RoboBoat 2021: Technical Design Report

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***Abstract* —This paper presents the details of work developing the autonomous surface vehicle, MAKARA MH4 XX, made by the Universitas Indonesia team for the 2021 RoboBoat. It highlights the initial strategy for completing various obstacles and overall changes made by the team to overcome setbacks from the previous design. This paper will also include further details regarding the creative decision-making of the engineering team and outlines mechanical on top of electrical studies regarding the robot design.**

Keywords: Autonomous Surface Vehicles, Artificial Intelligence, HYSUCAT, Machine Learning

I. COMPETITION STRATEGY

A. Mandatory Navigation Channel

The algorithm for this mission is straightforward. The MAKARA MH4 XX will detect buoys and drive through the middle of them. Initially, the MAKARA MH4 XX will receive GPS [1] location as input for the control node. Skynode will then guide the boat with the current location as state and GPS [1] location as the setpoint. When the MAKARA MH4 XX is in place, it will start the mission one node and infer the starting buoys to get the desired degrees, hence turning the boat into facing the center of the finish line. The main challenge of this mission is to determine the length of the arena. Several degrees of error in starting point will result in the boat straying from the trajectory. Meanwhile, having a pure straight trajectory is nearly impossible. With that in mind, the MAKARA MH4 XX will continuously center itself by running the detection of buoys.

As informed in the machine learning section, the algorithm will give the locations of green and red buoys (starting buoys) relative to the camera. The program will constantly find the center of those two buoys and drive through it. If the program did not find any buoys, it would keep moving forward until it found the other two buoys (finish line) and, as before, drive through the center of it.

Additionally, suppose the red buoy is out of sight and only the green buoy is visible, in that case, the MAKARA MH4 XX needs to move to the left to find the red buoy. Otherwise, if only the red buoy is visible, the MAKARA MH4 XX needs to move to the right to see the green buoy.

The program will end when the MAKARA MH4 XX arrives at the region of interest near the end of the finish line. We will estimate the finish line's GPS [1] location and construct an area of interest several meters around it due to the lack of information regarding the precise location. When the boat arrives, the control node will send the kill signal through the program and send a signal to start the second mission.

B. Obstacle Channel

After completing the first mission, we will prioritize the obstacle channel as the algorithm is very similar to the mandatory navigation channel with the addition of a program to avoid the yellow buoys.

The deep neural network will inform the image processing node of the center point of every buoy. In addition to moving through the center of green and red buoys, this program will have another algorithm when the three buoys are detected. The boat will calculate the distance between the red-yellow buoys as A and green-yellow buoys as B. The program will then compare A and B and go through the path with the most significant width relative to the camera input.

With this approach, the MAKARA MH4 XX could effectively find the path between every buoy. The program will stop when the boat arrives at the region of interest near the area's finish line.

C. Speed Gate

MAKARA MH4 XX will pass through the middle of the gate formed from a red and green buoy in the speed gate mission. After that, the MAKARA MH4 XX will move straight to search for the blue buoy. It will keep moving forward until a blue buoy is seen on the left side of the boat.

When the blue buoy is detected, the software will run a program to place that buoy into the specific setpoint by moving the servo, hence turning the boat. Using that setpoint, we can make the MAKARA MH4 XX rotate around the blue buoy. The main problem is to determine when the MAKARA MH4 XX should stop turning around the blue buoy. The MAVROS node will remember the degrees when the rotation program starts and publish it to overcome that problem. While rotating, the software will continuously compare the initial degrees with the current degrees. When the condition of 360 degrees (with 5-10 tolerance value) is achieved, the program will stop, and the program to find green and red buoy will start again, guiding the boat into the starting point of the mission. As to prevent the early turning of the boat when it detects the blue buoy, we will set a minimum size of the blue buoy relative to the camera.

D. Acoustic Docking

For this mission, we use a stereo camera and a hydrophone array. Initially, the MAKARA MH4 XX will drive into the GPS [1] location of the arena. When the ASV finds the dock, the hydrophone will continuously receive a signal from the beacon and publish values in the form of degrees and distance between the boat and the beacon. MAKARA MH4 XX will start to calculate the degree of signal coming from the beacon [2], [3], [4] as a PID input that will adjust the turning direction of the MAKARA MH4 XX with the desired degree as the setpoint and current degree as a state.

With this approach, the ASV could find the dock with the beacon and stop when its distance fulfills specific values.

E. Obstacle Field

This mission requires the ASV to use color detection in order to detect and avoid certain buoys, except for the special one in the center, namely pill buoy. This buoy is set to be the capstone of the arena, and the MAKARA MH4 XX will rotate around it while simultaneously avoiding other buoys.

