BRACU Duburi AUV Technical Design Report

BRAC University (BRACU Duburi)

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***Abstract*—For RoboSub 2025, the Underwater Robotics team of BRAC University (BRACU Duburi) developed Duburi 4.2 with a clear focus on reliability, ease of maintenance, and reliable task performance to maximize points. The hull was optimized for maneuverability, and thruster placement was improved for greater stability. Additionally, the internal layout was restructured for modularity, which helps the team access key components quickly and perform rapid maintenance during competition. Built on ROS2, the software architecture employs state-of-the-art computer vision algorithms to detect and track objects, enabling Duburi 4.2 to autonomously perform tasks. Every engineering decision was guided by intensive, multi-phase testing to ensure Duburi 4.2 delivers robust performance at RoboSub 2025.**

Fig. 1: BRACU Duburi 4.2

I. Competition Strategy

Duburi 4.2 is the most advanced version of our autonomous underwater vehicle to date, building on operational experience from RoboSub 2023 with Duburi 4.0 [1] and further development of Duburi 4.1 [2]. Although we were unable to participate in RoboSub 2024 with Duburi 4.1 [2] due to national emergencies, this additional time was dedicated to rigorous testing and system-level improvements, leading to the development of Duburi 4.2. Our experience at RoboSub 2023 revealed critical challenges in underwater stability and maintenance of the vehicle, which directly shaped our vision to upgrade the AUV. To address these previous challenges and ensure the vehicle remains dependable, we implemented targeted improvements in mechanical layout, control responsiveness, and modular architecture.

A. General Strategy

The main strategy behind Duburi 4.2 is to maximize points by focusing on reliable task completion. Drawing on multi-phase testing, we prioritized dependable performance over added complexity. While the AUV can attempt tasks in any order, we will select those with the highest proven reliability and scoring potential.

B. Competition Strategy: Course Strategy

1) Collecting Data—Gate

For the opening task, Duburi 4.2 will begin at the dock, aligned with the gate. The team will attempt the Heading Out (coin flip) to secure bonus points and determine the initial orientation. After initialization, the AUV will submerge and align with the gate using IMU readings combined with real-time visual detection.
Gate traversal will proceed in two stages: Duburi

4.2 will first locate the gate using a search algorithm, then center its approach via visual homing [3]. The AUV will target the marker with the highest detection confidence between the Reef Shark and the Sawfish.

As the vehicle approaches the gate, its IR-based system will ensure precise timing to dive beneath the correct side. After passing through, Duburi 4.2 will execute a controlled roll or pitch maneuver to maximize bonus points.

2) Navigate the Channel—Slalom

The slalom task was prioritized due to its clear point value and alignment with the AUV's proven strengths in visual detection and path control. After reaching the buffer zone, the AUV will detect and align with the central red pipe using vision. Using distances specified in the RoboSub 2025 handbook [4], it will adjust heading with trigonometric calculations to select the correct side. As the AUV navigates the channel, the control system maintains its path, and IR sensors help avoid collisions. This approach, validated by testing, supports reliable task completion.

3) Tagging—Torpedoes

High confidence in Duburi 4.2's vision-based actuation will guide our approach to the torpedo task. The AUV will first identify the vertical board using its vision system and then, using DVL-based localization, position itself so that its torpedo launcher is aimed at the target corresponding to the marine animal selected during the gate task. The vehicle will launch the first torpedo from the required distance. After repositioning and confirming its location using both DVL and vision, the AUV will launch the second torpedo to maximize points.

4) Drop a BRUVS—Bin

The bin task is chosen for its proven reliability in marker placement. After entering the buffer zone, the AUV will navigate using its front camera and sensor fusion from IMU and DVL. As it approaches the bins, the vehicle will switch to its bottom camera for visual detection, advancing in small steps and pausing to scan left and right. This process will continue until a bin is detected or the preset distance is reached. Once found, the AUV will align over the correct half based on the selected marine animal and release the first marker. It will then reposition and deploy the second marker to maximize points.

5) Ocean Cleanup—Octagon

As the AUV approaches the octagon, it will use its front camera to identify the task area. Upon entry, Duburi 4.2 will immediately resurface for entry points, then perform a controlled rotation to align with the target image from the gate task. The AUV will submerge, locate and collect the first trash sample using its bottom camera and grabber, and resurface with the object. It will then submerge again to place the sample in the basket, repeating this process for the second sample. To earn bonus points, Duburi 4.2 will perform two additional controlled full rotations within the octagon before exiting.

6) Return Home

For the Return Home task, the AUV will use sensor fusion of DVL, IMU, and vision data to return to the start gate and resurface.

II. Design Strategy

To execute Duburi 4.2's strategy of high-reliability, rapid task turnover, and fault-tolerant operation at RoboSub 2025, we re-engineered the mechanical, electrical, and software subsystems. The following sections detail the key improvements that collectively reduce drag, simplify maintenance, and increase autonomous accuracy.

A. Mechanical Subsystem

1) Material and Hull Architecture

Duburi 4.2 features an octagonal hull, optimized for low drag and precise maneuverability in any direction, supporting fast, controlled movement during competition tasks. We retained Marine 5083 grade aluminum for its proven durability; no leaks or corrosion have occurred even after years of field use. The hull incorporates three acrylic windows set in brass frames. Two of these windows are dedicated to cameras, positioned at the front and bottom, providing clear views for navigation and task execution, while the third window is used for system access. To further enhance reliability, a latex-based balloon system protects the critical electrical kill switch, adding fault tolerance without complicating maintenance. This year's major structural update is a modular, hydrodynamic lower stand with standardized mounts for rapid attachment of mission hardware. The stand's streamlined design reduces turbulence and enables fast subsystem swaps or upgrades. These choices result in a compact, robust hull that emphasizes reliability, easy integration, and adaptability, preparing Duburi 4.2 for dynamic mission demands and supporting our competition strategy.

Fig. 2: Rendering of Duburi 4.2

2) Propulsion system

Building on previous competition experience, our AUV retains T200 thrusters for reliable propulsion and system consistency. This year, we strategically repositioned the depth thrusters farther apart to address pitching during descent, as identified through operational feedback. This adjustment has resulted in greater stability and level submersion, enabling precise six-degree-of-freedom control for smoother and more predictable maneuverability during missions.

3) Torpedo

For RoboSub 2025, the torpedo system (Fig. 3) is built around a robust slingshot launch mechanism, paired with a streamlined, hydrodynamic body refined using CFD analysis. Launches are guided by a linear rail for stable, accurate trajectories, and the updated plastic and aluminum construction increases both rust resistance and durability. Field tests show the redesigned torpedo consistently travels up to 5 feet, offering improved precision and reliability for the Mapping task.

Fig. 3: Torpedo Launching System

4) Grabber

Duburi's grabber (Fig. 4) is a custom, waterproof mechanism, precision-machined in-house from aluminum for long-term underwater reliability. Integrated current sensors detect successful grasps and trigger safety protocols when needed, while validation tests confirm dependable operation for up to four hours submerged. This high-precision, durable grabber is essential for effective object retrieval in tasks such as the Octagon.

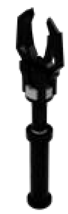

Fig. 4: Grabber

5) Dropper

Duburi 4.2's dropper (Fig. 5) features a solenoid-based mechanism for precise, reliable marker release. The marker is shaped for straight, deviation-free descent and built from rust-resistant, plastic-coated aluminum for repeated use. This efficient, robust design ensures consistent accuracy during competition tasks.

