Roboboat 2022: Technical design report

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Abstract

The boat designed by team Vyuha representing Bannari Amman Institute of technology features SWASH type hull design to overcome the challenges in Roboboat 2022 competition. The team aims to build a boat with optimal dimensional and design features to achieve the best possible results in the event. The team worked on to clear the first three tasks due to the time constraints along with the design and feasible manufacturing techniques to reduce the cost factor. The boat was designed and developed to provide better stability, quick recognition over the environment and obstacles, quick reaction, better maneuverability and control. The team developed the boat with these design features to exhibit a good performance to compete in the Roboboat 2022 event.

Competition strategy

The main motive of team Vyuha is to design and develop a boat which is very effective in the roboboat 2022 event. Being the first time in the roboboat event the team aims to design and manufacture an effective model to compete, and due to the time constraints, the team aims to clear first three tasks.

Design Creativity

A. Hull design:

A SWASH type hull was preferred for the ASV (Autonomous surface vehicle) as they have higher stability against water current. The SWASH hull can also provide better maneuverability and it is wave resistant which is quite crucial for an autonomous boat. The boat was designed using the solidworks software where the primary focus was on the weight, drag, stability and maneuverability. The boat was designed in such a way that it can be very effective in the given tasks considering the path, work and dimensional constraints.

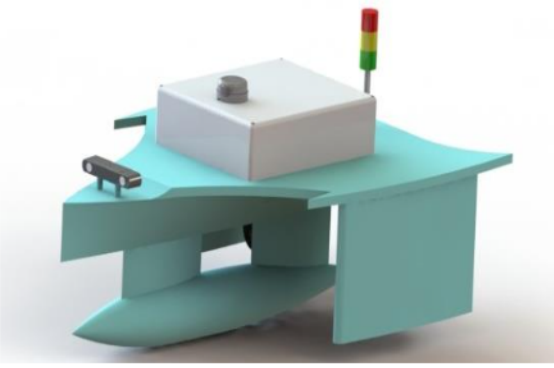

Fig.1 Hull Design

Table 1:

Length(mm)	Height(mm)	Width (mm)	Draft(mm)
1010	450	700	200

The submerged part of the boat was made to be hollow in order to improve the buoyancy along within such a way that the drag the side supporting studs.

Table 2:

Buoyancy	
Volume of boat	62737533 cm^3
Weight of boat	25.56 lbs.

The hollow submerged hull part was designed in such a way that the drag remains lesser. Also, the supporting studs and the attachment studs from the main hull to the submerged hulls are designed with hydro foil concepts. The main hull is designed with a sharp curve in order to tear off the fluids hence reduces the drag force. The main hull is attached with the submerged hull with two hydrodynamically designed studs in order to provide better maneuverability as the water can flow between the studs while making a turn. The placement of support studs was based on the area required to place the propulsion system components. Also, the design was made by considering the parameters like prismatic coefficient, midship coefficient and other similar parameters.

Table 3:

Coefficients	Values	Standard Values
Prismatic coefficient	0.62	0.61
Midship coefficient	0.68	0.78
Waterplane coefficient	0.235	0.71

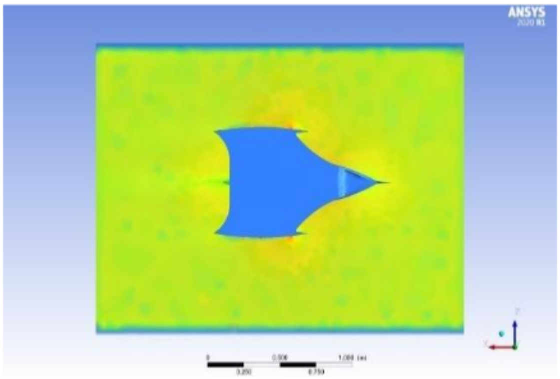

Fig.2(a) Hydrodynamic Analysis

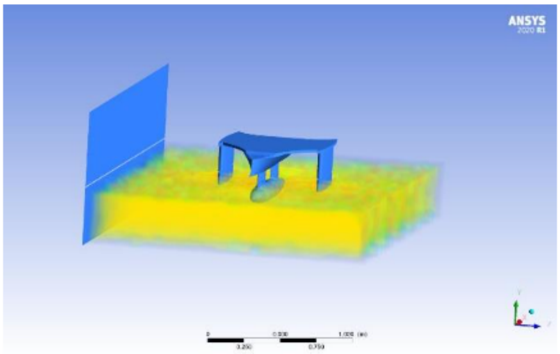

Fig.2(b) Hydrodynamic Analysis

The model was analyzed with Ansys with a movement speed of 5 m/s and ended up with good results.

