RoboBoat 2023: TDR - VYUHA 2.0

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***Abstract*—Introducing a revolutionary new approach to Roboboat 2023, our research delves into the complexities of ASV and this report offers ground-breaking insights into ASV. The Autonomous Surface Vehicle (ASV)was engineered with a modular architecture to facilitate rapid prototyping and enhance portability.VYUHA 2.0 ASV uses optimized model architecture to accomplish the specified tasks with the use of ROS Framework providing a powerful communication for coordination between various control components. Eventually, Deep-Stream provides us with optimized hardware-accelerated inference to detect objects on Jetson ORIN, in case our hull needs to be stabilized and move faster. A swash boat design enables it to have a sizable, sturdy platform that is capable to handle simultaneous multi-threading commands. In our ASV, the electrical subsystems play a vital and crucial role in the overall operation. By upgrading our IMU, GPS, and thruster configurations for this year's Vyuha 2023 ASV, we made a giant leap forward from last year's Vyuha 2022 ASV. As a result of the Pixhawk orange cube being used, the sensor suit and thruster control have become much more precise, efficient, fast, and reliable. A new omnix- four thruster configuration has improved the accuracy of the ball shooting mechanism as well as the water jet mechanism for better accomplishment of the task.**

***Index Terms*—VYUHA 2.0, Autonomous Surface Vehicle, ROS framework, ZED 2i Cam, Jetson ORIN, Multi-threading.**

I. Introduction

Generally, ASVs are robotic vehicles that operate on the surface of the water for recording oceanographic information from the sea bed. These ASVs are using different types of propulsion mechanisms, electrical and software subsystems. These ASVs are facing different challenges in water bodies. Most of the researchers are developing a variety of solutions to the problems faced. The RoboBoat 2023 competition aims to design and develop the Autonomous Surface Vehicle (ASV) which is capable of performing different tasks autonomously by using different sub-systems. The VYUHA 2.0 is the RoboBoat team from Bannari Amman Institute of Technology to compete in the RoboBoat 2023 Event from India. The team was initiated by Third and Second-year students from different engineering backgrounds. The team aims to design and develop a new competitive Computer Vision based ASV with good stability [3], hydrodynamic performance, structural integrity, and maneuverability to perform the task given. This experience will help us to gain in-depth knowledge in the field of Robotics and acts as a precursor to our success in tackling the challenges in RoboBoat 2023 competition.

The Technical Design Report (TDR) comprises of the following sections: Section II explains the competition goals and the achieving strategy of our team. The effective designing strategy of our Computer Vision based Autonomous Surface Vehicle (VYUHA 2.0) is discussed in section III. Section IV gives a detailed explanation of testing and simulation results. The acknowledgment details are given in section V and followed by references and appendixes.

II. Competition Goals and its achieving Strategy

VYUHA 2.0 is the enhanced ASV system for all tasks with the intention of tackling all autonomous tasks and has a higher likelihood of success. As a result, this year's hard duties will be successfully completed by our team. ZED 2i, an industrial AI stereo camera, and Pixhawk Cube Orange with ADSB have been integrated into the system to perform the tasks and face the durable and versatile challenging environments.

A. *Importance of Hull design in task accomplishment*

The hull design is the most important structural entity of the ASV. In order to complete the tasks, the hull needs to be stabilized and move faster for task accomplishment. After completing an intensive survey, we have planned to design a swash boat design which enables to have a sizeable, sturdy platform that is appropriate for completing tasks in RoboBoat 2023, like feeding the fish, ponce de Leon, and Magellan's route due to its supremacy of design and benefits like the stability due to the distance between the hulls, especially in choppy waters. The hull design is depicted in figure 1. The novelty of the ASV design resides in developing high-performance structure boats. The hulls are often designed to reduce drag in water (hydrodynamics) [3]. However, our ASV has been redesigned such that half of it is submerged in water