Fig. 5: Dropper

B. Electronic Subsystem

1) Battery pack

Duburi 4.2 uses a dual Lithium Polymer (LiPo) battery system to optimize power delivery in its compact hull. Assigning one battery to propulsion and the other to computation and sensors reduces electrical noise and improves sensor accuracy, addressing issues seen in previous lithium-ion packs. This upgrade enables longer, more stable missions and streamlines maintenance, directly supporting reliable navigation and precise competition. performance.

2) Kill Switch
To maximize operational safety and reliability, the team has adopted a latex-based kill switch for robust emergency power cutoff. Field testing showed that the previous magnetic switch introduced compass interference and was prone to moisture-related failure, compromising system responsiveness. The new balloon-based design is fully non-magnetic, physically isolated, and corrosion-resistant, eliminating these risks. As a result, Duburi's emergency power cutoff is now more robust and reliable, directly supporting safe and fault-tolerant mission performance during competition.

3) Modular Division
Prioritizing modularity and ease of maintenance, this year's design features a restructured internal architecture that allows rapid access to all major components during competition. All major components are now arranged in separate stacked modules, with the eight ESCs consolidated onto a single horizontal board for efficient access and plug and play replacement. The custom power distribution board and dual Lithium Polymer battery system further support this modular design by reducing internal wiring, improving electrical isolation, and separating propulsion from computational and sensor power. Validation during pool trials and field repairs demonstrated that these modular systems minimize downtime and enable fast upgrades, providing a tangible advantage in competition scenarios.

4) Microcontroller
Duburi 4.2 relies on the ARM-based Pixhawk microcontroller for its compact design and proven reliability. Although custom controllers were tested, Pixhawk provided superior stability and seamless integration with our system. This choice ensures efficient command execution and supports consistent, dependable operation during competition.

5) Communication system
Reliable communication between the AUV and ground station is achieved through the FathomX Power over Ethernet interface. This system replaces the earlier fiber optic setup, which was fragile and difficult to manage. FathomX delivers robust connectivity, supports standard wiring, and simplifies maintenance. The result is stable, low latency data exchange during missions, directly improving operational reliability and field performance.

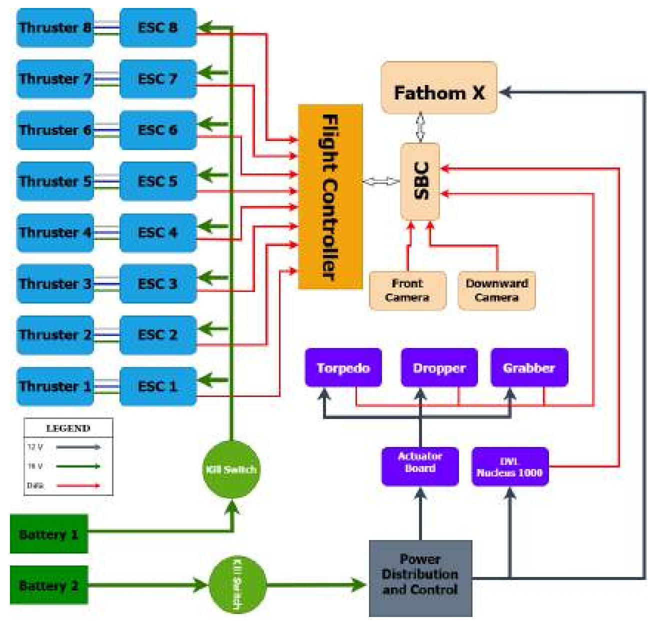

Fig. 6: Electronic Subsystem Architecture

6) Actuation Board
Duburi 4.2 replaces relay-based peripheral control with a MOSFET-based switching system to enable faster and more precise actuation for underwater tasks. Integrated gate drivers and logic isolation have improved signal reliability and system stability in testing. The custom PCB with test points and status LEDs simplifies diagnostics and maintenance. These upgrades support dependable, efficient mission performance during competition.

C. Software Subsystem

Duburi 4.2's software subsystem is designed with a clear focus on modularity, reliability, and real-time responsiveness. The architecture is organized into three primary domains: control, autonomous, and planning. Each domain is developed to ensure mission objectives are achieved efficiently, with an emphasis on creative problem solving and robust engineering.

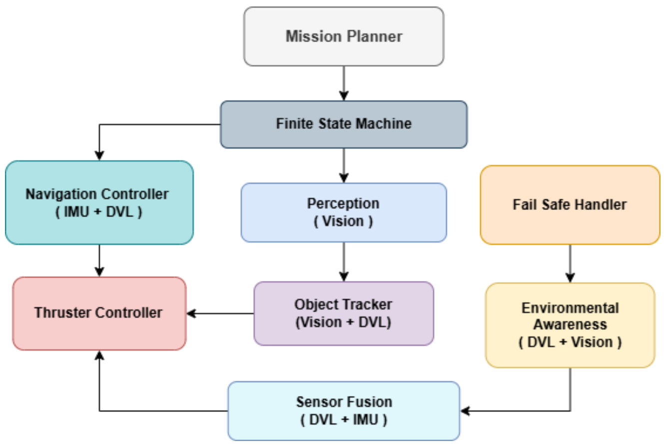

Fig. 7: Software Subsystem Architecture

1) Control

The control subsystem of Duburi 4.2 is anchored by ROS2, Pixhawk, and PyMavlink, forming a robust link between planning and vehicle actuation. ROS2 enables real time multi threaded execution, ensuring smooth coordination between control, planning, and sensor feedback. The control node communicates with Pixhawk to issue commands and receive sensor data such as heading, depth, and DVL based position, forwarding this to the state machine for six degrees of freedom maneuvers. This year, we have incorporated a Doppler Velocity Log (DVL) to provide precise underwater velocity and position data, significantly enhancing localization accuracy during complex mission tasks. Pixhawk's Extended Kalman Filter fuses IMU, DVL, and other sensors for stable operation. Leveraging Pixhawk for PID control and filtering streamlines development and calibration using MAVLink. The system flexibly integrates alternative IMU or point cloud inputs, keeping all packages synchronized and adaptive to mission needs. This modular yet unified architecture directly supports competition reliability, precise movement, and robust performance in both testing and competition.

2) Autonomous

Our AUV achieves full autonomy by integrating perception and control subsystems through a publish-subscribe communication structure, with the control system as the master node. The autonomy stack is built on ROS2 nodes, where the execution control node directs movement. The vision system uses YOLOv11 [5] as its primary detection model, which outperformed last year's MobileNet v2 in accuracy and robustness due to improved attention mechanisms and better multi-object classification. Advanced computer vision techniques such as visual homing enable precise target alignment and mission actions. Sensor fusion with Extended Kalman Filtering strengthens pose estimation and situational awareness.

As a result, our AUV autonomously executes complex task sequences with minimal operator intervention and consistently achieves high task completion rates in testing. By tightly integrating perception, adaptive control, and real-time autonomy, the software stack ensures Duburi 4.2 meets RoboSub 2025 requirements for adaptability, reliability, and performance.

