RoboBoat 2022: Technical Design Report Gamantaray Roboboat Team

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Abstract—**To participate in the annual international RoboBoat competition (IRC) 2022, the Gamantaray team proposed Bandeng as an ASV (Autonomous Surface Vehicle) designed to compete in IRC; the ASV can operate autonomously and recognize its environment. Using a catamaran hull, Bandeng has lower frictional resistance, better buoyancy, and maneuverability than any other hull. Using a combination of GPS and ultrasonic sensors supported by a vision system YOLOv4-tiny speeds up the object detection process and increases the ship's accuracy in sensing and recognizing its environment. The mission planner acts as a GUI and GCS will be the interface to set the direction of the ASV. Using Kalman Filter has proven to have more significant accuracy than raw output sensor. The Kalman Filter reduces noise and increases sensor accuracy in detecting objects and adjusting the safe distance of the ship from surrounding objects. The shooting actuator system uses ultrasonic sensors to adjust the servo angle by changing the distance with an interval of 100cm and YOLOv4-tiny as object identification to ensure the mission can finish successfully.**

Keywords—ASV, Catamaran, Vehicle Control System, YOLOv4-tiny, Kalman Filter

I. INTRODUCTION

Bandeng is the first autonomous vehicle designed and built by Gamantaray as the first participation of Universitas Gadjah Mada in the annual international Roboboat competition of 2022. The long journey in developing Bandeng has gone through a lot of research and related experiments conducted by Gamantaray UGM, especially by our technical and non-technical teams, to build the best version of the autonomous vehicle.

II. COMPETITION STRATEGY

A. Team Management

In International Roboboat 2022 Competition, the Gamantaray team assigned a leader to manage inter-divisional coordination. In addition, the leader receives suggestions from the supervisor and decides if necessary. The leader also determines each division's design, strategy, and work system. In manufacturing the vehicle, the Gamantaray team comprises two departments to do their respective tasks, the Technical and Non-technical department. The Technical department consists of the mechanic, electronic, and programmer divisions. The mechanic division is responsible for the ASV overall design, starting from hydrodynamics and analysis, manufacturing and assembly, and choosing the design. The electronic division determines specifications for each electronic component on the vehicle, sets up the wiring system, and maintains and takes care of the reliability and safety of electronic circuits on the ASV. The programmer division is in charge of creating an image processing program for ASV's navigation and control program for ASV's maneuvers.

The Non-technical department is responsible for all competition's administrative needs, such as Technical Design Report (TDR), Demonstration Video, and Team Website. This department consists of the manager, logistic, media and publication, admin and finance, and sponsorship division. The manager is responsible for teamwork's efficiency in production and reporting and monitoring the team's progress to achieve the target that has been arranged. The logistic division is responsible for all the technical needs, including purchasing components and equipment and rental places for ASV trials. Media and publication play a role in content production, such as graphic design, multimedia, and the team's website. Admin and finance manage the team's finances and itineraries during the competition. Sponsorship helps the team seek assistance, especially from external sources, usually in funding.

B. Mission Approach

Bandeng is equipped with vision and control technology using YOLOv4, GPS, Pixhawk, and Ultrasonic Sensors. In this competition, Bandeng demonstrated 3 of the 6 missions given by the 2022 RoboBoat committee, including snack run, skeeball game, water blast, and return to home.

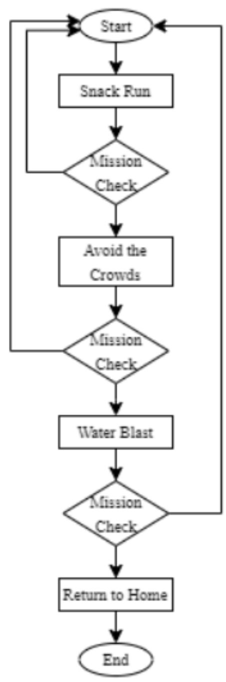


Fig. 1. Mission Flow Chart of Gamantaray Bandeng

1.) Snack Run

The first mission to demonstrate is a snack run. We made this decision based on the battery capacity required at full throttle thrust to perform the best ASV maneuvers. In achieving this mission, ASV uses a navigation system and object detection to recognize its environment and is supported by several setpoints. After the ASV detects two gate buoys, the GPS navigation system will set the ASV's destination point by creating a route around the blue buoys that the vision system has detected. The vision system will trigger the servo to turn the ASV around the blue buoy and direct it to the gate for the next mission.

