RoboBoat 2022: Technical Design Report
Barunastra ITS RoboBoat Team

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***Abstract*—This report discusses the strategy and design choices of Barunastra ITS when developing an Autonomous Surface Vehicle (ASV) to compete in Roboboat 2022. The ASV named Nala Theseus was designed with modularity in mind to fulfill the goal of having the ability to quickly perform design iteration and have the ASV be portable. The ASV had each of its components tested both individually and simultaneously through software simulation, ground testing, and water testing.**

***Keywords*—Mobile Robots, Machine Vision, ASV.**

I. Competition Strategy

A. General Strategy

For Roboboat 2022, Barunastra ITS intended to solve all the autonomy challenges. Optimizing the ASV system for all the challenges has high risk of failure. Therefore, the team planned to iteratively develop and test the ASV to solve challenges one by one ordered from the most familiar to the least. A change in the ASV system to approach a less familiar challenge must not cause failure for the already successfully solved challenge.

There are two new challenges for this year's competition which are Skeeball Game and Water Blast challenge. The team expected that these two challenges require more design iterations than other challenges. Therefore, easy modifiability become one of the main considerations in the ASV design.

Furthermore, as the team based in Surabaya, Indonesia, the development, and testing of the ASV are executed in Surabaya. Transporting the ASV to the competition site is a challenge itself. To maximize the development and testing time and reduce the shipping cost of the ASV, the team planned to bring the ASV together with the team's personnel via airplane as a baggage for the flight. This means that the ASV must be able to fit in the baggage dimension limit of most airline.

For this, the team designed a new ASV Nala Theseus. Nala Theseus was designed with the principle of modularity in mind. Each independent pieces of the ASV could be made, designed, packed, modified, or replaced individually which fulfill the desired goal of having quick design iteration.

B. Course Strategy

On its mission, Nala Theseus will attempt the Snack Run immediately after the mandatory Navigation Channel demonstration. Since the Snack Run is timed, attempting this challenge early is better as the battery would be plentifully charged at that time, enabling the thruster to have more power.

A capable computer vision system is required for the snack run because the ASV will rely on its camera to detect gate and marker buoy which in worst-case is located 100 ft away from the ASV [1]. Adding to that, the computer vision is required for the Avoid the Crowds. On this challenge, when encountering obstacle buoys within the pathway, the ASV will look for the nearest sufficient gap between the buoys and compute the trajectory to surge through the middle of that gap. To achieve that, the ASV will rely on the system to detect the obstacle along the way. Therefore, Nala Theseus' computer vision is developed to be able to detect objects that are near or far from the ASV.

To accommodate the Find the Seat at the Show and Water Blast, the ASV is developed with a propulsion and control system that support station keeping. These abilities are accommodated by the three-thrusters system. The three-thrusters system is built to accommodate pivoting, path following, and orientation lock motion which enable the ASV to move sideways during the docking process and maintaining its pose.

The modular-designed ASV's hull is also designed to maximize maneuverability and minimize the pitch and roll oscillation. These features are needed in the Avoid the Crowds to keep the ASV stable while surging through obstacle-filled pathway. Fiberglass was chosen to be the ASV build material due to its durability. This is very important especially on the Skeeball Game challenge because the ASV would ram into the Skeeball dock to fix its distance to the holes.

The LiDAR laser-scan data and camera image are fused to estimate distance, position, and orientation of the platform of various challenges. In the Find the Seat at the Show, it is used for estimating the dock's position so that the ASV could rotate itself in a way such that its camera directly faces the docks and move sideways to find its assigned dock. The fused data is also used to fix the ASV distance to the Water Blast's platform so that the ASV could shoot water accurately.

