BRACU Duburi AUV Technical Design Report

BRAC University (BRACU Duburi)

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***Abstract*—For RoboSub 2026, BRAC University underwater robotics team, BRACU Duburi, advances its dual-vehicle configuration as a deliberate strategy to maximize its scoring potential, with each vehicle designed and specialized to perform its own role with the utmost reliability. Duburi 4.5 is built for sensor-guided precision and Dubomini 2.0 for maneuver-dominant tasks, the two operating in parallel and coordinating mid-run over an in-house inter-vehicle communication to cover more of the course within the run window. Principal contributions include a vision-guided torpedo with onboard terminal alignment, a stepper-driven scooping grabber, a centralized power management board, and a YOLO26 perception pipeline. Each was validated through unit, integration, and full-system testing, ensuring both AUVs are prepared to autonomously and reliably execute the full RoboSub 2026 mission.**

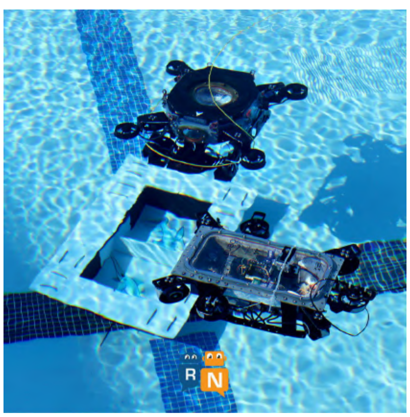


Fig. 1: BRACU Duburi's dual-vehicle deployment.

I. Competition Strategy

A. Core Strategy

Our objective at RoboSub 2026 is to score as many points as possible through reliable task completion. To achieve this, we refined our dual-vehicle strategy, now in its second iteration. The course is split between two specialized AUVs running in parallel, each given as many tasks as it can handle reliably. Together, the two vehicles maximize task completion while minimizing total run time.

Duburi 4.5 is our primary AUV, carrying the full sensor suite of forward and downward cameras, DVL, and IMU alongside the actuator package of grabber, dropper, and torpedo launcher. Its larger mass and higher rotational inertia make it slower to reorient but more stable about a commanded setpoint, suiting it to the precision tasks that require sustained station-keeping and controlled manipulation.

Dubomini 2.0 is our agility-focused secondary AUV, built around an eight-thruster configuration optimized for rotational authority and rapid maneuvering. It is assigned the maneuver-dominant tasks where speed and agility take priority over actuation.

B. From 2025 Deployment to 2026 Refinement

Three issues from the RoboSub 2025 deployment of Duburi 4.2 and Dubomini 1.0 [1] directly shape the 2026 design, each addressed at the subsystem level in Section II.

The first was run time. The team could not complete the full course within the competition time frame. The 2026 response distributes the course across Duburi 4.5 and Dubomini 2.0 by specialization, deploying both in parallel so the full course is completed ahead of schedule, within the allotted run window.

The second was localization drift on Duburi, caused by magnetic interference, often from environmental sources, that corrupted the heading estimate during runs. For 2026 we strengthened the heading estimate by fusing inertial heading with DVL data, so no single interference-corrupted reading can dominate it.

The third was early signs of electrolysis on the torpedo and dropper power lines, observed across the varied water conditions between development and competition. For 2026 we developed a new low-side actuation board that holds the actuator lines inactive between firings, which eliminated the electrolysis seen in earlier builds.

C. Task Allocation

Task	Vehicle	Primary Requirement
Gate	Duburi	Baseline traversal, vision-led
Gate with style	Dubomini	Rotational agility
Slalom	Dubomini	Continuous navigation
Torpedo	Duburi	Sensor-fused alignment, launcher
Bin	Duburi	Stationkeeping, dropper
Octagon	Duburi	Close-range work, grabber
Return Home	Dubomini	Navigation, validated in 2025

TABLE I: Task allocation across both vehicles.

D. Mission Execution

Both vehicles are deployed at the start of the run, with Dubomini holding station until released by inter-vehicle communication (IVC) from Duburi.

Begin Assessment - Gate (Duburi). Duburi submerges and aligns with the gate through fused inertial and visual sensing. A search pattern locates the gate, after which visual homing centers the approach and identifies the role marker with the highest detection confidence. The coin-flip role determines the side of traversal, and the vehicle passes through at neutral orientation.

Deploy - Torpedoes (Duburi). Duburi navigates to the board under DVL-aided localization and identifies the target visually. It stations at the farther firing distance of 0.46 m, aligns to the larger opening, and fires the first torpedo. The vehicle then re-aligns to the smaller opening and fires the second.

IVC Handoff. On completion of Deploy - Torpedoes, Duburi transmits a release signal to Dubomini, and parallel execution begins.

Begin Assessment - Gate (Dubomini). Dubomini approaches the gate under inertial and visual guidance, passes through on the role-matched side, and executes a controlled roll for style points.

Avoid Debris - Slalom (Dubomini). The central red pipe is detected visually and used as the alignment reference, with the vehicle holding the role-consistent side. Heading is corrected against the pipe positions across each of the three sets, with depth maintained within the pipe plane.

Recon - Bins (Duburi). Duburi navigates to the bin area under sensor suite and switches to the downward camera for marker detection. It stations above the first role-matched bin, releases the first marker, then realigns over the second bin and releases the second one.

Resupply - Octagon (Duburi). Duburi approaches the octagon under vision-aided guidance and confirms entry from detection of target images. It surfaces inside the perimeter, descends to the central table, and uses the downward camera and grabber to collect the first role-matched item. The item is placed in the corresponding basket, after which the vehicle returns for the second. With both items placed, our primary AUV faces the correct image and performs two yaw rotations.

Return Home (Dubomini). On completion of Avoid Debris - Slalom, Dubomini executes a return trajectory under inertial heading control with visual landmark correction, surfacing in the start area to close its run.

II. Design Strategy

For RoboSub 2026, the mechanical, electrical, and software subsystems were re-engineered for reliability, rapid task turnover, and fault-tolerant autonomy.

A. Mechanical Subsystem

The mechanical subsystem is designed for reliability, modularity, and maintainability, retaining proven structures and redesigning payloads only where tasks require.

1) Hull and Material

Across multiple competition cycles and extended local testing, the 4.2 hull has shown no leakage and no observable corrosion, and the same hull is carried into the 4.5 build. The material is Marine 5083 aluminum, selected for its strength-to-weight ratio and the well-characterized behavior of the alloy across standard tempers [2], with documented fatigue and corrosion resistance under chloride exposure [3] that gives margin against the varied water conditions encountered before competition. The octagonal cross-section is retained for its near-uniform drag from any heading, which keeps Duburi predictable to control as it maneuvers and holds position during precision tasks. Three brass-framed acrylic viewports carry the front and downward cameras and an internal access port, and a modular stand beneath the hull, introduced in 2025, mounts the grabber, dropper, torpedo launcher, and DVL on standardized fixtures, allowing mission hardware to be removed and reinstalled between wet-test sessions without re-fixturing.