The usage of color detection is implemented because the differentiating aspect of the pill buoy is its size and color. Two programs will run simultaneously: buoy avoidance and pill buoy detection. The former will be responsible for avoiding every buoy it detects by changing the course of the MH4 XX. The algorithm is the same as the previous mission, which is by making an inference. Meanwhile, the latter will try to find the pill buoy that satisfies the criteria of it. To find the exit path, the MH4 XX will calculate the difference from the first time it rotates relative to the middle object, possibly 360 degrees, with several error tolerances. This exit approach is similar to exiting the rotating program of speed gate mission.

F. *Object Delivery*

For this last mission, we will use an autonomous drone, where the drone will take off after the ASV has arrived at the designated GPS location, then pick the specified object in the middle of the arena. After that, the drone will automatically move above the selected location—the four points in the corner—with the help of automated flying by MAVROS.

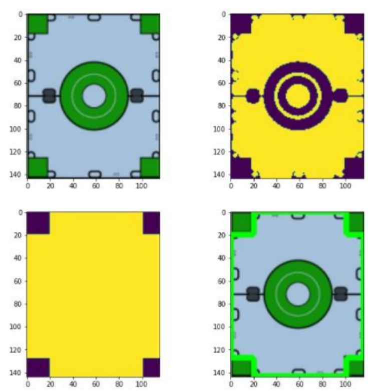


Figure 1. The area from aerial view

The algorithm for detecting each corner will use a simple shape detection using OpenCV [5] that runs on an SBC. The camera that faces downward will take an aerial view and position it to the center of each square at the arena's edge.

II. DESIGN CREATIVITY

A. *Software Architecture*

Our team uses Robot Operating System (ROS) as the primary communication framework for this year's competition. It is sufficient to control the flow of every mission and divide every script within a node for easier management. Moreover, ROS supports MAVROS software to communicate with Skynode (motor controller) and easy-to-use software for our simulation, Gazebo [6], [7].

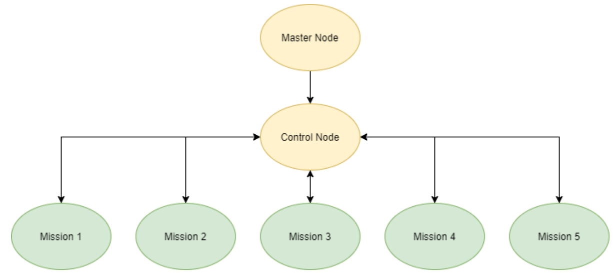


Figure 2. Mission control system

Figure 2 shows the overall control communication between every mission for the competition. The master node will react as the ground control station, which controls the communication between the MAKARA MH4 XX and the ground. The control node will communicate in a two-way scenario with every control node of every mission. Mission 1 node is the mandatory navigation channel where it will be the first node to run. That node will move the MAKARA MH4 XX to the designated GPS coordinates of the first mission. After it finishes, the Mission 1 node will report back to the control node. The control node will receive the input and do a callback to stop the mission one program and run the Mission 2 node, bringing the MAKARA MH4 XX to the GPS [1] coordinates of the next task. This software will run sequentially until Mission 5 node is completed.

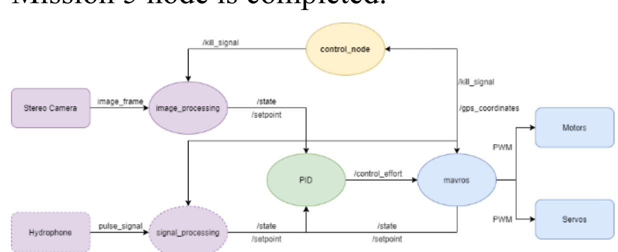


Figure 3. Mission node architecture

Figure 3 shows the typical architecture for every mission that includes two primary sensors, a stereo camera and a hydrophone array [2], [3], [4] (specialized for the acoustic docking mission). Initially, control_node will publish GPS [1] coordinates of the arena, and MAVROS will override the actuators to that location, and the program will run. For the PWM controls, our team uses a PID that is subscribed to every node-connected sensor. The PID node will listen for the state and setpoint of MAKARA MH4 XX, and with the constants of K_p, K_i, and K_d, it will publish a control_effort to the MAVROS node (Skynode) and will be forwarded to the actuators. After the MAKARA MH4 XX finishes the mission, it will publish a kill signal to the control_node. The control_node will publish another kill signal to every node to stop the program and continue to the next mission.

