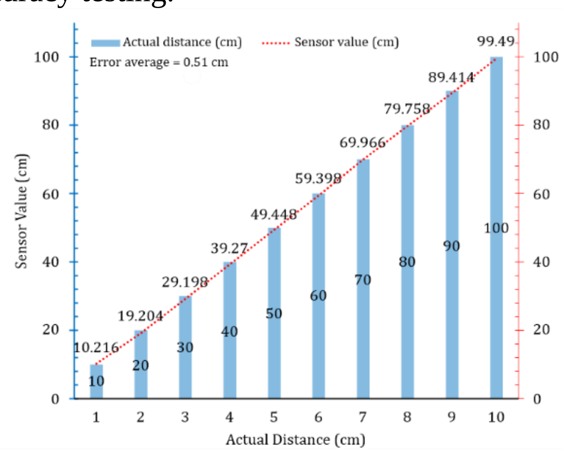


Figure 11. Ultrasonic Sensor Testing against Obstacles

Based on the test results, there is an average error value between the actual distance and the value on the sensor of 0.51 cm. To overcome the stated error value, adjustments have been made to the detection program to change the error value on the ultrasonic sensor.

D. Power Durability

Endurance testing was conducted on Mandakini Hydra using a standard speed of 1.5m/s. We used a battery with a capacity of 8000mAh 4 cell in the propulsion system and 5500mAh 4 cell in the computing system. The tests were conducted with an initial voltage of each battery of 4.1V.

To complete all the missions, a final voltage of 3.78V was generated for the propulsion system, and the computing system produced a final voltage of 3.85V when the test was carried out seven times to complete all of the missions with an initial battery condition of 4.1V to 3.7V as the empty voltage of the battery. The results of the endurance testing are shown Figure 12.

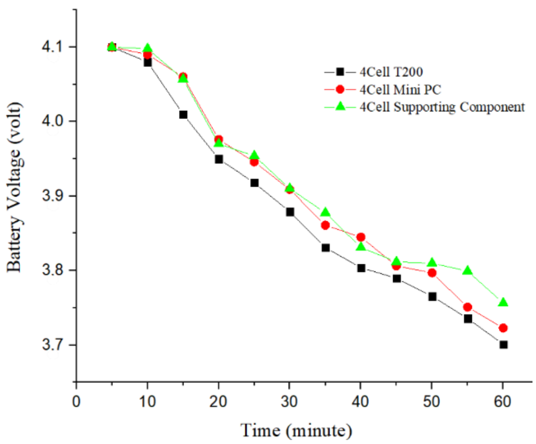


Figure 12. Power Durability Test

E. Object Detection

The team used five architectural models to train custom models, and there are three types of devices were used in each architectural model. Before starting the training, it is necessary to collect samples and then divide the samples into two parts, 65% for training models and 35% for data validation. The model architecture data tested using Jetson Nano, Raspberry Pi 4, and Intel NUC are shown in Table 5.

Table 5. Object Detection Test Results

Architecture Model	mAP (%)	FPS	Device
TensorFlow Lite	25.69	7.6	Raspberry Pi 4
Mobilenet_v1 TRT	35.1	27.7	Jetson Nano
Mobilenet_v2 TRT	37.5	42	Jetson Nano
TensorFlow 2	85	4	Intel NUC
YOLOv4-tiny	38.1	15	Intel NUC

The results of the sample data and the several steps train tested provide the average FPS and average value of detection certainty. Based on the collected test data, the team chose to use the TRT mobilenet_v2 because we detected a comparison between its FPS and mAP values compared to other architectural models. The average FPS obtained is 42 and mAP 37.5 percent, so the team also chose Jetson Nano as the device to provide optimal performance in terms of object detection.

IV. CONCLUSION

Based on an evaluation of last year's shortcomings, this year's boat, Mandakini Hydra perfects Mandakini Catra 2023. The team has researched in term of manufacturing, object detection algorithms, navigation systems, and computer vision. The effectiveness of the weight and volume ratio of the Mandakini Hydra 2024 hull increased by 22.3% and 57.1% compared to those of the Mandakini Catra 2023 hull. In terms of computer vision and object detection, the used FPS increased 4.52 times. In addition, the navigation system's accuracy increased by about 0.27 judging by the radius error value when focusing toward waypoints. The team has carried out tests both experimentally and in terms of, software simulation and water testing so that Mandakini Hydra can optimally complete all the missions in the International Roboboat Competition in 2024.