Dubomini shares the same Marine 5083 aluminum, keeping the fabrication pipeline consistent, but its hull diverges in form. The cross-section is rectangular rather than octagonal, driven by the vehicle's small size: at this scale the drag penalty of a flat-sided hull is negligible at low cruise velocity, while the gain in usable internal volume is significant. Subsystems mount on modular trays that use the extra internal space the flat hull provides. The front camera sits behind an acrylic viewport inside the main hull and the downward camera in a separate external pressure housing beneath the vehicle, while viewport framing, penetrator standards, and fabrication practice are shared with Duburi. No manipulator hardware is carried, consistent with Dubomini's allocation to maneuver-dominant operations.

(a) Duburi 4.5 (b) Dubomini 2.0

Fig. 2: Renderings of both vehicles.

2) Eight-Thruster Configuration

An eight-thruster configuration gives Duburi full six-degree-of-freedom control [4]. It delivered the authority Duburi's precision tasks needed in 2025, holding station and positioning it accurately, so it carries into the 4.5 build unchanged.

Dubomini's thruster count goes from seven to eight. In the 2025 build, the single heave thruster sat off-center, generating a pitch torque $\tau = F_T \times d$ that caused oscillation during descent. The 2026 layout adds a second heave thruster mirrored across the centerline, cancelling the torque $\tau = (F_T \times d) - (F_T \times d) = 0$ N·m and increasing net heave force to $2F_T$, making descent fully stable.

3) *Vision-Guided Torpedo*

The 2025 torpedo performed reliably at shorter range, deriving its aim from the carrier vehicle. As greater firing distances carry a higher scoring value, the 2026 torpedo was redesigned to perform its own terminal alignment, achieving the accuracy required at extended range without relying solely on Duburi's position at launch. The redesigned torpedo (Fig. 3) carries its own terminal guidance: a forward-facing camera, an ESP32-S3 microcontroller, and six thrusters. After Duburi stations against the target board, the torpedo's camera locates the nearest opening through classical computer vision, and its thrusters align the bore axis with the opening and fire once aligned. By correcting its own aim at this final stage, the torpedo no longer depends on Duburi holding a perfect position at launch.

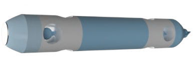


Fig. 3: Redesigned Torpedo

4) *Position-Tracked Compliant Grabber – Evil Claw*

To secure points reliably in the Octagon task, the 2026 grabber was redesigned with three goals: confirming a successful grasp, controlling jaw width, and gripping off-center objects. The 2026 design (Fig. 4) replaces the DC motor with a stepper, giving the control stack precise control of jaw position by step count and making any intermediate width directly addressable. The closure kinematics were also redesigned: rather than closing the fingers straight inward, the new mechanism combines inward motion with forward translation, so the fingertips trace a scooping arc and wrap beneath the object. TPU fingers add compliance for objects not precisely centered on the gripper.

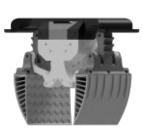


Fig. 4: Grabber – Evil Claw

5) *Solenoid Marker Dropper*

The dropper (Fig. 5) is retained from the 2025 build without mechanical modification. The solenoid-driven release performed reliably across wet testing and competition deployment, and no failure mode in the mechanism itself justified redesign. The electrolysis observed during 2025 competition was traced to the firmware signaling layer rather than the actuator hardware, and is addressed in the Electrical section.

Fig. 5: Dropper

B. *Electronic Subsystem*

Both vehicles operate on a redesigned electrical architecture developed this cycle around three priorities: reliability, maintainability, and power stability. The redesign addresses the failure modes that recurred across earlier generations, electromagnetic interference, unmanaged wiring, and slow fault diagnosis, treating each as a design constraint rather than a tolerated limitation. The two vehicles are built on a shared backbone (Fig. 6, Fig. 7) and diverge only at the actuator and propulsion stages, allowing a single architecture to support both a precision platform and an agile one without duplicated effort.

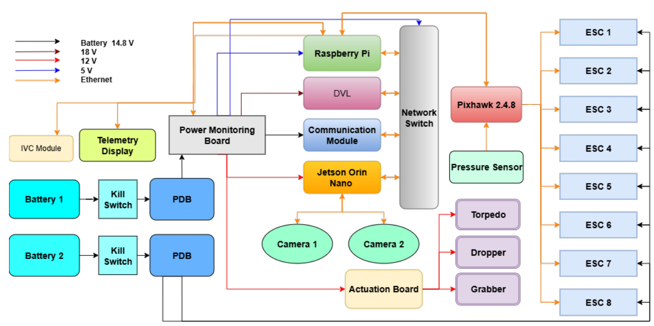


Fig. 6: Duburi 4.5 electronic subsystem architecture.

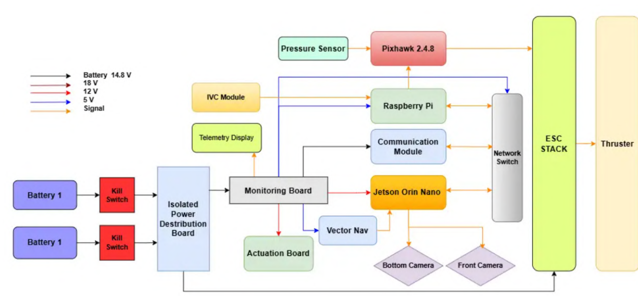


Fig. 7: Dubomini 2.0 electronic subsystem architecture.

1) *Centralized Power Distribution*

Power distribution was rebuilt to resolve the EMI and grounding issues that had complicated earlier builds.

Custom synchronous buck converters replace the bulkier commercial modules, operating cooler and recovering interior hull volume, while a dedicated monitoring board on each vehicle measures per-channel voltage and current and reports them in real time, advancing fault isolation from estimation to direct observation. On Dubomini, a Smart Power Distribution Board consolidates routing, subsystem protection, and kill-state propagation onto a single board, with expansion headroom reserved for the torpedo, dropper, and grabber actuators, enabling the platform to scale without a further redesign.