The overall software is written in Python with ROS 18.04 equipped with an embedded machine learning model for more accurate image processing. We simulate the software using Gazebo [8] with custom environments that resemble the arena of every mission. [7]

B. *Object Detection with Machine Learning*

This method further develops our team's object detection method in 2019, which still uses the usual object detection and color detection using OpenCV. We choose to build a machine learning method because color detection is not robust enough. The ship has difficulties differentiating buoys that have similar colors with the environment. We also have to repeatedly adjust the HSV constants that fit with the current lighting.

To detect the buoys and possible obstacles, we use the deep learning model as our approach. We take the input from the camera, then label the object's frame by frame and feed it into our deep learning model. Knowing that we do not have many image datasets for the buoys, we use another approach to boost our model accuracy, namely Transfer Learning.

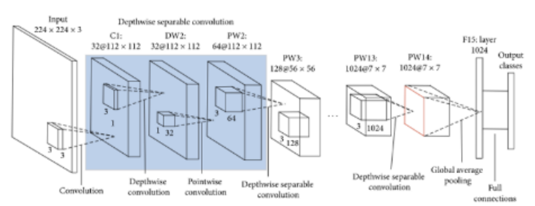


Figure 4. MobileNet-V2 Architecture

Transfer learning is a process of building a custom machine learning model based on a pre-trained model that has learned from thousands of images. The pre-trained model that we will use is MobileNet, a trained model that has classified thousands of objects. The model is built on a simplified architecture that builds lightweight deep neural networks using depth-wise separable convolutions. We use MobileNet as our transfer model because it has fewer parameters, small network size, and faster performance. By using this method, the detection of objects in each mission will be more accurate. Therefore, the robot will move in the mission arena more directed and accurately with a better detection rate. Moreover, transfer learning will reduce the computation needed and save our team a lot of time and resources [9], [10], [11], [12].

Model	ImageNet Accuracy	Million Mult-Adds	Million Parameters
1.0 MobileNet-224	70.6%	569	4.2
GoogleNet	69.8%	1550	6.8
VGG 16	71.5%	15300	138

Table 1. MobileNet comparison

First, we will load the pre-trained model and decide which layer to take as our custom model's foundation [10]. We decided to take the layer somewhere in the middle where the model has learned to detect lines and possibly colors. Then, we will collect our custom datasets that include objects that we have labeled and train them for several epochs. The initial model will be used as the baseline. We will further improve the model by making an inference with other images to check if the model is sufficient to do the missions. If the result is unsatisfactory, we will repeat the process and fine-tune it.

When the model is sufficient, we will convert it into a more lightweight model by making a TensorFlow Lite model and deploy it on MAKARA MH4 XX. The boat will take an image frame from the camera and make an inference that gives the location of buoys and objects relative to the camera. That location will be the state and fed into the PID node to produce the control effort for the actuators. Having this approach will result in a more robust detection while still lightweight enough with the help of using the Tensorflow Lite model.

This whole process uses Tensorflow as the machine learning framework paired with Python language. The model will be trained on a cloud platform such as Google Colab, and the model will make the inference locally on the MAKARA MH4 XX.

C. Autonomous Drone

For the sixth mission of this competition, we will be using an autonomous drone [14]. The drone will be equipped with a Pixhawk 4 Mini as a flight controller and a Jetson Nano, a Single Board Computer (SBC). The Pixhawk will receive input from the Single Board Computer.

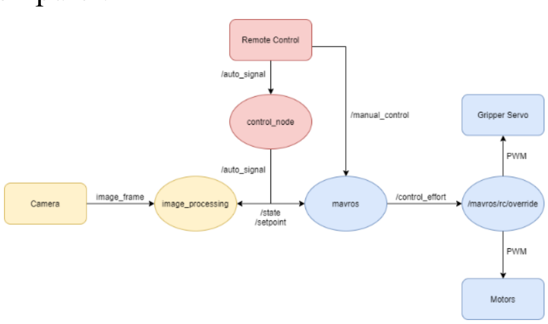


Figure 5. Drone software flowchart

The autonomous flight will detect shapes using a simple OpenCV [5] program. The program will detect contour from the image frame, and it will detect vertices of the figure seen in the image. Because we only want to notice squares, we will include the figures or shapes with four vertices. Furthermore, we will calculate the aspect ratio of the vertices. A square will have an aspect ratio near 1.

After successfully filtering the square from the rest of the background, the drone will position the camera right above the middle of the square and drop its load. After that the drone will get another load and position itself to the next square until the mission is finished.