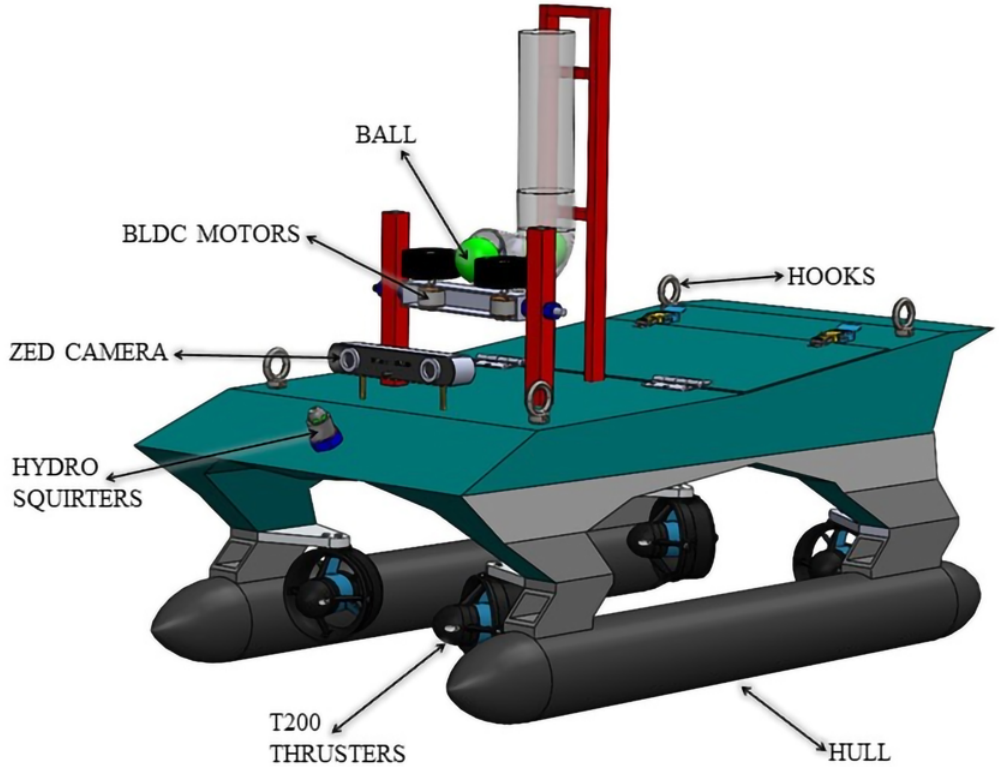

Fig. 1. Diagrammatic view of VYUHA 2.0 ASV

and the other half is suspended in air, making it both aerodynamically and hydro-dynamically resistant. Greater payload capacity due to the area available above the hulls, Better station-keeping features of the Small Waterplane Area Single Hull (SWASH) type design make them less susceptible to wave action and more at ease in choppy waters [4].

B. Strategy for Channel Navigation, Path Following, and Speed Challenge

We are planning to use the ZED 2i 3D Camera for channel navigation, buoys are detected and their midpoints are estimated, pose estimates are made, and distances are calculated. Based on this data, collision-free navigation vectors are created. The Pixhawk steers the boat based on the collision-free navigation vector it creates. The Gate Buoys are geo-fenced and the navigation is based on waypoints assisted by collision avoidance algorithms. In parallel, Manatees and jellyfish are counted and reported to Ground Control Station (GCS) using Mavlink Telemetry [5]. The boat navigates based on waypoints, assisted by Real Time Kinematics, in order to complete this task faster and to optimize the turning radius.

C. Strategy for Ocean Cleanup

This task is performed by the H3 - balanced elements based Hydrophones, which communicate with the acoustic pingers and estimate the pinger's location. The boat then navigates to that position and picks up the ball.

D. Strategy for Docking, Fish Feeding and Fountain of youth

In order to accomplish this task, we trained the boat to navigate to the dock using GPS coordinates and vision assistance when it reaches the dock. The algorithm calculates the projectile based on the projectile angle it begins to adjust its arm position and starts to shoot the ball into the bucket. Boats navigate to docks using vision, and when a target face is detected, the boat adjusts itself to get better water-spraying projectiles. As soon as the boat reaches a steady position for the projectile, the boat goes to position hold and begins spraying water into the nozzle. By using this same strategy, the boat returns back to home.

E. Ball cannon and Water Blaster Mechanism

The proposed VYUHA 2.0 ASV contains both the water blaster hose and the ball shooter. A Brushed Motor DC (BLDC) serves as the actuator for the ball shooter, a device that resembles a ball shooter. An incremental encoder on the motor provides information on its angular position and speed. The screw can consequently be used to change the ball's launching velocity in order to get the right angle based on the inputs from the Tf-TRT YOLO-v4 algorithm. To control the angular position of the ball shooter system's end, a water blaster hose is connected with ASV. This system has fewer moving parts and is lighter in weight.

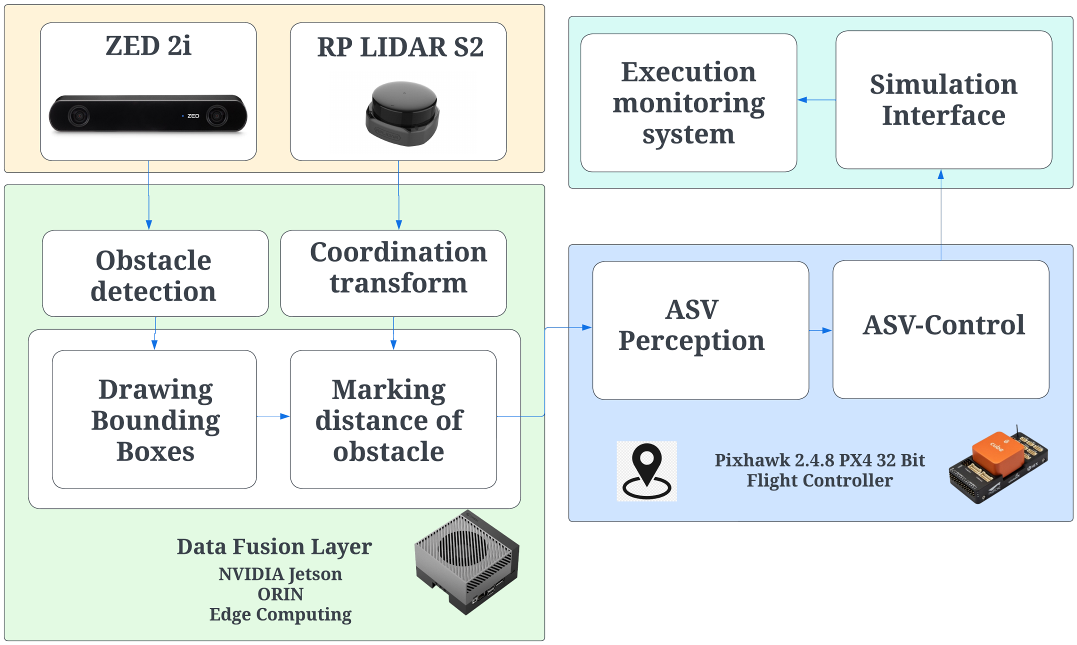

Fig. 2. Computer Vision-based Software Architecture

III. Design Strategy

A. Effective Hull Design

The SWASH-type hulls are exists so far only in research articles. But results of computer simulations as well as extensive test results have been very promising and they started to realize it [6]. We are convinced that this principle works for our hull design. These hulls are selected for offshore and rough water purposes because they can steadily knife the waves. To achieve this, a draft and a wedge shape are added and stability is maintained. These hulls are also more suitable for shallow waters and less power is required due to their buoyancy. However, this type of hull performs well in choppy conditions [7]. Hull dimensions may vary depending on the type of boat being built. The boat length, width, height, and angles are ought to be considered for optimizing the hull. Computational techniques use different methods based on relocating and scaling hull segments. Computational methods are always facilitating the hull design and easily allow numerical parameters to be modified for better design. Other physical factors such as buoyancy, hull shape, and the boat material used must be taken into account to have an effective and successful design for our ASV.