2) Kill Switch and Safety Systems

Safety motivated a deliberately divergent design philosophy, with each vehicle retaining the kill mechanism best suited to its operational maturity and role. Duburi continues to use the team's in-house waterproofed mechanical kill switch developed through earlier research and testing cycles. The design has demonstrated reliable operation across multiple deployments and remains justified through its proven field performance and maintainability. Dubomini, by contrast, adopts a newly developed encoder-based kill switch integrated directly into the Smart PDB architecture. Reading switch state through an encoder produces a cleaner and more repeatable kill response while enabling direct digital state propagation through the distribution system. Integrating the kill logic into the isolated Smart PDB also simplifies handling during deployment and testing, improving operator awareness and electrical safety on deck.

3) Actuation System Redesign

The actuation system was rebuilt for reliability and electrical efficiency. Earlier builds switched the solenoids through relays that wore mechanically and responded slowly; high-side MOSFET switching now replaces them, reducing both response delay and conduction loss. The grabber drive likewise transitions from a DC motor to a stepper for finer positional control. All three actuators, torpedo, dropper, and grabber, are consolidated onto a single Actuation Board that reports the status and telemetry of each, unifying payload control within a single observable interface.

4) Flight Controller

Both vehicles continue on the Pixhawk flight controller, a decision of restraint rather than reach. Newer, more powerful platforms were within easy grasp, but Pixhawk was kept precisely because it had already earned its place, its inner-loop behaviour tuned, characterised, and proven stable across successive cycles. The high-level work, autonomy, perception, and outer-loop control, was deliberately lifted onto the companion computer, leaving the flight controller to do the one thing it does reliably and nothing more. The result is a clean division of labour: heavy computation stays off the inner loop, a validated control architecture is preserved intact, and the team avoids the quiet, compounding cost of trading proven hardware for untested capability.

5) Inter-Vehicle Communication

The dual-vehicle strategy depends on the two AUVs remaining coordinated, so the team developed an in-house Inter-Vehicle Communication (IVC) modem from two half-duplex transceivers. Underwater acoustic channels are inherently bandwidth-limited [5], so the link carries only low-bandwidth coordination data sufficient to keep the vehicles synchronized through the parallel run, avoiding the cost and overhead of a full acoustic modem.

C. Software Subsystem

The software stack is shared across Duburi 4.5 and Dubomini 2.0, with platform-specific configurations layered on a common codebase. Its structure follows the same three-domain organization used in 4.2: low-level control, autonomous perception, and mission planning. The domain boundaries are unchanged this year; the revisions within each are described below.

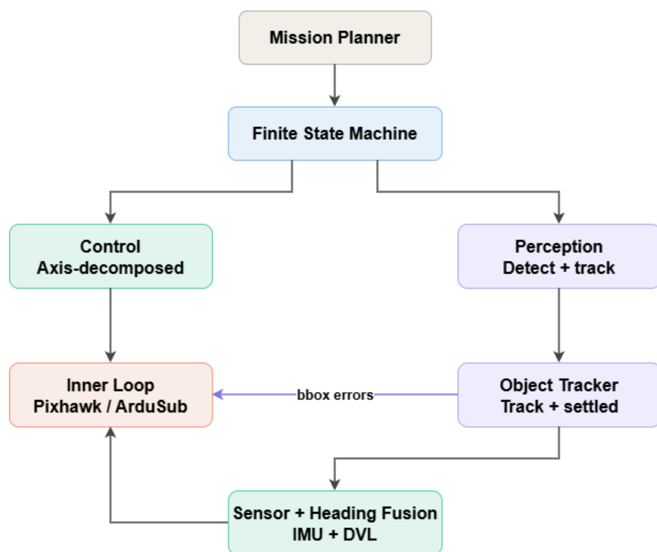


Fig. 8: Software Subsystem Architecture

1) Dual-Loop Control Architecture

The control stack builds on the inner-loop architecture proven in 4.2, but the software has evolved substantially this cycle, reworked around a cleaner inner/outer-loop split, a fusion-backed heading-hold, formalized axis-decomposed motion modules, and a complete second-vehicle control path. The Pixhawk, running ArduSub, owns the inner loop: attitude stabilization, depth hold, and thrust allocation across the eight-thruster configuration, with its onboard EKF fusing IMU, depth, and DVL streams into a pose estimate that drives the PID controllers. The Jetson Orin Nano runs the outer loop under ROS2 Humble [6], [7], dispatching setpoints and consuming telemetry in return. The split is deliberate: stabilization stays on a platform with tuning data accrued across cycles, while the companion's compute is reserved for autonomy and perception. Motion is decomposed along principal axes, forward, lateral, yaw, and depth each driven by an independent module, so concurrent commands compose without inter-axis coupling. A heading-lock holds a background stream against the vehicle's heading, kept stable by fusing inertial heading with DVL position so that interference on any one input cannot dominate the estimate, the configuration that proved most reliable in pool testing. DVL-aided distance moves promote open-loop translation into closed-loop displacement commands for tasks needing sub-meter positioning, a capability introduced with the DVL in 4.2 and refined this cycle. Dubomini 2.0 carries no DVL, falling back to inertial dead-reckoning over short segments and visual landmark correction over longer ones, a trade-off its task allocation permits, since it never holds station over the extended paths where dead-reckoning drift would dominate.

2) Visual Perception and Autonomous Tracking

Perception is implemented as a four-stage pipeline on the Jetson (Fig. 9), with detection and tracking revised for 2026. The preprocessing stage applies classical computer-vision enhancement [8] to correct the color cast and haze of underwater imagery, so the detector receives a clean image in both clear and turbid water. Ultralytics YOLO26 [9] replaces the YOLOv11 model used in 4.2, chosen for NMS-free inference, which lowers post-processing latency on edge hardware, and small-target-aware label assignment, which improves detection of smaller props. The model undergoes domain-specific pretraining on underwater imagery followed by fine-tuning on a custom dataset of pool footage with task-specific augmentations simulating varied underwater conditions, following the principle that domain-specific pre-training outperforms general initialization [10].

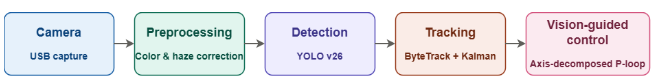


Fig. 9: Perception-to-control pipeline

ByteTrack [11] assigns and maintains target identities across frames, directly addressing the identity instability that undermined tracking in 4.2, where turbidity and occlusion consistently fragmented detections into flickering, short-lived tracks. Absent from the prior pipeline, it represents one of the more consequential additions to the perception stack this cycle, delivering steady and consistent tracks across a full run even under low-confidence detections. Vision-guided motion reuses the axis-decomposed control modules that handle open-loop maneuvers. A vision primitive reads the latest track, computes the error from frame center, and issues a proportional correction on that axis, with multi-axis primitives combining yaw, lateral, and depth alignment.