For the landing, the drone will detect the superstructure of the ship then land on it. We also equip the drone with a pool noodle to give buoyancy as a precaution if the drone lands on the water

D. Hull Design

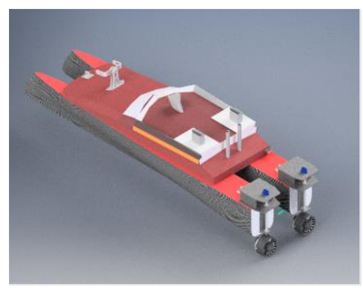


Figure 6. ASV design

ASV Specification	
Length	1,5 m
Beam	0,38 m
Depth	0,16
Displacement	16,27 kg

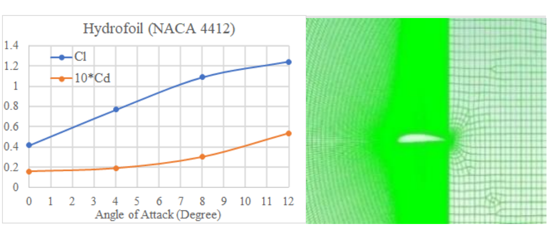
Table 2. ASV Specification

MAKARA MH 4 XX uses the HYSUCAT (Hydrofoil Supported Catamaran) design concept. The basic principle of the HYSUCAT is a high-performance hydrofoil system in the tunnel between the two hulls. The hydrofoil system is comprised of the main foil placed between and parallels with the hull's bottom, slightly toward the ship's center of gravity. In the tunnel at the transom, aft has two smaller trim foils that work like tail wings on an aircraft to ensure a level-planning attitude [10]. The choice of this concept is because HYSUCAT has several advantages. It is much more comprehensive than a comparable-sized catamaran or monohull, especially when heavily loaded and at high speeds. Research shows a reduction of resistance by about 40% due to foil [13]. The ASV performance is significant for competition, especially at speed gate mission tasks.

The catamaran's two hulls provide natural stability while at sea, making it easier to control, hard to capsize, while it doesn't require stabilizers. With a catamaran design, the ASV can rotate with less forward movement, which is very hard to do with a monohull. Catamaran allows a large superstructure area that makes electrical components more convenient to install and maintain.

MAKARA MH 4 XX uses a semi-displacement hull type to reduce the resistance and increase the amount of carried items. Besides that, the ASV uses reverse bows or wave-piercing bows design to improve performance by reducing pitch resistance. The added benefit of the reverse bow is a higher speed and a much more comfortable movement at sea. The higher speed and motion at sea occur due to pitching, which increases hull resistance, reduces the underwater layer's efficiency due to unstable flow, and causes uncomfortable movement [16].

E. Hydrofoil Technology



(a) (b)

Figure 7. (a) Hydrofoil lift and drag coefficient, (b) Hydrofoil mesh in ANSYS

Hydrofoil design uses NACA 4412 profile because that foil provides a high lift coefficient in a relatively small attack angle. The hydrofoil is simulated by using CFD software ANSYS Fluent. The results of the CFD are quite accurate, only slightly different from the NACA website. We choose the 8-degree angle of attack based on the outcome because it has a good lift coefficient and drag coefficient value.

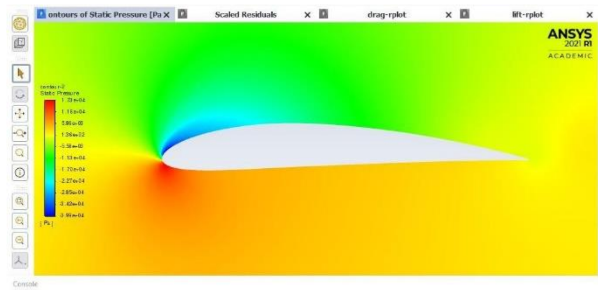


Figure 8. Pressure contour of hydrofoil at 8˚ angle of attack

The hydrofoil generates lift, which causes most ships to rise above the water. Therefore, reducing the wet area (resistance) provides two significant results: reduced resistance and increased buoyancy. The hydrofoil boats are much better than conventional boats (monohull or catamaran) without foil. Hydrofoil makes ASV can carry more weight with lower power and faster speed. The proprietary foil and hull design improves maritime navigation and overall stability.

F. Material Selection

To pursue the best combination between strength, efficiency, and sustainability, we had chosen Carbon Fiber Reinforced Polymer (CFRP) composites and High-Density Polyethylene (HDPE) primary materials for the MAKARA MH4 XX.

The hulls of MAKARA MH4 XX are made from CFRP. It is more robust and lighter than fiberglass [15], ensuring power transfer efficiency from the thrusters to gain optimal power and excellent maneuverability. However, due to the electrical conductivity property of CFRP [17], this material tends to block radio signals vital for the boat's communication.