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3. Prof. Ahmad Yunus as Vice Rector of Universitas Sebelas Maret who has helped in the administrative area.
4. Dr. Eng. Aditya Rio Prabowo, Prof. Syamsul Hadi, and Dr. Eng. Indri Yaningsih as supervisor who provided advice and support.

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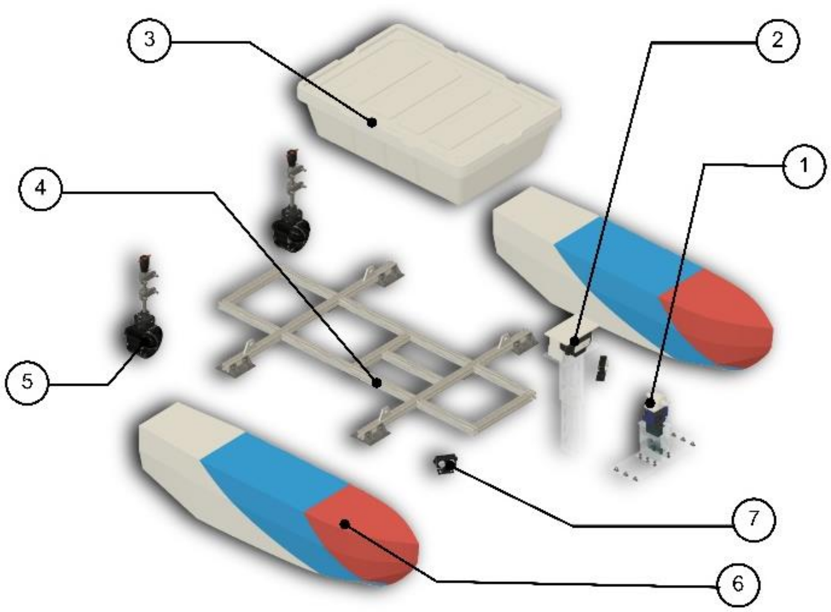
Appendix A: Component Specification

Component	Vendors	Model/Type	Specs	Custom/Purchased	Cost	Year of Purchase
ASV Hull	Custom Handmade with Fiberglass	Catamaran Symmetric	3 layers fiberglass LOA= 0.92 m Depth= 0.21 m Breadth = 0.69 m	Custom	$70	2023
Platform	-	T-Slot	Aluminum T-Slot Extrusion	Purchased	$20	2023
Propulsion	Blue Robotics	T200	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Awarded	N/A	2023
Power Propulsion System	Tattu	Li-Po Battery	10000mAh 25C 14.8V	Purchased	$125	2023
Power Computer System	Zeee	Li-Po	5200mAh 50C 14.8V	Purchased	$72	2023
Motor Controls	Blue Robotics	ESC	https://bluerobotics.com/store/thrusters/speedcontrollers/besc30-r3/	Awarded	N/A	2023
CPU	NVDIA Developer	Jetson Nano	https://www.seeedstudio.com/Jetson-10-1-H0-p-5335.html	Purchased	$400	2023
Teleoperation	3DR Robotic	3DR Radio Telemetry	433-434.79MHz	Purchased	$32	2023
Compass	Matek	M10Q-5883	http://www.mateksys.com/?po5883	Purchased	$63	2023
Inertial Measurement Unit (IMU)	Cubepilot	Cube Orange	https://ardupilot.org/copter/docs/common-thecubeorange-overview.html	Purchased	$320	2023
Camera	Logitech	C920 Pro	https://www.logitech.com/en-gb/products/webcams/c920-pro-hd-webcam.html	Purchased	$82	2023

Servo	Power HD	LF-20MG	https://www.chd.hk/	Purchased	$15	2023
Water Blast Pump	Sakai	-	12V DC 3A 0.6MPa	Purchased	$6	2023
Microcontroller	Arduino	Arduino Nano	-	Purchased	$7	2023
Algorithms	Bengawan UV Roboboat Team	-	-	Custom	-	2023
Vision	OpenCV	-	TensorRT	Custom	-	2023
Autonomy	Bengawan UV Roboboat Team	-	-	Custom	-	2023
Engineering Simulation Software	ANSYS Inc.	Ansys Aqwa	N/A	Faculty License	N/A	N/A
Design Software	Maxsurf	Maxsurf Modeller	N/A	Collaboration License	N/A	N/A
Navigation Simulation Software	Ardupilot	Mission Planner	N/A	Opensource 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: Mechanical Design



