Technical Design Report of Hangor 1.0, An Autonomous Underwater Vehicle

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***Abstract* — Team BengalSub proudly marks the debut in the RoboSub 2025 competition with an indigenously designed and fully fabricated Hangor, autonomous underwater vehicle (HAUV). Built from precision-cut aluminum sheet and custom-developed watertight enclosures, HAUV reflects a commitment to innovation, resilience, and hands-on engineering. As a first-time participant, team HAUV navigated numerous technical and logistical challenges-from limited local access to specialized components to resource constraints and the steep learning curve of underwater autonomy. Despite these barriers, multidisciplinary team HAUV successfully integrated mechanical, electrical, and software subsystems into a robust and modular platform capable of executing complex underwater tasks. The vehicle features a vision-based navigation system, a compact and hydrodynamic frame, and sealed electronics housing tested for pressure resilience. The development journey emphasizes rapid prototyping, iterative design validation, and adaptive problem-solving in a low-resource setting. By participating in RoboSub 2025, team HAUV aim not only to gain critical exposure to advanced global robotics but also to demonstrate the rising capabilities of Bangladesh in marine technology. BengalSub represents a leap toward localized innovation, with ambitions to contribute to the blue economy, environmental monitoring, and STEM inspiration across the nation.**

***Keywords* — AUV, Self-Designed Hull, VN200, Object Detection, Image Processing, Hydrophone, TensorRT, MAVLink, ROS, Pixhawk, Behavior Tree.**

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) are important tools for underwater inspection, environmental monitoring, and marine robotics research. However, designing a reliable, competition-ready AUV within the constraints of limited local resources, component availability, and environmental unpredictability remains a significant challenge. Overcoming these challenges is necessary to ensure long-duration, stable, and precise operations in real-world underwater scenarios, particularly in RoboSub competitions.

Previous AUV projects have shown significant progress but still face notable limitations. The BRACU Duburi TDR implements a modular power management system but lacks integrated thermal monitoring and dynamic load balancing under changing mission conditions, limiting operational stability [1]. IIT Bombay's Matsya 6D demonstrates compact system integration with advanced manipulation but does not detail underwater connector reliability under repeated pressure cycles, risking mission interruptions [2]. Caltech's Dory achieves precise control using advanced controllers and a gimbaled camera system but lacks a dynamic mission adaptation framework, reducing flexibility during unexpected environmental changes [3]. FEFU-IMTP employs a hydrophone array for acoustic localization but does not integrate advanced filtering or machine learning-based denoising for pinger detection in noisy environments [4]. NUS Bumblebee 3.5 uses deep learning perception systems but at the cost of increased energy consumption and bulky acoustic systems, which limit operational range [5]. Desert WAVE's Phoenix focuses on redundant propulsion for fault tolerance but lacks modular, hot-swappable power designs, which slows field servicing [6]. Team Inspiration's Græy and Orange use ROS for modular system management but do not address structured EMI shielding and sensor crosstalk, leading to inconsistent sensor readings [7]. ARVP's Arctos and Auri platforms use structured acoustic localization and robust mechanical systems but do not document fine manipulator control, which is important for precision competition tasks [8], [9].

To address these limitations, the Hangor Autonomous Underwater Vehicle (HAUV) has been developed by team BengalSub as a modular, efficient, and adaptable platform for RoboSub 2025 while demonstrating the potential for marine robotics in Bangladesh. HAUV integrates layered safety systems, thermal-aware power management, and precision-oriented sensor fusion for accurate navigation and stable underwater operation. The platform uses a modular design to allow rapid debugging and future expansion while maintaining adaptability for different mission tasks. Using a behavior-tree-based autonomous mission framework, HAUV can dynamically adjust mission priorities based on environmental input, ensuring robust and efficient task execution. Key features of HAUV are:

- Layered, actively monitored power management with thermal protection and load balancing
- Lightweight, hydrodynamic aluminum chassis with custom watertight enclosures tested for pressure
- Real-time YOLOv8-based object detection fused with acoustic and inertial localization
- Behavior-tree-based mission planning for dynamic task reprioritization
- Six-degree-of-freedom maneuverability with PID-controlled ESC thrusters
- Modular sensor integration including hydrophones, IMU, depth sensors, and dual cameras
- Structured EMI shielding and organized cable management for underwater reliability

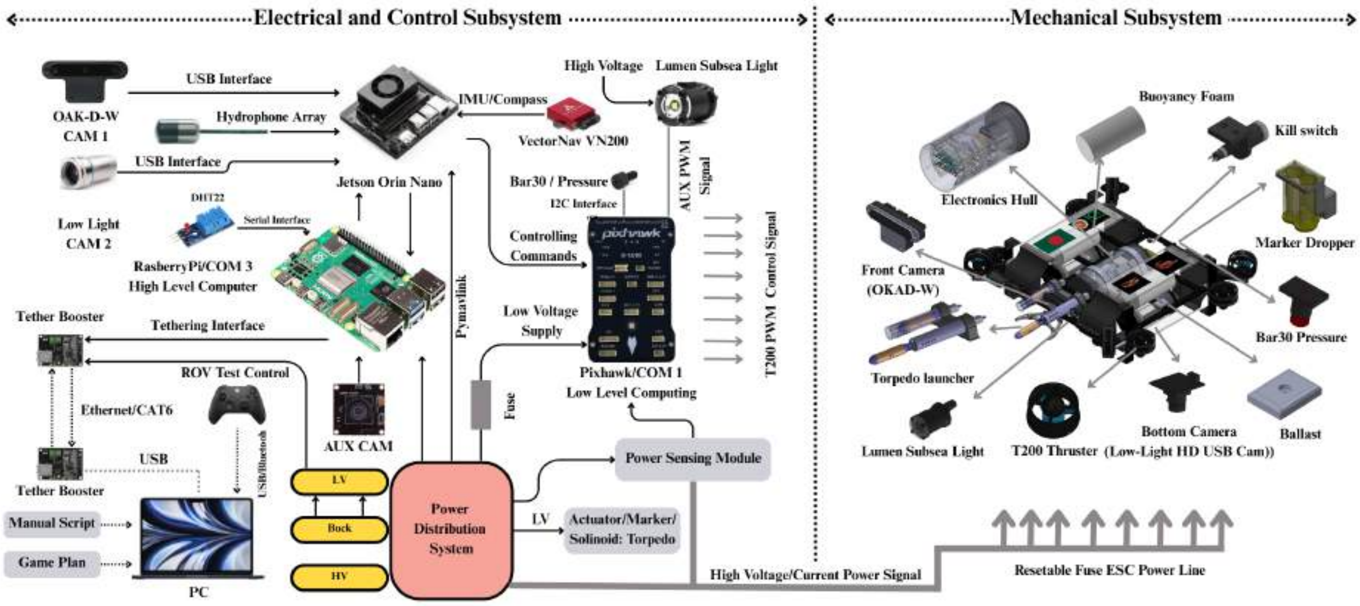

Fig. 1: Overall system design of HAUV 1.0

II. Competition Goals

To succeed in RoboSub 2025, team system prioritizes modular autonomy, real-time adaptability, and mission-focused decision-making. The vehicle integrates vision, localization, and control logic to execute tasks dynamically while ensuring safety and robustness.

A. *Competition Strategy: Task Execution*

HAUV follows a prioritized pipeline, tackling reliable tasks like the gate and buoys first, then moving to complex ones [10]. Each modular task uses YOLOv8 perception and mission-specific actions, with transitions managed by a behavior tree.

a) ***Task 1 (Passing the gate):*** HAUV detects gates using YOLOv8 on its front camera. If vision fails, sonar estimates the gate's location, and if both fail, dead reckoning with IMU and depth data is used. After passing the gate, HAUV performs yaw rotations for style points, using VectorNav feedback and MAVROS commands to the Pixhawk for stable turns. It records its position using sensor fusion and continuously updates its location during the mission to reduce drift.

b) ***Task 2 (Navigating the Channel):*** After gate traversal, HAUV uses its downward camera to detect and follow the floor marker toward the next task. It uses the front camera and HSV detection to identify red and white poles, performing a smooth slalom by adjusting heading based on pole positions. A PID controller ensures stable turns while maintaining constant depth for bonus points.

c) ***Task 3 (Dropping a BRUV):*** HAUV uses its downward camera to detect the BRUV bin and aligns the dropper over its center using visual servoing. It stabilizes using IMU and depth data with PID control. After alignment, it releases up to two markers sequentially for accurate placement, ensuring precise drops while maintaining a steady hover to maximize scoring.

d) ***Task 4 (Tagging):*** HAUV uses YOLOv8 and its front camera to detect the Sawfish or Reef Shark, prioritizing the first animal seen at the gate. It aligns with the tagging window, re-detects the target, and calculates its center using segmentation. Using IMU and depth data for stabilization, HAUV aligns its torpedo system and fires accurately at the target.

e) ***Task 5 (Ocean Cleanup ; Octagon):*** HAUV uses a hydrophone array to localize the pinger via TDoA and navigate to the octagon's center. Its downward camera with YOLOv8 detects and classifies trash items, extracting coordinates for precise targeting. Using its manipulator or dropper, it sorts and places two items of each class into correct bins. An internal counter tracks drops before executing N yaw rotations, ensuring accuracy using IMU and odometry feedback.

f) ***Task 6 (Returning Home):*** To return, the AUV navigates back to the recorded gate position using PID control based on this localization. As it nears the gate, HAUV uses YOLOv8 vision to detect and align with the gate; if vision fails**,** sonar or dead reckoning provides fallback guidance. Finally, it smoothly passes through the gate using the same control strategy as before.

B. *Contingency and Fail-safe Strategy*

A multi-layered safety system is employed: hardware kill switch, software disarming via MAVROS, and watchdog nodes that monitor mission health. In case of sensor failure, localization fallback ensures minimal functionality, and in critical errors, the vehicle halts or surfaces autonomously.

III. System Design And Implementation

The HAUV is built on a modular system design, integrating electrical, control, and mechanical subsystems for efficient underwater missions. The system diagram is shown in Fig. 1. The electrical and control subsystem uses a Jetson Orin Nano for real-time object detection, sensor fusion, and mission planning. It interfaces with a Raspberry Pi for communication, control scripting, and tether testing, using a CAT6 Ethernet line for high-speed data during surface debugging. HAUV integrates an OAK-D-W front camera for navigation and a low-light bottom camera for floor tracking and marker alignment, with an auxiliary camera for additional views. The VectorNav VN200 IMU provides orientation data, while a Bar30 sensor measures depth. A hydrophone array connected to the Jetson enables acoustic localization, and a DHT22 sensor monitors internal temperature and humidity. The Pixhawk Cube manages low-level control, receiving commands via MAVLink and sending PWM signals to T200 thrusters for six-degree-of-freedom maneuvering. It also controls the marker dropper and torpedo launcher through solenoid circuits. A structured power distribution system delivers stable high and low voltage, using buck converters, power monitoring, and resettable fuses, while separating high-current lines to reduce noise. An external kill switch ensures safety during emergencies.