3) Planning

Mission task execution is managed by a finite state machine implemented in ROS2, which defines the sequence and logic of competition tasks. The state machine coordinates transitions between navigation, perception, manipulation, and recovery based on real-time feedback. This modular approach enables rapid strategy adjustments and robust error handling. By decoupling mission logic from low-level control, we improve maintainability and adaptability, ensuring that Duburi 4.2 can rapidly adjust to changing mission requirements and consistently achieve reliable task performance.

III. Testing Strategy

From the very beginning, our team made testing a central part of how we built and improved Duburi 4.2. Starting from January 2025, we spent six to eight hours a day, at least four days a week, in a cycle of pool trials, lab work, and simulation-based experiments. We began by validating components and calibrating subsystems, then moved to integrating everything together and finally challenged the full system with stress testing. At each stage, we learned from setbacks and successes, using every lesson to improve reliability and performance. All these phases and lessons ultimately made Duburi 4.2 reliable and ready to take on the challenges of RoboSub 2025.

A. Electrical and Power System Integrity

To address past issues with electrical stability, the new dual battery power system was thoroughly validated. Each battery independently supplies either the propulsion or computational units, and both underwent sustained load testing under simulated mission conditions, including induced faults like overcurrent and voltage imbalance. We introduced a latex-based, nonmagnetic kill switch and verified its underwater reliability, eliminating compass interference from the previous magnetic design. These tests confirmed consistent voltage delivery and improved safety, supporting reliable long-duration missions without system degradation.

B. Watertight Integrity and Payload Mechanisms

Watertightness was rigorously tested by submerging each compartment with paper towels inside and monitoring for leaks during ten minute intervals. Any sign of moisture prompted immediate redesign and retesting to ensure system integrity. In parallel, all payload mechanisms including the torpedo, dropper, and grabber were validated for consistent underwater actuation across multiple cycles. The torpedo achieved over four feet of range, the dropper delivered markers with reliable accuracy, and the grabber maintained performance throughout high cycle immersion testing, confirming subsystem reliability for competition.

C. Subsystem Calibration and Control Tuning

We begin by calibrating the accelerometer, compass, and other onboard sensors to ensure accurate sensor fusion for navigation. The AUV auto tunes its control parameters, with manual PID adjustments made during pool trials to achieve stable and reliable movement. We validate straight-line travel in headlock mode, check for correct rotation and level depth hold, and monitor for oscillations or drift. This comprehensive process ensures the vehicle consistently maintains precise heading and depth throughout all missions.

D. Vision and Simulation Testing

The vision system was validated under a range of lighting, visibility, and distance conditions using printed targets and submerged props, with the transition from MobileNet v2 to YOLOv11 [5] greatly improving detection robustness. Complementary simulation in ROS2 environments exposed edge case performance issues, enabling continuous refinement of the autonomy stack and strengthening the perception to actuation pipeline. Additionally, we developed custom simulation scenarios in Unreal Engine 5 to recreate diverse competition tasks and environmental challenges, ensuring system reliability and performance before field deployment.

E. Stress and Endurance Testing

Duburi 4.2 was stress tested in both local waterbodies and the Bay of Bengal, exposing the vehicle to increased salinity, wave turbulence, and floating debris. The vehicle maintained full operational capacity throughout multiple deployments, and any observed anomalies such as minor actuator pressure warping were addressed and incorporated into standard operating procedures.

IV. Acknowledgements

The progress of BracU Duburi would not have been possible without the unwavering support and encouragement from Brac University, whose resources, technical guidance, and financial assistance enabled every stage of this project. We extend our sincere thanks to Dr. Syed Ferhat Anwar, Vice Chancellor; Dr. Sadia Hamid Kazi, Chairperson of the Department of Computer Science and Engineering; Dr. David Dowland, Registrar; and especially Dr. Md. Khalilur Rhaman, whose continuous guidance and mentorship have been invaluable to the team.

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We also extend our sincere appreciation to the faculty, staff, and volunteers who provided logistical support, facilities, and assistance with outreach. The dedication, teamwork, and enthusiasm of every member of Duburi have been essential to our achievements.

References

[1] S.M. Minoor Karim, O. Fatima, S. Abdullah *et al.*, "BRACU Duburi AUV Technical Design Report," Technical Design Report, RoboSub 2023, San Diego, CA, USA, 2023. [Online]. Available: https://robonation.org/app/uploads/sites/4/2023/06/TDR_Brac_University_RS2023.pdf

[2] S.M. Minoor Karim, M. Hasin Alif, N. H. Omi *et al.*, "BRACU Duburi AUV Technical Design Report," Team BRACU Duburi, RoboSub2024, Irvine, CA, USA, 2024. [Online]. Available: https://robonation.org/app/uploads/sites/4/2024/07/RS24_TDR_BRAC-compressed.pdf

[3] D. M. Lyons and N. Petzinger, "Visual homing for robot teams: do you see what I see?," *Unmanned Systems Technology XXIV*, vol. 14, 2022. doi: 10.1117/12.2618818

[4] RoboNation, "RoboSub 2025 Official Handbook," 2025. [Online]. Available: https://robosub.org/competition/handbook/

[5] R. Khanam and M. Hussain, "YOLOv11: An Overview of the Key Architectural Enhancements," *arXiv preprint arXiv:2410.17725*, 2024. [Online]. Available: https://arxiv.org/abs/2410.17725

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost	Year of Purchase
ASV Hull Form/Platform	Built In-House	Custom Aluminium	-	Custom	$ 509	2023
Waterproof Connectors	BlueRobotics	Potted Cable Penetrator	Penetrator	Purchased	$ 108	2022
Propulsion	BlueRobotics	T200 Thrusters	T200 Thruster	Purchased	$ 1600	2024
Power System	Tiger	5400mAh Lithium Polymer Battery	Lipo Battery	Purchased	$ 130	2022
Motor Controls	BlueRobotics	Basic ESC	Basic ESC	Purchased	$ 288	2019
CPU	Nvidia	Nvidia Jetson Orin Nano	Nvidia Jetson Orin Nano	Purchased	$ 499	2024
Teleoperation	-	-	-	-	-	-
Compass	VectorNav	VectorNav VN200	Vectornav VN200	Sponsored	Sponsored	2022
Intertial Measurement	VectorNav	VectorNav VN200	Vectornav VN200	Sponsored	Sponsored	2022
Unit (IMU)	VectorNav	VectorNav VN200	Vectornav VN200	Sponsored	Sponsored	2022
Doppler Velocity Logger(DVL)	Nortek Group	Nucleus 1000	Nucleus 1000	Sponsored	Sponsored	2023
Camera(s)	BlueRobotics	Low-Light HD USB Camera	Low-Light USB Camera	Purchased	$ 198	2021
Hydrophones	-	-	-	-	-	-
Algorithms: Control	-	-	Thresholding, PID, Kalman Filter	Custom	-	2021
Vision	-	-	Transfer Learning	Custom	-	2021
Localization and Mapping	-	-	-	-	-	-
Autonomy	-	-	Machine Learning, IMU Heading	-	-	2022
Open-Source Software	-	-	ArduSub, Python Libraries	-	-	2023