Part List		
Item	**Part Name**	**Quantity**
1	Water Blast	1
2	Camera	1
3	Component Box	1
4	Frame	1
5	Thruster	2
6	Hull	2
7	Ultrasonic Sensor	2

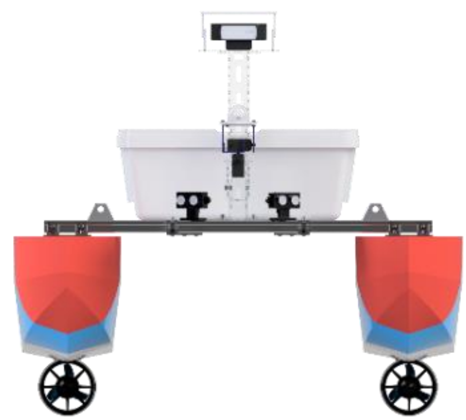
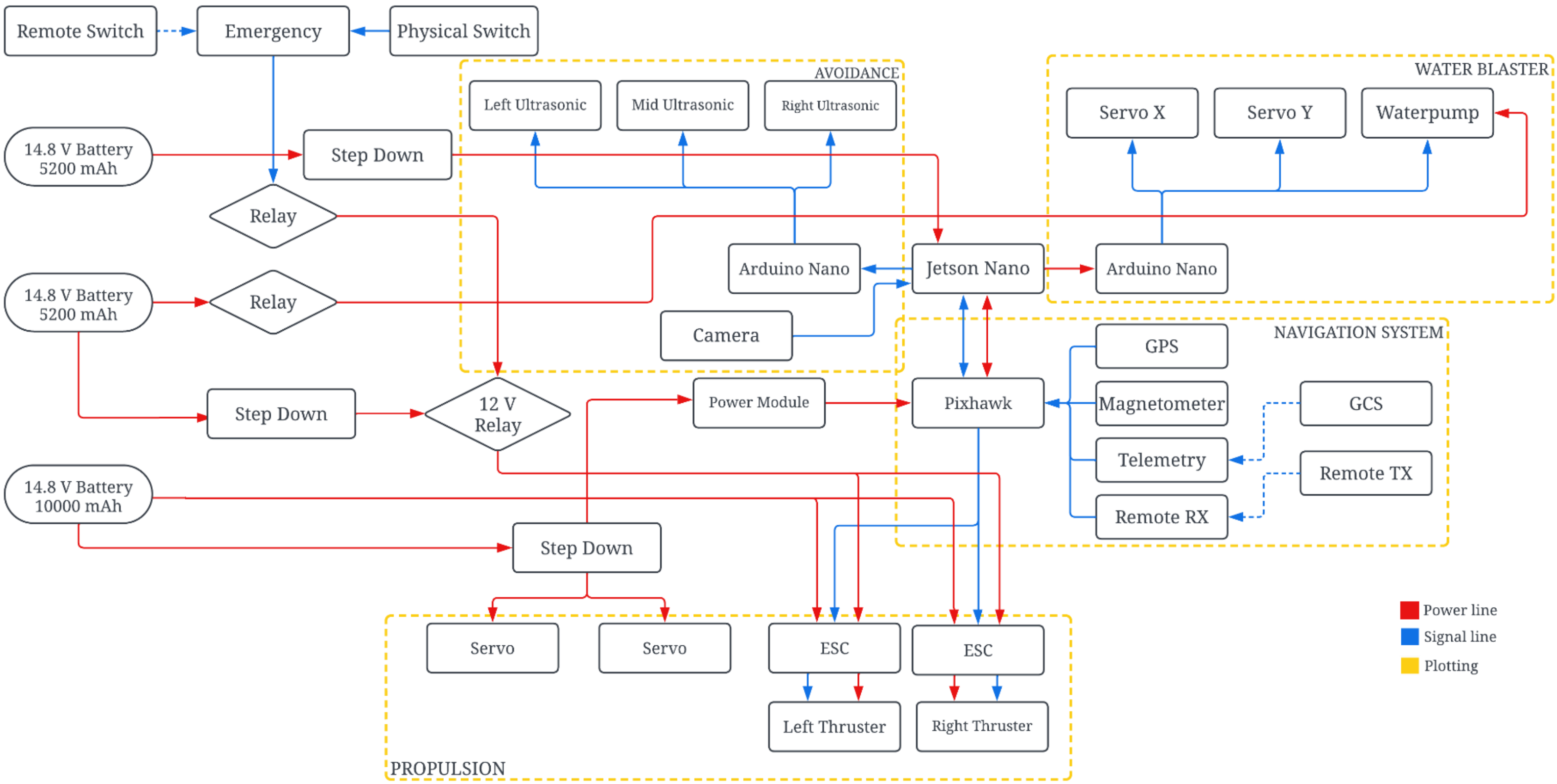