Mechanically, HAUV uses a lightweight aluminum frame with a watertight electronics hull. Adjustable ballast and buoyancy foam ensure stability, while the dropper, launcher, and thruster placements maintain balance during tasks. Integrated Lumen subsea lights support low-visibility missions. This system ensures stable, precise control for RoboSub 2025 missions.

A. *Mechanical Subsystem*

The mechanical subsystem of HAUV was designed to provide a robust, modular, and hydrodynamically efficient structure capable of operating in underwater environments with high stability and ease of maintenance.

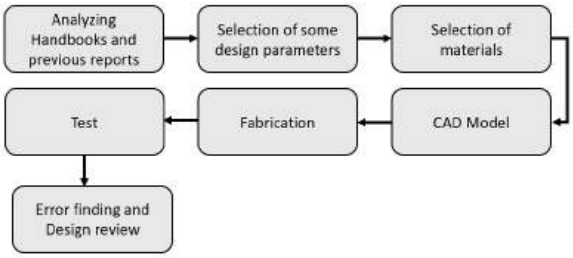

Fig. 2: Workflow diagram of the mechanical subsystem

The design process followed a systematic workflow that included material selection, CAD modeling, simulation, and fabrication and the block diagram is illustrated in Fig. 2.

Fig. 3: AUV designed in SolidWorks

Initially, the team conducted a comparative analysis of previous RoboSub teams' designs and studied the official RoboSub 2025 handbook and rulebook to identify structural requirements and constraints [11]. This informed our decision to use a CNC machine to cut a 5 mm aluminum 5083 sheet, which will be used to build the hull of the AUV as well as high-stress mounting brackets and clamps, selected for their corrosion resistance, strength-to-weight ratio, and underwater durability. Weight estimation was performed before and after machining to ensure the AUV maintained near-neutral buoyancy. SolidWorks was used for the 3D modeling of the full AUV structure, which included thruster mounts, electronics bay, watertight enclosures, torpedo mechanisms, and payload fixtures that is shown in Fig. 3. Special attention was given to the compact and modular design, allowing rapid assembly and component accessibility.

a) *Main Frame:*

The main frame of HAUV, shown in Fig. 4, is made from lightweight marine-grade aluminum 5083 for strength and low weight. It uses a flat, grid-like base with vertical brackets and cross-supports for modular subsystem mounting. The structure is optimized for rigidity against forces from eight T200 thrusters. An open-frame design ensures efficient water flow and easy maintenance, while cutouts reduce weight and mounting points support sensors, payloads, and protective skirting.

Fig. 4: Aluminum-5083 frame

b) *Electronics Enclosure*

HAUV is equipped with three main watertight enclosures, each designed for high reliability and easy maintenance which is shown in Fig. 5. The central dome-shaped enclosure houses sensitive computing units such as the Jetson Orin Nano and flight controller (Pixhawk), while the side cylindrical enclosures are designated for batteries and power management systems. The electronics component for the CAD is sourced from [12]. These enclosures are built from a combination of aluminum caps and acrylic or polycarbonate bodies, sealed using precision-machined O-rings and marine-grade cable glands.

Fig. 5: Electronics encloser

The transparent bodies allow visual inspection of internal indicators, and modular separation reduces risk in the event of partial failure. The design also allows rapid disassembly for debugging and recharging.

c) *Marker Dropper:*

The marker dropper, shown in Fig. 6, is integrated into the lower front of HAUV for accurate marker release using a servo-based system. Positioned for unobstructed vertical drops, it is protected by the frame while allowing easy reloading. Made from corrosion-resistant materials, it ensures reliable underwater operation. Its precision is essential for scoring during tasks in RoboSub missions.

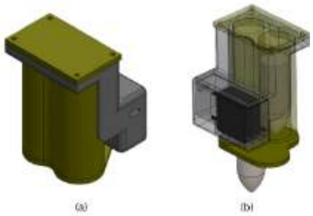

Fig. 6: (a) Outside view, (b) Inside view of marker dropper

*d) **Torpedo Launcher:***

The dual-tube torpedo launching system, shown in Fig. 7, is mounted at the front of HAUV for accurate linear projection during firing tasks. Securely integrated into the frame, the system uses spring-loaded or motor-driven mechanisms for controlled release. Symmetric positioning maintains balance during launches, while the protective frontal design minimizes drag. This setup ensures reliable, precise torpedo deployment without generating excess torque on the frame during missions.

Fig. 7: (a) Torpedo, (b) Torpedo Launcher

*e) **Weight Balance and Buoyancy***

Weight distribution and buoyancy control are critical for underwater stability. HAUV achieves this through symmetrical placement of battery pods, thrusters, and enclosures, aligning the center of mass near the center of buoyancy. Adjustable ballast and buoyancy foam correct minor imbalances within frame cavities. This design achieves near-neutral buoyancy, enabling precise 6-DOF control while reducing energy consumption during hovering and maneuvering. The following formulas [13] are utilized to make the AUV bouncy neutral:

Weight of AUV, W= $M \cdot g$
Buoyant Force, $F_{buoyant} = V.\ \rho_{water}.\ g$
Buoyancy Conditions:
Neutrally Buoyant: $F_{buoyant} = W$, the AUV at constant depth
Positively Buoyant: : $F_{buoyant} > W$, the AUV floats upward
Negatively Buoyant: $F_{buoyant} < W$, the AUV sinks
For close to neutral buoyancy:

$$F_{buoyant} \approx W$$

$$(M+m)g - \left(V + \frac{m}{\rho_b}\right)\rho g = 0$$

Here, m is the mass and ρ_b is the density of buoyancy foam or ballast weight.

B. *Electrical Subsystem*

The electronics subsystem of the HAUV manages power, sensing, and control. A 4S battery powers thrusters and lights, while a 3S battery powers computing and sensors through regulated converters. The Jetson Orin Nano handles vision and mission planning, with a Raspberry Pi for communication. The Pixhawk Cube controls eight T200 thrusters and actuators via PWM signals. Integrated sensors include the OAK-D-W and bottom cameras, a hydrophone array, Bar30 depth sensor, and VectorNav VN200 IMU, ensuring stable navigation and task execution during missions.

*a) **Electronics Bay:*** Fig. 8 shows the CAD model of the electronics bay of the HAUV. The design features a watertight cylindrical hull housing key electronics, including the Jetson Orin Nano for onboard processing, Raspberry Pi 4B for communication, and Pixhawk 2.4 for low-level control. The VectorNav VN200 provides inertial data, while a GPS/GNSS module is included for surface testing and alignment. Electronic Speed Controllers (ESCs) are arranged for efficient wiring to the T200 thrusters.

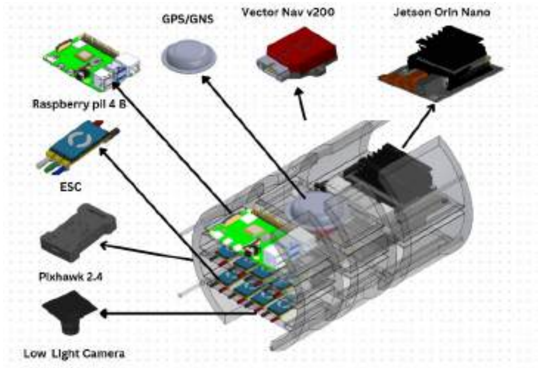

Fig. 8: CAD model of electronics bay

A low-light camera is mounted for downward visual tasks. This compact, organized layout ensures accessibility, modularity, and stable operation during underwater missions.

*b) **Power Distribution System:*** The power distribution system of the HUAV is shown in Fig. 9. The system uses two battery packs: a 4S 30C 8000mAh battery for high-voltage loads and a 3S 20C 3500mAh battery for low-voltage electronics. Power from both batteries passes through fuses and relays before distribution.

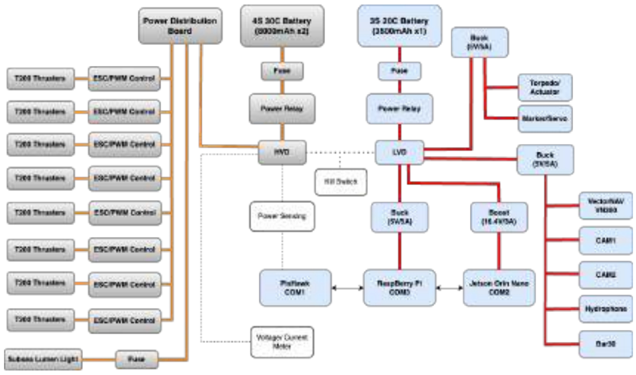

Fig. 9: High level overview of the power distribution system

A high-voltage distribution line powers the Pixhawk COM1 and eight T200 thrusters via ESC/PWM control, with current protection using resettable fuses. A low-voltage distribution line supplies the Jetson Orin Nano, Raspberry Pi, sensors, and actuators through regulated 5V and 16.4V outputs using buck and boost converters. A power sensing module monitors system voltage and current, while a manual kill switch provides emergency cutoff. This structured system ensures stable, protected, and efficient power delivery across all subsystems during underwater missions.

1. ***High Voltage Power Calculation***: Each of the 8 T200 thrusters is driven by an ESC, operating at 14.8 V (4S) with a maximum current of 12 A under load.

$$I_{max} = 8 \times 12A = 96A$$

For continuous mission estimates (60% utilization):

$$I_{cont} = 0.6 \times 96A = 57.6A$$

Total power:

$$P_{thrusters} = V \times Icont = 14.8V \times 57.6A = 853W$$

For lumen subsea light peak current at 15 V:

$$I = 15 / 15 = 1A$$

$$P_{light} = 15V \times 1A = 15\ W$$

Total high voltage power:

$$P_{HVD} = 853W + 15W = 868W$$

2. ***Low Voltage Power Calculation***: The LVD supplies the Jetson Orin Nano, Raspberry Pi, Pixhawk, sensors, and actuators. Estimated consumption are depicted in Table 1:

Table I: Low voltage component power

Component	Power (W)
Jetson Orin Nano	20
Raspberry Pi 4B	8
Pixhawk	2
VN200 IMU	1.5
Bar30 Depth Sensor	0.5
Cameras	10
Hydrophone	2
Actuators (Marker, Torpedo)	10 (peak)
Total (approx.)	**54 W**

Using two 4S 8000mAh batteries:

$$Capacity = 2 \times 8Ah \times 14.8V = 236.8Wh$$

Estimated runtime at continuous operation:

$$t_{HVD} = 236.8\ Wh / 868W = 0.27h \approx 16min$$

At 50% load during typical missions:

$$t_{HVD} = 236.8\ Wh / 434W = 0.55h \approx 33min$$

Using a 3S 3500mAh battery:

$$Capacity = 3.5Ah \times 11.1V = 38.85Wh$$

$$t_{HVD} = 38.85\ Wh / 54W = 0.72h \approx 43min$$

c) ***Power Distribution PCB:*** Fig. 10 shows the power distribution PCB developed for the HAUV. The left image displays the fabricated PCB, while the right image shows the layout designed in KiCad. This board manages organized, reliable distribution of high and low voltage across subsystems.