II. Design Creativity

A. *Hull Design*

The challenges require the ASV to have excellent stability and maneuverability. Thus, Nala Theseus (Fig.1) is designed to reduce wave disturbance so that the ASV can remain stable in higher amplitude or longer wavelength. It has a bigger beam to overall length ratio value than the ASV that had been manufactured in the previous years. This design effectively reduces disturbance to the ASV and the camera, especially rolling (X-Axis) and pitching (Y-Axis) motion. Its stability would affect the ability of the ASV to return to its equilibrium point after receiving external forces.

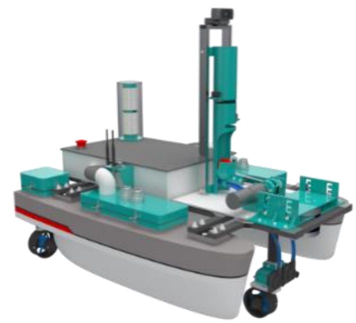


Fig. 1 Nala Theseus Design

By using the modularity concept, a frame made of hollow steel is used to connect the hulls. It also becomes the deck of the ASV for the component arrangement. Mostly, Nala Theseus' components are above the water which makes the center of gravity slightly above the water. To overcome this, low freeboard is the best option, so roll and pitch rotations can be kept to a minimum. Based on those considerations, Nala Theseus' dimension is designed to (be as in Fig. 2) meet those needs.

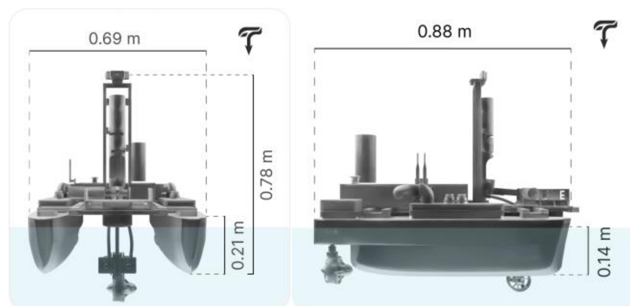


Fig. 2 Nala Theseus Principal Dimension

TABLE I. BEAM-LENGTH RATIOSTA

BEAM-OVERALL LENGTH RATIO	
NALA G4 (2019)	0.5455
NALA POSEIDON (2021)	0.4950
NALA THESEUS (2022)	0.7954

B. *Propulsion and Control System*

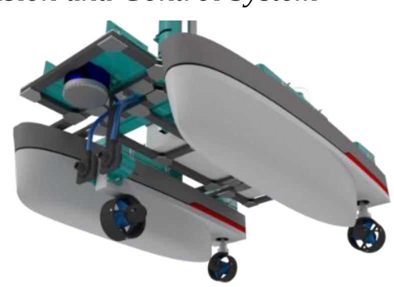


Fig. 3 Propulsion system

Nala Theseus uses three thrusters. Two azimuth thrusters are mounted on the stern of the ASV and one fixed bow thruster is mounted on bow area as shown in Fig.3. Using these three thrusters, the ASV would be able to perform 3 types of motion: pivoting, orientation-locked motion, and path following. Pivoting is when the ASV change its orientation without changing its position. Orientation-locked motion is when the ASV change its position without changing its orientation. Path following is when the ASV follows waypoints.

For the pivoting motion, the two azimuth thrusters will orient itself to be perpendicular to the ASV's center of gravity. To perform orientation-locked motion, the two azimuth thrusters will orient itself to point towards the ASV's center of gravity and the azimuth thrusters will have opposing thrust. The bow thruster will function as the orientation controller.

Nala Theseus uses the path following algorithm developed for the previous 2021 RoboBoat Competition. This algorithm uses the sum of the ASV's heading error and the ASV's perpendicular distance to the path as an input to a PID controller. As seen on 2021 RoboBoat Competition [2], this algorithm converges better than heading only control. With these three motions, the ASV would be able to quickly follow a path or position itself in a specific position and orientation.