3) Finite State Mission Planner

Task execution is sequenced by a finite state machine in ROS2, defining transitions between navigation, perception, manipulation, and recovery states. The decoupling of mission logic from low-level control is retained from 4.2, letting task strategy be revised without disturbing the control or perception stacks. The FSM consumes the same control and perception interfaces used elsewhere, confining task-specific logic to the planning layer.

The notable 2026 addition is folding the inter-vehicle hand-off into the FSM: the IVC release signal is registered as a transition condition on both vehicles, so the dual-vehicle coordination of Section I is handled within the same framework that governs every other transition. This covers the failure case as well, if the IVC signal does not arrive within a bounded window, Dubomini transitions to a fallback state and proceeds with its task set, treating Duburi's run as timed out, so the deployment does not fail on a single point of communication loss.

III. Testing Strategy

Testing ran continuously from day one, not as a final hurdle but as part of the build itself, threaded into every decision the team made. Every fault was caught at the lowest level possible: bench first, simulation, then pool, an order earned through cycles where shortcuts had cost the team dearly. Duburi is a proven platform, the product of years of pool time and hard-won iteration, so its retained subsystems required only refinement, while new additions were stress-tested without compromise. The real work, the long nights and unforgiving sessions, was Dubomini. New to the architecture, it and every new subsystem across both vehicles were verified against the exact tasks they were built for, nothing taken on trust and nothing carried forward unproven. The full testing strategy, validation criteria, and graceful degradation procedures are detailed in Appendix D.

A. One Layer at a Time: Module to Mission Testing

Testing was strictly layered. Nothing advanced to the next level until the one below was fully solid. Modules were verified individually on controlled inputs, then pushed through component testing under load, and finally driven through full subsystem integration. At the top sat mission-level validation: each task verified in isolation, chained into multi-task runs, then executed end-to-end with shuffled ordering to expose timing and handoff faults. The guiding principle was clear: catch every fault at the lowest level possible, because a problem buried inside an integrated run costs far more time and pool access than we can afford.

B. Proving the Parts: Component and Subsystem Validation

Every subsystem had to check out on its own before it went into the vehicle, retained hardware re-verified under the new setup and new hardware tested against the task it serves.

1) Power and Payload: Electrical and Mechanical Validation

The dual-bus battery was load-tested under simulated mission conditions, with overcurrent and voltage-imbalance faults deliberately forced to confirm correct response. The centralized power board was verified across all rails under both idle and full operational load, and the MOSFET actuation board switched reliably across thousands of cycles, eliminating the contact wear that plagued the relays it replaced. Kill switches were verified underwater under active propulsion, and watertight integrity confirmed through timed submersions across every compartment. Actuators were benchmarked against their predecessors: the redesigned torpedo landed correctly in roughly 7 out of 10 attempts compared to the older system's 3, the grabber held jaw width precisely with the scooping closure and compliant TPU fingers securing even off-center objects, and the dropper released consistently without fault across repeated cycles.

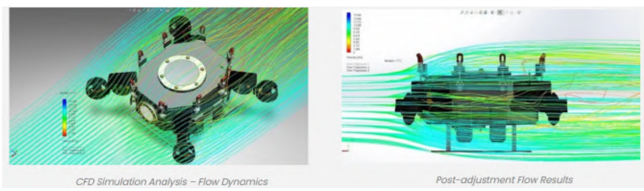


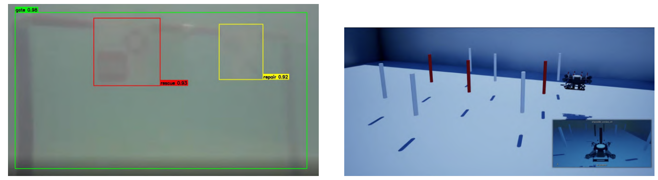
Fig. 10: Duburi 4.5 CFD velocity streamline analysis.

2) Sensing and Stability: Control Stack Validation

Because each vehicle carries a different stack, validation was scoped to what each relies on. On Duburi, where precision hinges on trustworthy state estimation, the priority was sensor fusion: calibrating the IMU and compass and verifying the DVL bottom-track for the closed-loop distance moves manipulation demands. Hydrodynamic checks were pushed upstream, with CFD run across Duburi's frame (Fig. 10) to surface any drag or flow-separation anomalies in software before pool time. PID gains were subsequently tuned across all six degrees of freedom. On Dubomini, where the premium is on agility, testing centered on the eight-thruster layout, confirming the added heave thruster had resolved previous limitations.

3) Seeing the Course: Perception Validation

Perception was treated as a continuous refinement problem, tested across simulation and pool until the pipeline behaved as the mission required. Task-specific fine-tuned YOLO models were trained on custom datasets drawn from our own pool footage and validated across both clear and turbid water, ensuring known behavior under real conditions. Classical computer-vision filters were applied ahead of detection and refined through repeated trials, improving accuracy, easing inference, and stabilizing frame-to-frame output where earlier runs had flickered. ByteTrack was validated for stable identity tracking through brief occlusions, confirming target identity was preserved without reassignment errors. Closed-loop vision primitives were verified for reliable and repeatable alignment onto settled targets. Ahead of any pool deployment, the full autonomy stack was exercised in ROS2 and Unreal Engine 5, recreating competition tasks under varied conditions to surface edge cases in software before they could surface in the water.



(a) Gate detection (b) Slalom Task

Fig. 11: YOLO26 detections and simulation.

C. Rehearsing the Run: Integration and Handoff

Mission testing scaled from single tasks to the full coordinated run. Each task was verified in isolation, then chained into sequences. Several task orderings were evaluated across both vehicles, and the current sequence emerged as the one that scored the most points within the least run time. The inter-vehicle communication was tested in water, measuring handoff timing and confirming the fallback for a missing release signal. The aim was to prove the run as one coordinated system, not two vehicles sharing a pool.

D. Beyond the Pool: Environmental Endurance

Both vehicles were stress-tested in local waterbodies and the Bay of Bengal, with higher salinity and wave turbulence. The dual-battery system held up through a six-hour continuous run, and any anomaly observed across deployments was rolled into standard operating procedures.

E. Competition Readiness

Both vehicles are competition-ready, with all major subsystems validated in water, and remaining sessions devoted to perfecting uninterrupted mission autonomy.