B. Computer Vision-based Software Architecture

The use of ROS in our VYUHA 2.0 has the advantage of being able to handle large amounts of sensor data. In addition to ZED 2i Cam and RPLIDAR S2, VYUHA 2.0 gives a consistent ranging resolution. As part of ROS, processing sensor data, including the Point Cloud Library (PCL) is used for processing RP LIDAR S2 data as well as data from other 3D sensors. Additionally, the ROS framework provides a powerful communication framework called the ROS Master; ROS (Robot Operating System) master is used for coordinating communication between the different nodes in the ROS system. In ASV, the ROS master is responsible for coordinating communication between the vehicle's various sensors, actuators, and control systems. It includes navigation data from GPS and depth sensors, control commands for the propulsion system, and sensor data from the ZED2i camera or LIDAR information as shown in Figure2. Implementing ROS master on an ASV allows us for a flexible and modular system design, allowing various components to be added, removed, or replaced on demand.

1) Computer Vision: Our VYUHA 2.0 ASV utilizes computer vision to perform tasks such as obstacle detection, collision avoidance, localization, navigation, and mapping as shown in Figure4. In order to detect and classify floating buoys in the competition arena, image processing, object recognition, image segmentation, and machine learning approaches have been applied to the camera and RP LIDAR S2 data have been collected by our ASV. In turn, the ASV has been programmed to avoid obstacles or follow a predetermined path based on this information. The detailed software process is shown in Figure 4. In this ASV, we have proposed a modified YOLOv4-Tiny algorithm for a high frame rate and it has a small model size compared to ordinary YOLO architecture making it a great option for our autonomous surface vehicle (ASV) [10]. Since our optimized model is small, it can run efficiently without consuming too much power. Additionally, our ASV high frame rate

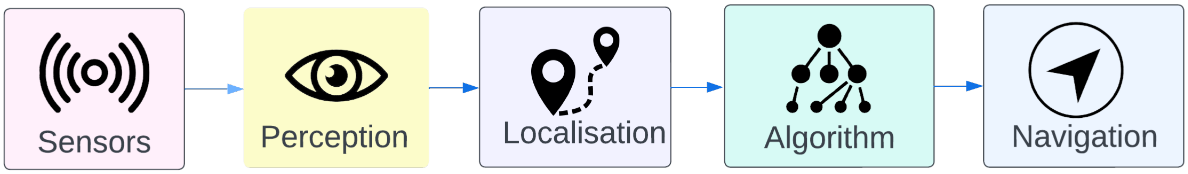

Fig. 3. Process Flow

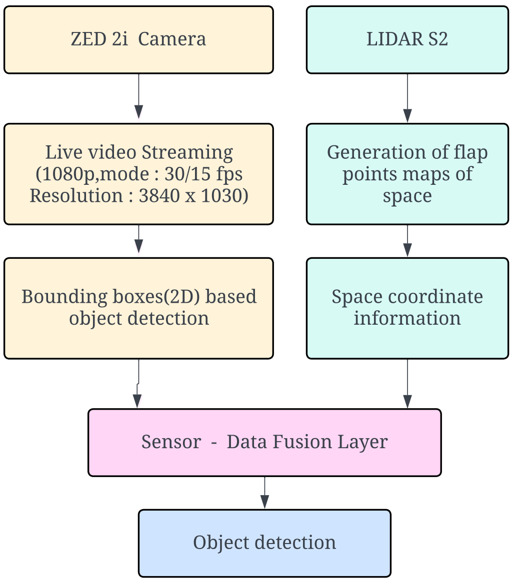

Fig. 4. Computer Vision-based Software Architecture for object detection

allows it to process the images quickly, allowing it to identify objects and make decisions in real-time. The optimized model achieves high FPS while maintaining good accuracy, making it an ideal model for our ASV. Additionally, the TensorRT library had been used to optimize the performance of YOLOv4-Tiny on Jetson Orin, providing an even better balance of speed and accuracy for ASV [11], .

2) Tf-TRT YOLO-v4 Tiny Algorithm: Annotate and collect a large dataset of images and video of objects that the vehicle may encounter, such as boats, buoys, other colored balls, and dock color and shape. We have trained this neural network with YOLO-v4 tiny architecture and selected appropriate hyperparameters, including the number of layers learning rate. Utilizing TensorRT libraries and the reduced number of layers in the network to optimize the model for real-time use compared to the previous ones [13] - [17]. The optimized model is incorporated with the sensor and control system of our ASV enabling us to monitor and maintain the model on a continuous basis in order to adapt to changing environmental conditions. We faced challenges to detect objects on moving vehicles because of the variability and unpredictability of objects in water also the reflection of sunlight via water was a major issue that faced by us. The computer vision-based object detection is shown in Figure**??**. As a result, the model may need to be continually updated and retrained to collect the new data. Everything that tends with the goal in our mind is to get our network to run as fast as possible in our hardware. Thus, this could be achieved by fusing those layers into one operation by saving its memory and bandwidth. Eventually using Deep-Stream provides us with optimized hardware-accelerated inference to detect objects on Jetson ORIN, leveraging the GPU and other hardware acceleration engines for maximum performance. This results in low latency, high accuracy, and real-time detection.