Appendix B: System Analysis and Flowcharts

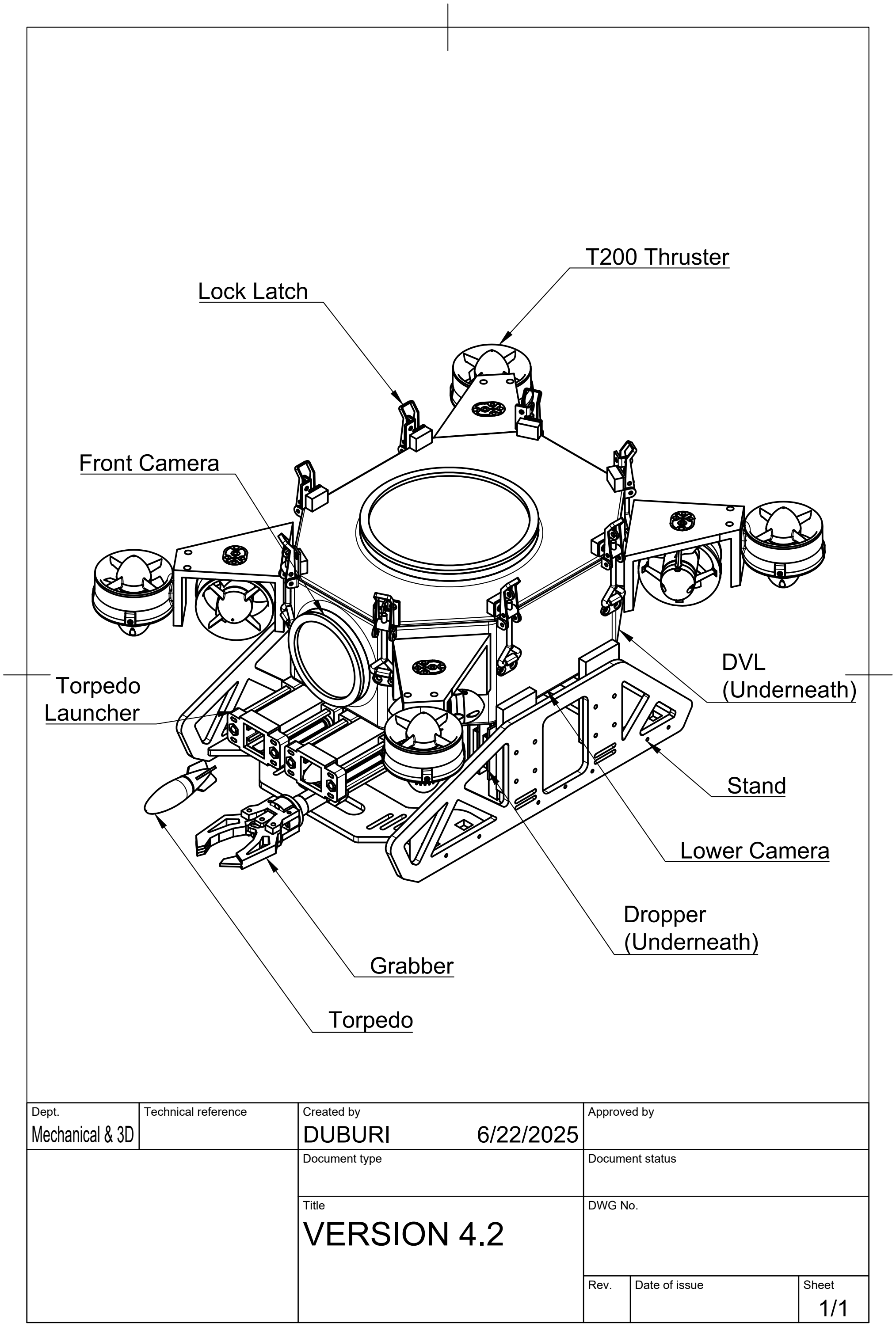


Fig. 8: Duburi 4.2 Burst View

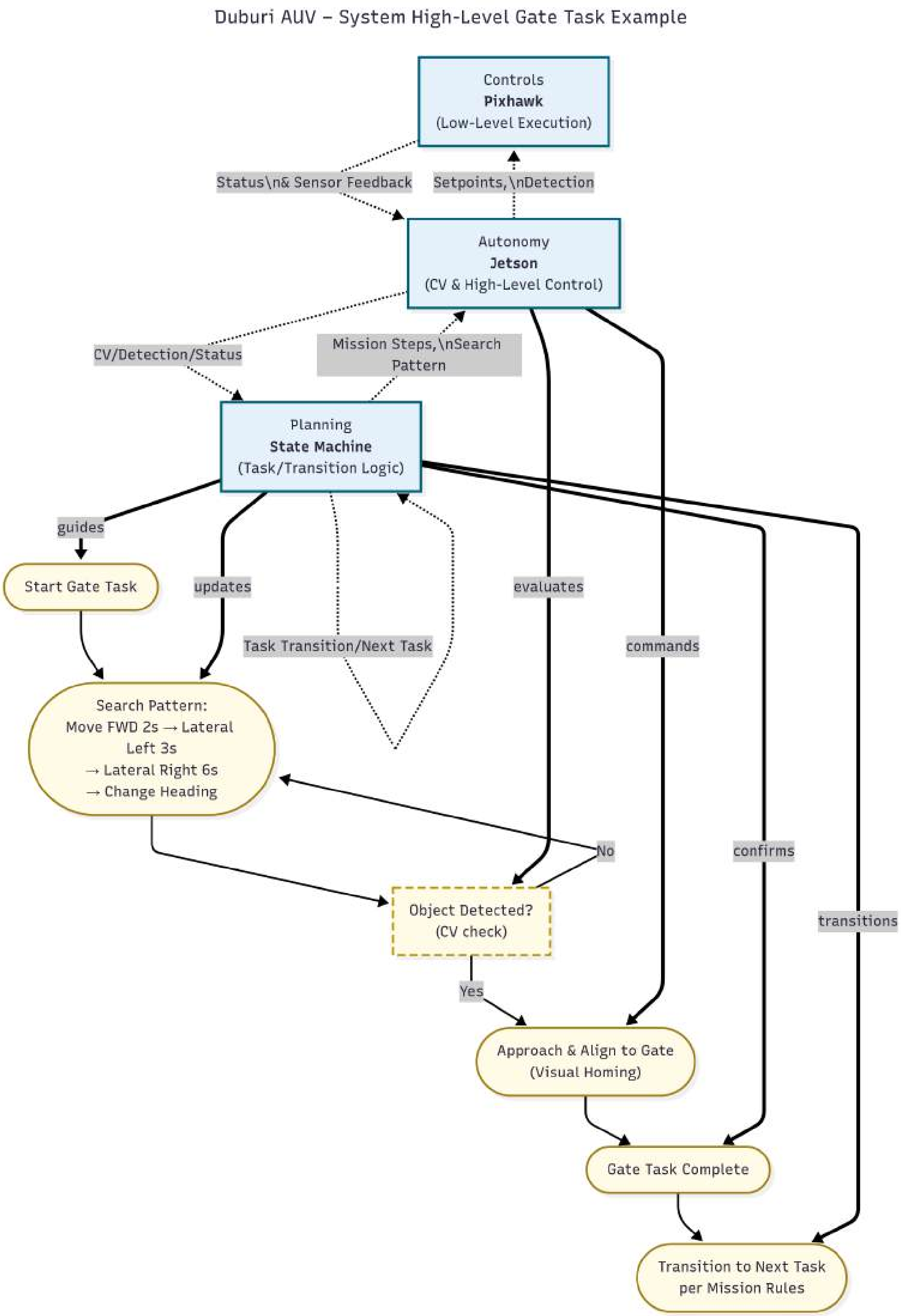


Fig. 9: Search Pattern

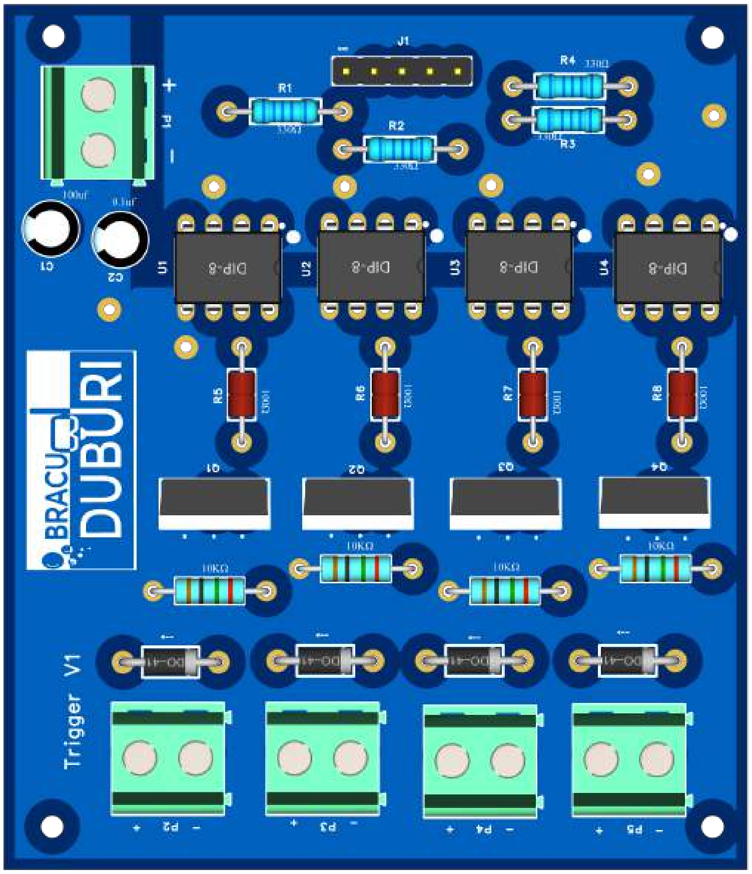


Fig. 10: 3D PCB MOFSET Trigger

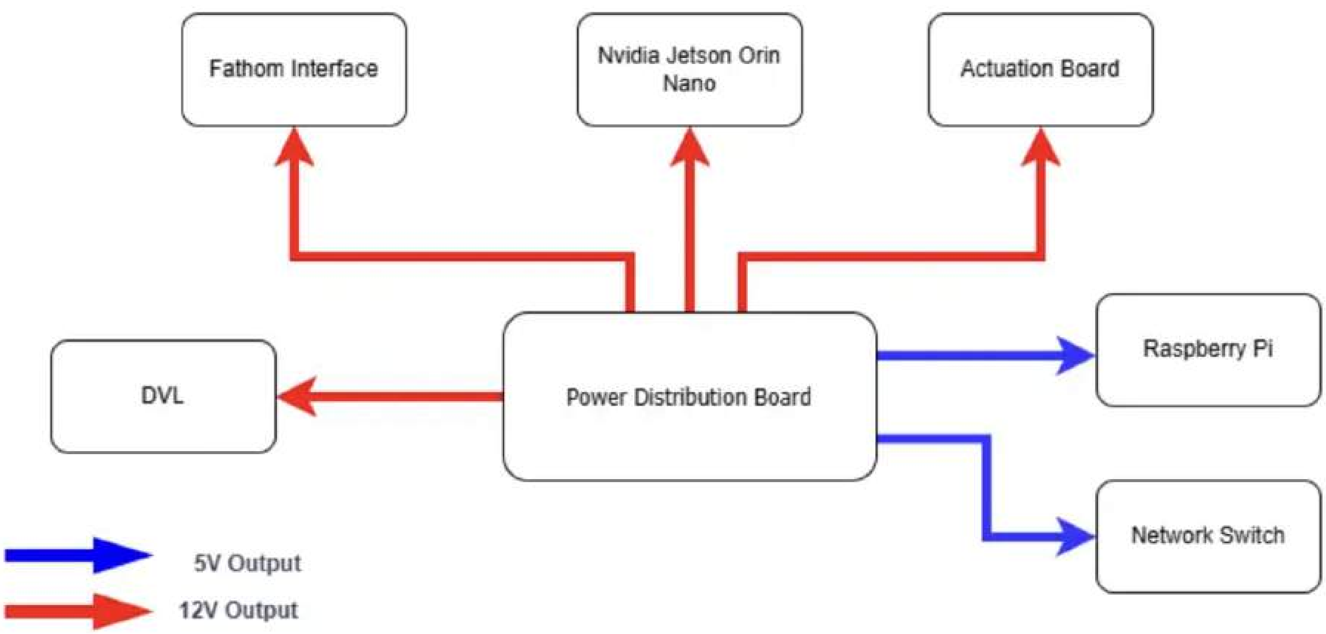


Fig. 11: Power Distribution Board

Appendix C: Testing Box

Primary Components

- Duburi 4.2
- Base-station laptop
- Task-specific props for mission simulation

Electrical Equipment

- Jetson Orin Nano
- Raspberry Pi
- Doppler Velocity Log (DVL)
- Multimeter
- Lithium-Polymer (LiPo) batteries
- LiPo Guard
- LiPo battery charger
- Fathom ROV tether
- Fathom-X tether interface board
- Joystick
- USB Type-C cable
- USB Type-B cable
- Ethernet cables
- HDMI cable
- Network switch
- Multiplug
- Keyboard
- Type-C hub

Mechanical Equipment

- Soldering kit
- Wire cutter
- Wire stripper
- Glue gun
- Epoxy
- Silicone grease
- Thermal tape

- Masking tape
- Double-sided tape
- Duct tape
- Tolsen toolbox
- Screw kits
- Zip ties
- Drill kit
- PVC pipe
- Rope
- Nuts
- Tissue

Appendix D: Test Plan and Results

1. Summary Table of Test Campaign

Test Area	Objective	Pass/Fail	Key Outcome or Change
Mission Readiness	End-to-end mission execution	Pass	Improved object anchoring, smoother run
Control Calibration	Stable & precise motion	Pass	PID tuning, stable performance
Battery Management	Safe, reliable power delivery	Pass	Upgraded battery configuration for 6hr runtime
Torpedo and Dropper System	Launch reliability per distance	Pass	Adjusted springs, torpedo reliable for greater than 4ft, no jams
Watertight Integrity	No leaks in any compartment	Pass	Assembly SOP improved, no leaks remain

2. Scope

- Goal: Ensure every critical system and integrated vehicle can perform as required in pool and simulated competition environments.
- Tested: Navigation, autonomy, control, battery, payload mechanisms, watertightness.