IV. Acknowledgements

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Appendix A: Component Specifications

Duburi 4.5

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost	Year of Purchase
Buoyancy Control	BlueRobotics	R 3312	Subsea Buoyancy Foam	Purchased	$170	2024
Frame	Local	Marine Aluminium 5083	Custom machined marine-grade aluminium 5083	Custom	$509	2023
Waterproof Housing	-	-	-	-	-	-
Waterproof Connectors	BlueRobotics	Potted Cable Penetrator	Penetrator	Purchased	$ 108	2022
Thrusters	BlueRobotics	T200 Thrusters	T200 Thruster	Purchased	$ 1600	2024
Motor Controls	BlueRobotics	Basic ESC	Basic ESC	Purchased	$ 288	2019
High Level Control	Local Supplier	Pixhawk 2.4.8	STM32-based autopilot running ArduSub firmware for vehicle stabilization and navigation control	Purchased	$ 120	2024
Actuators	-	-	-	-	-	-
Propellers	-	-	-	-	-	-
Battery	Tiger	6200mAh Lithium Polymer Battery	Lipo Battery	Purchased	$ 130	2025
Converter	-	-	-	-	-	-
Regulator	-	-	-	-	-	-
CPU	Nvidia	Nvidia Jetson Orin Nano	Nvidia Jetson Orin Nano	Purchased	$ 499	2024
Internal Comm Network	TP-Link	TP-Link SF1005D	5-port network switch	Purchased	$ 6	2025
External Comm Interface	BlueRobotics	Fathom-X Tether Interface	Ethernet-over-tether communication between the vehicle and control station	Purchased	$ 140	2023
Compass	Nortek Group	Nucleus 1000	Nucleus 1000	Sponsored	Sponsored	2023
Inertial Measurement Unit (IMU)	Nortek Group	Nucleus 1000	Nucleus 1000	Sponsored	Sponsored	2023
Doppler Velocity Logger (DVL)	Nortek Group	Nucleus 1000	Nucleus 1000	Sponsored	Sponsored	2023
Manipulator	Local Supplier	IP68-rated underwater stepper motor	IP68-rated underwater stepper motor	Purchased	$ 40	2026
Algorithms: Control	-	-	Thresholding, PID, Kalman Filter	Custom	-	2022
Vision	-	-	Transfer Learning	Custom	-	2022
Acoustics	-	-	-	-	-	-
Localization and Mapping	Nortek Group	Nucleus 1000	Nucleus 1000	Sponsored	Sponsored	2022
Autonomy	-	-	Machine Learning, IMU Heading	-	-	2022
Open-Source Software	-	-	ArduSub, Python Libraries	-	-	2022
Inter-Vehicle Communication	Custom	Acoustic Communication Prototype	Experimental custom acoustic signaling system using frequency-based underwater audio communication	Custom	$ 50	2026
Programming Language(s)	-	-	Python	-	-	2022

Dubomini 2.0

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost	Year of Purchase
Buoyancy Control	BlueRobotics	R 3312	Subsea Buoyancy Foam	Purchased	$170	2024
Frame	Local	Marine Aluminium 5083	Custom machined marine-grade aluminium 5083	Custom	$350	2025
Waterproof Housing	-	-	-	-	-	-
Waterproof Connectors	BlueRobotics	Potted Cable Penetrator	Penetrator	Purchased	$ 108	2022
Thrusters	BlueRobotics	T200 Thrusters	T200 Thruster	Purchased	$ 1600	2024
Motor Controls	BlueRobotics	Basic ESC	Basic ESC	Purchased	$ 288	2019
High Level Control	Local Supplier	Pixhawk 2.4.8	STM32-based autopilot running ArduSub firmware for vehicle stabilization and navigation control	Purchased	$ 120	2024
Actuators	-	-	-	-	-	-
Propellers	-	-	-	-	-	-
Battery	Tiger	6200mAh Lithium Polymer Battery	Lipo Battery	Purchased	$ 130	2025
Converter	-	-	-	-	-	-
Regulator	-	-	-	-	-	-
CPU	Nvidia	Nvidia Jetson Orin Nano	Nvidia Jetson Orin Nano	Purchased	$ 499	2024
Internal Comm Network	TP-Link	TP-Link SF1005D	5-port network switch	Purchased	$ 6	2025
External Comm Interface	BlueRobotics	Fathom-X Tether Interface	Ethernet-over-tether communication between the vehicle and control station	Purchased	$ 140	2023
Compass	VectorNav	VectorNav VN-200	VectorNav VN200	Sponsored	Sponsored	2022
Inertial Measurement Unit (IMU)	VectorNav	VectorNav VN-200	VectorNav VN200	Sponsored	Sponsored	2022
Doppler Velocity Logger (DVL)	VectorNav	VectorNav VN-200	VectorNav VN200	Sponsored	Sponsored	2022
Manipulator	Local Supplier	IP68-rated underwater stepper motor	IP68-rated underwater stepper motor	Purchased	$ 40	2026
Algorithms: Control	-	-	Thresholding, PID, Kalman Filter	Custom	-	2022
Vision	-	-	Transfer Learning	Custom	-	2022
Acoustics	-	-	-	-	-	-
Localization and Mapping	-	-	-	-	-	-
Autonomy	-	-	Machine Learning, IMU Heading	-	-	2022
Open-Source Software	-	-	ArduSub, Python Libraries	-	-	2022
Inter-Vehicle Communication	Custom	Acoustic Communication Prototype	Experimental custom acoustic signaling system using frequency-based underwater audio communication	Custom	$ 50	2026
Programming Language(s)	-	-	Python	-	-	2022