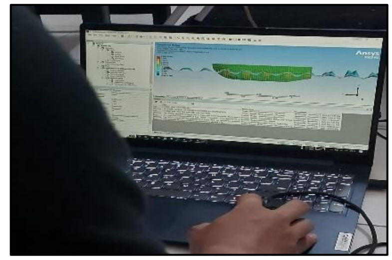
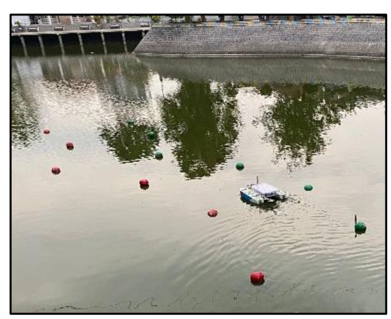
Table B-1. Principal Dimension Mandakini Hydra

Parameters	Value	Unit
Length Overall (L_{OA})	0.91	m
Beam Overall (B_{OA})	0.73	m
Demihull Beam (B)	0.18	m
Depth (D)	0.21	m
Draft (D_{WL})	0.12	m
Displacement	14	kg
Length Waterline (L_{WL})	0.85	m
Demihull Spacing (S)	0.55	m
Block Coefficient (C_B)	0.34	-
Wetted Area	0.40	m^2

Appendix C: Electrical Diagram



Appendix D: Testing Plan and Documentation

Date	Target	Result	Documentation
October 16-21, 2023	1. Object detection simulation. 2. TensorRT algorithm FPS and mAP checking. 3. Simulation of stability, RAO, and resistance with Ansys Aqwa and Ansys Fluent software.	1. Object detection programs can recognize the shape of objects. 2. Obtaining an FPS of around 42 and good accuracy. 3. Obtaining data on stability, RAO, and resistance results using Ansys Aqwa and Ansys Fluent software.	
October 23-27, 2023	1. Propulsion system checking. 2. Buoyancy test. 3. Maneuver tests with turning and zig-zag motions. 4. Thrust test.	1. Propulsion system with thruster T200 can move well. 2. The boat can float in the water without leakage. 3. The boat can maneuver well by avoiding obstacles. 4. The boat can move with a thrust of 11 kg.	
October 28-31, 2023	Navigation system simulation using Mission planner software combined with python program and PID control	1. The boat can move towards the specified waypoint with the pyMavlink program. 2. Obtaining the best PID control parameters based on testing through Mission Planner software. 3. The boat can maneuver well.	
November 4-16, 2023	Navigation Channel, Follow the Path, and Speed Challenge missions testing with multiple sensors	1. The program on the boat successfully provided motion commands in the Navigation Channel mission. 2. The boat is able to detect ball obstacles and can pass the Follow the Path mission. 3. The boat can maneuver according to the trajectory of the Speed Challenge mission with pre-set parameters.	

		4. The object detection program's algorithm can count the number of yellow balls on the Follow the Path mission.	
November 17-28, 2023	Docking and Duck Wash missions testing	1. The camera can detect images in the Docking missions and the boat can stop at the docking site. 2. Water blast can shoot water and hit the target with a two-axis arm servo mechanism that is able to move according to the target location. 3. The boat can perform the Docking mission according to the target and move backwards to continue the mission.	
November 30, 2023 – December 16, 2023	Testing all missions	1. The object detection algorithm and the program used run well. 2. Navigation system to perform mission transfer runs accurately. 3. The boat is capable of all missions. 4. All sensors can work well to identify objects on all missions.	