3. Schedule

Phase	Month(s)	Activity
Planning & R&D	Jan 2025	Protocol design, subsystem prep
Initial Bot/Control Testing	Feb 2025	First pool tests, control test
Task Integration & Debugging	Mar–Apr 2025	Subsystem merges, bug fixes, props ready, dataset collection
Competition Task Dev/Test	May–Jun 2025	Full runs with tasks/props
Continuous Testing & Final Fix	Jul 2025	Regression, issue resolution, optimization

4. Resources and Tools

- **Hardware:** Duburi 4.2, Pixhawk, Jetson, DVL, T200 thrusters, custom grabber, LiPo batteries, torpedo/marker launchers.
- **Test Environments:**
  - Pool: 35×7×2m for mission tests, 10×10×4m for calibration.
  - Lab benches for electronics and battery validation.
  - Immersion tub for watertight tests.
- **Equipment:** Multimeter, resistive load, torque wrench, underwater cameras, base station laptop, FathomX tether.
- **Software:** ROS2, custom navigation suite, simulation tools.

5. Test Environment

- Main pool: Used for navigation, mission, and system-level tests. Controlled water depth, props anchored.
- Lab: Safe, dry space for electronics and battery validation.
- Water immersion tub: For watertightness checks on hulls and housings.

6. Risk Management

Risk	**Prevention/Response**
Water Leakage,	Leak tests, vacuum seal checks
Power fault	Real-time monitoring, kill switch
Mechanical failure	Pre-test inspection, spares ready
Safety	Emergency retrieval, safety gear

7. Test Procedures and Results

7.1 Mission Readiness Test

Objective: Validate autonomous mission execution in competition-equivalent scenarios.

Steps:

1) Initialize all subsystems and complete calibration sequence.
2) Execute untethered autonomous mission.
3) Monitor gate detection, task sequencing, and surface recovery.
4) Record comprehensive success/failure metrics.

Criteria:

- Pass: : Vehicle successfully submerges, completes all tasks autonomously, and resurfaces without intervention.
- Fail: Task abortion, uncontrolled drift, sensor loss, or incomplete mission execution.

Results:

- Initial attempt failed due to mission prop drift.
- Problem resolved through upgraded anchor system implementation.
- Result: PASS - Complete autonomous mission execution achieved with consistent object detection and zero manual interventions.

7.2 Control System Calibration and Motion Stability

Objective: Optimize Duburi's 6-DOF motion control for minimal overshoot and precise trajectory tracking.

Steps:

1) Neutral buoyancy optimization through ballast adjustment.
2) PID parameter tuning for each motion axis.
3) Disturbance rejection testing under simulated current conditions.

Criteria:

- Stable trajectory maintenance, overshoot below 5%, accurate setpoint tracking.
- Fail: Erratic motion behavior, sustained oscillation, excessive position drift.
- Results: PASS - Achieved stability across all axes with oscillation elimination and 60% reduction in yaw error following trim adjustment.

Results: Stable across all axes. Oscillation removed after PID and trim updates.

7.3 Power System and Battery Validation

Objective: Confirm endurance, safety, and load management of dual-battery configuration.

Steps:

1) Continuous mission simulation over 6-hour duration.
2) Comprehensive voltage, current, and temperature monitoring.
3) Underwater kill switch functionality validation.

Criteria:

- Pass: Stable voltage delivery, no thermal issues, reliable kill switch activation.
- Fail: Battery degradation, safety system trips, overheating, or signal interference.

Results:

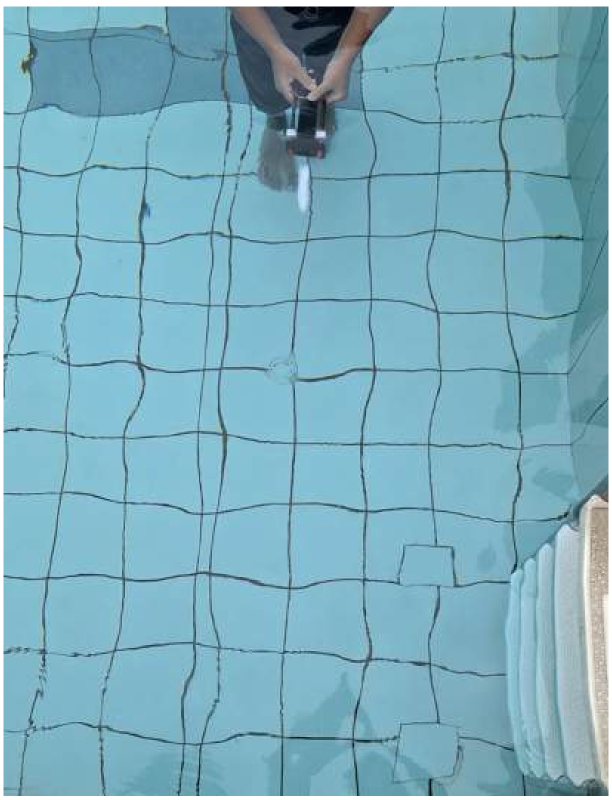
- Corrected one solder joint issue during initial testing.

- Final Result: PASS - System achieved 6-hour continuous runtime with reliable emergency response capability.

7.4 Payload Mechanism Validation

Objective: Consistent launch, meet minimum distance, no jams.

Subsystem	Test Protocol	Success Criteria	Results
Torpedo	8 launch cycles from fixed distance	Range over 4ft, stable trajectory, zero jams	PASS (Average: 4.1ft, 0 failures)
Dropper	Bottom-targeting with dual marker release	Center accuracy, no bounce behavior	PASS
Grabber	25 underwater grip/release cycles	Secure grip maintenance, clean sensor triggering	PASS



(a) Torpedo launching in progress

(b) Torpedo fully launched

Fig. 12: Torpedo delivery sequence: (a) during launch, (b) after launch

7.5 Vision System Validation

Objective: Validate detection robustness across varied lighting and occlusion scenarios.

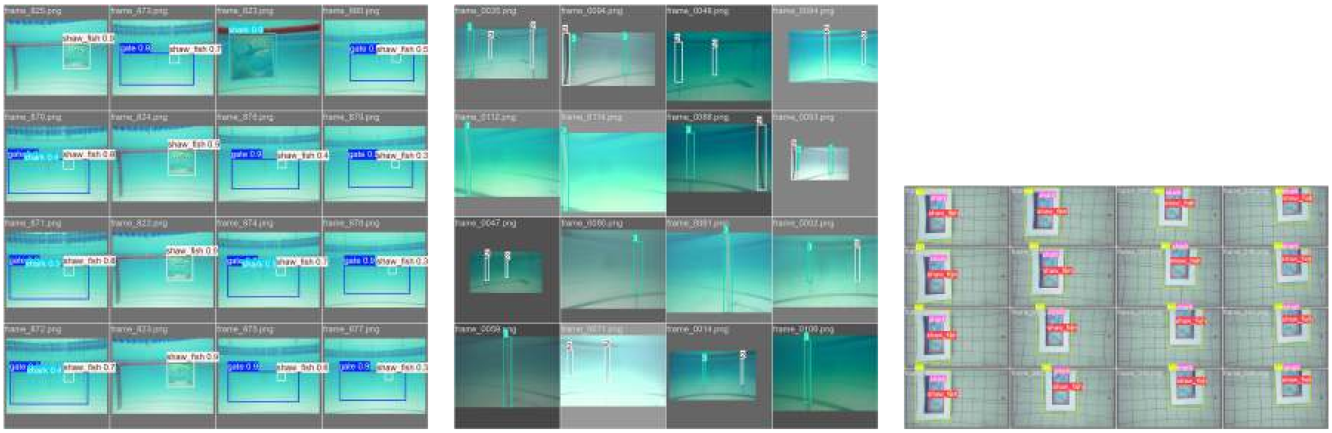
Steps:

1) Object detection testing across multiple angles, colors, and distances.
2) Performance comparison between YOLOv11 and MobileNet architectures.