2.) Avoid The Crowds

The next demonstrated mission is Avoid the Crowd. By using ASV's ability to sense and recognize its surrounding environment, ASV is expected to be able to detect multiple sets of gates designated by pairs of red and green buoys. We used both navigation and vision systems in running out this mission. The navigation system uses ultrasonic and GPS sensors to run the vehicle on track. In contrast, the vision system uses trained machine learning to detect buoys and maintain a distance between the ASV and the buoy.

3.) Water Blast

The third mission is a water blast. This mission required ASV’s ability in recognizing its surrounding environment and demonstrate ASV’s precise control and shooting. The ASV is expected to be able to detect targets and shoot water right at the target[1]. When the vision system detects a shooting target, the frame will send pixel data to the Arduino, which triggers a relay to launch the pump. To shoot water, we use a vertical servo which will aim at targets vertically.

4.) Return to Home

The last mission to achieve is return to home. after the ASV has completed all its assignments, it will return to the launch point (home) by passing through the gate created with 2 black buoys[1]. On its way back to the launch point, the ASV operates autonomously and avoids the surrounding obstacles by using its navigation and object detection system.

III. DESIGN CREATIVITY

Design is a crucial aspect of building an ASV. ASV's performance is also determined by the design that we make. In other words, design is an essential strategy in following a competition. Each part of the system that composes ASV will be explained in this chapter, including the software architecture, hull design and characteristics, vehicle control system, ASV recognition, and GUI (Graphic User Interface).

A. Software Architecture

The software architecture in Bandeng is divided into 2 parts, namely the navigation system and object detection system.

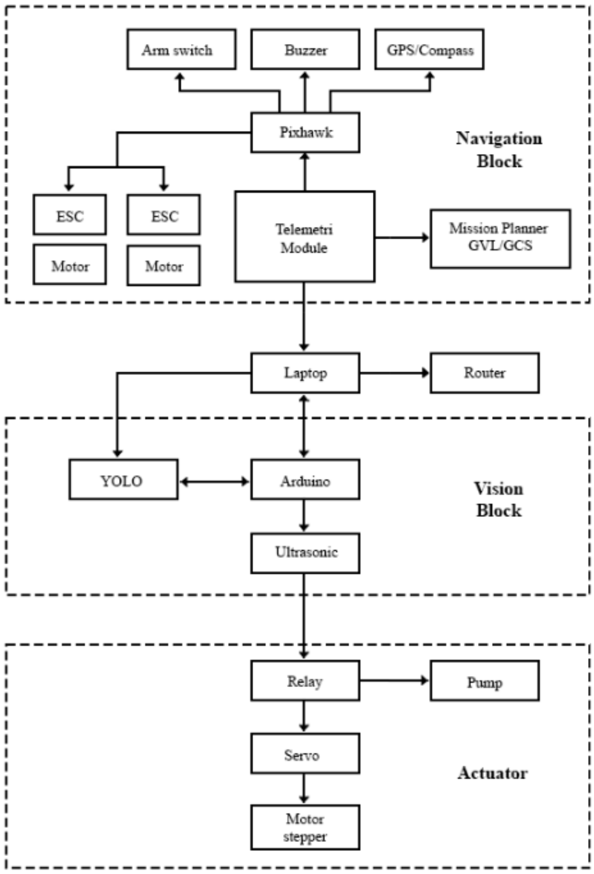


Fig. 2. Software Architecture

The navigation system used is the Pixhawk 2.4.6 flight controller connected to a GPS sensor. Data from the Pixhawk is transmitted via the telemetry module to the GCS (Ground Control System) on the laptop. Telemetry data can track the ASV status in real-time, allowing pilots to monitor its position, latitude, and longitude to ensure a smooth and efficient movement[2]. Pixhawk is also connected with an ARM switch, ESC (Electronic Speed Controller), and Motor Driver. The GPS sensor will get latitude and longitude data from ASV coordinates. These coordinates will be sent to the Pixhawk flight controller and processed to determine the next vehicle point.

B. Hull Design and Characteristic

To perform all missions on the International Roboboat of 2022, we require to build an ASV with good stability on the water. In addition, the ASV is expected to be able to maneuver quickly to complete the mission well. Bandeng is well-designed with a hull length of 110cm and a width of 50cm.