Fig. 10: Power distribution PCB layout and hardware construction for the HAUV

It includes multiple XT60 and terminal outputs for thrusters, computing, and sensor lines, with large electrolytic capacitors for voltage ripple smoothing during load changes. Screw terminals simplify connection and maintenance, while wide copper traces ensure low-resistance paths for high-current ESC lines. This design ensures stable, clean power delivery critical for underwater mission reliability during RoboSub.

The detailed descriptions of the propulsion and actuation system, microcontrollers, camera interfaces, communication modules, and sensor interfaces are provided in Appendix C for reference.

C. *Software and AI Subsystem*

HAUV's software and AI subsystem is built with a scalable, resilient, and modular architecture to manage autonomous operations in real time in an underwater setting. The NVIDIA Jetson Orin Nano is used for high-performance parallel computing in this ROS (Robot Operating System)-developed system, with a Raspberry Pi 4 for auxiliary duties. The three main parts of the software architecture are the System Communication, Path Planning, and Vision System. The Fig. 11 shows a high-level overview of the software and autonomous system architecture.

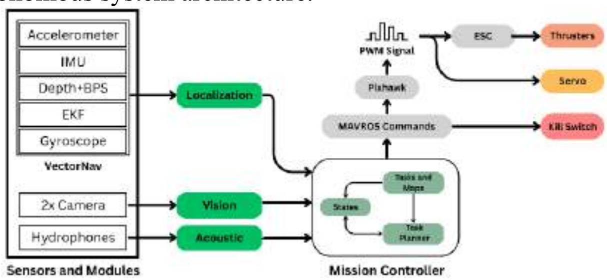

Fig. 11: High level software system architecture

a) ***Object Detection and Image Processing:*** HAUV employs a downward-facing camera for path tracking, ocean cleanup task, and drop point recognition, and a front-facing camera for object detection (such as gates and buoys). Real-time object detection is done using YOLOv8, which is accelerated on the Jetson using TensorRT, and image preprocessing is done by OpenCV which is illustrated in Fig. 12. The outputs are utilized for mission logic and navigation and are published as ROS topics.

Fig. 12: Gate detection using YOLOv8 model

b) ***Path Planning and Localization:*** A Behavior Tree (BT) for modular, reactive decision-making is used to maintain mission autonomy, with each node handling functions like actuation, search, and alignment. With PID-based thruster control, motion commands are transmitted to the Pixhawk through MAVROS. An Extended Kalman Filter (EKF) that combines information from the VectorNav IMU, depth sensor, and barometric pressure sensor maintains localization.

*c) **System Communication:*** ROS and MAVLink serve as the communication backbone. ROS controls data flow between modules, whereas MAVROS connects high-level commands to the Pixhawk. Sensors such as the hydrophone, power module, and motor controllers communicate using serial, UART (Universal Asynchronous Receiver/Transmitter), and GPIO (General-Purpose Input/Output). A watchdog node checks system health and initiates fallback behaviors when needed.

IV. Missions Strategy and Execution

HAUV uses a modular ROS-based architecture managed by a Behavior Tree for adaptive decision-making and task flexibility. It prioritizes tasks based on reliability and scoring, dynamically retrying or skipping as needed. Tasks begin with the gate and channel, progressing to advanced missions for efficient execution during RoboSub 2025.

The detailed task execution, perception, control, and recovery strategies are depicted in Appendix D.

V. Testing and Validation

A. *Mechanical*

To ensure HAUV performance and safety, mechanical testing and simulation-based validation were conducted. Structural analysis in SolidWorks using static load testing on the Aluminum 5083 frame showed a maximum stress of 1.82×10^7 N/m², well below its yield strength, ensuring a high safety factor which is illustrated in Fig. 13. CFD simulations assessed hydrodynamic performance, revealing streamlined water flow with minimal drag and consistent pressure distribution that is illustrated in Fig. 14. These results confirm that HAUV's design is strong, stable, and energy-efficient for reliable underwater operation during missions.

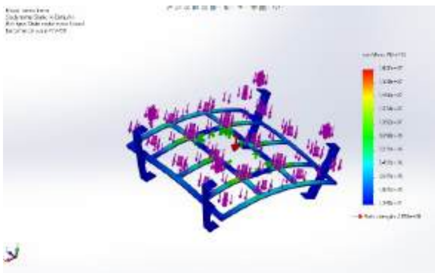

Fig. 13: Strength test of the frame

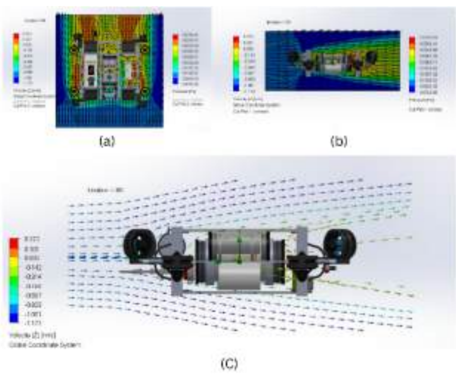

Fig. 14: (a) Top view, (b) Front view cut plot and (c) Vector plot of CFD

B. *Electrical*

Fig. 15 shows the voltage (blue), current (red), instantaneous power draw (yellow), and average estimated power draw (green) of HAUV under different thrust conditions. The voltage remains stable with slight dips during peak loads, while the current and power draw spikes correspond to dynamic thrust changes during testing. The average estimated power draw gradually increases, reflecting higher propulsion demand over time. This analysis helps in verifying battery sizing, power distribution stability, and energy efficiency during varying underwater maneuvers for RoboSub mission profiles.

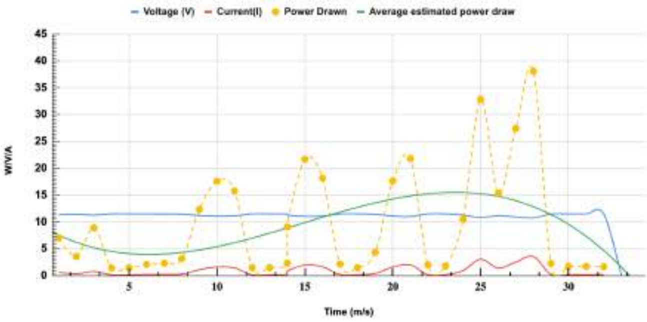

Fig. 15: Power draw curve under different thrust condition

C. *Software*

Fig. 16 illustrates the loss curves from YOLOv8 training using synthetic underwater data [14] for HAUV's object detection tasks. The plot tracks bounding box loss and classification loss for both training and validation over 120 epochs. A clear downward trend indicates effective learning, with training losses decreasing steadily and validation losses closely following. The box loss reduces from 0.7 to 0.25, while the classification loss drops below 0.15, confirming robust convergence. This validates the synthetic dataset's effectiveness in preparing HAUV's vision system for underwater detection tasks under varying conditions during RoboSub missions.

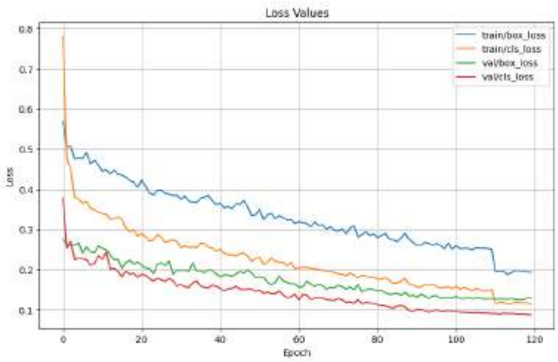

Fig. 16: Loss curve during training procedure

VI. Challenges and Highlights

HAUV faced key challenges across all subsystems:.

Mechanical: Balancing volume-to-weight ratio for buoyancy and ensuring watertight integrity in custom enclosures.

Software: Achieving fast real-time detection with efficient algorithms.

Electrical: Configuring VectorNav and stabilizing power delivery without damaging components.

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APPENDIX: A
COMPONENT SPECIFICATIONS

Component	Vendor	Model/ Type	Specifications	Custom/ Purchased	Year of Purchase	Cost
Buoyancy Control	Blue Robotics	Buoyancy foam R-3318	6 Pieces	Purchased	2025	$300
Frame	Local	Custom aluminum	Modular	Custom	2025	$120
Waterproof Housing	Local	Custom enclouser	Acrylic tube with rubber sealer	Custom	2025	$130
Waterproof Connectors	Local	Custom ABS	ABS filament	Custom	2025	$20
Frame Anodizing	Rainbow	Gloss Black (39)	Black	Purchased	2025	$9
Thrusters	ROV Maker	T200	Brushless thruster	Purchased	2025	$1200
Motor Control	Blue Robotics	Basic ESC BR-100344	Electronic speed controllers	Purchased	2025	$342
Low-Level Control	Robotics Bangladesh	Pixhawk Flight Controller	Advanced 32-bit Cortex-M4 ARM high-performance processor	Purchased	2025	$120
Actuators	Robotics Bangladesh	MG996R	180-degree servo	Purchased	2025	$14
Battery	Eee Tech	Lipo Battery 14.8V	4S 45C 10000mah	Purchased	2025	$200
Converter	Robotics Bangladesh	Voltage Regulator Buck Converter	Max 5-40V to 1.2-3.6V Step down	Purchased	2025	$10
CPU	Nvidia	Jetson Orin Nano	6-core CPU, 1024-core GPU, 20 TOPS AI	Purchased	2025	$600
Internal Comm Network	n/a	CAN, MAVLink Protocol	n/a	n/a	2025	n/a
External Comm Interface	BRB	Ethernet	CAT6	Purchased	2025	$10