C. *Ball Shooter and Water Blaster*

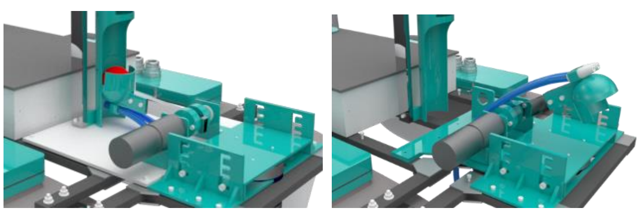
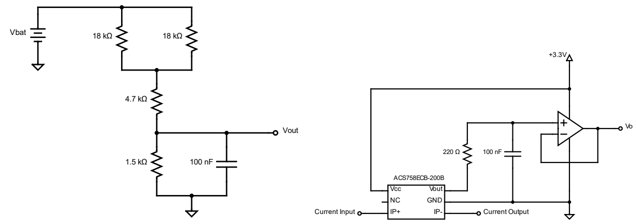


Fig. 4 Ball Shooter and Water Blaster System

The ball shooter and water blaster hose are integrated as one system. The ball shooter is a catapult-like system that uses DC brushed motor as its actuator. The motor is attached with incremental encoder to give feedback about its angular position and angular velocity. With this, the launching velocity of the ball can be controlled by PID controller to make sure that it is consistent under several battery voltage conditions.

The water blaster hose is attached to the end-effector of the ball shooter system to control its angular position. Rather than having its own vertical aiming system, this integrated system has fewer moving parts and less weight.

D. *Power Management*



(a) (b)

Fig. 5 Voltage sensing circuit (a), Current sensing circuit (b)

The power management system is required to manage the electrical power flow and to monitor the battery voltage's source and actuator's current, so if there is anomaly in the ASV's system, the electrical power source could be cut off as soon as possible. The power management system was designed on a single printed circuit board that could be connected to the microcontroller's board.

To recognize the battery voltage's source, the monitoring system is arranged as a voltage divider circuit (Fig. 5a) to produce a lower voltage which could be received by the microcontroller's analog-to-digital converter (ADC). To monitor the actuator's current, the power management board uses ACS758ECB-200B sensor that can read the current up to 200 A (Fig. 5b) [3]. This sensor uses the hall effect principle to do the current sensing process [4].

The power management system uses relays to cut the current flow. The relays were connecting ASV's each actuator to the power sources and can be triggered by emergency actuator's push button on the ASV's or emergency external remote.

E. *Software Architecture*

The software architecture of Nala Theseus uses Robot Operating System (ROS) [5]. Using ROS, the ASV software are designed to be loosely coupled ROS packages where each package conforms to the "single responsibility principle". This allows the ASV to easily use custom ROS packages from the previous RoboBoat Competitions and have the development and testing of the ROS packages done individually. With this, the software development time can be shortened.

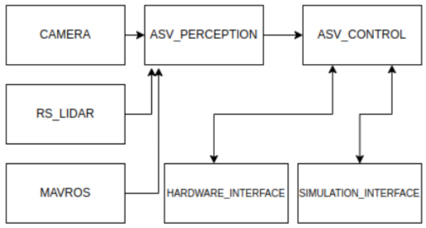


Fig. 6 Nala Theseus Software Architecture

The ROS packages deployed in Nala Theseus can be seen on Fig. 7. The *camera*, *rs_lidar*, and *mavros* are responsible for obtaining sensor readings from camera, LiDAR, and Pixhawk inertial sensors, respectively. *asv_perception* package would subscribe to the sensors stream data, fuse them, then publish information about the ASV and its surrounding objects information.

The *asv_control* is a package that is responsible for controlling the ASV action based on the prevailing environment around the ASV. This package subscribes topics published by *asv_perception* and publish the appropriate control command. These control commands will be subscribed by either *hardware_interface* or *simulation_interface*.