TABLE 1 MAIN DIMENSION OF GAMANTARAY BANDENG

ASV Dimension	
Length	110cm
Breadth	50cm
Height (Hull Only)	30cm
Displacement	26,06kg
DWL	15cm

Based on the dimensions and needs of the Roboboat 2022's mission, the catamaran hull type was chosen as Bandeng's hull. As a type of multihull, the catamaran consists of two hulls separated by a deck construction at a certain distance[3]. A catamaran hull type has several advantages compared to a monohull. A catamaran has lower frictional resistance so that the power required for the ASV to maneuver becomes smaller than using any other type of hull[4]. Also, a catamaran hull is considered to have better buoyancy and maneuverability than a monohull[5]. In addition, the deck between the two hulls is relatively spacious and can be used to store components to complete all missions[6].

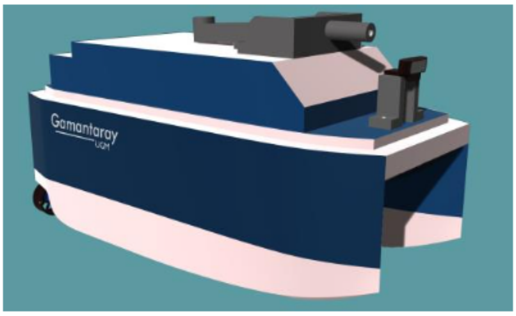


Fig. 3. Proposed Gamantaray Bandeng Design

The thruster T200 motor is known to have a maximum power of 390W (16V). No ship propulsion works with 100% efficiency[7], so in this calculation, it is assumed that the thruster motor operates with an efficiency of 70% and produces the following power values.

$$Hp = 70\% \times 390W \quad (1)$$

In making the ASV prototype, the hull is assumed to have a C value of 150, and the vehicle's weight value obtained from Maxsurf's data is 26.06kg. One method for estimating the speed of a ship is called Crouch's Planing Speed Formula. Then the speed of the ASV is obtained as follows.

$$Speed = \frac{C}{\sqrt{\frac{Lbs}{Hp}}} \quad (2)$$

From (2), the final result is the ASV speed when it is moving in a straight line is 5.353m/s. The value of C in the calculation is the value of the actual ASV, while what is calculated is the prototype ASV. So the calculation is only an approximation and not absolute.

In addition, the speed calculation is also carried out using the Maxsurf Resistance software with the slender body method. The speed results obtained are 2.4 m/s.

C. Vehicle Control System

The navigation system on Bandeng uses the Pixhawk 2.4.6 flight controller with the help of GPS and ultrasonic sensors. The ultrasonic sensor is chosen because it is easy to obtain, affordable, and reliable in completing missions. The ultrasonic sensor size is relatively small and straightforward to utilize in any mechanical technology project and has a brilliant non-contact range recognition between 20mm and 4m with a precision of 3mm[8]. When the ultrasonic sensor detects an object in front of it, it will send data to the Arduino, moving the servo to avoid and adjust the safe distance between the vehicle and the object. Ultrasonic sensors also play a role in adjusting the angle and detecting the shooting area with the help of a vision system that detects objects using machine learning algorithms.

Next up is the shooting actuator system. On the Gamantaray Bandeng, there are 2 (two) shooting systems, where a vision system and ultrasonic sensors assist both firing systems on the ship. The shooting system used for skeeball missions and water blast missions uses the help of a stepper motor as an actuator to move the catapult arm in throwing the ball toward the target. A stepper motor is used because of their high reliability, low cost, high torque at low speeds, and simple construction that operates in almost every environment[9]. The shooting system on the water blast mission uses a water pump to pump water from the environment, activated by a relay. Based on the vision system that detects the target, the ultrasonic sensor will adjust the servo angle in aiming at the target and shoot water through the nozzle.

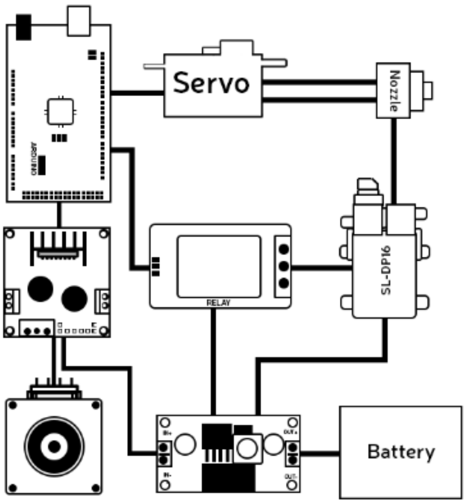


Fig. 4. Shooting Actuator System Diagram

In a dynamic system, there is uncertain information, such as the ultrasonic sensor output, where there is still much noise. Using the Kalman Filter algorithm to produce accurate and clean output is necessary. Kalman filter is a technique used to estimate a parameter's value at a particular time. The Kalman filter technique is used to obtain an estimated state value by reducing noise using previously obtained data so that the ASV can shoot accurately and on time.