We chose HDPE to be the material for the superstructure buildings (which houses most of the boat's electrical components). Other benefits of using HDPE are anti-corrosive, durable, weather-proof, and non-toxic. Using HDPE also makes the boat more environmentally friendly because it is 100% recyclable [18]. That also reduces marine pollution as governed by The International Convention for the Prevention of Pollution from Ships (MARPOL).

G. *Propulsion System*

MAKARA MH 4 XX uses two T200 Blue robotics thrusters for ship propulsion. Thrusters are placed on the stern below the hull to get maximum performance and keep the thrusters in water even when the hull gets lift force because of the hydrofoil. A servo is also installed in each thruster with the azimuth propeller to have a shaft to control thruster direction. The servo-controlled shaft helps thruster movement when turning, so the turning radius of the ASV is not too large.

H. *Power Management*

MAKARA MH4 XX has a power source that comes from four Lithium Polymer (LiPo) battery packs. Each has a built-in battery level indicator used to determine the remaining battery capacity and current-voltage rating. Every pack has a fuse connected to the same relay. This is to protect the circuits from overcurrent and overvoltage. The relay regulates the power of the ASV electronic when the ASV is remotely controlled and is connected to five lines. The first line is a buck converter that converts the power source voltage to 9 V, which the router uses. The second line is a step-up voltage regulator that stepped up the voltage to 19 V, which the Apple Mac Mini M1 used to run ZED 2i. The third and fourth lines are connected to Blue Robotics Electronic Speed Controllers (ESCs), used to regulate the speed of T200 Thrusters effectively and efficiently. Lastly, the fifth line is connected to a warning light. The buck converter with an input of 12 V and an output of 5 V is connected to an Arduino Nano that connects the receiver and warning light. In addition, the power and data from the Mac Mini M1 will be passed along to the stereo camera, hydrophone, and Skynode. From Skynode, power and data are sent to the kill-switch and three servo motors to make them work flawlessly. The left and right servos per se are used to move azimuth propeller on the thrusters [19].

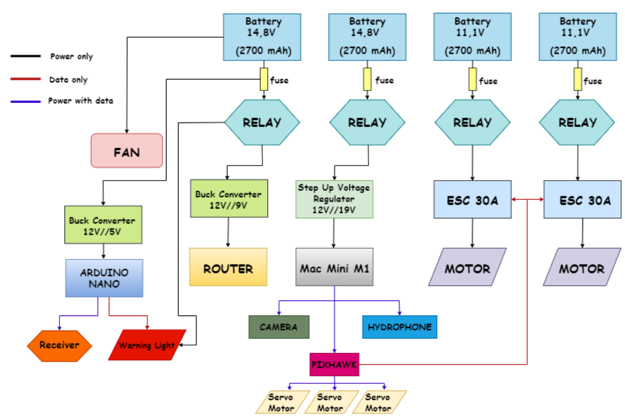


Figure 9. Power distribution

What is more, a link flows directly from the battery that is not connected with the fuses and relay, used by four 12 V fans—our simple yet effective and cost-efficient cooling solution for the ASV. The ASV power management can be considered competitive using advanced circuit boards built by us and top-notch components.

I. *Fail-Safe Mechanism*

The Fail-safe mechanism in MAKARA MH4 XX aims to stop the thrusters' operation when an emergency occurs. This mechanism is utilized using an onboard mechanical kill switch, and a wireless kill switch operated from a remote control. This mechanism stops the thrusters by cutting out the power to the Electronics Speed Controllers (ESCs), which drive all the thrusters. The onboard mechanical kill switch works by cutting power to an Arduino Nano that triggers the Arduino to switch a relay that connects the ESCs to the primary power source, eventually turning the thrusters off. On the other hand, the wireless kill switch works by sending a signal to an onboard receiver. This receiver will transmit a digital signal to Arduino Nano to switch a relay that connects the ESCs to the primary power source.

These systems are simple yet effective. It provides several benefits to prevent an incident that is unknown and cannot be controlled. With this, the ground control station can tell the boat when to start the system.

J. Communications

The MAKARA MH4 XX implements its onboard systems communication, control, and health monitoring by utilizing an Ethernet-based communication backbone. Communication with the judges and the execution of tasks are controlled by the main onboard computer, the Mac Mini M1. MAKARA MH4 XX external communication is amplified by NanoStation M5, manufactured by Ubiquiti Networks [11]. It is a 5GHz Hi-Power 2x2 MIMO AirMax TDMA Station. It's a revolutionary design that combines a high gain antenna system, advanced radio architecture, and highly researched and developed telecommunications firmware that provides up to 150+ Mbps real outdoor throughput and up to 15km+ range. This phenomenal performance that the station provides will benefit MAKARA MH4 XX in executing tasks and external communication. Alternatively, the MAKARA MH4 XX can be controlled remotely by using a 2.4GHz commercially available radio control system that allows an independent direct command and control link. This system toggles the boat from manual mode and autonomous mode for troubleshooting and acts as emergency stop functionality.