The *hardware_interface* package is responsible for forwarding the control commands from *asv_control* to the hardware, a microcontroller, using User Datagram Protocol (UDP). On the other hand, the *simulation_interface* forwards the control command to the ASV's Gazebo simulation environment that has been developed for the 2021 RoboBoat Competition [2]. With these 2 interface packages, the ASV could be tested in water and in simulation without changing anything in the codebase.

F. *Computer Vision*

Nala Theseus uses the same computer vision system as [2]. But, unlike the previous years' ASVs, Nala Theseus uses Jetson TX2 as its onboard computing device to minimize the ASV weight. Jetson TX2 has limited computing power, therefore a small but accurate and fast object detection algorithm is needed to be replaced. With such consideration in mind, Nala Theseus updated the object detector on computer vision system from YOLOv4 to YOLOv4-Tiny-3l.

YOLOv4-Tiny-3l is a slight modification of the YOLOv4-Tiny architecture. It uses 3 YOLO detection layer instead of 2 like the regular YOLOv4-Tiny [6]. Adding one more detection layer makes the neural network able to predict with 3 more anchor that can be specialized for small bounding boxes, making it able to detect small objects or objects that are far away.

III. EXPERIMENTAL RESULT

A. *Hull Characteristics*

In analyzing the performance, Nala Theseus is compared to Nala G4 (2019) in the simulation of resistance using Ansys Fluent and Response Amplitude Operator (RAO) using Maxsurf Motions. For each simulation, each model is simulated in speed of two knots or 1.033 m/s.

TABLE II. CFD SIMULATION RESULT

Model	Speed [m/s]	Resistance [N]	Volume Fraction
Nala G4 (2019)	1.033	-21.838	0.969
Nala Theseus (2022)	1.033	-19.008	0.947

Based on the results of the CFD simulation, it can be concluded that Nala Theseus' hull resistance is better than Nala G4's because it has a smaller resistance and volume fraction value in the same simulation conditions. The wave height data was also obtained earlier in the resistance analysis. RAO is a function that provides the amplitude value of the oscillatory motion of a vessel due to waves on a certain point [7]. In this analysis, the point that is used as the reference for calculating RAO is the camera (Appendix D), which the results are as follows:

TABLE III. RAO SIMULATION RESULT

Ship Model	Parameter	m0	Unit	RMS	Unit	Significant Amplitudo	Unit
Nala G4 (2019)	Abs. vertical motion	0.000643	m2	0.025	m	0.051	m
	Abs. vertical velocity	0.000458	m2/s2	0.021	m/s	0.043	m/s
	Abs. vertical acceleration	0.000869	m2/s4	0.029	m/s2	0.059	m/s2
Nala Theseus (2022)	Abs. vertical motion	0.000157	m2	0.013	m	0.025	m
	Abs. vertical velocity	0.000085	m2/s2	0.010	m/s	0.019	m/s
	Abs. vertical acceleration	0.000081	m2/s4	0.010	m/s2	0.021	m/s2

Based on the simulation results, the absolute vertical motion, velocity, and acceleration value on Nala Theseus are better than Nala G4 because the values are smaller so that the response to the force acting on the hull does not have a major effect to the camera on each wave encounter [8].

B. *Computer Vision*

Several YOLOv4 models were benchmarked on the onboard computer Nvidia Jetson TX2. The following benchmark shows that YOLOv4-tiny-3l is the perfect balance of speed and accuracy for the purpose of competing in Roboboat 2022.

TABLE IV. PERFORMANCE SEVERAL YOLOv4 MODELS

Model	FPS	mAP
YOLOv4	2.89	93.1
YOLOv4-tiny	15.59	81.12
YOLOv4-tiny-3l	15.89	84.4

C. *Propulsion and Control System*

The pivoting, orientation-locked motion, and path following control system was both tested on simulation and on water. All three-motion behaved as expected when running test on the Gazebo simulation environment. When running a water test, all motion also successfully followed the expected behavior except the orientation-locked motion. On water, the orientation-locked motion control has too long settling-time causing the ASV has its position changed before the orientation is locked.