Appendix D: Water Testing Result

Testing	Documentation
Thruster Testing	
Maneuver Testing	
	

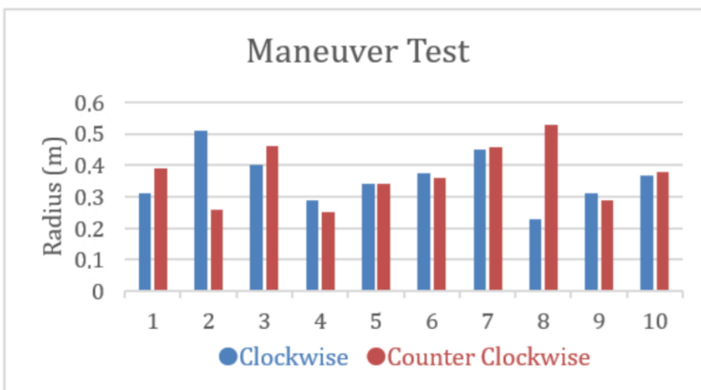


Figure D-1. Maneuver Test

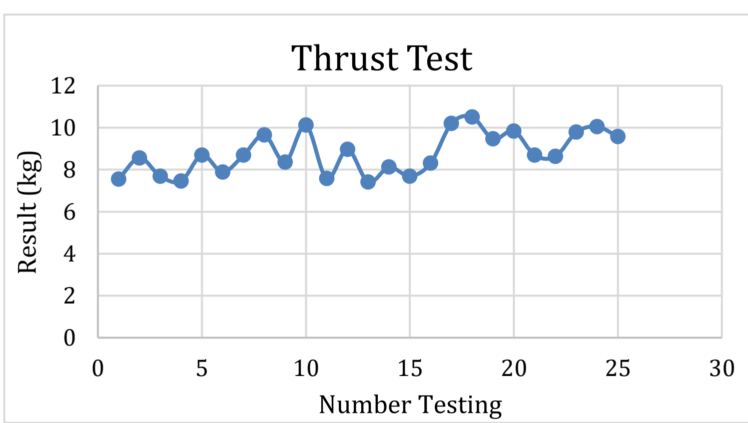
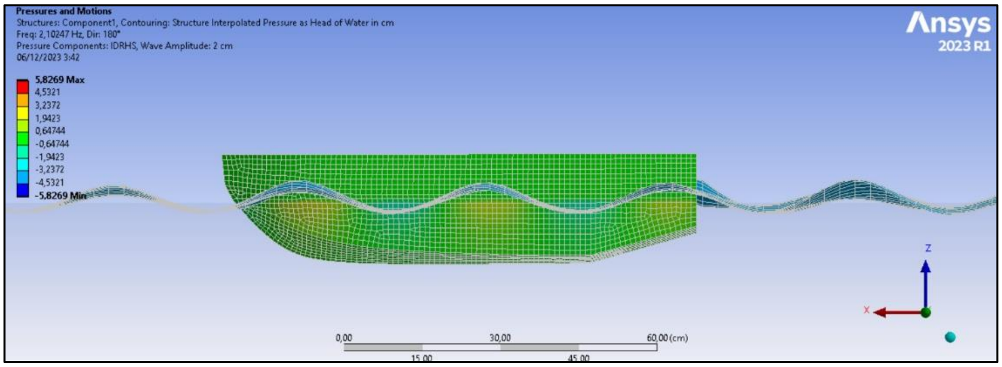


Figure D-2. Thrust Test

Appendix E: Simulation Ansys Aqwa

1. Simulation Ansys Aqwa Mandakini Hydra (2024)
   Environment
   Wave Amplitude: 0.02 m
   Wave Frequency: 2.10247 Hz
   Direction: 180 degrees