Programming Language 1	n/a	C++	n/a	n/a	2025	n/a
Programming Language 2	n/a	Python	n/a	n/a	2025	n/a
Compass and IMU	VectorNav	VN200	GPS-aided IMU, 9-axis, high-precision	Purchased	2025	$3500
Cameras	Luxonis	OAK-D-W	12 MP RGB camera module with auto focus	Purchased	2025	$649
Hydrophones	Aquarian Hydrophone	H1a Hydrophone	4.5mm OD	Purchased	2025	$366
Manipulator	BengalSub Custom	Custom	ABS, TPU	Custom	2025	$50
Algorithms: Vision	n/a	YOLO V3	Real-time object detection algorithm with high speed and good accuracy	n/a	2025	n/a
Algorithms: Acoustics	n/a	Time Difference of Arrival (TDoA)	n/a	n/a	2025	n/a
Algorithms: Localisation/Mapping	n/a	ROS2	n/a	n/a	2025	n/a
Open Source Software	n/a	ROS, Gazebo	Various Multiple Packages	Open Source	2025	n/a
Team Size	n/a	n/a	29 people	n/a	2025	n/a
HW/SW Expertise Ratio	n/a	n/a	2:1	n/a	2025	n/a
Testing Time: Simulation	n/a	n/a	280 hours	n/a	2025	n/a
Testing Time: In-Water	n/a	n/a	25 hours	n/a	2025	n/a

APPENDIX: B
TOOLS AND EQUIPMENTS

1) Electrical Equipment

- Solder gun and stand
- Solder wire
- Wire strippers (standard and AWG precision)
- Ethernet cables and LAN spool
- HDMI cables
- Micro USB cables for screens
- Test screen
- Multimeter
- Spare, charged Li-Po batteries
- Battery chargers (Li-Po compatible)
- Extension cords and power strips
- Screwdrivers (various sizes)
- USB extenders and hubs
- Scissors
- USB ASP programmer
- Glue gun and glue sticks
- Arduino Uno boards with cables
- Spare ATmega and CAN ICs
- Duct tape and insulation tape
- Jumper wires
- Single-strand and AWG wires for harnessing
- Mouse and keyboard
- Heat shrink tubing and heat gun
- Crimping tools and connectors
- XT60, XT30 connectors
- Digital oscilloscope (for signal debugging)
- Bench power supply
- PDB test board
- USB-to-UART interfaces
- Hot air rework station (for PCB repairs)

2) Mechanical Equipment

- Allen key and spanner set
- Precision screwdrivers (PSD)
- Drill machine with assorted bits
- Epoxy resin, mixing cups, sticks
- Cardboard, tissue, chalk for layout work
- Duct tape, insulation tape
- Zip ties (various sizes)
- Rope for handling and lowering AUV
- Nuts, bolts, washers (stainless steel preferred)
- Buoyancy foam and floats
- Mini hacksaw and blade replacements
- Scissors and utility knife
- Calipers and measuring tape
- Sandpaper for edge finishing

- Threadlocker for critical fasteners
- Ballast weights and mounting straps

3) Testing and Integration Equipment

- Water tank or access to pool for testing
- Tether spool and slip ring if applicable
- Kill switch test harness
- Tether booster modules
- Laptop with ROS Noetic, MAVROS, and mission software
- Jetson Orin Nano and Raspberry Pi for integration testing
- Pixhawk Cube with accessories
- Hydrophone array with test pinger
- Cameras (OAK-D-W, low-light USB) for vision pipeline validation
- Spare thrusters and ESCs for quick swap during pool tests
- Digital scale for weight checks
- Leak detection sensors and vacuum pump for hull testing

APPENDIX: C
SYSTEM ARCHITECTURE, FLOWS AND DIAGRAMS

Electrical System Configuration

a) ***Propulsion and Actuation:*** The propulsion and actuation system of the Hangor Autonomous Underwater Vehicle (HAUV) is designed for stable, precise, and efficient underwater navigation and task execution during RoboSub missions. HAUV uses eight T200 thrusters arranged to provide full six-degree-of-freedom (6-DOF) control, enabling the vehicle to translate and rotate along all axes with stability during complex maneuvers. Each thruster is controlled using BLHeli ESCs rated for 30 A continuous current and powered by a high-voltage distribution system at 14.8 V (4S). The ESCs receive precise PWM signals from the Pixhawk low-level controller, ensuring consistent thrust adjustments during mission operations.

Thruster positioning is optimized to maintain the vehicle's center of gravity and minimize torque imbalances during rapid changes in direction or speed. This symmetrical configuration reduces energy consumption during hovering and enables smooth transitions during slalom, gate traversal, and marker alignment tasks. Additionally, the propulsion system's modular design allows for easy replacement of individual thrusters or ESCs during maintenance. For actuation, HAUV includes a servo-controlled marker dropper and a dual-tube torpedo launcher with spring-loaded mechanisms for controlled deployment. The marker dropper is positioned at the vehicle's centerline to allow unobstructed vertical marker release, while the torpedo launchers are aligned horizontally at the front, providing accurate linear projection during task execution. The actuation system's design ensures reliability and repeatability, which are essential for scoring during competition tasks, while the protective frame structure minimizes damage during unintentional impacts. This integrated propulsion and actuation system enable HAUV to execute tasks efficiently while maintaining stability and control in dynamic underwater environments.

b) ***Microcontrollers:*** Microcontrollers serve as the critical backbone of HAUV's control and execution systems, bridging high-level decision-making with precise, real-time actuation. They process sensor inputs, manage command distribution, and execute closed-loop control algorithms for stable operation during complex underwater missions.

1. ***Low Level Computer/Pixhawk (COM1)***: The Pixhawk Cube Orange is the primary low-level controller for HAUV, responsible for executing motion commands, managing stabilization, and providing reliable vehicle control. It receives high-level velocity and position commands from the Jetson Orin Nano via MAVLink and executes them by generating precise PWM signals for the ESCs connected to the T200 thrusters. Using its onboard IMU, integrated barometer, and external depth sensor data, the Pixhawk maintains stable attitude, depth, and position using PID-based control loops, enabling fine control during tasks like marker drop, slalom navigation, and BRUV alignment.

   The Pixhawk also manages auxiliary actuators, including the marker dropper and torpedo launcher, using digital outputs and solenoid drivers. Its firmware configuration in ArduSub allows for custom tuning of PID parameters and mission profiles to match HAUV's hydrodynamic characteristics. Fail-safe features, including manual kill switch integration and automatic disarming on fault detection, are implemented to ensure system safety during testing and operation. The Pixhawk interfaces with the ROS environment via MAVROS, enabling synchronized mission execution and real-time feedback to high-level computers. Its modular wiring with labeled connectors allows easy servicing and system reconfiguration between testing cycles, ensuring reliable low-level control for mission-critical underwater tasks.

2. ***High Level Computer/Jetson (COM2)***: The Jetson Orin Nano acts as HAUV's high-level computation platform, handling perception, mission planning, and autonomous decision-making. It runs ROS Noetic and mission packages, managing YOLOv8-based object detection and OpenCV pipelines for

real-time visual perception tasks. The Jetson processes data from the front and bottom cameras, hydrophones, and sensor arrays to identify objects, track targets, and navigate pathways during missions.

Using a behavior-tree-based mission controller, the Jetson prioritizes and executes tasks dynamically, enabling robust mission completion even under variable conditions. It sends velocity and position commands to the Pixhawk via MAVROS, bridging high-level perception with low-level actuation. The Jetson also manages task fallback strategies, switching between sonar, vision, and dead reckoning when primary perception methods fail. The device is optimized for energy efficiency, balancing high compute load during YOLOv8 processing with thermal management within the sealed electronics enclosure. It supports real-time debugging and log monitoring during pool tests via SSH and direct tethered connections, ensuring rapid iteration during system validation. The Jetson's integration with the ROS ecosystem allows seamless expansion of perception and control nodes, ensuring scalability for advanced tasks and research extensions beyond RoboSub 2025.

3. ***High Level Computer/RaspberryPi (COM2)***: The Raspberry Pi 4B complements the Jetson by handling secondary computing tasks, data logging, and system management. It manages acoustic localization by processing hydrophone array signals for pinger detection using TDoA algorithms, providing heading estimates during the octagon and trash collection tasks. The Pi also acts as a communication bridge during surface testing, allowing real-time mission monitoring and debugging through Ethernet tether connections.

   The device runs lightweight ROS nodes for system health monitoring, power status tracking, and secondary perception validation, providing redundancy in critical systems. Its GPIO interfaces are utilized for sensor triggering and manual control override functions during field testing. The Raspberry Pi's modular integration enables quick replacement or upgrades, while its low power consumption ensures minimal impact on the vehicle's energy budget. Together with the Jetson, the Raspberry Pi ensures that HAUV has robust, layered high-level control and mission management for stable, autonomous underwater operation.

c) ***Camera Interface:*** The camera interface enables HAUV's vision-based navigation and task execution using front-facing and downward-facing camera systems. These systems provide high-resolution image streams for object detection, floor marker tracking, and BRUV alignment during missions.

1. ***CAM1***: The front-facing OAK-D-W camera is used for object detection, gate detection, and navigation tasks using YOLOv8 and OpenCV pipelines running on the Jetson Orin Nano. Its wide-angle, high-resolution output supports real-time target tracking and environmental awareness, essential for gate traversal, slalom, and animal tagging tasks.

2. ***CAM2***: The downward-facing low-light USB camera supports floor marker tracking, bin detection, and alignment tasks. It provides stable visual feedback under variable lighting conditions, supporting precise marker drops and trash collection tasks during mission execution.

d) ***Communication Module:*** HAUV uses a robust communication system to ensure reliable data transfer and mission monitoring. A tether booster and CAT6 Ethernet cable enable high-speed data exchange during surface testing and debugging. Internal communications use serial connections and MAVLink for data transfer between the Jetson, Raspberry Pi, and Pixhawk, supporting real-time command execution and status feedback. This system ensures low-latency, stable communication for autonomous and manual override operations.

*e) **Sensor Interfaces:***

1. ***Power Sensing***: Sensor interfaces enable HAUV to collect, process, and utilize environmental data for navigation, localization, and mission execution. Interfaces are designed for reliability and modularity, supporting real-time data integration during missions.

2. ***Pressure Sensing***: A power sensing module continuously monitors voltage and current across high and low voltage lines, providing real-time power status feedback for mission planning, energy optimization, and safety cutoffs.

3. ***Humidity***: A DHT22 sensor monitors humidity and temperature within the electronics enclosure, enabling early leak detection and thermal management to protect sensitive electronics during missions.

Future Iteration of Electrical System

a) ***Power Budget Improvement:*** Fig. 17 graph represents the AUV's minimal idle Power consumption remains low (~1.48–1.51 W), with a steady current of ~0.13 A and a stable voltage near 11.5V. There are no noticeable spikes or drops,indicating clean and efficient operation. Implement a sleep/low-power standby state when no thrust is needed.Use pulse-width modulation (PWM) optimization to further reduce idle power.