D. ASV Recognition

For computer vision, we use the YOLOv4-tiny architecture to implement custom object detection. YOLOv4-tiny is a lightweight version of the YOLOv4 we used in our previous tests. Based on the earlier trials and several studies, YOLOv4 requires mighty GPU computing power to realize real-time object detection for multiple mobile devices and embedded devices. To solve the problem, we use a lightweight method, YOLOv4-tiny. The YOLOv4-tiny method is designed based on the YOLOv4 to have a faster object detection speed. It has a relatively more unimplicated network structure and fewer parameters. Although they have lower detection accuracy, the accuracy can meet actual demands[10].

YOLOv4-tiny has sufficient capability for our algorithm. In addition, the use of YOLOv4-tiny is based on the device we use to get optimal results. The dataset that we use is obtained from internal data. With a custom dataset, we hope that the algorithm will work optimally and improve the accuracy of the Map.

Fig. 5. Dataset Sample Labelling

E. Graphic User Interface

The Graphic User Interface (GUI) used by Bandeng is a mission planner. The mission planner acts as a GUI as well as a GCS (Ground Control System) which will determine the waypoints on the vehicle[11]. The mission planner will set its parameters and then upload it to Pixhawk so that the ASV can move according to the specified waypoint.

Fig. 6. Mission Planner Interface

IV. Experimental Result

A. Hull Performance

We use Maxsurf software to determine the displacement and DWL of the ASV. We also do trials to ensure the calculation results from the software are similar to actual conditions.

In the Maxsurf software, we get the ASV's displacement is about 26kg with a DWL of 15cm. When ASV was tested and observed, we found out that the DWL was about 11cm. The ASV's displacement difference also caused the difference in DWL. The decrease in the DWL value indicates that the displacement of the ASV is less than 26kg, so the DWL value also decreases.

Table 2 Hull Dimension Comparison

ASV Dimension		
Characteristic	***Design***	***Manufactured***
Length	110 cm	110,5 cm
Breadth	50 cm	50 cm
Height (Hull Only)	30 cm	33 cm
Displacement	26,06 kg	24 kg
Draught Waterline Length (DWL)	15 cm	11 cm

The stability calculation of ASV Gamantaray Bandeng was run using the Maxsurf Stability Advance software simulation software. One of the parameters generated from the simulation is the Righting Lever (GZ) which is represented in the form of a curve. Based on this curve, the maximum GZ value of the ship design is 12.95cm at an angle of 33.6 degrees. The resulting angle has met the criteria set by the International Marine Organization (IMO), which is greater than 25 degrees.

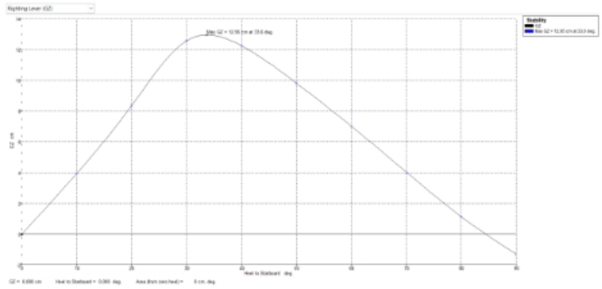


Fig. 7. The GZ Curve from the Stability Simulation

The ASV stability test is carried out by applying pressure to one side of the ASV so that the ASV will experience a slope at a certain angle. From the stability test, the maximum slope of the vehicle so that it can still return to the initial slope is 30 degrees. These results indicate that the ASV has good stability and is suited to the simulated design plan.

Fig. 8. ASV Manual Stability Test

For ASV resistance analysis, we run the simulation using Maxsurf Resistance software. Since we used a catamaran-type hull, the method we use is the slender body. The simulation is run at a speed range of 0-10m/s. In Fig. 9, the resistance increases significantly from 0 to 2.5m/s with a resistance of 158,350N. At a speed of 2.5-10m/s, the resistance increases slowly.