K. Control System

MAKARA MH4 XX is equipped with a control system based on Robot Operating System (ROS) and OpenCV. This control system controls the boat's trajectory to match the referenced trajectory generated using OpenCV-based image processing. The referenced trajectory is created by utilizing an algorithm that determines the distance midpoint between the buoys that form the surface vehicle path. The PID (proportional-integral-derivative) control law is chosen to minimize the difference between the referenced trajectory and the actual trajectory. PID control law is selected because this algorithm is easy to implement. The actual trajectory itself is acquired from the center point of the image taken by the onboard camera in real-time. The control algorithm will drive the servos in the stern of the boat to a certain angle to reduce the delta amidst these two trajectories. This control law algorithm is implemented on the onboard computer, generating control signals for the servo motors. These control signals are converted into Pulse Width Modulation (PWM) signals using Skynode, which later drive the servo motors.

L. Camera & Sensors

In the past RoboBoat Competitions, our team utilized Logitech C920 [20]. This outdated camera presented some drawbacks. Our solution for these problems is to invest in ZED 2i, a newly released cutting-edge stereo camera.

ZED 2i works by utilizing neural networks and a pair of camera sensors simultaneously to reproduce human-like vision. It is also elevating our ASV's performance on complex autonomous behavior. It has a built-in Inertial Measurement Unit (IMU) and robust third-parties integrations (OpenCV and TensorFlow).

Furthermore, for this 14th RoboBoat Competition, we settled to include PHOD-1 [1], an omnidirectional hydrophone sensor that is fully compatible with the frequency and pulse rate.

M. Computing Performance

One of the significant concerns regarding the electrical components of our ASV is the Intel® NUC5i7RYH, which is outmoded in terms of processing power and poor performance to power consumption ratio relative to today's standard. Henceforth, this year, we eventually decided to adopt Apple Mac Mini M1.

Apple Mac Mini M1 is wholly supported by the software architecture used, Robot Operating System (ROS). Other than that, The Mac is directly making it possible to minimize the overall energy needed by the entire system [21], reducing the network latencies, and improving processing load [23] & data transfer speeds [22].

III. EXPERIMENTAL RESULTS

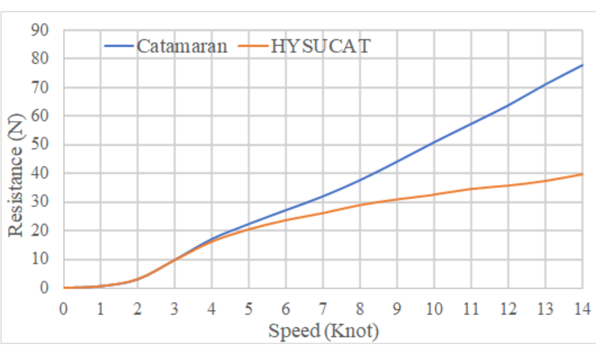


Figure 10. Resistance comparison of HYSUCAT and catamaran.

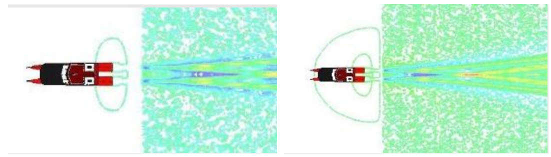


Figure 11. HYSUCAT wave profile and Catamaran wave profile at 12 knots.

Performance of ASV is analyzed using Maxsurf Resistance software with a slender body method to calculate catamaran resistance with and without hydrofoil. This calculation considers the reduction of lift coefficient due to decrement in the submergence depths of the hydrofoil [20]. The result shows that the resistance reduces about 40% at high speed. Figure 11 indicate that the wave-making resistance of HYSUCAT is much smaller than a catamaran. It significantly improves the performance of ASV since wave-making resistance contributes about 40-60% of total resistance for high-speed ships [7].

Figure 12. Drone simulation in Gazebo

With this pandemic restriction, the most suitable solution to test out the missions is to simulate all the missions inside a digital environment, a simulator with ach mission simulated specifically inside an isolated environment. This simulator is called Gazebo Simulator [8], a simulator that is perfect for simulating robots, including drones and boats, by integrating the simulator with PX4 for autopilots, using ROS to run the codes. The simulations are done by adding assets to create a replica of the arena and robots.