C. Electrical Sub-systems

1) Propulsion Systems: After the research phase, the T200 thruster was observed as the best choice for our ASV design. The T200 thruster is a compact and efficient propulsion system that uses an electric motor to drive a propeller. The T200 thruster requires less power to produce a given amount of thrust compared to other propulsion systems, which results in improved battery life and lower operating costs. The T200 thruster is also highly reliable, with robust construction and high-quality components that can withstand harsh underwater environments. Its high efficiency, robust construction, and ease of installation make it an ideal choice for our ASV to cruise through the given tasks with relative ease. In VYUHA 2.0, we are using a four-thruster configuration model because it proves to be more stable, and accurate, and improves the overall maneuverability of the vehicle during unpredictable waves in the pond when compared to last year's two-thruster configuration (VYUHA 1.0). The electrical sub-system configuration of VYUHA ASV is shown in Figure5. These thrusters will be placed at a 45-degree tilt, and this placement will give our ASV the ability to easily move through obstacles.

2) Control Systems: Our Team VYUHA 2.0 ASV uses Pixhawk Cube Orange with ADSB as a flight controller that controls the other parts of our system [8]. Pixhawk along with the software autopilot, the waypoint, and the navigation system [18] is controlled by our computer vision-based Tf-TRT YOLO-v4 Tiny Algorithm. The longitude, latitude, and turning radius of our system are determined accurately by the inbuilt IMU. The location is determined accurately by external Here 3–CAN GPS with M8P for cost-effective high-precision positioning due to its RTK-supported GNSS chip [18]. The

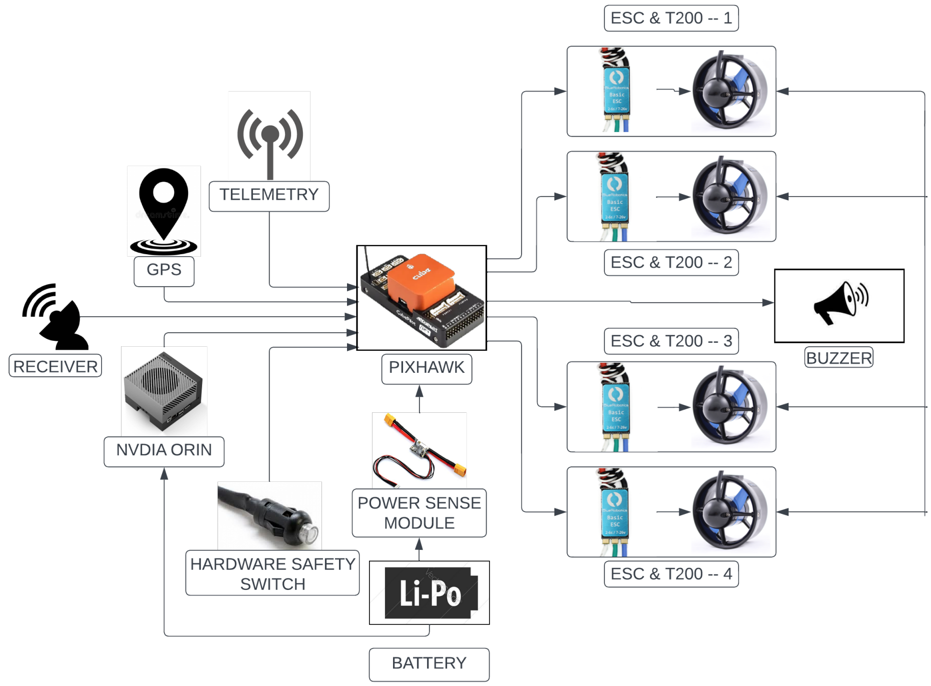

Fig. 5. Electrical Sub-system with four thruster configuration

motor and thruster are controlled by the Pixhawk with the reference to the input signal from the ZED 2i Camera and LIDAR S2.

IV. Testing Strategy and Simulation results

The drag resistance of the proposed VYUHA 2.0 ASV has less drag value compared with the previous version of ASV because the major portion of its surface area is above the water [1]. The prismatic coefficient value is also increased by the value of 0.6 instead of the typical 0.85 for VYUHA 2.0. The hull must be sturdy in wavy situations to complete tasks like feeding the fish and fountain of youth, as the ASV satisfies this criterion [9]. The proposed Vyuha 2.0 has an appropriate water line area and wetted surface area of 0.005 m2 and 0.146 m2. The bows section is designed sharper to knife the wave which also helps for the better motion of ASV. The speed of the hull versus resistance graph showed low resistance with increased speed and stability as shown in Figure6. These parameters will lead to more efficient vessels with better cruising speed compared to other ASV designs for effective task accomplishment.

For a better operation of Pixhawk during the planned tasks, we tested the inbuilt sensors (Magnetometer, gyroscope, Accelerometer, and orientation lock). After the testing phase, we fine-tuned these sensors for more getting more accuracy, and efficient operation of Vyuha2.0 while performing and acing the tasks. We tested all the above-mentioned sensors individually, obtained the result data, plotted them in a graph, and started the tuning process. This year, we tested the ESC