The ASV went straight for 18 meters in the speed test and took 18 seconds. Based on these results, the ASV's average speed is 1 m/s. These results show the difference between the trial and the simulation. The difference in value occurs because of the maximum speed limit that has been set in the program. Speed limiting is used to obtain a stable and safe vehicle movement so that the ASV's components are safe if there is an accident during the trial.

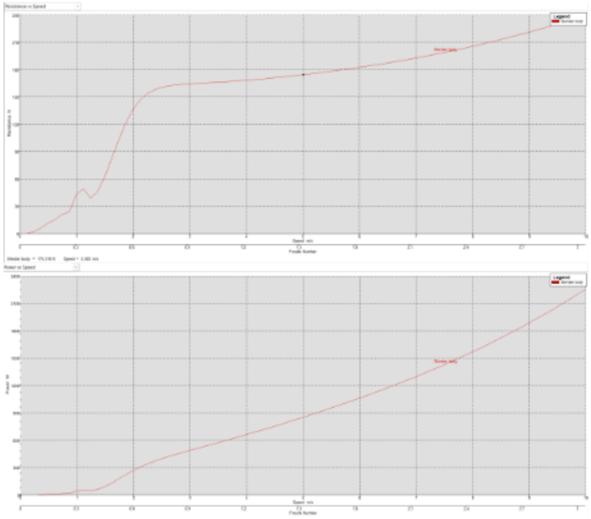


Fig. 9. Resistance Curve Both in ASV Simulation and Trial

B. Computer Vision Performance

In selecting the method for object detection, we tested 2 (two) types of architecture, namely YOLOv4 and YOLOv4-tiny, using input from a portable webcam. The test was run using two different devices, namely Intel NUC i7 and Lenovo Legion 5 laptops with each processor Intel i7 11 series CPU and GTX 1650 8GB GPU.

TABLE 3 MODEL COMPARISON OF YOLOV4 AND YOLOV4-TINY

Method	FPS	mAP(%)
YOLOv4	15.6	60,4
YOLOv4-tiny	36.8	96,2

TABLE 4 DEVICE COMPARISON OF INTEL NUC I7 AND LENOVO LEGION 5

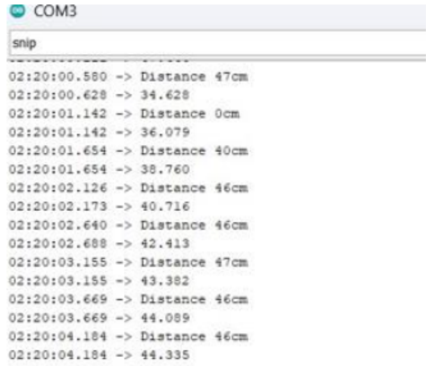
Device	FPS
Intel i7 11 series CPU	20-25
GTX 1650 8GB GPU	36

Table 3 and 4 compares each architecture and device used in the test. In the table, YOLOv4-tiny has higher accuracy and FPS values when running vision algorithms on portable devices. Meanwhile, device testing using Intel NUC i7 and Lenovo Legion 5 laptops only resulted in a difference of 6-10fps. The Intel NUC i7 has a slightly higher fps value than the Lenovo Legion 5, so we decided to use the Intel NUC i7, which has the latest processor from Intel.

Fig. 10. Mission Flow Chart of Gamantaray Bandeng

C. Sensing Performance

The ultrasonic sensor data recorded on the Arduino serial monitor shows the presence of noise that affects the sensor's accuracy. In Fig. 11, the sensor data appears to vary with a range of 1-10cm.

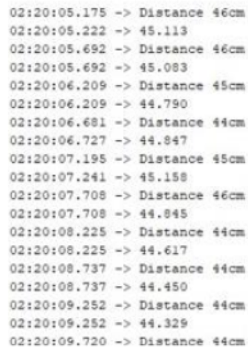


COM3

snip

```
02:20:00.580 -> Distance 47cm
02:20:00.628 -> 34.628
02:20:01.142 -> Distance 0cm
02:20:01.142 -> 36.079
02:20:01.654 -> Distance 40cm
02:20:01.654 -> 38.760
02:20:02.126 -> Distance 46cm
02:20:02.173 -> 40.716
02:20:02.640 -> Distance 46cm
02:20:02.688 -> 42.413
02:20:03.155 -> Distance 47cm
02:20:03.155 -> 43.382
02:20:03.669 -> Distance 46cm
02:20:03.669 -> 44.089
02:20:04.184 -> Distance 46cm
02:20:04.184 -> 44.335
```