The simulation went smoothly. Our code works as intended, which allows the MH4 XX to complete all simulated missions successfully. Even then, we believe that the performance could still be improved. For example, adding more assets with various colors and sizes allows for more rigorous simulations like actual robot trials that we do in real life.

Our ability to properly simulate robot trials brings us many great benefits. With a simulation, we can test the robot anytime and anywhere we want. Not to mention it also allows for a much quicker retrial in case of failure. This approach is beneficial in the early stages of robot creation, where a failure is almost inevitable. Furthermore, with a simulation, any kind of damage taken by the robot in an actual trial could be prevented. This results in fewer resources wasted to fix said robot.

Unfortunately, due to the limitations of the hardware specifications in Ubuntu, the operating system used to simulate the boat, the simulation for testing out boat-related missions can't be held. Only drones could run within a simple environment without any tools to support the actual environment. Therefore, to make up with the simulator, we will use animations, both 2D and 3D, to simulate how the boat can complete each mission.

That being said, Gazebo Simulator is still the perfect software to test our robot due to its versatility.

IV. ACKNOWLEDGEMENTS

We would like to express our gratitude to God as we were able to finish this project. Other than that, none of this project could have been done without the support from Universitas Indonesia, especially from the Universitas Indonesia's Robotics Teams. This team would like to thank the endless support and guidance this university gave us. We also thank Mr. Muhammad Arif Budiyanto and Irfan Rahadi for always helping us throughout the project. And lastly, we would like to appreciate our beloved team for the hard work, especially in finishing this project.

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Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Cost (If New)
ASV Hull Form	AMV UI	MAKARA MH4XX	Epoxy resin, Carbon Fiber Reinforced Polymer, and High-Density Polyethylene	$136.27
Waterproof Connectors	Blue Robotics	M10 Cable Penetrator for 8mm Cable	https://bluerobotics.com/store/cables-connectors/penetrators/penetrator-10-25-a-8mm-r2/	$50
Propulsion	Blue Robotics	T200	https://www.robotshop.com/media/files/rb-blu-27_-_documentation.pdf	$169
Motor Controls	Blue Robotics	Basic ESC 30A	https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	$27
Servo Motors (Steering Motors)	Savox	SV-0236MG	https://www.savox-servo.com/Servos-c-1338/Brushed-Motor-c-1340/Savox-Servo-SV-0236MG-Digital-High-Voltage-DC-Motor-Metal-Gear/	$90.14
Teleoperation	FrkSky Electronic Co., Ltd.	Tandem X20S	https://www.frsky-rc.com/wp-content/uploads/Downloads/Manual/TANDEM%20X20/TANDEM%20X20%20Manual.pdf	$474.99
Receiver	FrkSky Electronic Co., Ltd.	ARCHER SR10 PRO	https://www.frsky-rc.com/wp-content/uploads/Downloads/Manual/ARCHER%20SR10%20PRO/ARCHER%20SR10%20PRO%20-Manual.pdf	$49.50
Hydrophones	Sparton	PHOD-1	https://www.spartonnavex.com/product/phod-1-hydrophone/	$995
Aerial Vehicle Platform	DJI	FlameWheel 450 Basic Quadcopter Drone Kit	http://dl.djicdn.com/downloads/flamewheel/en/F450_User_Manual_v2.2_en.pdf	$59
Drone Single Board Computer	NVIDIA	Jetson Nano	https://developer.nvidia.com/embedded/jetson-nano-2gb-developer-kit	$59
Drone Flight Controller	Holybro	Pixhawk 4 Mini	https://github.com/PX4/px4_user_guide/raw/master/assets/flight_controller/pixhawk4mini/pixhawk4mini_technical_data_sheet.pdf	$207.95