Criteria:

- Pass: mAP greater than 90%, stable target reacquisition, accurate object classification.
- Fail: Missed detections, tracking loss, poor occlusion handling.

Results: PASS — YOLOv11 demonstrated higher precision than the MobileNet baseline.

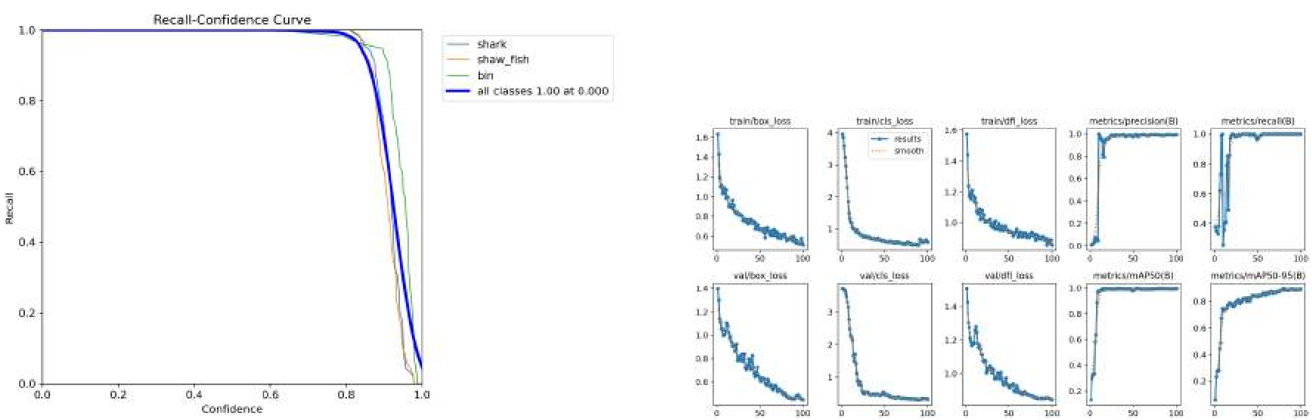


(a) Gate detection under variable lighting and distance.

(b) Slalom task: multi-object tracking with occlusion.

(c) Bin task: robust object classification.

Fig. 13: Representative results for YOLOv11 detection across core RoboSub tasks: (a) Gate, (b) Slalom, and (c) Bin. Each demonstrates detection robustness under real-world variations in lighting, occlusion, and class similarity.



(a) Recall-confidence curve for all classes.

(b) YOLOv11 training and validation metrics.

Fig. 14: YOLOv11 performance analysis: (a) Recall-confidence curves, (b) Loss, precision, recall, and mAP progression over training epochs.

7.6 Environmental Stress and Endurance Testing

Objective: Validate Duburi's operational robustness under real-world deployment conditions.

Test Environment: Bay of Bengal and local waterbodies (variable salinity, current, and lighting conditions).

Steps:

1) Multiple deployment and recovery cycles.
2) System behavior monitoring under environmental stress.
3) Component wear, leakage, and actuator performance assessment.

Criteria:

- Pass: Zero structural/mechanical failures, complete operational cycles.
- Fail: Component degradation, water ingress, actuator malfunction.

Results: PASS — Zero leakage incidents, sustained autonomous operation. Minor actuator stiffness was corrected and standard operating procedures were updated accordingly.

7.7 Simulation-Based Testing with Unreal Engine 5

Objective: Evaluate autonomy, perception, and control algorithms in a high fidelity virtual environment before field testing. **Test Environment:** Custom-designed RoboSub pool and task scenarios modeled in Unreal Engine, featuring dynamic lighting, moving props, and randomized obstacle placement.

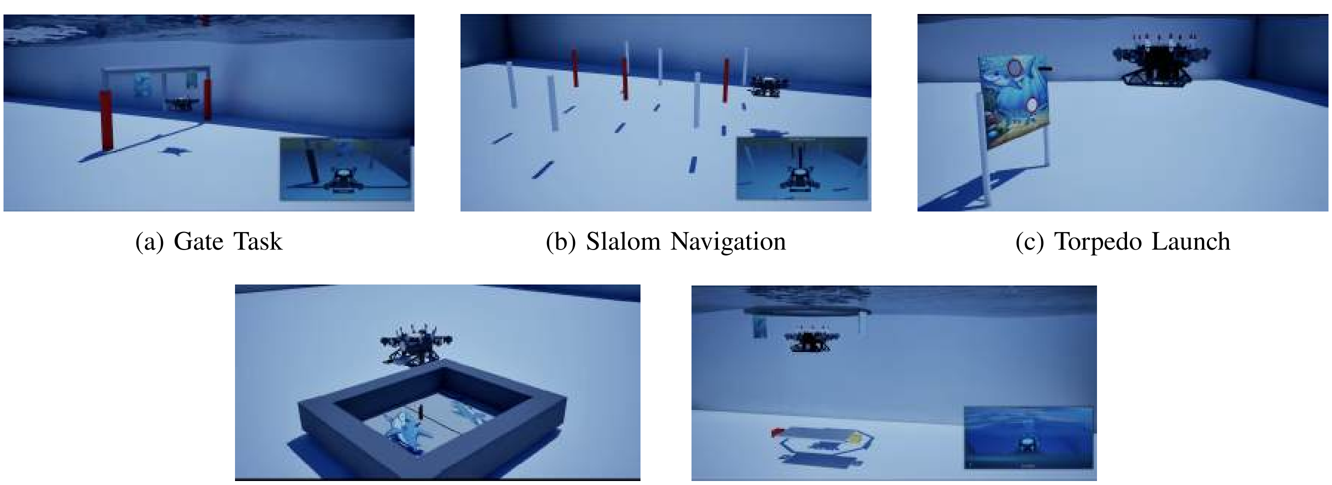
Steps:

1) Mission task execution in simulated pool with randomized initial conditions.
2) Evaluation of object detection and navigation under varying virtual turbidity and lighting.
3) Autonomy stack stress testing with simulated failures and sensor noise.

Criteria:

- Pass: Greater than 85% task completion, robust navigation, effective debugging.
- Fail: Collision with obstacles or critical mission failure.

Results: PASS — The AUV consistently completed all simulated tasks and the virtual pool environment allowed us to quickly identify and fix key issues.



(a) Gate Task (b) Slalom Navigation (c) Torpedo Launch

(d) Bin Drop (e) Octagon Surface

Fig. 15: Simulation-based testing in Unreal Engine: (a) Gate task execution, (b) Slalom navigation, (c) Torpedo launch, (d) Bin drop, (e) Octagon surfacing.

Appendix E: Outreach Activities

1. Strategic Vision for Outreach

Following RoboSub 2023, Duburi redefined its outreach mission. Witnessing the immense potential among underprivileged youth in Bangladesh, our team became committed to bringing robotics and engineering closer to those who lack access but show remarkable curiosity and talent. Our vision is to inspire, mentor, and empower these students, demonstrating that underwater robotics is not just for a select few but for all.