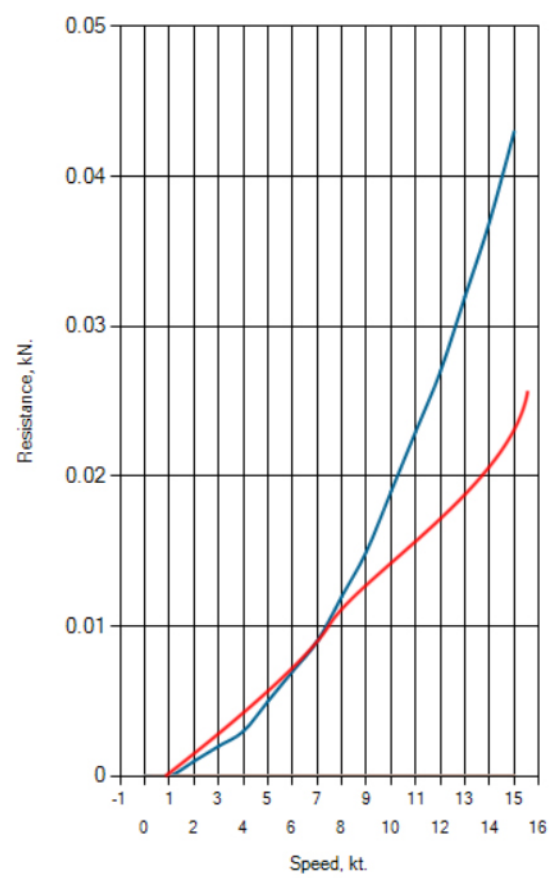

Fig. 6. Speed of the hull with drag resistance

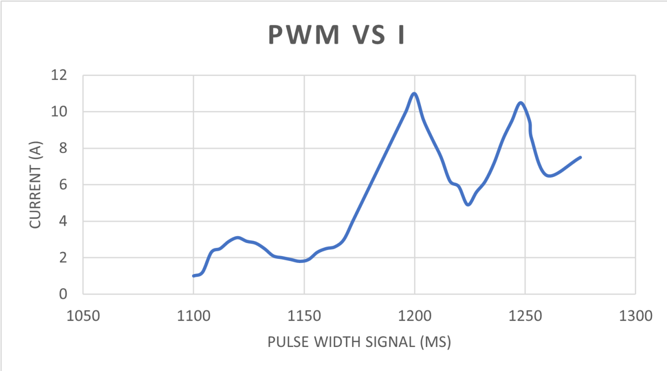

Fig. 7. Linear Motion Behaviour Analysis

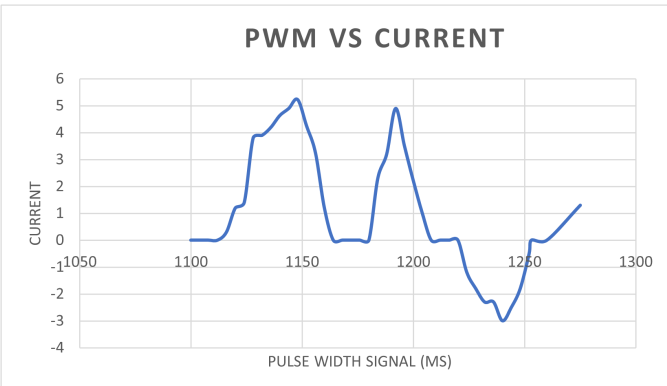

Fig. 8. Circular Motion Behaviour Analysis

accuracy of Vuyha2.0. ESC accuracy analysis is done to determine the Pulse Width Modulation (PWM) signal values at which the thruster starts from 0 rpm and the maximum speed the ASV can attain in both forward and reverse directions.

We have conducted two different tests to check and determine ESC accuracy for linear behavior and circular behavior. A linear behavior test is done to get the required data for line tasks like navigating the Panama Canal and Magellan's Route. In the linear behavior test, the thruster starts rotating at the peak value of 1110 to 1250 ms of PWM signal, the maximum speed in the forward direction is obtained at1180 ms of PWM signal, and the maximum speed in the reverse direction is obtained at 1280 ms of PWM signal. A circular behavior test is done to get the required data for tasks that include more curves like the northern passage challenge. In the circular behavior test, the thruster starts rotating at 1100 ms of PWM up to 1280 ms PWM signal, the ASV fully turns towards the right direction and it fully turns toward the left direction [19]- [22]. The data obtained during the testing phase is neatly plotted in a graph as depicted in 7-8. This behavior helps the ASV to reduce the response and running time for the completion of the task.

The proposed Tf-TRT YOLO-v4 Tiny Algorithm is the modified architecture of the original YOLO model. This YOLO-v4 model has low accuracy and sensitivity to small objects. In order to improvise these limitations, we used Deep-stream and Tensor RT library to enhance performance up to 20 times higher than the ordinary model. As a result, shown in Table 1, the Tf-TRT YOLOv4 Tiny model had been chosen as the best model for accomplishing specific tasks in the arena Depending on a number of factors, including the size of the dataset, and higher FPS (approx. 68 FPS). The complexity of small objects being detected is high compared to other models especially helps in detecting and tracking buoys. The smaller model size (92.0M) helps in multithreading to run multiple functions in the same parallel sequence. Similarly, thresholding, edge detection, or blob analysis had been used to locate the ball and to determine its trajectory additionally; our system is designed to be the best effective ball shooting mechanism, it is important to carefully consider the lighting conditions, the background, and the camera's position to handle occlusions.

Acknowledgment

We, VYUHA 2.0 Team have been fortunate in receiving support, assistance, resources, funding, and encouragement from our College Management of Bannari Amman Institute of Technology, Professors, and Mentors from industrial firms for the design and fabrication of ASV. We gratefully acknowledge the contribution, encouragement, and whole support from our Unmanned Underwater Vehicle Lab In-charges, Prof.D.Selvamuthukumaran, Assistant Professor of Mechanical Engineering, and Prof. V. Baranidharan, Assistant Professor of Electronics and Communication Engineering. Without them, our story would have remained just like a bubble in our heads. The comments, ideas, hardworking and togetherness of our seniors (VYUHA 1.0 Team for RoboBoat'22) greatly helped us in giving the final shape to our new version of ASV (VYUHA 2.0). We gratefully acknowledge the contribution of each of them. We are also highly indebted to Dr. Venkatesan R, Scientist (Retd), National Institute of Technology, Chennai, and currently working as an Adjunct Professor, University of Massachusetts Dartmouth, USA for his guidance and constant supervision as well as for providing necessary information regarding the project.