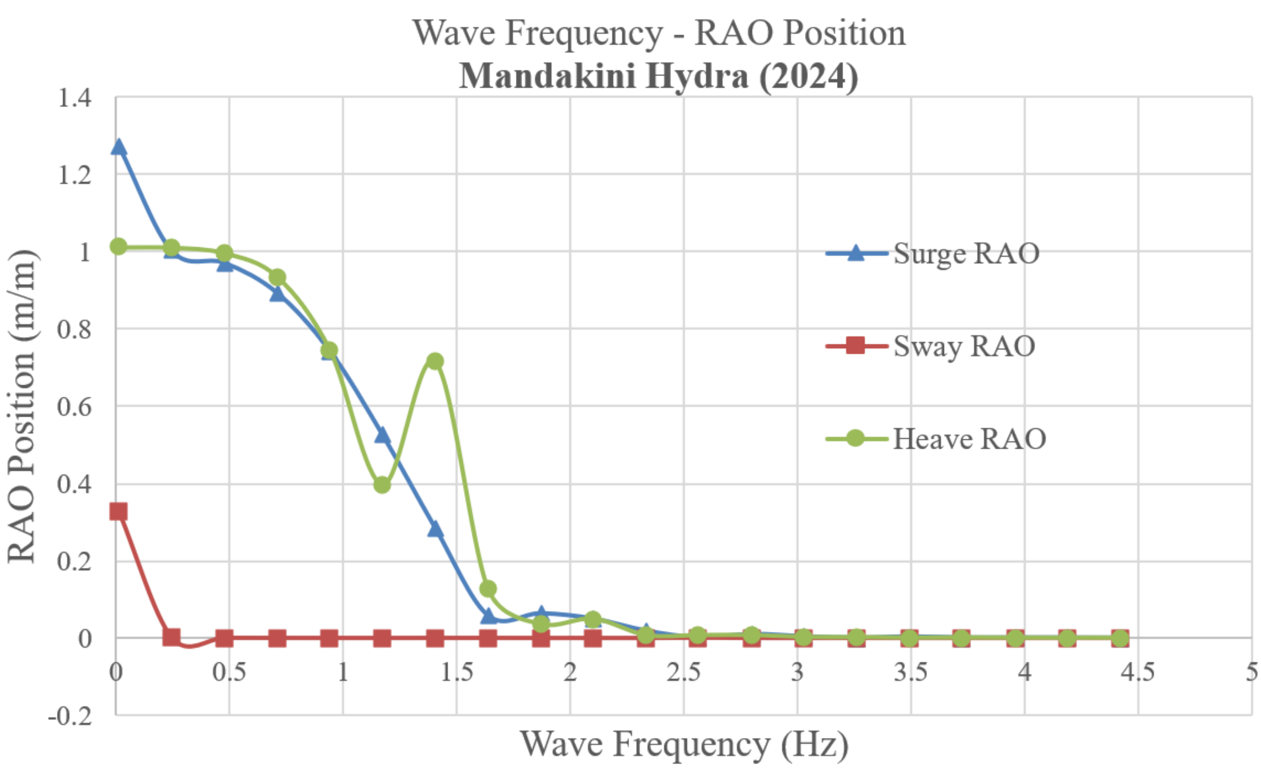


Figure E-1. Ansys Aqua Simulation Results from Mandakini Hydra (2024)

2. Simulation Ansys Aqwa Mandakini Catra (2023)
   Environment
   - Wave Amplitude: 0.02 m
   - Wave Frequency: 2.13784 Hz
   - Direction: 180 degrees