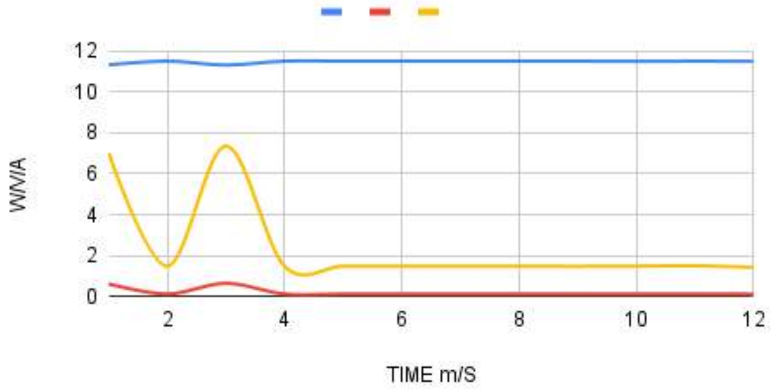

Fig. 17: 25% power mode analysis

Fig. 18, the HAUV operates at a moderate thrust level. Power usage increases to ~4–7 W with currents ranging between 0.3 A and 0.7 A. Voltage begins to show minor sag (~11.2V), but overall remains within a safe range. Initial signs of voltage drop suggest wiring or power delivery limits. Efficiency could drop if sustained at this mode for long periods. Use lower-resistance wiring to minimize voltage loss. Add localized capacitors near the motor controllers to handle small power surges.

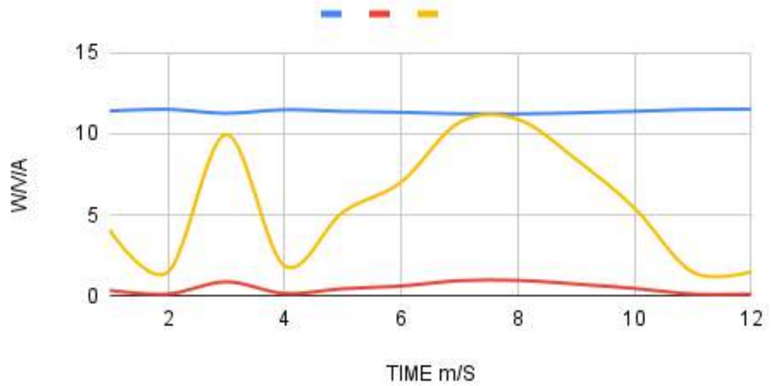

Fig. 18: 50% power mode analysis

Fig. 19, the AUV operates at a moderate thrust level. Power usage increases to ~4–7 W with currents ranging between 0.3 A and 0.7 A. Voltage begins to show minor sag (~11.2V), but overall remains within a safe range. Initial signs of voltage drop suggest wiring or power delivery limits. Efficiency could drop if sustained at this mode for long periods. Use lower-resistance wiring to minimize voltage loss. Add localized capacitors near the motor controllers to handle small power surges.

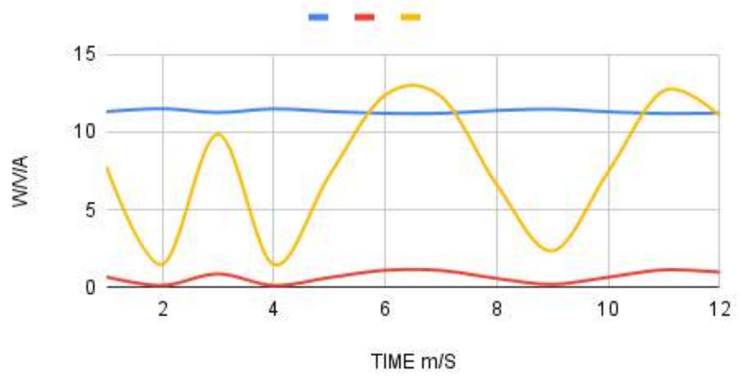

Fig. 19: 75% power mode analysis

This graph of Fig. 20 is designed for more aggressive maneuvering or high-speed travel. Power usage ranges from ~13 to 18 W, with currents up to 1.6 A. Voltage dips more significantly (~10.9V), and thermal or power regulation may become a concern during extended use. Not sustainable for long durations due to power demand. Potential for overheating or system instability in older components. Upgrade the battery pack to a higher C-rated (discharge-capable) model.

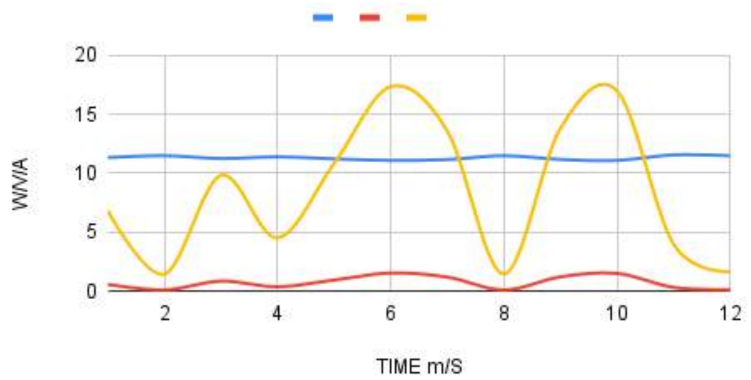

Fig. 20: 75% power mode analysis with all thruster running

b) ***Communication Link:*** The current communication system with the HAUV is based on a Cat 6 Ethernet cable. To enhance performance and increase operational flexibility, an upgrade is planned in two phases. In the first phase, the system will be transitioned to an optical fiber link, offering significantly improved resistance to electromagnetic interference (EMI), reduced signal loss, and a much greater communication range. This upgrade will provide a more stable and efficient data connection, supporting long-term goals which is shown in Fig. 21. The communication protocol will remain Ethernet, ensuring compatibility with existing infrastructure while leveraging the advantages of fiber optics.

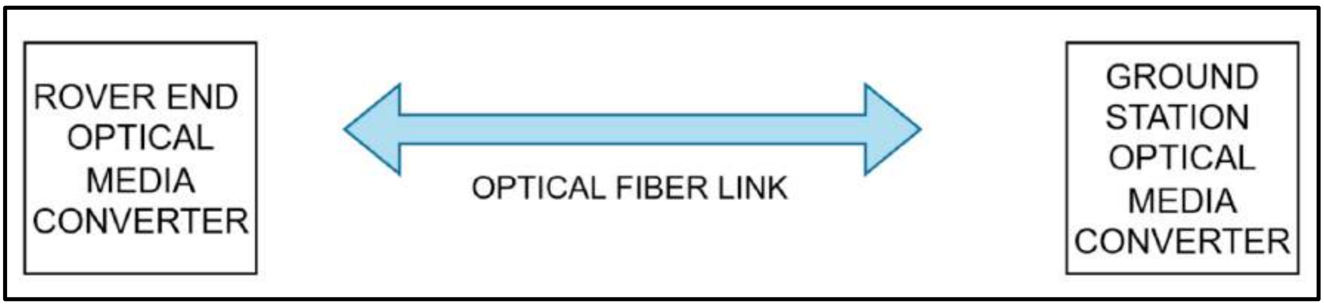

Fig. 21: Future wired communication link

For the final iteration, a wireless communication link with the HAUV is planned, offering greater range and enhanced operational flexibility which is shown in Fig. 22.

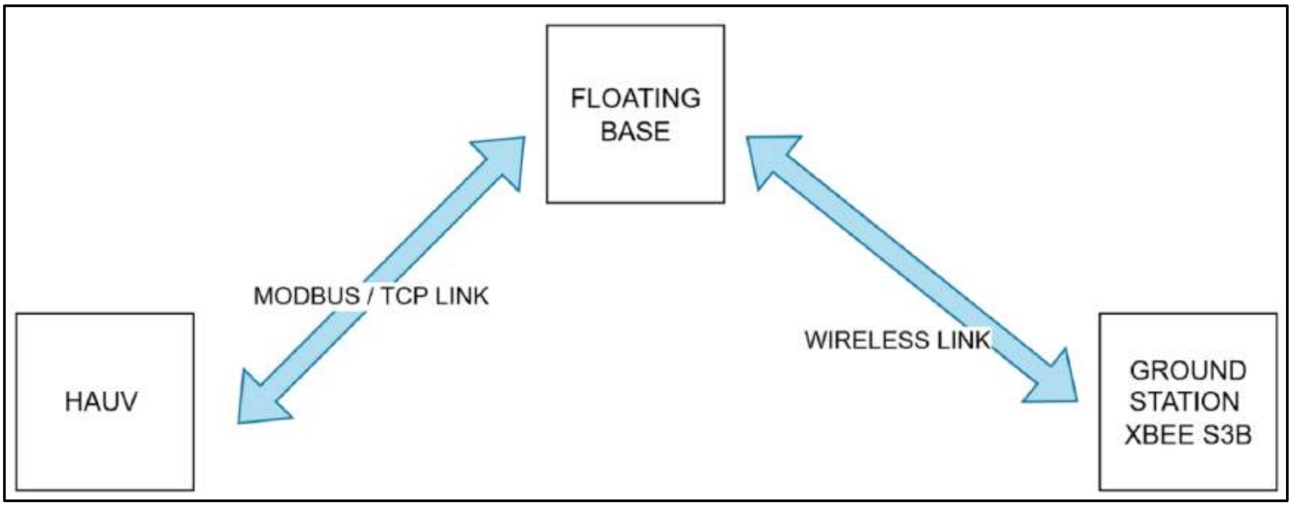

Fig. 22: Future wireless communication link

Modbus/TCP will be utilized for robust and standardized data exchange. A tether will be used to connect the HAUV to a floating communication module, which will serve as a relay between the underwater unit and the surface. From there, data will be transmitted wirelessly to the ground station using high-performance XBEE S3B modules, ensuring reliable and efficient communication throughout the mission.

c) ***Internal Communication System:*** The future internal communication architecture for the Hangor Autonomous Underwater Vehicle (HAUV) is designed for modularity, reliability, and ease of debugging during underwater missions which is shown in Fig. 23. This system enables seamless communication between propulsion, actuation, sensing, and computational units, ensuring efficient operation under mission constraints. At the core of the system is the Jetson Orin, which handles mission computation, real-time perception, and decision-making. It interfaces with a CAN Bus HAT that connects the Orin to the internal CAN bus for distributed subsystem communication. The CAN Bus HAT provides low-latency communication with the actuator board, ESC boards, and other CAN-enabled devices, ensuring reliable command distribution throughout the vehicle.