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S.No	Algorithm	Application	Tracker	Infer Resolution	Precision	GPU	Model Size	Map
1	Modified YOLOv4 Tiny Tf-TRT	3D Object Pose Estimation	NVDCF	960x544 to 192x256	INT8 FP16	68	92	79.53
2	Yolo-v4	3D Object Pose Estimation	NVDCF	930x514 - 172x236	INT8 FP16	48	97	77.41
3	SSD	3D Object Pose Estimation	NVDCF	512x512	-	40.2	90.6	79.33
4	Yolo-v7	3D Object Pose Estimation	NVDCF	256x256 -608x608	30	0.52	89.2	79.04
5	Faster R-CNN	3D Object Pose Estimation	NVDCF	242x242	13	30	108.1	94.48

TABLE I
COMPARISON TABLE OF PROPOSED TF-TRT YOLO-V4 TINY ALGORITHM MODEL WITH OTHER EXISTING MODELS

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APPENDIX A
LIST OF COMPONENTS

S.No	Component	Vendor	Model	Specs	Custom/ Purchased	Cost	Year
1	ASV Hull	Vyuha 2.0	0.9 X 0.45 X 0.68		Custom	$450	2023
2	IMU	Pixhawk	cube orange+	Cube Orange Plus AutoPilot with ADS-B	Purchased	$440	2023
3	GPS module	HEX	Here3 RTK GNSS Set	Integrated (RTK) for fast time-to-market	Purchased	$369	2023
4	Wire connectors	Robu.in	CH-813	Spring Lock Lever for 3 Wire line Connection	Purchased	$10	2022
5	Propulsion	Blue Robotics	T200 Thruster	7-20 volts,24-32 Purchased	Amps	$950	2022
6	Motor controls	Blue Robotics	R3 version	7-26 volts (2-6S)	Purchased	$170	2023
7	CPU	Nvidia	Nvidia Jetson Agx Orin Developer Kit	12-core Arm Cortex-A78AE v8.2 64-bit CPU 3MB L2 + 6MB L3	Purchased	$2,000	2022
8	Camera	Stereolabs	ZED 2i Stereo Camera	120° Wide-Angle FOV	Purchased	$500	2022
9	LIDAR	RP LIDAR	RPLiDAR S2	360 Degree – 30M Range	Purchased	$570	2022
10	Detection model	Vyuha 2.0	YOLO V4 tiny	Higher frame rate, Small model size	Custom	-	2023
11	Mission Planner	Ardupilot	-	-	Purchased	-	2023
12	Power sense module	Blue Robotics	New R2 Version	-	Purchased	$40	2022
13	Transmitter and receiver	Skydroid	Skydroid T12	2.4GHz , 12 Channel	Purchased	$450	2023
14	Battery	Zenmtech	Lipo, Zolta	25C 4S1P 10000mAh	Purchased	$220	2023
15	DC Motor	Orange	12V DC Motor 1000RPM	-	Purchased	$20	2022
16	Kill Switch	Generic	600V 10A	-	Purchased	$5	2023
17	Pipe	Ashirvad	PVC pipe	-	Purchased	$5	2023
18	Pipe	Ashirvad	PVC pipe	-	Purchased	$15	2023
19	Nozzle	Ashirvad	-	-	Purchased	$3	2023
20	Water Pump	Amazon	12V 80W	-	Purchased	$10	2023
21	Bolt and Nuts	TVS	-	-	Purchased	$12	2023
22	Hydrophone	Aquarian	H3 Balanced Element	High sensitivity Robust, low-mass design	Purchased	$250	2023