D. *Ball Shooter*

The ball shooter was tested by repeatedly shooting ball. The ball shooter test was done in the land by checking the ball's drop location using black tint on a whiteboard, when the ball drops there, the tint was erased. The result was the ball drop around 1.95 m away from the ASV using 80 percent motor power and 30^{o} of shoot elevation. The deviation is shown at Fig. 8 which the ball drop location indicated by white area inside the black circle.

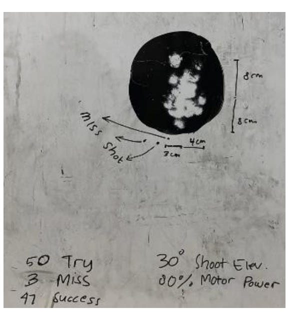


Fig. 7 Ball Shooter Drop Locations

E. *Water Blaster*

Water blaster was tested on the land assuming that the water blaster is in the best-case scenario which the ASV does not move at all. The ASV is located 1.5 m away from the water blast course while the water blaster hose is pointing at 154^{o} from the ball shooter start position. From this test, in average the ASV requires 16.53 seconds to fill the water blast's tank.

F. *Endurance*

The endurance of the ASV was tested at full throttle and half throttle to estimate the ASV's operation time. The result were 16 minutes at full throttle and 37 minutes at half throttle until the battery reached its safe minimum voltage at 3.7 V/cell. The battery capacity that is used in this testing was 8000 mAh. By this data, it can be concluded that the ASV may complete all the mission even on the worst case that the ASV is going full throttle all the time.

G. *Challenge Course Testing*

Fig. 8 Challenge course testing

A replica of the competition course was created in a local pond near the ASV development site. The team performed system integration test by attempting the autonomy challenges on water. So far, Nala Theseus has been assessed to successfully solve the mandatory Navigation Challenge, Snack Run, and Avoid the Crowds under several weather and light condition (Fig. 9).

IV. ACKNOWLEDGMENT

Barunastra ITS's research and achievement would not be possible without the help from various organizations and people. The team would like to express their deepest gratitude to the sponsors (Appendix E), including the Title Sponsor (ITS Robotics), Company Funding Support, Alumni and Donors.