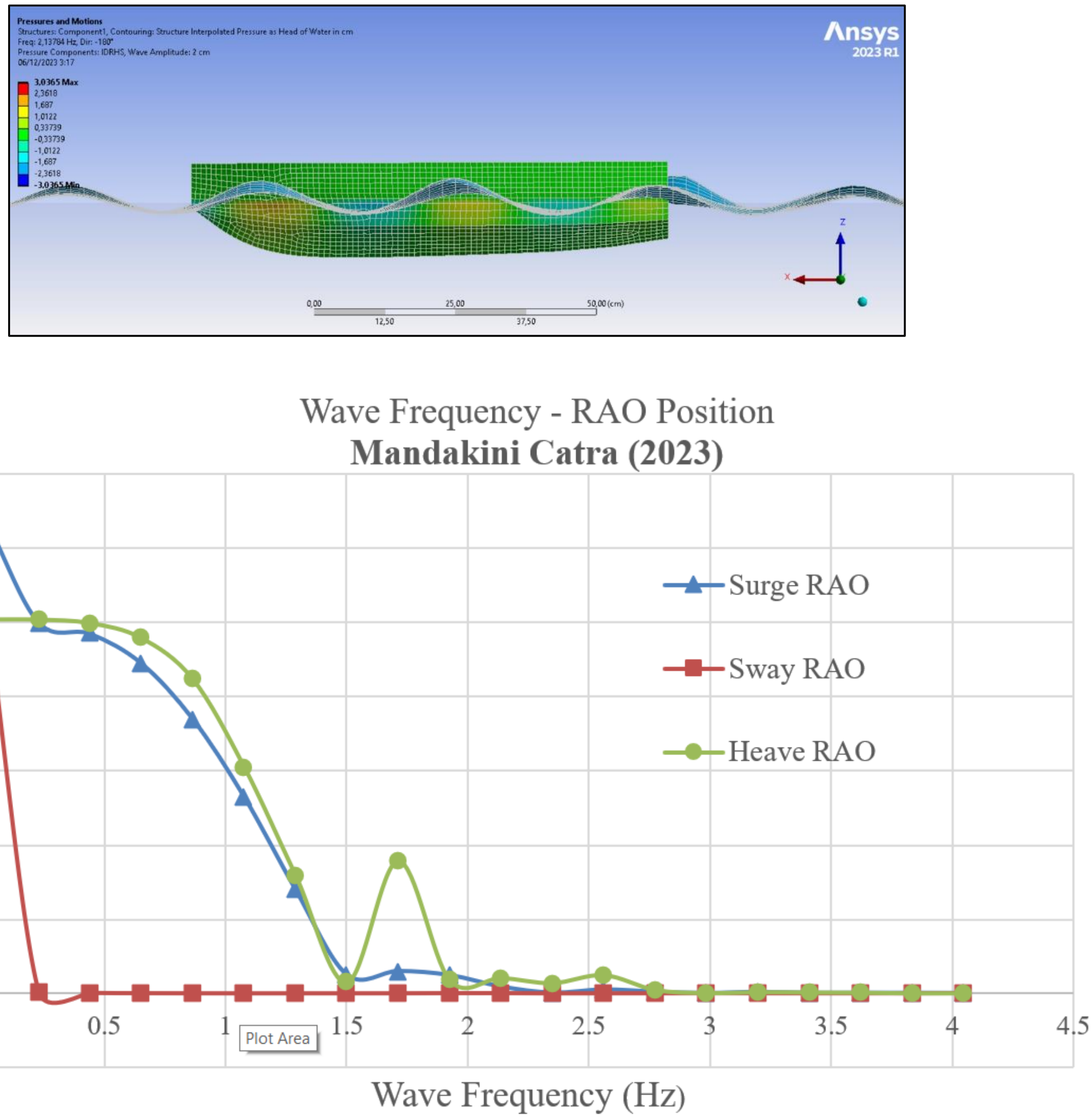


Figure E-2. Ansys Aqua Simulation Results from Mandakini Catra (2023)