B. Control System

Controller Architecture:

Pixhawk is an open-source autopilot system designed to control any unmanned autonomous vehicle such as rovers, drones and submarines. Our control system has utilized the Pixhawk 2.4.8 Microcontroller as the internal architecture itself consists of an IMU sensor, Magnetometer and a gyroscope. The GPS is externally interfaced with the controller which has a major role in our ASV for waypoint navigation and mapping which is performed in Ardupilot Mission Planner software. A Radio Control system composed of a transmitter and receiver module is embedded for the manual operation of the ASV. For autonomous operation of our ASV the Jetson nano computer has been used.

Sensor Units:

This team proposes the Pixhawk 2.4.8 autopilot with the rover configuration to control our boat. The boat has two sensor units to maximize the navigation development. Internal sensor units are built inside the boat controller and External sensor units are connected externally to the boat controller. Internal sensor unit consists sensors like Magnetometer, Accelerometer and Gyroscope. External sensor unit consists sensor like Global positioning system (GPS).

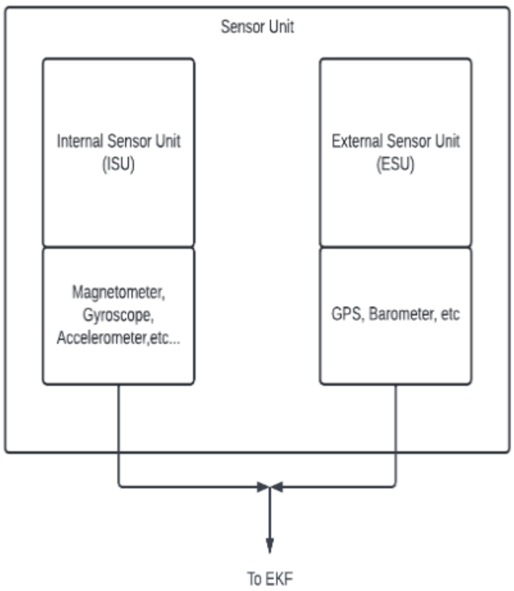

Fig.3 Sensor unit

Internal Sensor Unit (ISU)

Magnetometer is built and integrated into the main controller Pixhawk 2.4.8. By sensing the Earth's magnetic Field, this sensor will update information on the heading of the boat.

Accelerometer will sense and measure the acceleration forces acting on the boat to determine boat's position in space and monitor the boat's movement. By combining these sensors, a good navigation solution will be achieved to track the desired waypoint for the boat.

External Sensor Unit (ISU)

Global Positioning System (GPS) used in this boat will allow the boat to acquire its latitude and longitude point in real-time.

ASV Controller:

ASV controller is a core of our software design. The Extended Kalman Filter (EKF) is used to estimate boat's position, velocity, and angular orientation. By combining and fusing the data from ISU and ESU, EKF will produce the navigation solution on the boat. Data from the EKF will also be provided to L1 Control, which is the most powerful function for updating lateral acceleration on this vehicle. The lateral acceleration will be crucial for the PID controller in steering adjustment. So, that the boat may stay on the water at all times on the preferred path.