VI. References

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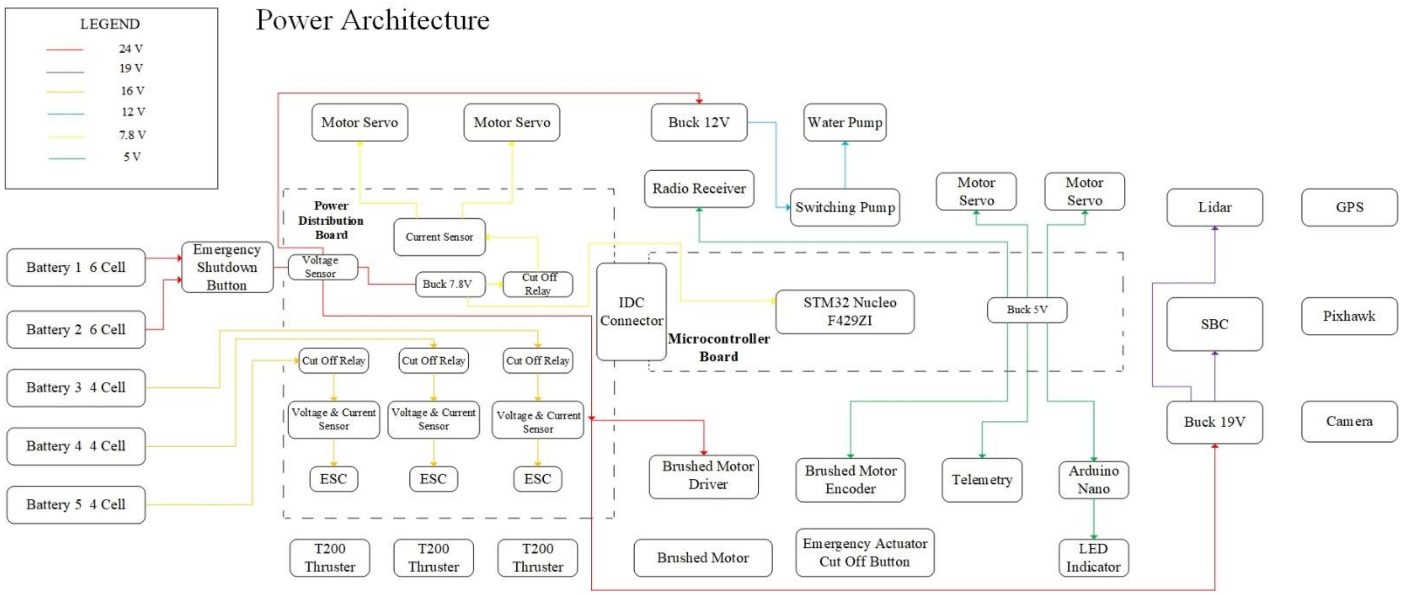
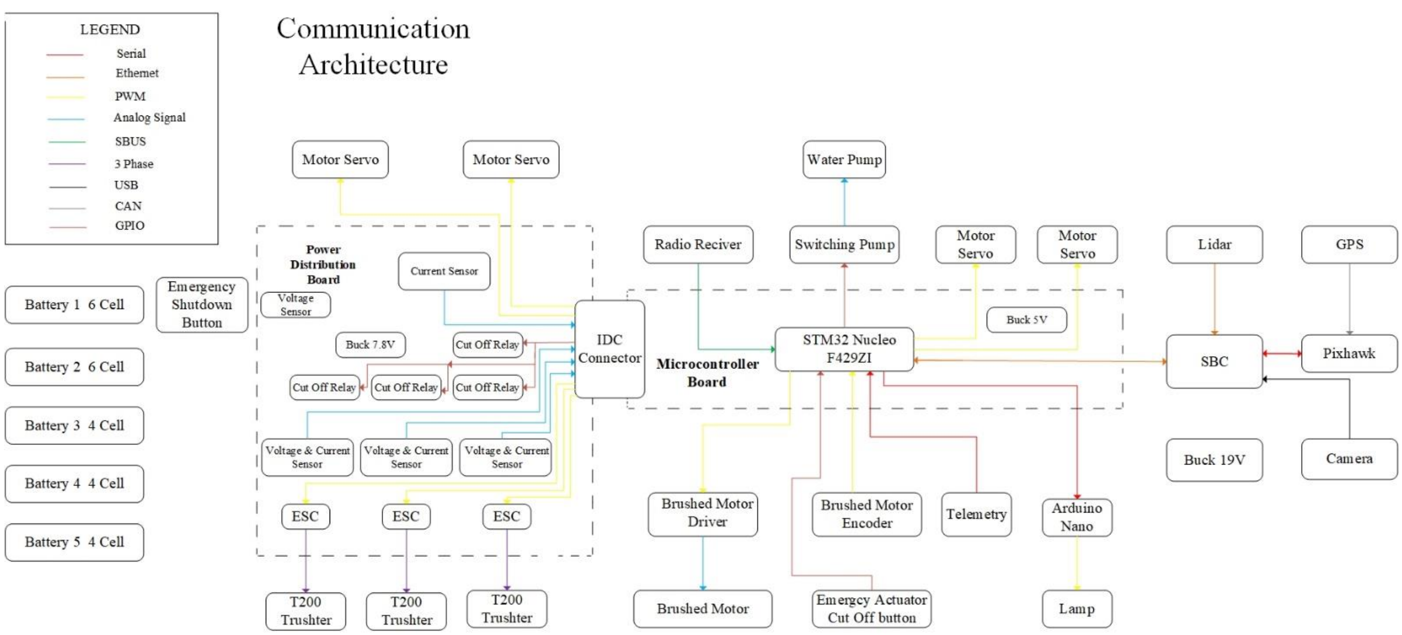
APPENDIX A: COMPONENT SPECIFICATION