Fig. 11. Ultrasonic Sensor Data Before using Kalman Filter



```
02:20:05.175 -> Distance 46cm
02:20:05.222 -> 45.113
02:20:05.692 -> Distance 46cm
02:20:05.692 -> 45.083
02:20:06.209 -> Distance 45cm
02:20:06.209 -> 44.790
02:20:06.681 -> Distance 44cm
02:20:06.727 -> 44.847
02:20:07.195 -> Distance 45cm
02:20:07.241 -> 45.158
02:20:07.708 -> Distance 46cm
02:20:07.708 -> 44.845
02:20:08.225 -> Distance 44cm
02:20:08.225 -> 44.617
02:20:08.737 -> Distance 44cm
02:20:08.737 -> 44.450
02:20:09.252 -> Distance 44cm
02:20:09.252 -> 44.329
02:20:09.720 -> Distance 44cm
```

Fig. 12. Ultrasonic Sensor Data After using Kalman Filter

We use the Kalman Filter method to overcome these disturbances, filtering sensor data and improving its accuracy so that the ASV can carry out missions optimally. Using the Kalman filter, we found that the resulting data has a not too much difference, around 1-5cm, and will directly increase the accuracy of the navigation and firing systems on the ASV.

D. Shooting System Performance

The identification process in object detection is run according to the data that has been trained. The ultrasonic sensor will measure the distance between the ASV and the object and send data to the Arduino Mega microcontroller. The distance data between ASV and shooting objects are useful in configuring the servo angle during skeeball and water blast missions to estimate the target position using an if-else statement every 100cm.

When the distance increases with intervals of 100cm, the angle on the servo will increase by 30 degrees, and vice versa. Then trigger the relay to turn on the pump according to the predetermined time.

At first, we wanted to do a skeeball mission, but there was an error where the attached catapult arm was still not long enough, so the ball couldn't be ejected perfectly. When we tried to replace the catapult arm with a longer size, the available space was not enough, and the stepper motor used was not able to withstand the load and rotate the catapult arm optimally.

V. Conclusion

Gamantaray Bandeng is the first representative from the Gamantaray Team of Universitas Gadjah Mada in the annual international RoboBoat 2022 competition. Gamantaray Bandeng is an ASV that is designed to run autonomously and able to detect its surrounding environment. In the RoboBoat 2022 competition, we focused on 4 of 6 missions: snack run, avoid the crowds, water blast, and return to home. Bandeng has 2 main systems, a navigation and object detection system. ASV navigation system used a combination of GPS and ultrasonic sensors connected to the Pixhawk 2.4.6. The telemetry module will transmit data from these sensors to the Mission Planner. Besides being a GUI (Graphic User Interface), the mission planner becomes a GCS (Ground Control System) that uses MAVLINK as a communication protocol. To run the main ASV navigation system, we used the flight controller Pixhawk 2.4.6. A tuning system and parameters are needed to make the ASV's movement smoother. The PID system is used to regulate the ship's turn rate and speed and keep the ASV within the parameters that have been applied.

The next main system is the object detection system. The algorithm used in detecting objects is a machine learning algorithm with a 1-stage CNN model, namely YOLOv4. The consideration of using the YOLOv4 algorithm is the high level of object detection accuracy and relatively fast detection time. The YOLOv4 model that we used is YOLOv4-tiny. The advantages of YOLOv4-tiny compared to YOLOv4 are that YOLOv4-tiny is lighter and has a faster fps even though it is running on devices with limited specifications and relatively low power consumption. The vision system for object detection is assisted using additional sensors, such as the ultrasonic sensor HC-SR 04, where the Kalman Filter is applied to increase the level of accuracy, reduce noise in the data, and refine data readings so that the ASV can maneuver and run shooting missions optimally. Gamantaray Bandeng has specifications of length 110cm, height 33cm, width 50cm, draft 10cm, breadth 24cm, and DWL 11cm. The ASV moves with the assistance of a thruster that works differentially. Gamantaray Bandeng has been designed and built according to the requirements and standards of the 2022 RoboBoat committee and trialed to ensure the vehicle can carry out its mission well. We always try to improve the capabilities and quality of our ASV through continuous research, development, and testing.