Appendix B: System Analysis and Flowcharts

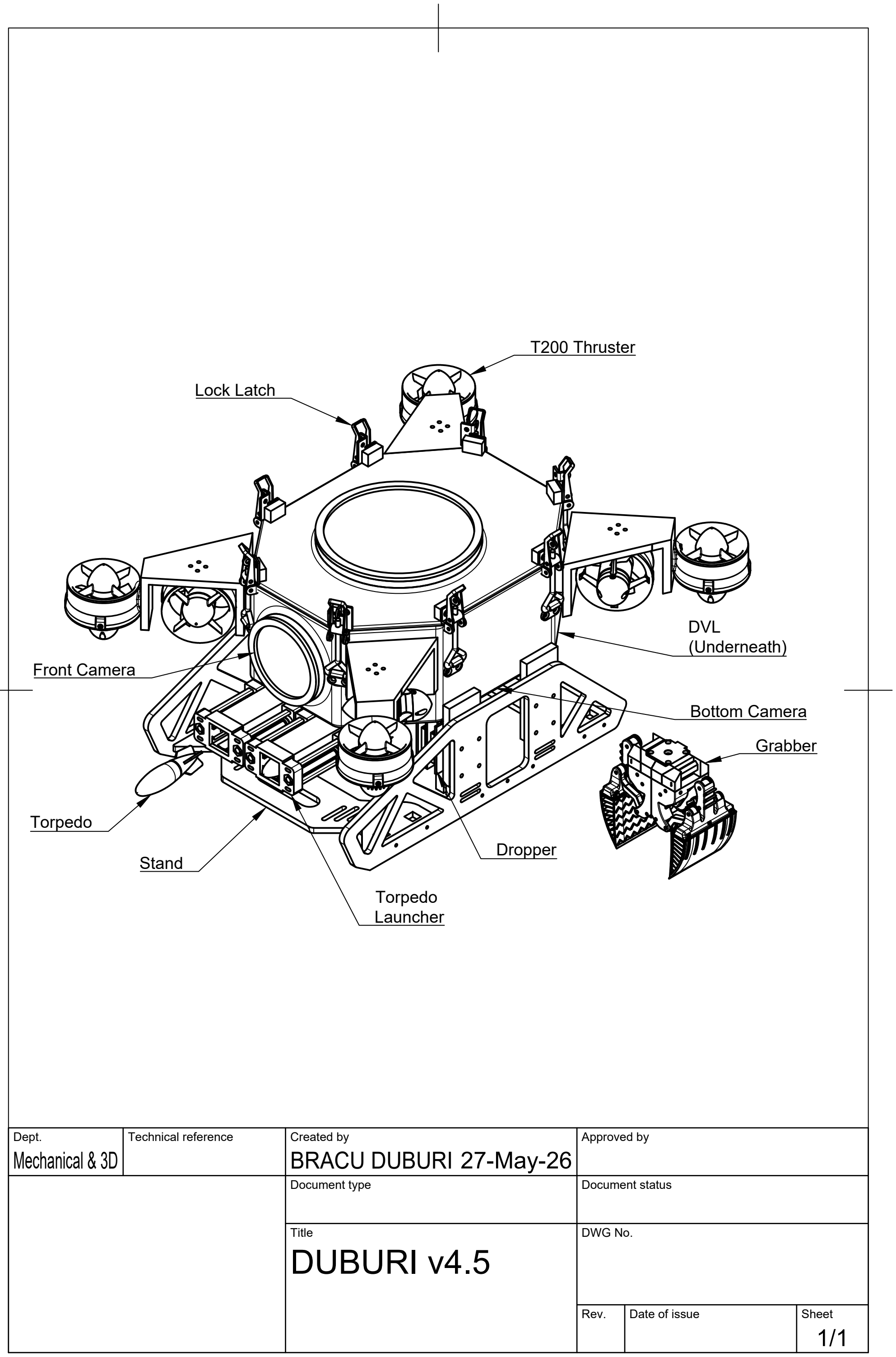


Fig. 12: Duburi 4.5 Burst View

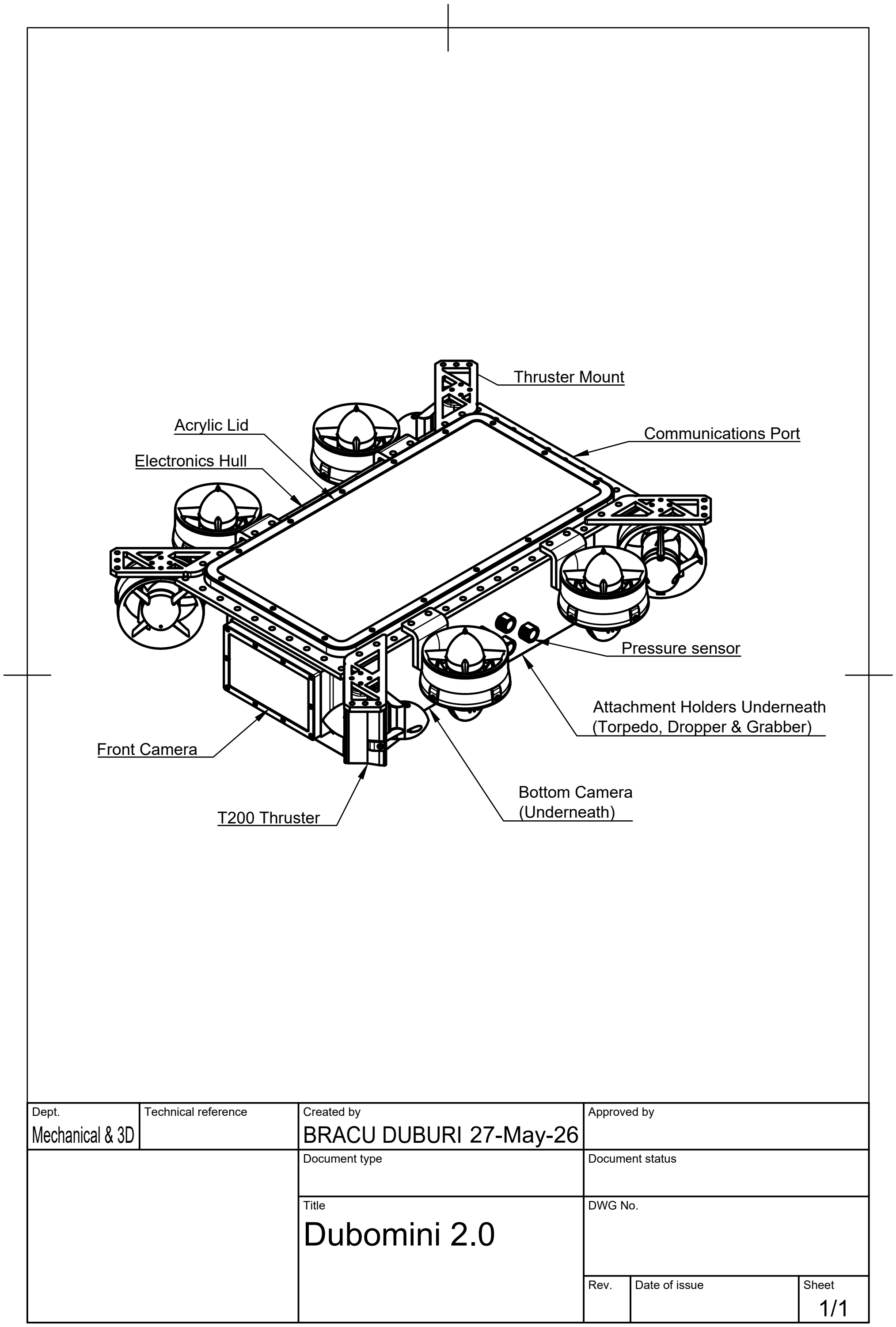
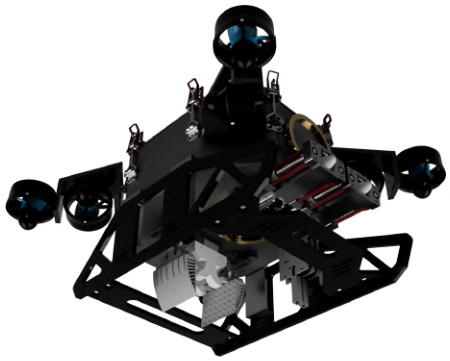
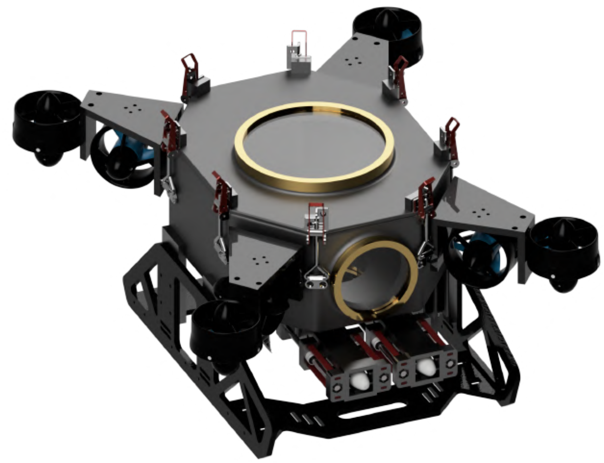