Component	Vendor	Model/ Type	Specs	Custom/ Purcashed	Cost	Year of Purchase
ASV Hull Form/Platform	Barunastra ITS	Catamaran Hull	Fiber Glass with LOA = 88 cm, Breadth = 70 cm, Height (Hull only) = 21 cm. Total Height = 80 cm, Draft = 14 cm, Displacement = 26,5 kg.	Custom	$272.00	2022
Waterproof Connectors	-	-	3P 20 mm waterproof aviation connector	Purchased	$6	2022
Propulsion	Blue Robotics	T200	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Purchased	$179.00	2021
Propulsion (Mover)	Savox	SB-2290SG	https://www.savoxusa.com/products/savsb2290sg-monster-torque-black-edition	Purchased	$178.00	2020
Power System	Tattu	-	4S 8000 mAh 15C Li-Po Battery	Purchased	$129.00	2020
Power System	Onbo	-	6S 5200 mAh 25C Li-Po Battery	Purchased	$68.00	2020
Motor Controls	Blue Robotics	Basic ESC	https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Purchased	$27.00	2021
CPU	Nvidia	Jetson TX2	https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/jetson-tx2/	Purchased	$849.00	2019
Teleoperation	Radiolink	AT9s Pro + R9DS	https://www.radiolink.com/at9spro	Purchased	$170	2021
Compass & Global Positioning System (GPS)	Cubepilot	Here3	https://docs.cubepilot.org/user-guides/here-3/here-3-manual#specification	Purchased	$160	2022
Inertial Navigation Unit (INS)	Cubepilot	Cube Orange	https://www.cubepilot.com/#/cube/specs	Purchased	$328	2022
Camera	Logitech	C930e	https://www.logitech.com/en-us/products/webcams/c930e-business-webcam.960-000971.html#specs	Purchased	$103	2020
LiDAR	LeiShen	LS-N301	https://www.leishenlidar.com/wp-content/uploads/2020/12/N301-specification.pdf	Purchased	$848	2022
LED Indicator(s)	Adafruit	NeoPixel	https://www.digikey.com/catalog/en/partgroup/flexible-8x8-neopixel-rgb-led-matrix/73472#datasheets	Purchased	$6	2022
Water Pump(s)	-	-	DC 12V Water Pump 8W	Purchased	$5	2022
Mini Servo(s)	Emax	ES08MA	https://emaxmodel.com/products/emax-es08ma-ii-12g-mini-metal-gear-analog-servo-for-rc-model-robot-pwm-servo	Purchased	$8	2022
Algorithms	Barunastra ITS	-	-	-	-	-

Object Detection	YOLOv4	Tiny-3l	-	-	-	-
Image Processing	OpenCV	-	-	-	-	-
Open-Source Software	ROS	Melodic	-	-	-	-