Acknowledgment

We would like to express our appreciation to the members of the Gamantaray Team for their hard work throughout the project. Furthermore, we are also grateful for the help and support provided by our supervisors, the Faculty of Engineering, Faculty of Mathematics and Natural Sciences, Vocational College, and Universitas Gadjah Mada. Other than that, this project would not be possible without the contribution and generosity of our sponsors. So, our gratitude also goes to our sponsors.

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APPENDIX A: COMPONENT SPECIFICATION

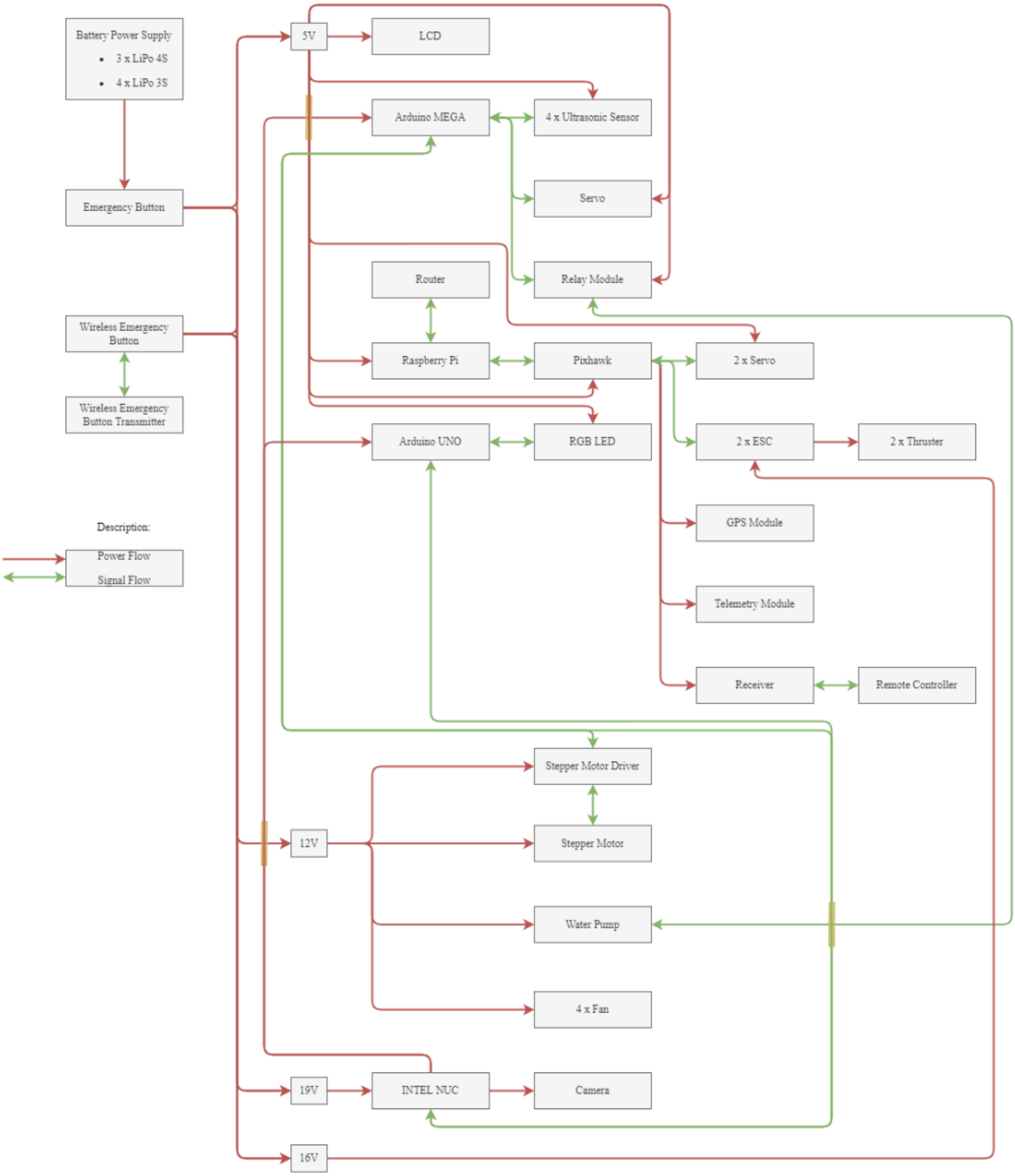

Fig. A Electrical Diagram

TABLE. A Component Specification

Component	Vendor	Model	Specification	Cost (USD)	Status
ASV HULL PLATFORM	Handmade, Plywood	Catamaran	LOA = 1.1m , H=0.3 m , B=0.5 m , T=0.15m	500	NEW
PROPULSION	Blue Robotics	T200	5.25 kgf	200	OLD
CPU	INTEL	NUC 10I7FNH	Intel® Core™ i7-10710U Processor	715	NEW
TELEOPERATION	TP LINK	TL-MR100	Interface 1 10/100Mbps LAN Port, 1 10/100Mbps LAN/WAN Port, 1 Micro SIM Card Slot Button WPS/Reset Button External Power Supply(EU) 9V/0.85A Dimensions (W x D x H) 6.06×4.49×1.42 in (154×114×36 mm) Antenna 2 Detachable External 4G LTE Antenna	53,1	NEW
COMPASS / GPS	UBLOX	M8N	Receiver type 72- channel u-blox M8 engine GPS/QZSS L1 C/A, GLONASS L10F, BeiDou B1 SBAS L1 C/A: WAAS, EGNOS, MSAS Galileo-ready E1B/C (NEO-M8N)	25	NEW
CAMERA	Logitech	c920	HD 1080p	70	OLD
TELEMETRY	3DR	RADIO TELEMETRY 433 mhz	433Mhz frequency band , receiver sensitivity up to -117d , transmit powerr 100mW , data rates 250kbps	27,4	
BATTERY	ONBO	ONBO 4S 10000 mAH 25 C	Typical Capacity : 10.000mAh Typical Voltage: 14.8V Dimensions: 168mm x 60mm x 43mm Approx Weight: 886 gram Continuous Discharge Current: 25C(250A) Burst Discharge Current: 50C(500A)	98,5	NEW