Propulsion and actuation systems, including the ESC boards and actuator board, are connected via CAN-enabled subconn interfaces, supporting thrusters, marker dropper, claw mechanism, and torpedo launcher. The ESC boards receive power from the power distribution board, which manages energy delivery from the port and standard battery banks while providing overcurrent protection. A status light system linked to the actuator board a 5V fan system powered via the camera cage breakout adapter, ensuring thermal stability during high-load missions. The VectorNAV VN200 IMU and depth sensor interface through the camera cage breakout adapter, providing navigation data to the Jetson Orin for sensor fusion and mission guidance. External CAN devices, including additional sensors or manipulators, are connected through External CAN1 and CAN2 ports, ensuring system scalability. The camera interface uses USB to the Jetson Orin for real-time image acquisition, while a network switch connected via Ethernet routes high-bandwidth data between the Jetson Orin, tether subsystem, and surface modules. Power-over-Ethernet allows integrated power and data transmission, reducing cable complexity. The kill and AUX switch enables manual system shutdown in emergencies, while structured cabling with labeled lines simplifies maintenance and troubleshooting. This future internal communication link architecture supports stable, modular, and scalable mission operations for HAUV, enabling advanced autonomy while maintaining system reliability during underwater missions and RoboSub competitions.

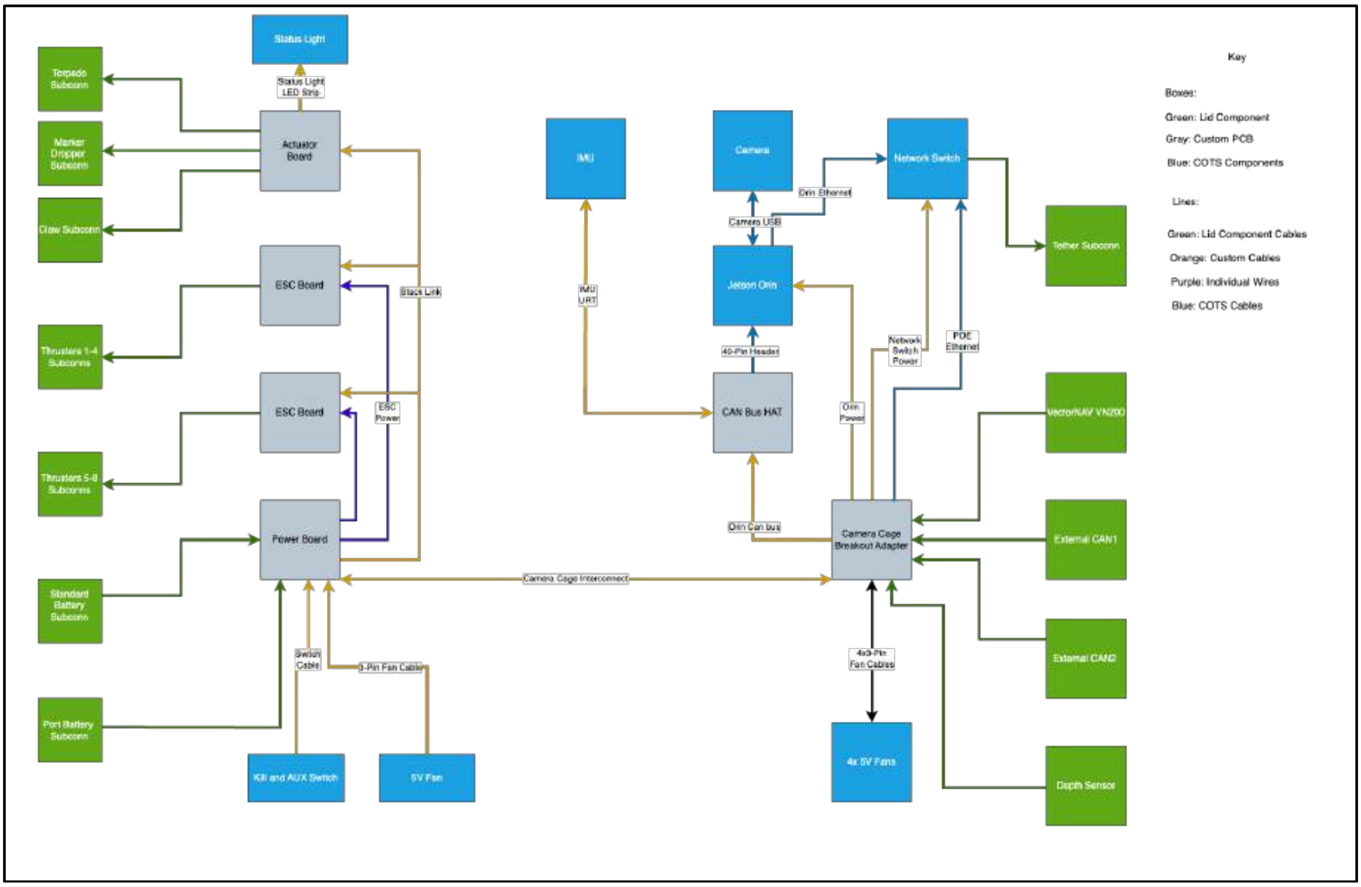

Fig. 23: Future iteration of internal communication link

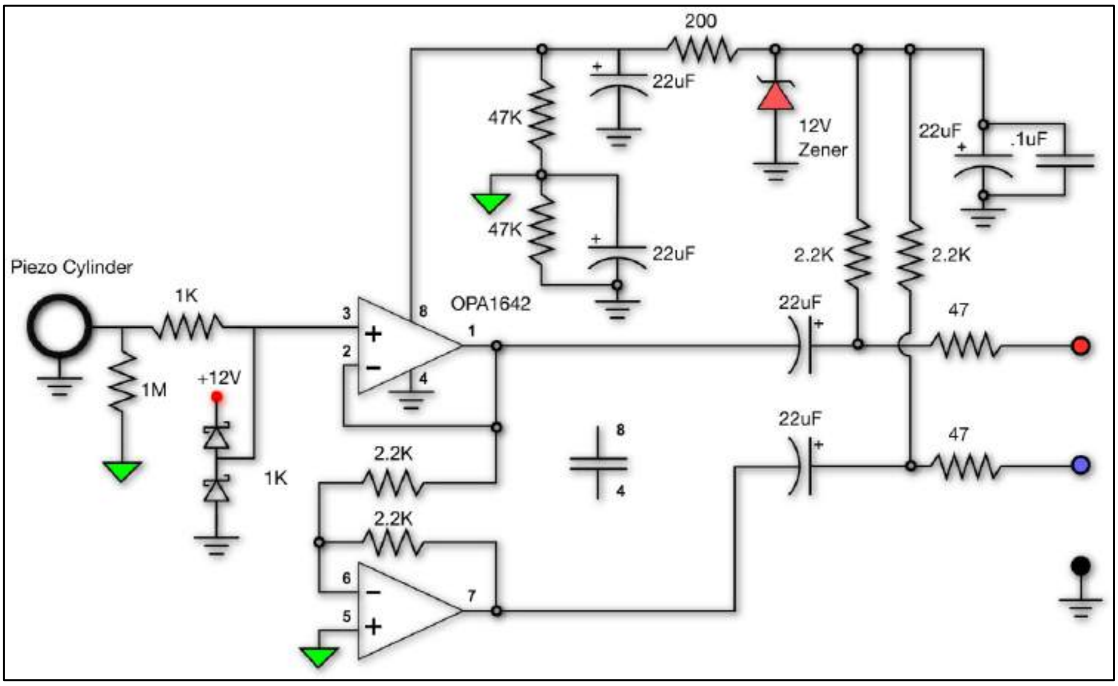

Fig. 24 (a): Hydrophone array schematics for specific location detection [15]

To reduce the high costs associated with commercial-grade hydrophones, the development of a custom hydrophone array tailored to specific application requirements was initiated as depicted in Fig. 24 (a). After several publicly available and open-source hydrophone designs were evaluated, the system was based on Gladys, a DIY hydrophone developed by Jules Ryckebusch [15]. This design was chosen due to its simplicity, cost-effectiveness, and proven performance in underwater acoustic sensing.

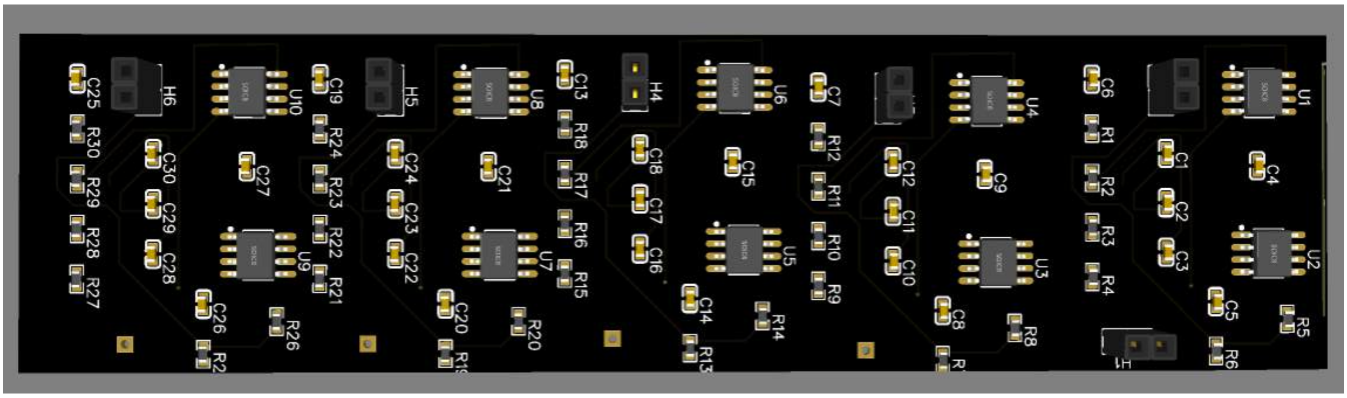

Fig. 24 (b): Team designed hydrophone array schematics for specific location detection

The custom system features a high-impedance piezoelectric buffer array circuit designed to interface with ceramic piezo elements commonly used in hydrophone applications. To achieve optimal performance, a series of modifications to the original Gladys design was implemented as shown in Fig. 24 (b). These modifications include the use of JFET-input operational amplifiers, such as the TL072, providing ultra-high input impedance and low noise characteristics. Each hydrophone channel is independently buffered to ensure electrical isolation and consistent signal fidelity across the array The architecture has been designed to be modular, allowing the number of hydrophones in the array to be increased or decreased easily as needed.