Appendix F: Object Detection and Computer Vision Testing

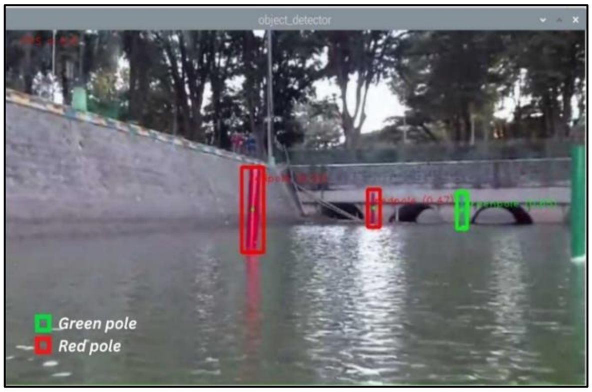


Figure F-1. Mandakini Catra 2023

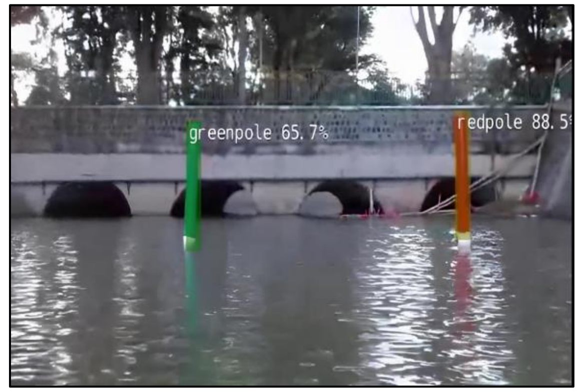


Figure F-2. Mandakini Hydra 2024

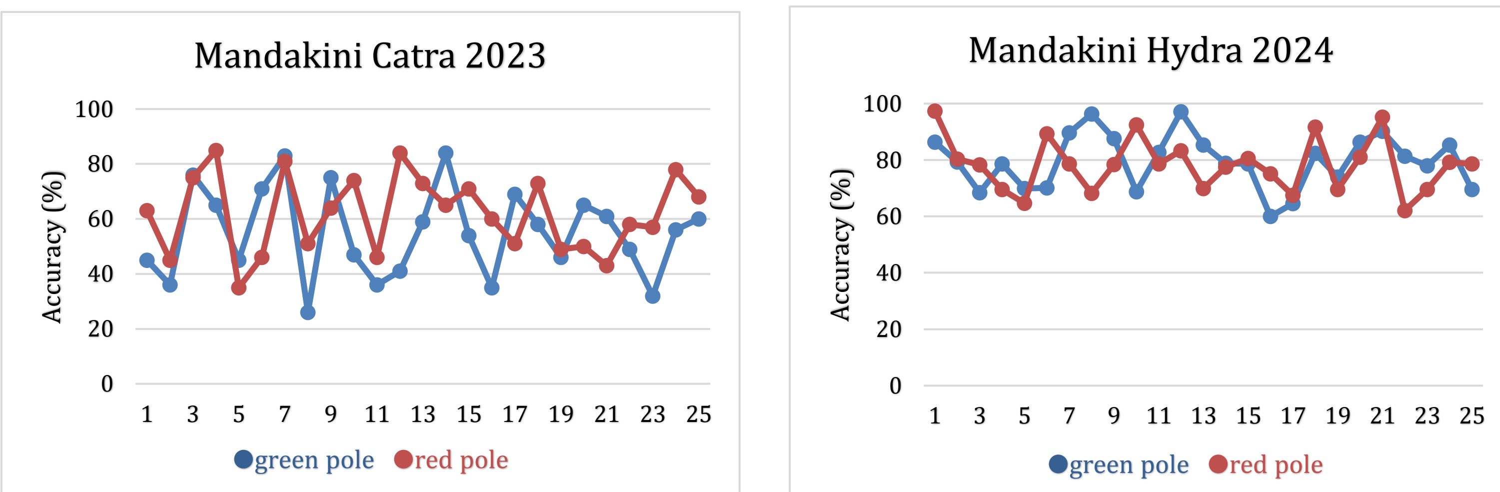


Figure F-3. Accuracy of Object Detection to Pole

Appendix G: Navigation System Testing

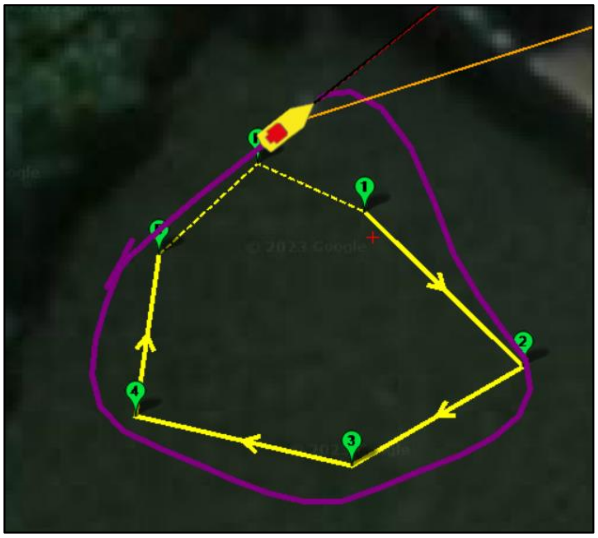
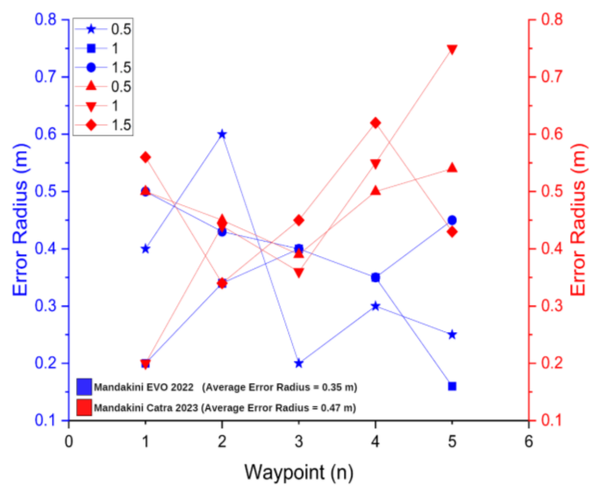


Figure G-1. Navigation Test Mandakini Catra (2023)

Figure G-2. Navigation Test Mandakini Hydra (2024)



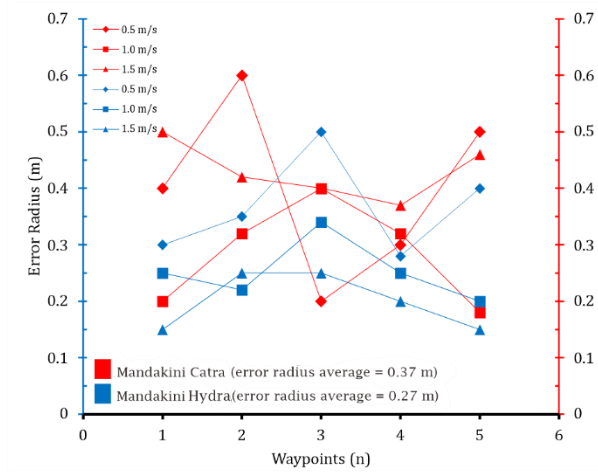


Figure G-3. Accuracy of Navigation System to Waypoints