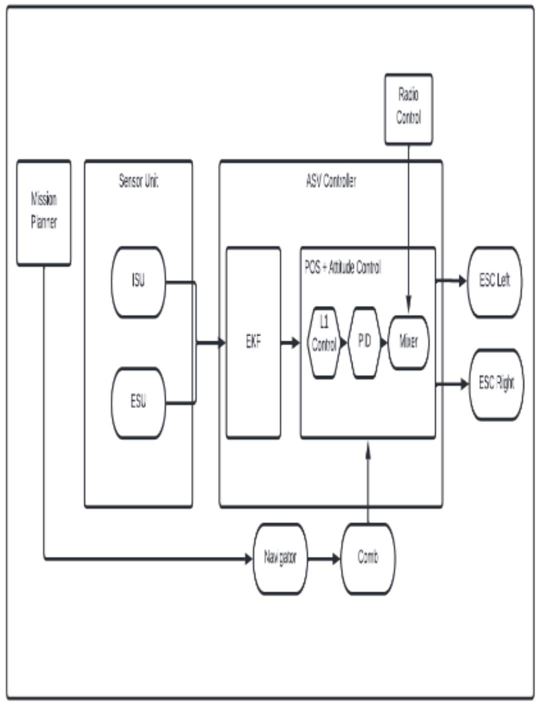

Fig.4 Software design

Position and Attitude control:

On the Block of Position and Attitude Control. The steering output for the ESC Motor will be determined by the L1 Control and PID Controller. With L1 Control, the AHRS and Waypoint computed from the EKF will be utilized to update the waypoint and provide the necessary acceleration.

Electrical architecture

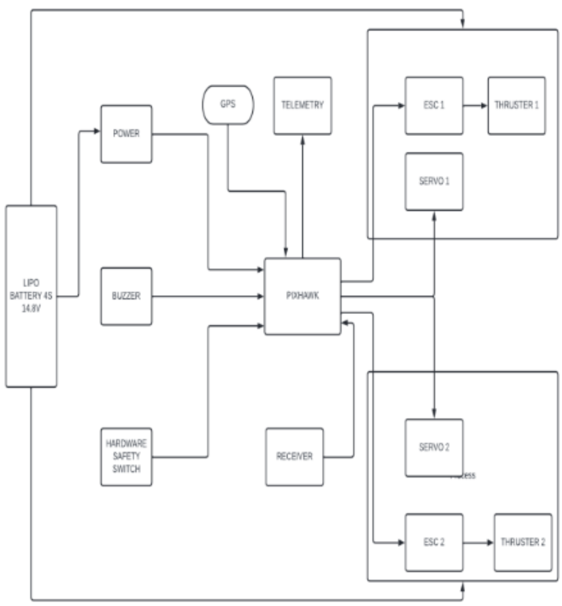

Fig.5 Electrical architecture

The Pixhawk which is an advanced autopilot designer has a handful of telemetry inputs such as GPS, Buzzer, Receiver, Hardware safety switch (which operates around 5V) and a power supply of 14.8v is step down to 5V(the power module provides a steady 5V to Pixhawk and allows the Pixhawk to measure the current and voltage of the main battery),Generally these input signals are given to Pixhawk ,After this process Pixhawk gives the control signal as output to the servo motors, electronic speed controller which operates around 8.2V and 14.8V,the servo and the thruster is connected through an axle shaft, so generally when the power supply is given the servo motor, the impact of rotation of the servo motor is transferred through the shaft to the thruster which results in the movement of the thruster.

C. Propulsion System

The system guarantees the continual output of ASV power and is an important part of the ASV. It consists of two direct-current (DC) brushless thrusters powered by a 16 V lithium-ion battery. The thrusters are equipped with two three-blade propellers with a diameter of 0.076 m, which are adjusted by two rotary speed controllers, respectively. The ASV contains a differential steering system and requires two inputs, n1 and n2 to regulate its heading direction, where n1 and n2 are the 2 propeller speeds in Revolutions Per Second (RPS). Electronic speed control controls the ASV velocity, and the differential speed controls the steering of the ASV.

Fig.6 *Propulsion System*

Obviously, line motion requires port and starboard thrusters to run at the identical speed, and the differential thrust is zero during this case. n_c and n_d represent the common mode and differential mode propeller speeds, respectively.

$$n = (n1 + n2)/2$$

$$n_d = (n1 - n2)$$

The ASV with the rudderless double thrusters must generate momentum by the differential thrust between the port and starboard propellers to vary the heading. During this process, the velocity of the ASV also changes. So, there's a coupling between the velocity and the yaw rate. In order to eliminate the results of coupling and maintain the rate of the ASV, $O_cX_cY_c$ must remain constant in any respect times, and $O_cX_cY_c$ changes around zero reckoning on the direction of the manoeuvre.