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APPENDIX: D
MISSION STRATEGY

With its modular, ROS Noetic-based architecture managed by a Behavior Tree, HAUV facilitates adaptive decision-making and flexible job execution. Starting with the gate and channel and working up to more complicated goals, tasks are ranked according to their dependability and scoring potential. In order to provide mission robustness, the system dynamically swaps, retries, or skips tasks based on sensor input and time limitations.

A. Autonomous Task Execution

The Behavior Tree initiates each task, which operates as a Python ROS node. YOLOv8 is used for gate traversal through the front camera, with dead reckoning and sonar serving as backups. Channel navigation does slalom and detects colored poles using OpenCV HSV filtering. Visual servoing is used for marker drop and alignment in the BRUV task. Tagging uses segmentation and YOLOv8 to identify and target the animal. Trash sorting employs a dropper for sorting, YOLOv8 for classification, and hydrophone TDoA for pinger localization. The AUV uses fallback guiding and cached localization to return.

B. Perception and Sensor Fusion

HAUV employs OpenCV for color-based tracking and YOLOv8 for object detection. ROS Python nodes process the feeds from the front and rear cameras. To ensure precise localization, an EKF combines IMU, depth, and pressure data; in the event that optical input is inaccurate, sonar and dead reckoning serve as a backup.

C. Control and Navigation

Heading, depth, and position are managed by control nodes using PID loops, which communicate velocity orders to Pixhawk over MAVROS. Different navigation techniques are used for different tasks, such as octagon approach using hydrophone TDoA, slalom using HSV poles, and path following using floor markers. ESC-controlled thrusters guarantee stable hovering and nimble movement.

D. Recovery and Safe-Fail Logic

A kill switch, software disarm via MAVROS, and watchdog nodes are all part of a multi-layered safety system. When primary sensors fail, the Behavior Tree manages task fallback by employing dead reckoning or sonar. Procedures for safe recovery are halted or surfaced in response to critical errors.

APPENDIX: E
ROS INTEGRATED GAZEBO SIMULATION

To validate the Hangor Autonomous Underwater Vehicle's (HAUV) control algorithms, sensor integration, and mission strategies before physical testing, a ROS-integrated Gazebo and Rviz simulation environment has been developed which is shown in Fig. 25. This simulation allows testing and refinement of the full software stack in a controlled, repeatable, and safe virtual underwater environment. The 3D model of the HAUV, as shown, is loaded into RViz using the /robot_description topic, ensuring that the URDF accurately reflects the vehicle's dimensions, thruster placements, and inertial properties. This detailed model includes all eight T200 thrusters, positioned precisely to replicate the real vehicle's six-degree-of-freedom maneuvering capabilities, ensuring accurate simulation of translational and rotational control in water.

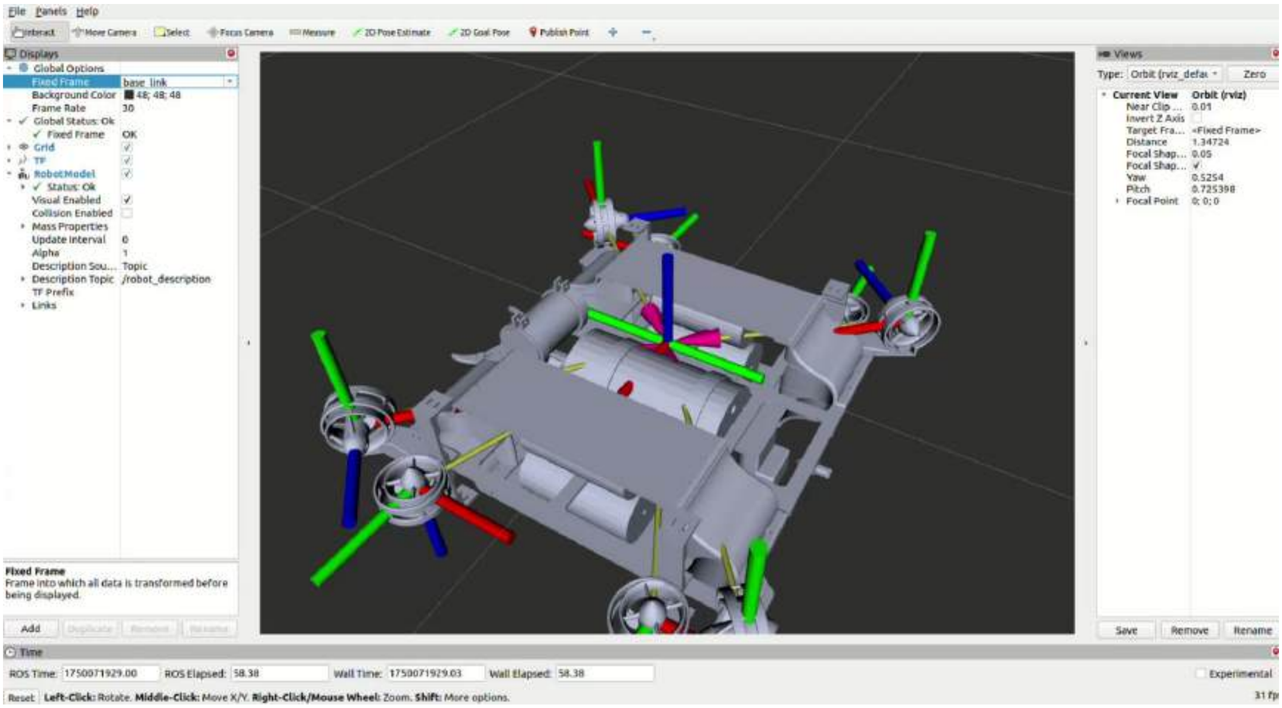

Fig. 25: ROS integrated rviz simulation

Gazebo, coupled with ROS Noetic, simulates the underwater environment by applying forces and torques to the HAUV's links based on thruster commands sent via ROS topics. The plugin uuv_simulator is utilized to model hydrodynamic drag, buoyancy, added mass, and water current disturbances, providing realistic vehicle dynamics. The PID controllers tuned within the Pixhawk firmware can be tested by issuing velocity or position commands through the ROS cmd_vel topic, with the system's response monitored in real-time within RViz. Sensor plugins simulate input from the IMU, depth sensor, and cameras, allowing sensor fusion algorithms like the Extended Kalman Filter (EKF) to be tested under various mission profiles. Acoustic pinger simulation, using Gazebo plugins, enables the testing of TDoA localization algorithms with simulated hydrophones, validating acoustic navigation systems without the need for pool tests. Mission scripts and the behavior tree architecture are deployed within this environment, enabling autonomous mission execution, including gate traversal, marker drop, slalom, and object detection tasks using YOLOv8 integrated within the Jetson Orin simulation node. YOLOv8 models are tested with synthetic underwater images rendered within Gazebo, ensuring detection reliability under varied lighting and visibility conditions. Network simulation tools in ROS and Gazebo are used to emulate tether communication delays and bandwidth constraints, allowing validation of system stability under realistic communication limitations during mission execution. Overall, the ROS-integrated Gazebo simulation environment enables the team to test the HAUV's perception.

APPENDIX: F
MECHANICAL SYSTEM DESIGN PARAMETERS

Components Name	**Specifications**	**Size (mm)**	**Machining Process**	**Quantity**
Frame	5803 marine-grade aluminum	625x625x5	CNC laser cutter	1
Joining clamp	Aluminum	3mm thick	Angle grinder, lathe drill	16
Water guide	ABS, Acrylic	150 x 625	3D printing, Angle grinder	4
Torpedo Launcher	ABS	D25 X L120	3D printing	2
Marker Dropper	ABS	D30 x L80	3D printing	2
Water-Tight Encloser	Acrylic, Rubber end cap	D150 x L300	Hydraulic bending, molding	1
Component Mountings	ABS	Variable	3D printing	10

APPENDIX: G
SOFTWARE SYSTEM ARCHITECTURE

The mission execution logic for HAUV follows a structured, modular flow designed to handle multiple autonomous tasks efficiently which is shown in Fig. 26. At the start of a mission, the AUV enters a scanning phase where it performs lateral strafing motions, brief pauses, and slight yaw rotations to detect task-relevant objects using its front-facing camera. If no object is detected, the AUV continues scanning in a loop. Once an object is successfully identified, the system transitions into the alignment phase, during which it calculates the distance and angular offset between itself and the detected target using bounding box pixel positions, camera intrinsics, and pose estimation from the localization module.

Upon alignment, the AUV moves toward the calculated task location and initiates the appropriate task-specific behavior. Task execution involves vertical or horizontal movement, object interaction (such as grabbing or releasing), and verification of task completion. If a task fails or cannot be completed successfully, the behavior tree logic enables the system to skip the current task and move to the next one. Certain tasks, like trash collection, involve subroutines triggered after localizing the pinger signal. In this case, the AUV ascends vertically and uses its downward-facing camera to search for debris. It then descends, grabs the object using a manipulator, ascends back, detects bin positions using vision, aligns itself accordingly, and finally releases the object. This entire mission flow is governed by a behavior tree executor, which ensures reactive decision-making, fallback handling, and smooth transitions between conditions, making the AUV capable of autonomous, multi-phase underwater operations.

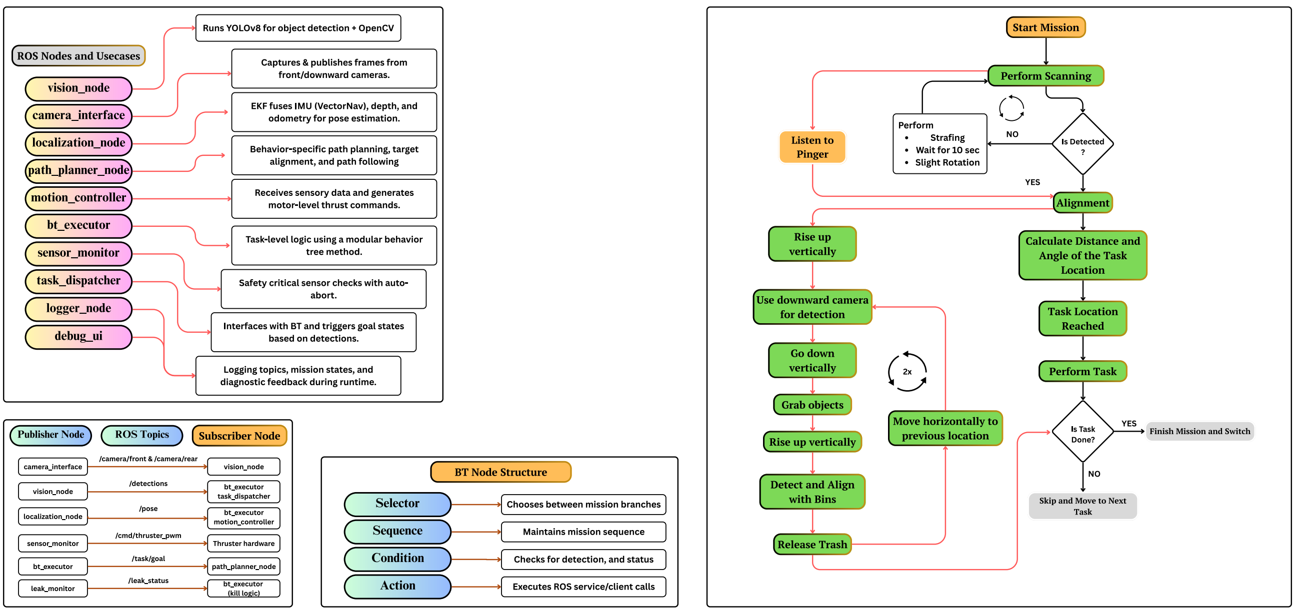

Fig. 26: Mission control flowchart

The YOLOv8x model used for real-time underwater object detection was trained and evaluated over 120 epochs. The graph provided illustrates the Mean Average Precision (mAP) scores across epochs, which are critical indicators of the model's detection performance.