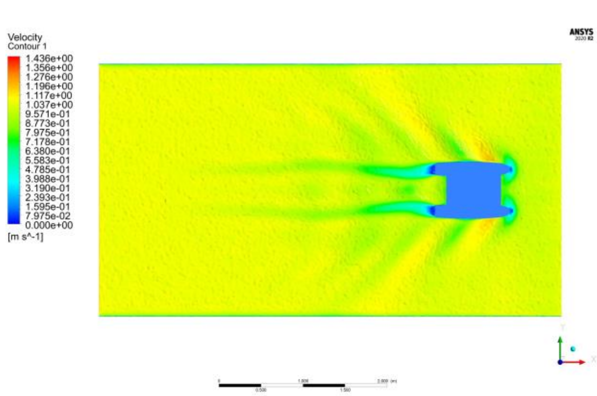
APPENDIX B: ELECTRICAL ARCHITECTURE

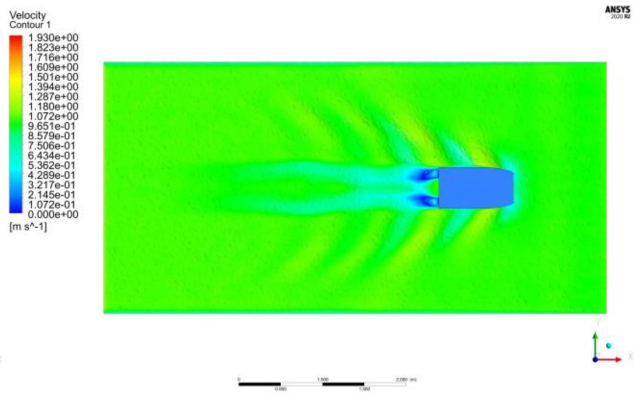




APPENDIX C: RESISTANCE ANALYSIS USING CFD

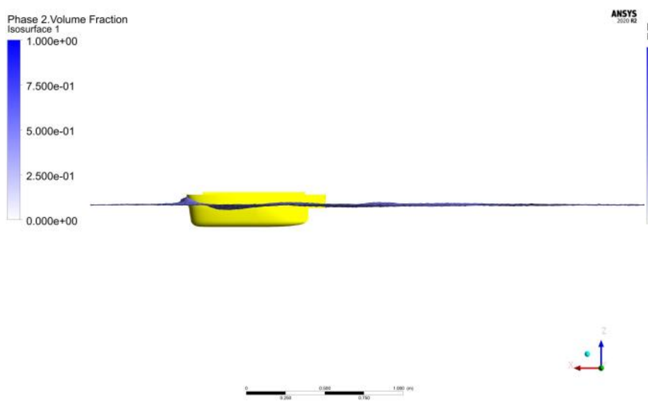
Resistance Analysis

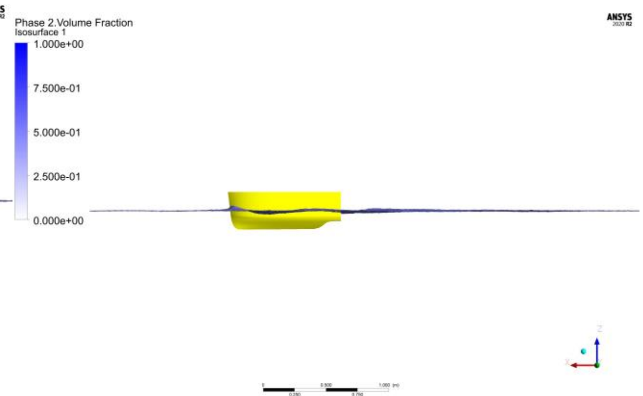




Nala Theseus (2022) Nala G4 (2019)

Wave Height Profile





Nala Theseus (2022) Nala G4 (2019)

APPENDIX D: CAMERA COORDINATE

Model	Long. Pos. [m]	Trans. Pos. [m]	Vert. Pos. [m]
Nala G4 (2019)	0.825	0.000	0.502
Nala Theseus (2022)	0.605	0.000	0.700

APPENDIX E: SPONSORS

A. Title Sponsors

Institut Teknologi Sepuluh Nopember (ITS Robotics) — For their financial support, equipment procurement, and academic support in our research.

B. Company Funding Support

Telkom Indonesia, Samudera Indonesia, Biro Klasifikasi Indonesia (BKI), Algas Mitra Sejati, Petrokimia Gresik, and Cumawis (Samudera Indonesia Group) — For their financial support.

C. Alumni and Donors

ITS alumni and donors — For their financial support and technical guidance.