APPENDIX B

ISOMETRIC VIEW OF VYUHA 2.0

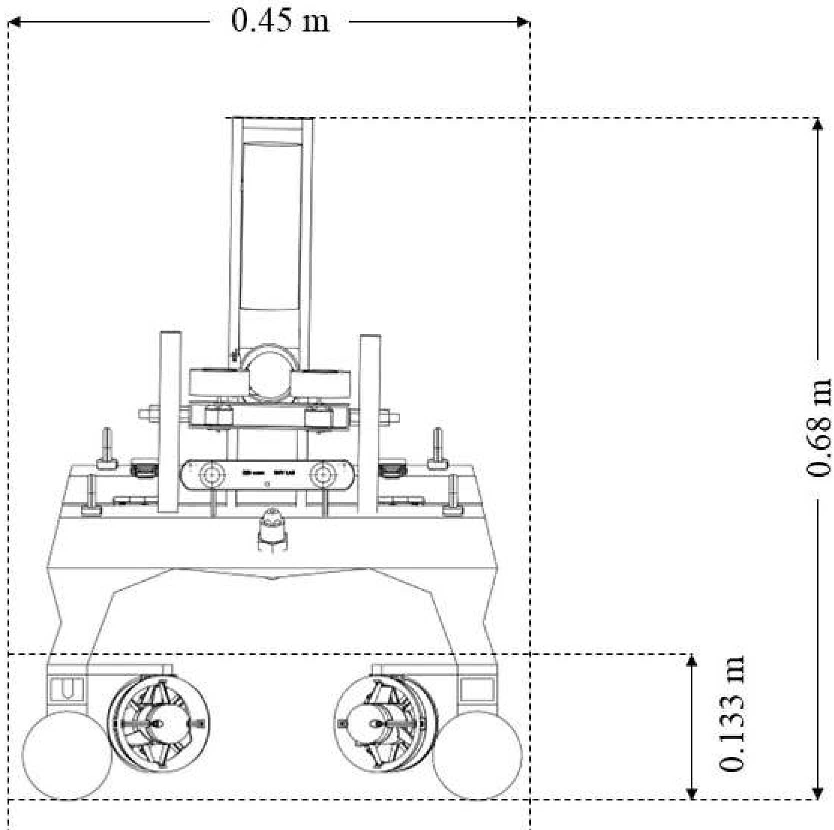

Figure A.2: Front View of VYUHA 2.0 ASV

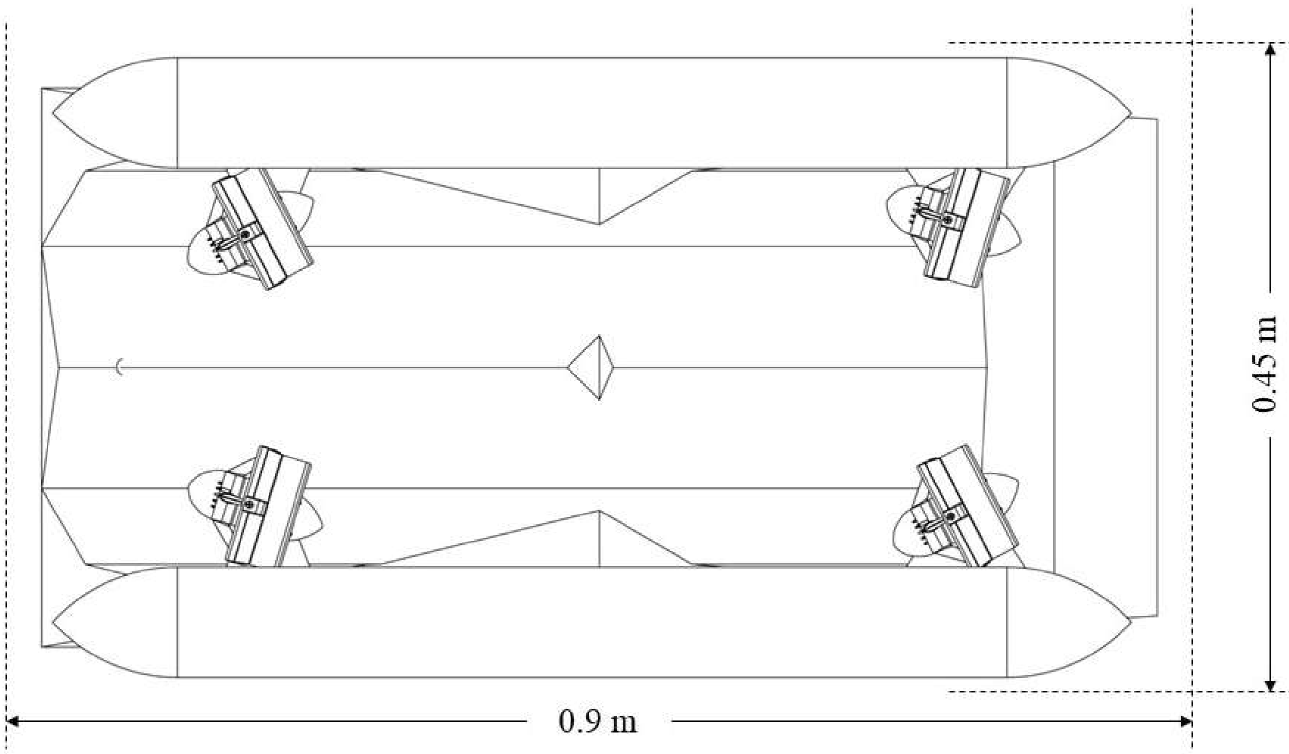

Figure A.3: Bottom View of VYUHA 2.0 ASV