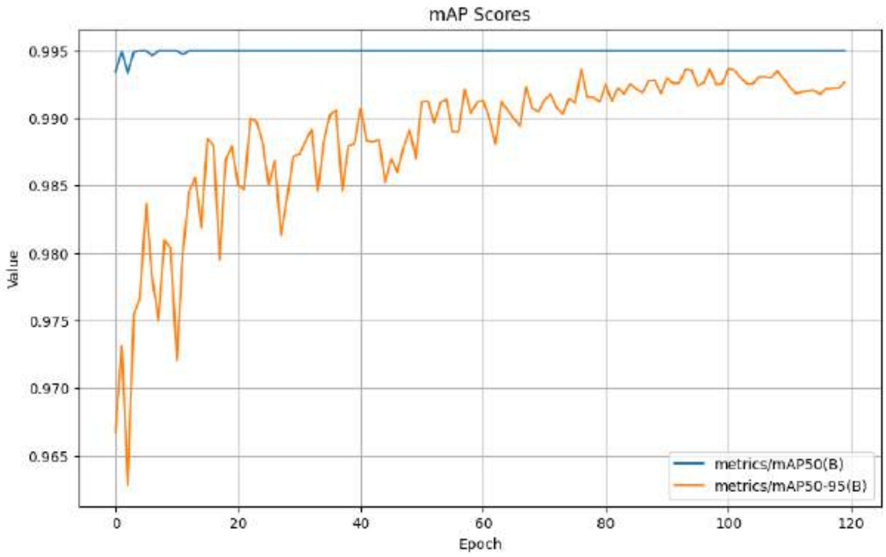

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Fig 27: Training and Loss Curves

The mAP@50 curve (in blue) quickly converges to a high value (~0.995) within the first few epochs and remains stable, indicating the model consistently detects objects with high precision at a 0.5 IoU threshold which is shon in Fig. 27. The mAP@50-95 curve (in orange) shows a steady upward trend, starting from ~0.965 and rising to around ~0.991 by the end of training. This curve averages mAP across multiple IoU thresholds (from 0.5 to 0.95 in steps of 0.05), thus reflecting the model's robustness in detecting objects with varying degrees of overlap accuracy. These curves validate that the YOLOv8x model has not only learned to identify objects reliably but also generalizes well across different levels of detection strictness. The stable and high mAP values across both metrics suggest the model is well-suited for deployment in real-time underwater missions, where precision and reliability are critical.

APPENDIX: H

AUV TESTING, COMMUNITY OUTREACH AND STEM ENGAGEMENT

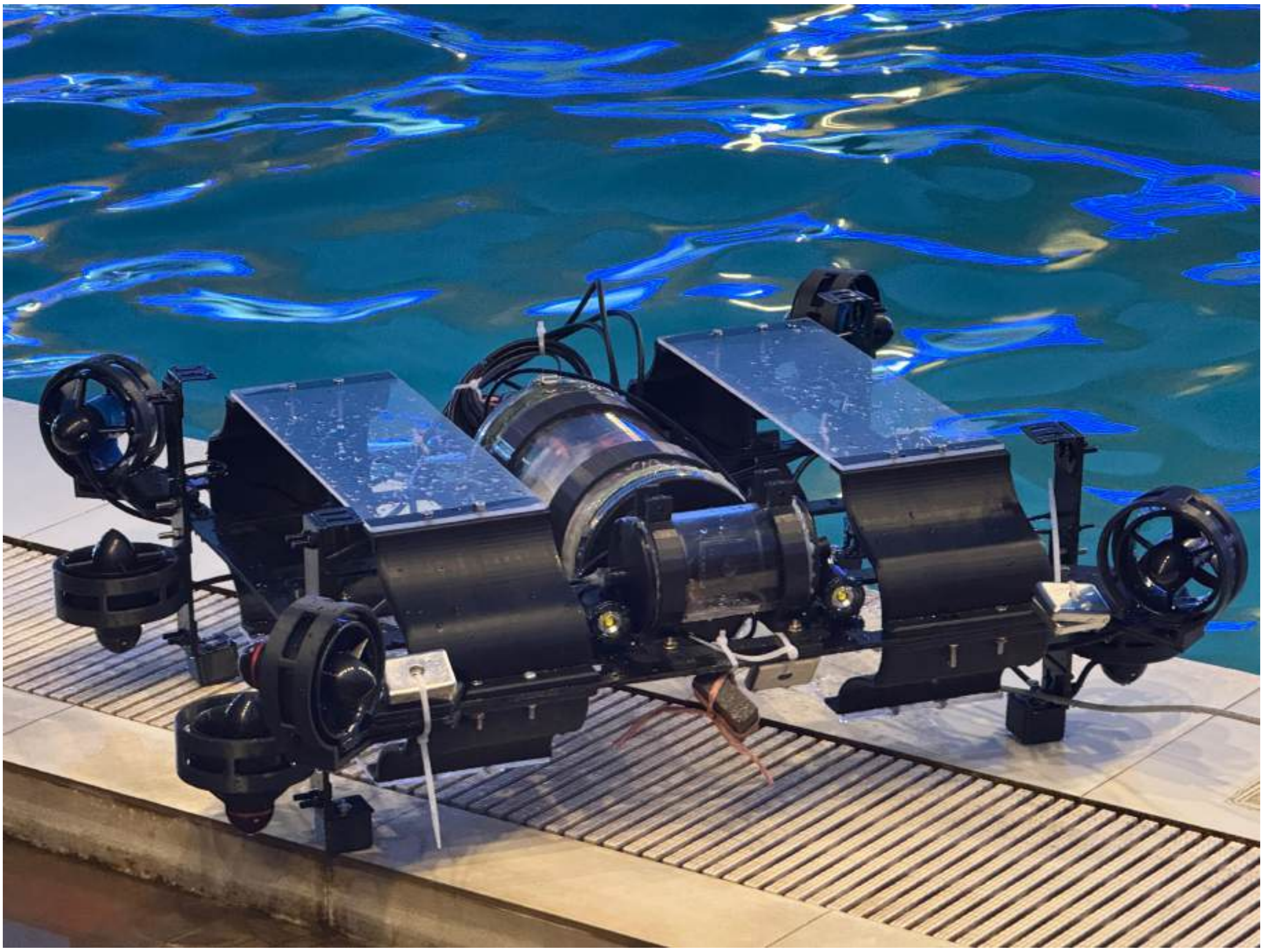

Fig. 28: Initial prototype of the HAUV 1.0

Fig. 29: First successful pool testing

(a) News covred by local news channel of Cox-bazar

Technology

Bangladeshi students are building a robot that can operate underwater and will participate in the US RoboSub competition.

Zahid Hossain Khan

The Bay of Bengal will be the center of Bangladesh's future economy. The future resources, gas and various minerals are hidden deep in the sea, and a group of Bangladeshi students are creating a special robot to conquer the sea. A group of students named Tech Autonomic Bengal Sub is trying to conquer the sea by creating a robot named 'Shark'. This shark will swim in one of the world's most prestigious underwater robotics competitions 'RoboSub 2025'.

The RoboSub competition is held annually in the United States. This year, it will be held at the Woollett Aquatics Center in California. Here, school, college, and university students from around the world compete with Autonomous Underwater Vehicles (AUVs). The main goal of the competition is to prepare students to face realistic challenges through oceanography, robotics, and artificial intelligence.

Read more about robots

Robo Tech Olympiad held at Uttara University

Opportunity to participate in the Asia-Pacific Open Championship of Robot Olympiad in the Philippines

Will robots replace humans in the future?

CUET is festive with robot

(b) Digital news published by Prothom Alo

(c) A television show on Jamuna about inspiring Bangladesh

Fig. 30: News media coverage

Team BengalSub has made significant strides in community outreach by leveraging digital media, printed news, and television platforms to share our mission and inspire the nation which is shown in Fig. 30. Our journey was featured by local news outlets in Cox's Bazar, capturing grassroots attention and showcasing young talent in regional innovation. A detailed digital article by Prothom Alo, one of Bangladesh's leading newspapers, highlighted our participation in the RoboSub competition and the technological aspirations driving our work. Moreover, our team appeared on a nationally broadcast Jamuna TV talk show, where we discussed our AUV project and its potential to inspire future engineers across Bangladesh. These platforms have amplified our visibility, connected us with supporters nationwide, and inspired youth to explore STEM fields and contribute to the country's technological progress.

Fig. 31: Community outreach program

Team BengalSub is deeply committed to inspiring the next generation of innovators through active STEM outreach. As part of our initiative, our team members conducted interactive sessions at local schools, where we introduced students to the fundamentals of robotics, underwater technology, and real-world engineering. A photograph of the community outreach and stem engagement is shown in Fig. 31. Through hands-on demonstrations, including showcasing our AUV components and control systems, we sparked curiosity and encouraged young minds to explore science and engineering. These sessions were designed to be engaging, inclusive, and practical—allowing students to ask questions, interact with components, and understand how classroom knowledge translates into cutting-edge robotic applications. Our goal is to make STEM more accessible and exciting, especially for students in underserved communities, and empower them to dream big in the fields of technology and innovation.

Fig. 32: Photograph of the AUV testing at Bay-of-Bengal, Cox's Bazar Sea Beach

Fig. 33: Team photographs before AUV testing at Bay-of-Bengal, Cox’s Bazar Sea Beach