Drone Motors	Tiger Motors	MN2212 KV920-V2.0	https://store-en.tmotor.com/goods.php?id=389	$46.90
Drone Motor Controls	Tiger Motors	AIR 20A 4S	https://store-en.tmotor.com/goods.php?id=367	$19.90
Drone Battery	Gens ace	Soaring 1000mAh 11.1V 30C 3S1P Lipo Battery Pack	https://www.gensace.de/gens-ace-soaring-1000mah-11-1v-30c-3s1p-lipo-battery-pack-with-xt60-plug.html	$14.62
Onboard Computer	Apple	Mac Mini M1 256GB	https://www.apple.com/mac-mini/specs/	$599
Microcontroller	Arduino	Nano	https://www.arduino.cc/en/pmwiki.php?n=Main/ArduinoBoardNano	$20.70
Camera, Inertial Measurement Unit (IMU), Magnetometer, and Barometer	Stereolabs	ZED 2i	https://www.stereolabs.com/zed-2i/	$499
Electrical Batteries	Team Orion	Team Orion LiPo 2700 3S 11,1V 50C XT60	https://teamorion.com/index.php?dispatch=products.download&product_id=57510	$37.99
Thrusters Batteries	Team Orion	Team Orion LiPo 2700 4S 14,8V 50C XT60	https://teamorion.com/index.php?dispatch=products.download&product_id=57511	$49.99
Router	Ubiquiti Networks	NanoStation M5	https://dl.ubnt.com/datasheets/nanostationm/nsm_ds_web.pdf	$92
Autopilot and Global Positioning System (GPS)	Auterion	Skynode	https://firebasestorage.googleapis.com/v0/b/gitbook-28427.appspot.com/o/assets%2F-LhKfvI1NMLmpzjCxDe_%2F-MXm8J-7eH-8CjlOPNpP%2F-MXm8d8QK2LL2eJFsA3Z%2FSkynode-datasheet_v1.2.4.pdf?alt=media&token=64b4039e-35d2-468c-9310-032aa938250d	$348
Cooling Fans	Coolerguys	120mm (120x120x25) 3000 RPM	https://www.coolerguys.com/collections/dc-12-volt-fans/products/coolerguys-	$17.95

		IP67 Fan CG12025H12	120x120x25mm-3000-rpm-ip67-fan-cg12025h12	
Warning Light	Dialight	557 Series LED Panel Mount	https://www.mouser.com/datasheet/2/109/diac_s_a0010151210_1-2265572.pdf	$17.64
Relay	SONGLE RELAY	4 Channel Relay Module	https://components101.com/asset/sites/default/files/component_datasheet/5V%20Relay%20Datasheet.pdf	$2.78
Step Up Voltage Regulator	XLSEMI	XL6012	http://www.xlsemi.com/datasheet/XL6012%20datasheet-English.pdf	$11.53
Buck Converters	XLSEMI	XL4016	http://www.xlsemi.com/datasheet/XL4016%20datasheet.pdf	$3.79
Fuses	Generic	15A Slow Blow Glass Cartridge	https://www.evelta.com/15a-6-35x31-8mm-slow-blow-glass-cartridge-fuse/	$0.21
Main Cables	Multicomp Pro	Twinflex PVC Battery Cable 10 AWG	http://www.farnell.com/datasheets/3148650.pdf	$6.072
Secondary Cables	TE Connectivity	Spec44 Series 22 AWG	http://www.farnell.com/datasheets/1456391.pdf	$2.7351
Mechanical Kill Switch	Schneider Electric	Harmony XALK178F	https://docs.rs-online.com/02ee/0900766b816e94e2.pdf	$64.53
Algorithms	AMV UI	Internal Development. Object Detection, Autonomous Drone		
Vision	AMV UI	MobileNet, Transfer Learning, OpenCV		
Localization and Mapping	AMV UI	Internal Development.		
Team Size (Number of People)	26			
Expertise Ratio (Hardware vs. Software)	1:1			
Testing Time: Simulation	8 hours			
Inter-vehicle Communication	Ubiquiti Networks	Rocket M2	https://dl.ubnt.com/datasheets/rocketm/RocketM_DS.pdf	$84.50

Appendix B: Outreach Activities

Aside from joining RoboBoat Competition, AMVUI team also actively participating in various events related to competition, academics even research. Moreover we also participate in exhibitions especially the one that held in the university to provide information about the technologies principally in the maritime industries, but that doesnt mean that we are limited to that scope. Here are some activities that we've been joining regularly:

1) Open Mind Robotics Team University Indonesia and Training

   In this opportunity the AMV team got the ability to introduce more about the technology as mentioned specifically on maritime industries but also we are able to talk about everyhting the team has been doing, this includes the reserach that our team has been doing along the way. This events were held by the university students who has interest in robotics system. As part of the event, we also trained the students things related to the robotics system such as basic in programming, electrical and mechanical.

   https://drive.google.com/drive/folders/1jt6ExVs-X4YXy5eY6-XWXDT9LcrfJmXC?usp=sharing

2) Facilitating students in comprehending courses

   Other than technology related we also help students to understand comprehending courses such as signals and system and other courses by facilitating them through the learning, this event usually held around examinations and finals.

   https://youtu.be/m7UDB5WyBVY

3) Exhibitions

   We also love to contribute on the events held in the university, besides this is a chance for us to promote our team and also educate others related to the manufacture of a robot and a boat especially for the underwater but also the surface one. This events usually open for public so we can reach wide community. The purpose of this events is usually to educate others what our university has related to reseach and innovation.