Three-DOF Dynamic Model

The availability of a sufficiently accurate ASV model enabling effective control design is imperative for both control methodology design and simulation study purposes. This requires a prior investigation of both a precise mathematical ASV model with reasonable system parameters. Generally, the study of a standard ASV dynamic model can be divided into two parts: *kinematics*, which treats only geometrical aspects of motion, and *kinetics*, which is the analysis of the forces causing the motion.

Fail safe mechanism:

In order to stop the motion of the boat during malfunctioning of the system, we use a kill switch to control its movement. In a fail-safe mechanism, we use transmitter-controlled regulation and Manual switch-based regulation to control the motor in case of fault. By interfacing the Arduino with the receiver, we get a continuous signal. The receiver and the manual switch are connected to the OR gate. The output of the

OR gate will control the relay. The relay passes the signal to the motor control. The motor will turn ON and OFF according to the signal received from the receiver and the manual switch.

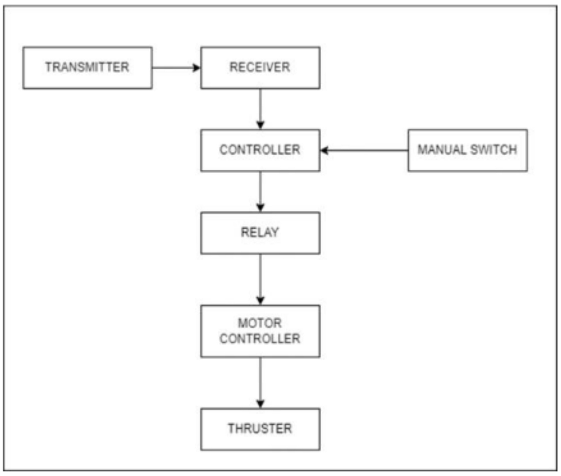

Fig.7 Fail safe mechanism

D. Computer Vision

Software Architecture:

We have used the Nvidia Jetson Tx2 nano as our on-board computer. This 7.5-watt single board computer on a module brings true AI computing to the edge. It features a variety of standard hardware interfaces that make it easy to integrate it into a wide range of products and form factors. For vision, we have used zed 2i, a stereo camera and LiDAR s2 to detect objects with spatial context and combine AI with 3D localization and consistent ranging resolution. To obtain the best of results, we planned the software architecture by considering these three parameters: Perception, planning and control.

Perception

In perception, we focus on integration of sensors and object detection. For object detection we used YOLOv5. It is a family of compound-scaled object detection models trained on the COCO dataset, and includes simple functionality for Test Time Augmentation (TTA), model assembling, hyperparameter evolution, and export to ONNX, CoreML and TFLite. The fusion of light detection and ranging (LiDAR) and camera data in real-time is important to enabling the depth of objects as well as the detection of objects at short and long distances and this has been achieved.

Planning

Using the data obtained from the perception sub-system, the vehicle performs behaviour planning wherein the most optimal behaviour to be adopted by the vehicle needs to be decided by predicting states of the vehicle as well as other dynamic objects in the environment into the future by certain prediction horizon Based on the planned behaviour, the motion planning module generates an optimal trajectory, considering the global plan as well as hard and soft motion constraints by working on various algorithms like *Voronoi Diagram , Cost Maps , State Lattices* and *Driving Corridor.*

Control

The control sub-system is responsible for accurately tracking the trajectory provided by the planning sub-system and for the same, we established the communication with NVidia jetson Tx2 and Pixhawk flight controller using serial communication by pymavlink and mavproxy for sending the commands to Pixhawk flight controller for ai based navigation.