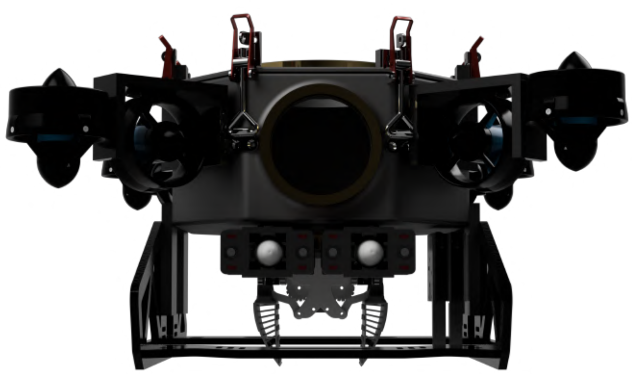
Fig. 13: Dubomini 2.0 Burst View



(a) Isometric view

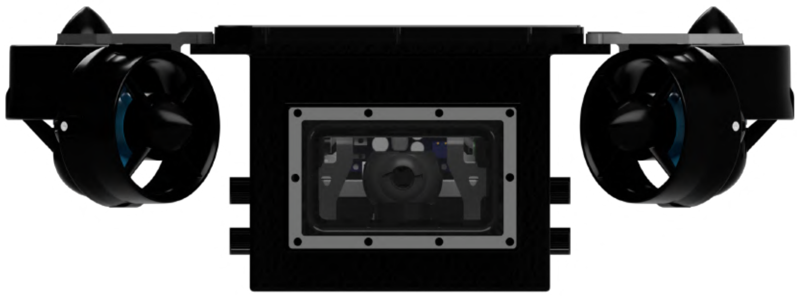


(b) Top view



(c) Front view

Fig. 14: Duburi 4.5 renders.



(a) Front view

(b) Isometric view

Fig. 15: Dubomini 2.0 renders.