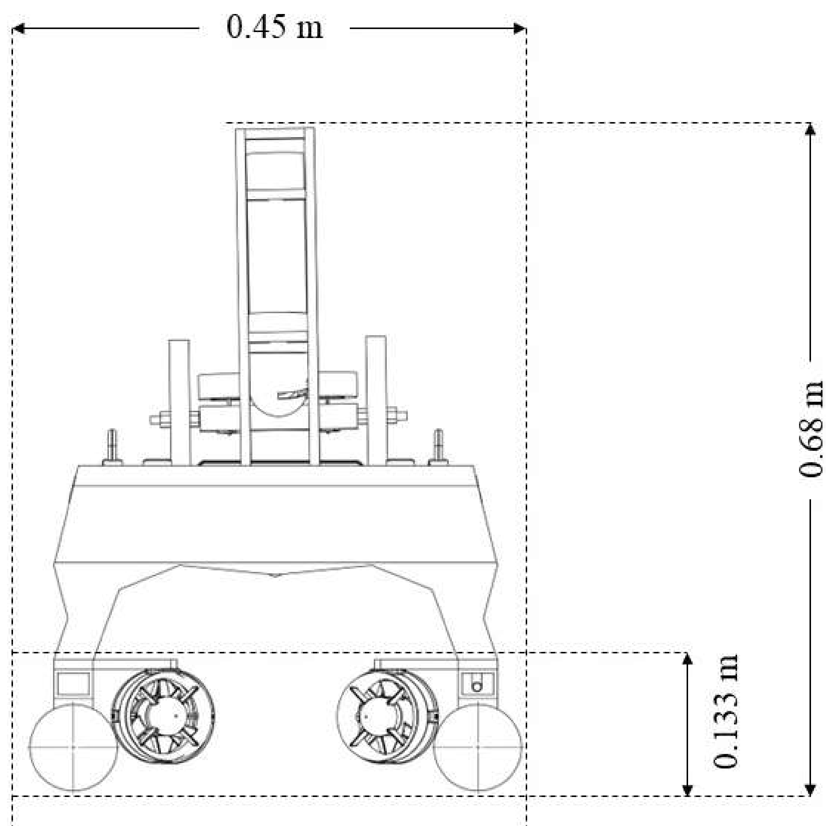

Figure A.4: Back View of VYUHA 2.0 ASV

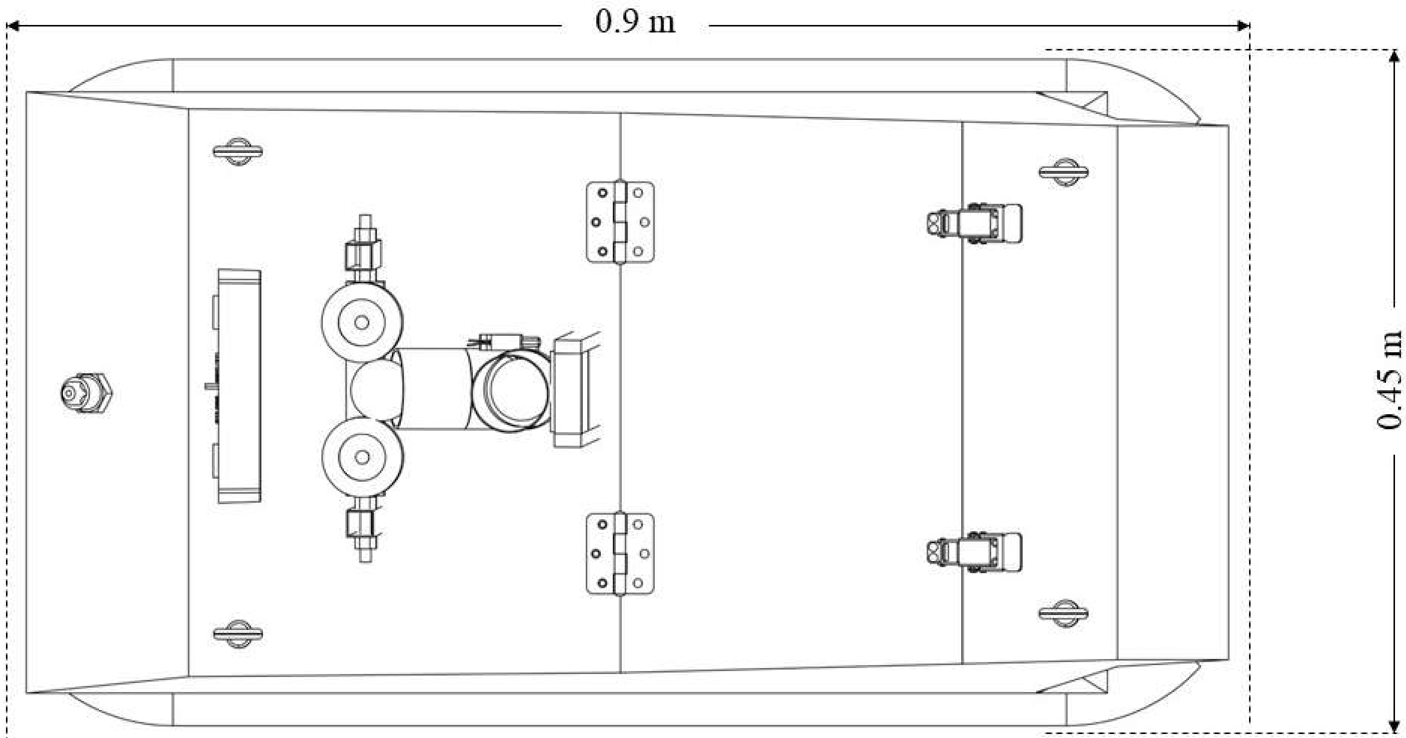

Figure A.5: Top View of VYUHA 2.0 ASV

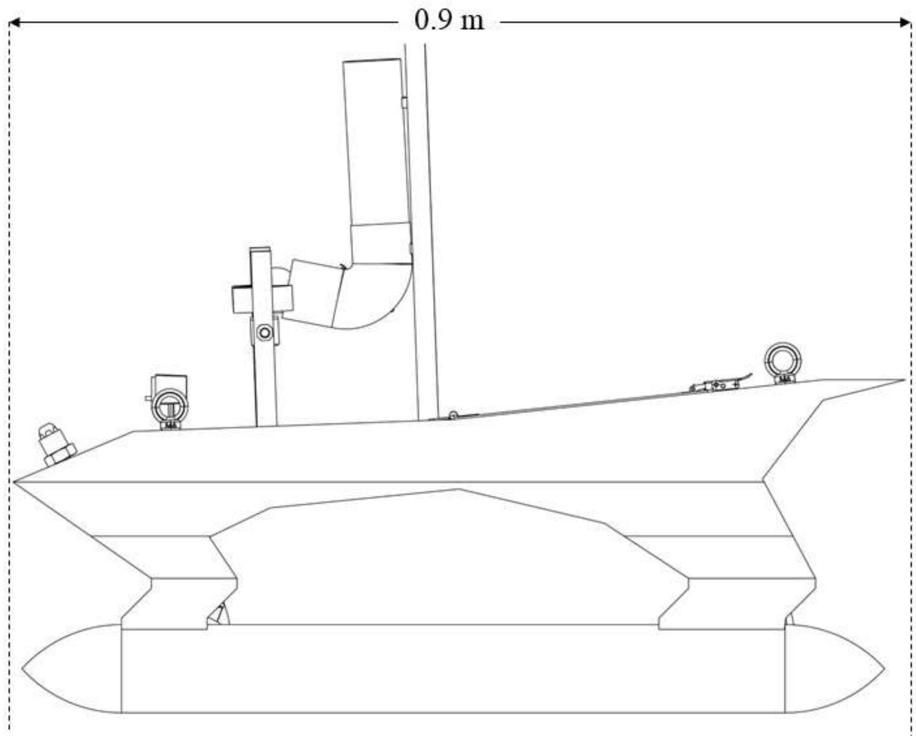

Figure A.6: Side View of VYUHA 2.0 ASV