	ONBO	ONBO 4S 16000 mAH 30 C	Typical capacity : 16000mAh Typical Voltage: 14.8V Dimensions: 195mm x 76mm x 47mm Approx Weight: 1368 gram Continuous Discharge Current: 30C (480A)	287,4	NEW
	TATTU	TATTU 3S 5200 mAH 35C	Minimum Capacity : 5200mAh Configuration : 3S1P / 11.1V / 3 sel Continuous Discharge Current: 35C Max Burst Discharge Rate: 70C Weight (20g): 338g Dimension: 132mm x 44.5mm x 26.5mm (LWH) Connector Type: JST-XHR-4P	26,3	NEW
	ONBO	ONBO 3S 2200 mAH 25 C	Typical capacity : 2200mAh Typical Voltage: 11.1V Dimensions: 111mm x 35mm x 23mm Approx Weight:179g Continuous Discharge Current: 25C(55A) Burst Discharge Current: 50C(110A)	27,37	NEW

	ONBO	ONBO 3S 5200 mAH 25 C	Typical capacity : 5200mAh Typical Voltage: 11.1V Dimensions: 149mm x 43mm x 31mm Approx Weight:375g Continuous Discharge Current: 25C(130A) Burst Discharge Current: 50C(260A)	46,60	NEW
SENSOR	HC-SR	HC-SR 04	Operating Voltage : 5 V Operating Current : 15mA Operating Frequency : 40KHz Measuring Range : 2 cm - 400 cm Measuring Angle : 15 degrees	5	NEW
RADIO RECEIVER	FLYSKY	FS-I6B	Channel: 6 Frequency Range: 2.4055--2.475GHZ Band Width Number: 140 Transmitting Power: 20dBm RF Receiver Sensitivity: -105dbm	45	NEW
RADIO TRANSMITTER	FLYSKY	FS-I6	Channels: 6 Channels Model Type: Glider/Heli/Airplane RF Range: 2.40-2.48GHz bandwidth: 500KHz band: 142 RF Power: Less Than 20dBm 2.4ghz System: AFHDS 2A and AFHDS Code Type: GFSK Sensitivity: 1024 Low Voltage Warning: less than 4.2V DSC Port: PS2;Output:PPM		OLD
NAVIGATION	Pixhawk	PIXHAWK 2	32-bit ARM Cortex M4 core with FPU	75	OLD
PROGRAMMING LANGUAGE					C/C++ , Python
TESTING TIME (simulation)					3 WEEKS
TESTING TIME (in water)					2 WEEKS
ALGORITHM					SELF DEVEL OPED ,
VISION	darknet	YOLOv4-tiny			YOLOV 4 , OPENC V
INTER - VEHICLE		RF			4R