2. STEM Engagement and School Outreach

Over the past year, Duburi visited more than ten schools and took part in six major outreach events across Bangladesh. Our engineers shared their experiences, demonstrated the AUV, and invited students to our university. This hands-on exposure gave students a tangible understanding of underwater robotics, transforming curiosity into real ambition. One memorable moment was when a young student, upon seeing our AUV for the first time, innocently asked, "Is this a boat" only to discover the world beneath the water's surface. Through these efforts, many students discovered new interests, with some now considering futures in science, engineering, and robotics.

(a) Duburi team members interacting with visitors and sharing knowledge at an institutional science fair.

(b) Young student exploring Duburi's AUV during a hands-on outreach session.

Fig. 16: Duburi's active participation in public events, engaging the wider community and inspiring young minds in robotics and technology.

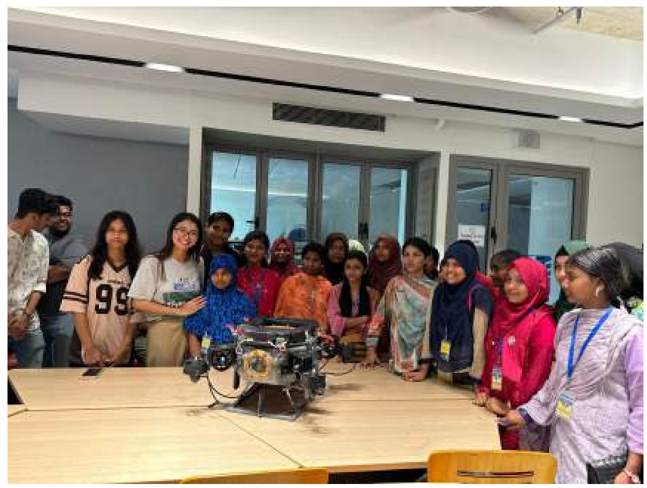
3. Promoting Diversity and Women's Participation

Diversity and inclusion are at the heart of our outreach. Many of Duburi's members are women, and they actively engage with girls' schools, serving as mentors and role models. Our outreach events encourage all students, regardless of background, to consider careers in STEM. Team members from disciplines such as computer science, electrical engineering, business, and biotechnology show that underwater robotics is a multidisciplinary field with opportunities for everyone. For us, the greatest success is when even one student leaves an event believing that they too can make a difference in science and engineering. By sharing their own journeys and challenges, our members help students see that there is no single path to success. We believe that fostering diverse perspectives not only strengthens our team but also inspires broader innovation in the field.

(a) Interactive session with girls' school students at the university lab.

(b) Duburi outreach event engaging female students in STEM activities.

(c) Young women participating in hands-on robotics demonstration.



(d) Group photo after a successful STEM engagement session for girls.

Fig. 17: Duburi's outreach efforts to inspire and empower girls and young women in STEM through direct engagement, demonstrations, and mentorship.

4. Alumni Engagement and Industry Collaboration

Dubotech represents the collective strength of our alumni network. This group consists of former Duburi members who, now active in professional and research domains, continue to support the team as mentors, collaborators, and advisors. Through Dubotech, current members gain valuable industry exposure and career guidance. The group regularly organizes seminars, connects the team to industry events, and has even represented Duburi at national platforms such as the Bangladesh Investment Summit. This enduring relationship demonstrates how student led initiatives can mature into national innovation hubs.

5. Global and Remote Mentorship Initiatives

Our mentorship extends well beyond the university. Duburi's alumni, both in Bangladesh and abroad, stay involved through online workshops, technical training, and ongoing guidance. These mentors share their experiences, helping each new generation of Duburi members navigate challenges and seize new opportunities. This growing network ensures that the team's expertise and culture of support are passed on year after year.

6. Distinguished Guest Interactions

This year, the Robotics Club of BRAC University hosted a special interactive session with NASA Chief Astronaut Joseph M. Acaba, which was attended by members of Duburi. Astronaut Acaba shared valuable insights on exploration, teamwork, and perseverance, drawing from his experiences on space missions and international collaboration. During the session, our team members engaged in thoughtful discussion, asking questions about robotics in space environments, the importance of interdisciplinary skills, and the mindset required to overcome challenges in scientific research. The event offered inspiration that reached far beyond technical knowledge, reinforcing the belief that with determination and vision, engineers from Bangladesh can aspire not only to reach for the stars but also to lead innovation beneath the waves.

Fig. 18: Duburi team members and alumni interact with NASA astronaut Joseph M. Acaba during a special session hosted by the Robotics Club of BRAC University.

7. Knowledge Sharing and Community Building

Communication is central to our outreach mission. Duburi regularly produces podcasts and invites alumni to share their journeys, from their first steps in robotics to their professional achievements. Our podcasts also feature and acknowledge people from local mechanics shops who have supported our work, as we want them to feel they are an integral part of this project. By highlighting the vital role of hands-on expertise and community collaboration, these stories create a sense of belonging and motivate both current and future members. Ultimately, our goal is to make underwater robotics a shared national ambition, fostering innovation across Bangladesh.

Fig. 19: Podcast session arranged by Duburi members.

8. Fostering a Nationwide Robotics Movement

The impact of our outreach is becoming increasingly visible as new student teams and schools across Bangladesh take up underwater robotics. This momentum represents meaningful progress toward developing a strong pipeline of young innovators nationwide. By sharing the experiences and achievements of these emerging teams, we are building a network of support and healthy competition that strengthens the entire robotics community. We believe that as more institutions join this movement, the collective spirit and ambition will drive Bangladesh toward new heights in science, engineering, and technology. robotics and contribute to the country's technological growth.

9. Innovation for Impact: Shaping Bangladesh's Future

Bangladesh's identity is deeply linked to its rivers and proximity to the Bay of Bengal, making underwater technology particularly relevant to the nation's future. Duburi's research and development team takes this responsibility seriously, addressing urgent challenges such as ocean monitoring, water quality, and plastic pollution, issues that directly affect the country's ecology and economy. During a recent field visit to Cox's Bazar, team members witnessed the impact of plastic pollution up close: plastic debris littering the shoreline, harming marine life, and threatening the livelihoods of local communities. This powerful experience motivated our team to take action and inspired the development of new initiatives that leverage autonomous underwater vehicles (AUVs) for environmental monitoring and data collection.

These efforts go beyond technology for its own sake. By focusing on real-world problems faced by our rivers and coastal areas, Duburi aims to create practical solutions that can help protect Bangladesh's natural resources. Our projects are designed not only to address local environmental issues, but also to demonstrate the potential for homegrown innovation in ocean technology. We believe that by tackling challenges close to home, we can empower the next generation of Bangladeshi engineers and researchers to become leaders in sustainable innovation, both nationally and on the global stage. Through these initiatives, Duburi is building a foundation for a future where Bangladesh is at the forefront of ocean science, environmental stewardship, and technological progress.

(a) Duburi team members engaging with local communities at the Bay of Bengal, raising awareness about underwater technology and ocean conservation.

(b) Field deployment of Duburi's AUV system, demonstrating hands-on technical outreach at the water's edge.

Fig. 20: Duburi's field outreach in coastal communities, combining public demonstration with applied ocean technology.