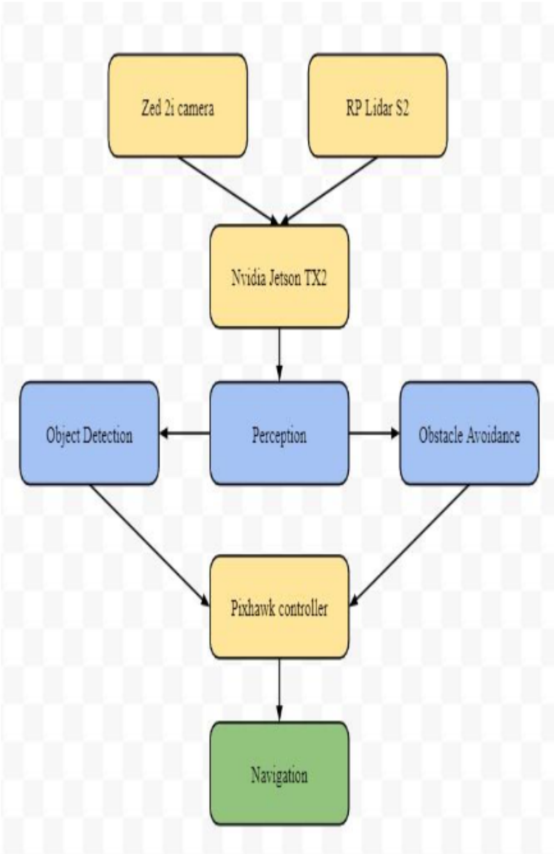

Fig.8 Software architecture

Experimental results

A. Control system

The experimental results of the proposed technique are presented in this section. The results of the trial include the required navigation channel, Avoid the Crowds, and Snack Run.

A. Mandatory Navigation Channel

Fig.9 Mandatory Navigation Channel

The boat must navigate between the gates without colliding with any of the buoys in the required navigation channel. According to the video, the boat navigates 6 feet away from the fence on its own. After adding several waypoints, the compass, GPS, and accelerometer automatically detect the navigation information (heading, longitude, and latitude) and update the changes (latitude and longitude). The L1 control and PID controller will utilize this information to alter speed and acceleration so that the boat stays on course. Furthermore. GPS data is used to create the visual user interface.

B. Avoid the Crowds:

Fig.10 Avoid the Crowds

The boat must navigate between the gates without colliding with any of the buoys in the required navigation channel. After adding several waypoints, the compass, GPS, and accelerometer automatically detect the navigation information (heading, longitude, and latitude) and update the changes (latitude and longitude). The L1 control and PID controller will utilize this information to alter speed and acceleration so that the boat stays on course. Furthermore. GPS data is used to create the visual user interface.

C. Snack Run:

Fig.11 Snack Run

The ASV's capacity to detect task aspects with object recognition and decision making is demonstrated in the Snack Run challenge. This job displays the efficiency of the hull form in conjunction with the propulsion system and the associated manoeuvrability. The ASV enters through gate buoys as rapidly as possible, circles the mark buoy (counter clockwise or clockwise), and escapes through the same gate buoys.

B. Propulsion System

The motion control problem for ASVs has been studied with a focus on those equipped with rudderless double thrusters due to their simple mechanical structure, flexible steering capability and some other associated benefits. It provides guidance for the modeling of general ASVs with rudderless double thrusters. Then, the model parameters were identified and verified through some standard motion measurements, including the acceleration test, circle test and zigzag test. Finally, based on the dynamic model, the Pixhawk control was employed to perform the path- following control of the ASV. Moreover, the controller could maintain good performance in both line and curve path-following. By consuming these advantages, we achieved the tasks mentioned by Roboboat competition.

System Identification and Experimental Validation

The goal of system identification is to obtain a simplified understanding of how the vehicle behaves, so that the control algorithm can accurately calculate control outputs to produce the desired vehicle response. System identification that requires a specific set of input time histories, extracts thrust and hydrodynamic parameters from standard motion measurements, which include the acceleration test, circle test and zigzag test. These tests are all open loop maneuverability tests. The data can be obtained from these tests by setting the speeds of the port and starboard propellers manually.

Simulink model:

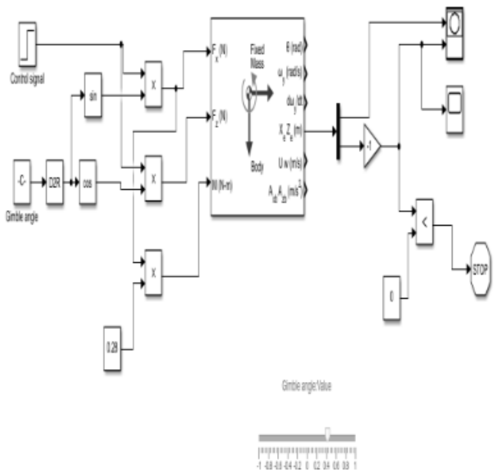

Fig.12 *Differential control*

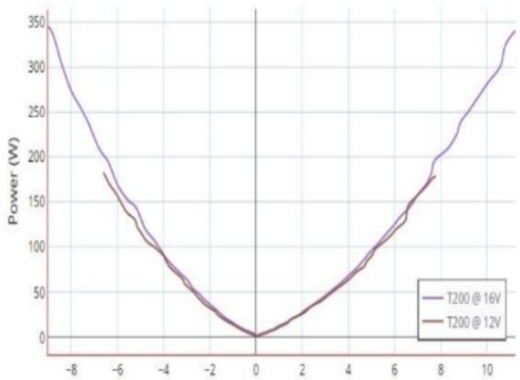

Fig.13 *Voltage – Power characteristics of T200*

Thruster Performance Experiment

In order to achieve motion control of the ASV, we need to know the relationship between control signal and the thrust on the ASV. For this test, the ASV was tied to a tension meter, connected to a fixed pole. Port and starboard thrusters were controlled by the same control signals to apply the thrust uniformly in the surge direction. When the line connecting the tension meter and the ASV was tight, that is, when the tension was stable, the tension meter reading could be obtained. The reading was the total thrust of the propulsion system. Three experiments were performed under the same experimental conditions, and the average of three readings of the tension meter was used as the final experimental result.

The corresponding thrust values under different control signals.

Table 4: PWM signal vs Thrust characteristics

PWM Signal (%)	0	10	15	23	32	39	45	52	63	69	74	81	92	99
Thrust (N)	0	12	15	25	33	40	45	53	64	70	75	80	93	100

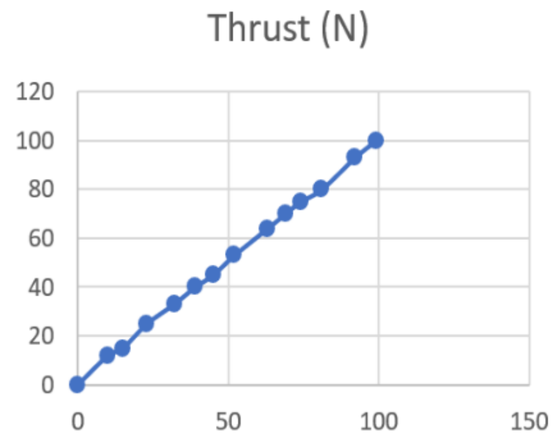

Fig.14 *Control signal and thrust characteristics.*

Fail safe

The result of the trial includes the required output like stop the boat using kill switch, switch ON and OFF control.

Failsafe working

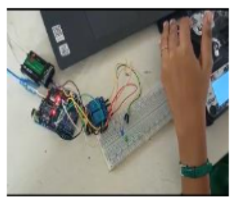
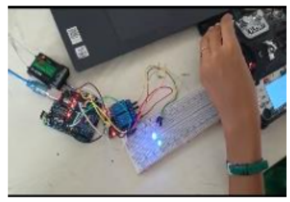

Fig.15 and Fig.16 Failsafe working

The action of the boat is completely stopped with the help of a kill switch. The connection of the kill switch process is given above. If the boat is crashed, the kill switch can be used to stop the boat. The failsafe signal is given to the receiver through a dedicated radio channel.

It is detected through the sensor when the boat gets crashed or any technical issue occurs. When the kill switch gets ON it stops the boat completely and it turns the motor OFF. So, we can avoid accidents and can handle any emergency situation by using a kill switch in the boat.

Reset latch

Relays are energized thus maintaining the circuit in open state. Once the power to the propulsion system is killed using any of these modes, the boat cannot be driven again. Releasing of relay latch using sperate switch is required for normal operation again.

Acknowledgement

The Vyuha team would like to thank Unmanned underwater vehicle laboratory and all of our advisors and faculty, in particular. Mr. Selvamuthukumaran D, Mr. Bharanidharan for allowing us access to their facilities and resources.

References

[1] T. Moore and D. Stouch, "A generalized extended kalman filter implementation for the robot operating system." Springer, July 2014.
[2] M. Labbe, "rtabmap ros," https://github.com/introlab/rtabmap ros, 2021.
[3] P.-J. Bristeau, P. Martin, E. Salaun, and N. Petit, "The role ¨ of propeller aerodynamics in the model of a quadrotor uav," 2009 European Control Conference, ECC 2009, 08 2009.
[4] "IEC 60529 Ingress Protection IP Code," International Organization for Standardization, Geneva, CH, Standard, 2001.
[5] A. Kazmi, A. Sinha, A. Velte, C. Ramee, D. Foreman, D. DiCarlo, E. Jahoda, E. Fu, E. Phan, J. Pattison, J. Adrande, J. Chau, L. Dorrian, M. Schlaff, M. C. Martin, M. Gilmartin, P. Meyer, P. Eddu, R. Rameshbabu, R. Kuramshin, R. Vepa, S. Fish, T. Daino, T. Campbell, and V. Chow, "Roboboat 2020: Technical design review,"
[6] B. Bingham, C. Aguero, M. McCarrin, J. Klamo, J. Malia, K. Allen, T. Lum, M. Rawson, and R. Waqar, "Toward maritime robotic simulation in gazebo," in Proceedings of MTS/IEEE OCEANS Conference, (Seattle, WA), October 2019.
[7] R. Summers, "Hydrophone development." [8] G. Bradski, "The OpenCV Library," Dr. Dobb's Journal of Software Tools, 2000.

Appendix A: component specifications

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost	Year of Purchase
ASV Hull Form/Platform	Self-developed	Swash hull	GFRP Length= 101 cm, breadth=70 cm, height= 45 cm and thickness= 2-4mm, Weight= 11.6 kg	Fabricated	$650	2022
Waterproof Connectors	Robu	CH 812	https://robu.in/product/ch-812-0-08-2-5mm-2-pole-wire-connector-with-spring-lock-lever-for-2-wire-line-splicing/	Purchased	$4	2022
Propulsion	Blue robotics	T200	Https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Purchased	$236	2022
Motor Controls	Blue robotics	Basic ESC	https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Purchased	$72	2022
Teleoperation	Generic	Radio Telemetry Kit 915Mhz Module for APM 2.5 2.6 2.8	https://robokits.co.in/multirotor-spare-parts/fpv-video-telemetry-camera/433mhz-telemetry-module-pair-for-pixhawk-and-apm-100mw-2km-range?gclid=CjwKCAjw7IeUBhBbEiwADhiEMXUJOMOnT44MAaiRT5JFbaVQ5sbUsgStKB7hvSFeWLuYFCYLL__PUxoCqLcQAvD_BwE	Purchased	$30	2022
CPU	Nvidia	Jetson tx2	https://developer.nvidia.com/embedded/jetson-tx2	Purchased	$450	2019
Inertial Measurement Unit (IMU)	Pixhawk	2.4.8	Https://robu.in/product/pixhawk-px4-autopilot-pix-2-4-8-32-bit-flight-controller/	Purchased	$274	2022
Doppler Velocity Logger (DVL)	Pixhawk	2.4.8	Https://robu.in/product/pixhawk-px4-autopilot-pix-2-4-8-32-bit-flight-controller/	Purchased	$274	2022
Camera(s)	Stereo Labs	ZED 2i	https://www.stereolabs.com/zed-2i/	Purchased	$499	2022
LIDAR	Zed	2i	Https://www.stereolabs.com/zed-2i/	Purchased	$549	2022
Algorithms	Rplidar	S2	Https://www.slamtec.com/en/S2	Purchased	$366	2022
Open-Source Software	Ardupilot	1.3.77	Mission planner	Free of cost	-	2022
Motor Controller	Pixhawk	Pixhawk 2.4.8	Datasheet	Purchased	179$	2022
Power Sense Module	Generic	Power Module 28V 90A for Pixhawk APM2.8 APM2.6 APM Flight Controller	Product Link	Purchased	$9.12	2022
GPS Module	Generic	NEO 7M GPS With	Product Link	Purchased	$18.58	2022

		Compass for APM 2.6/2.8 and Pixhawk 2.4.6/2.4.8				
Transmitter and Receiver	FlySky	Flysky FS-i6X 2.4GHz 6CH AFHDS 2A RC Transmitter and FS-iA10B 2.4GHz 10CH Receiver	Product Link	Purchased	$66.12	2022
Encoder	Generic	Pixhawk PPM Encoder Module With 8 Input Channels	Product Link	Purchased	$7.76	2022