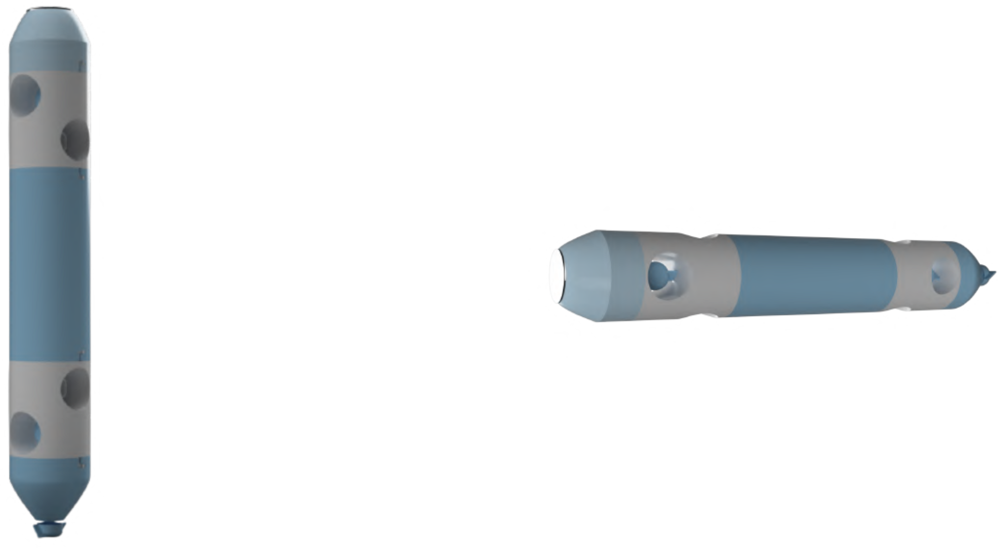


Fig. 16: Vision-Guided Torpedo

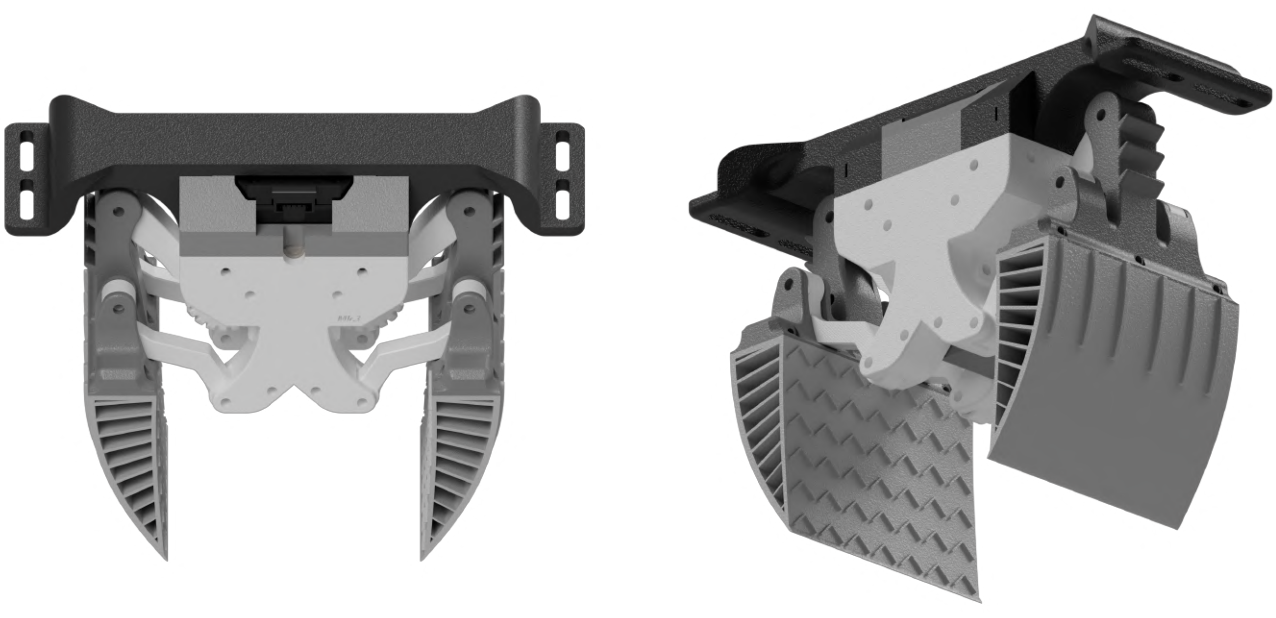


Fig. 17: Position-Tracked Compliant Grabber – Evil Claw

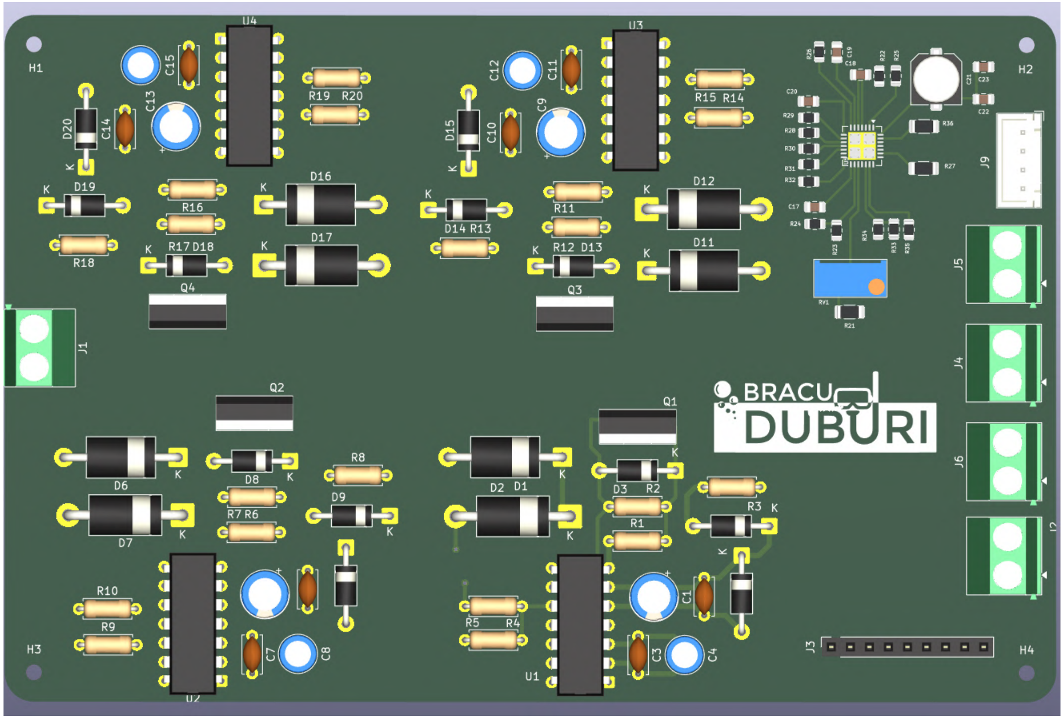


Fig. 18: Actuation Board PCB Layout

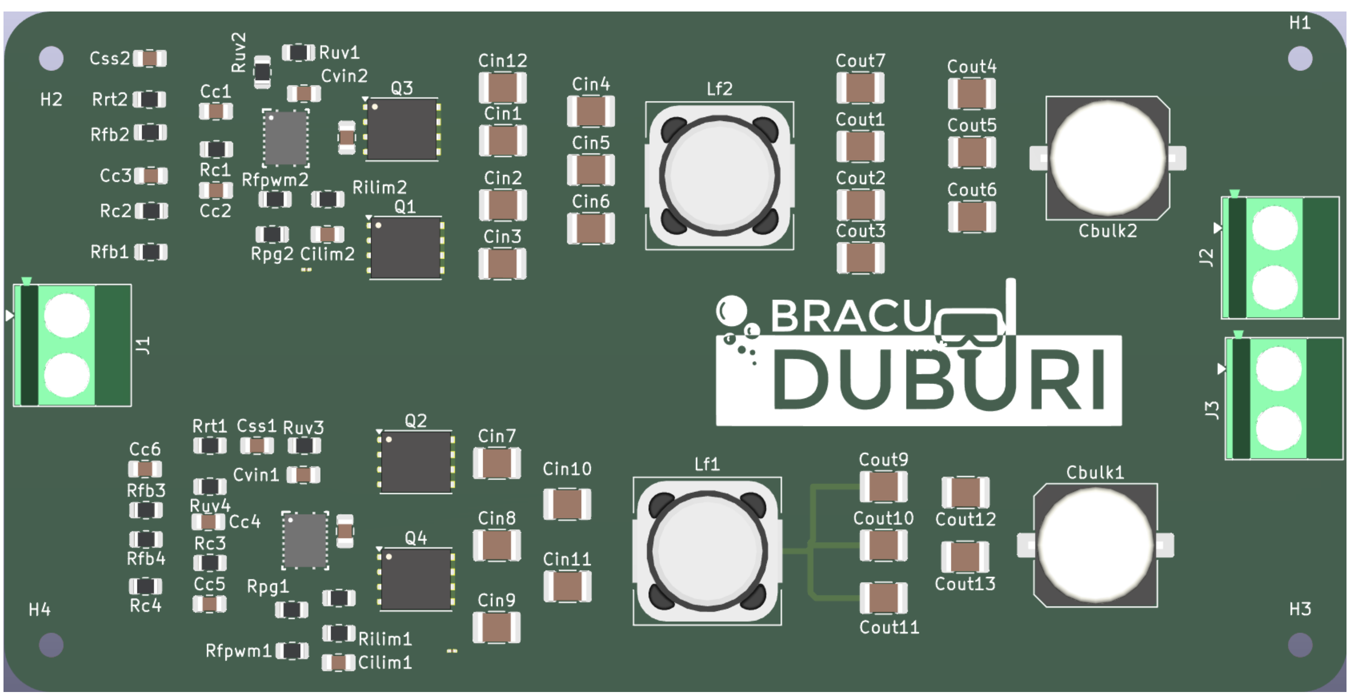


Fig. 19: Custom Synchronous Buck Converter Module

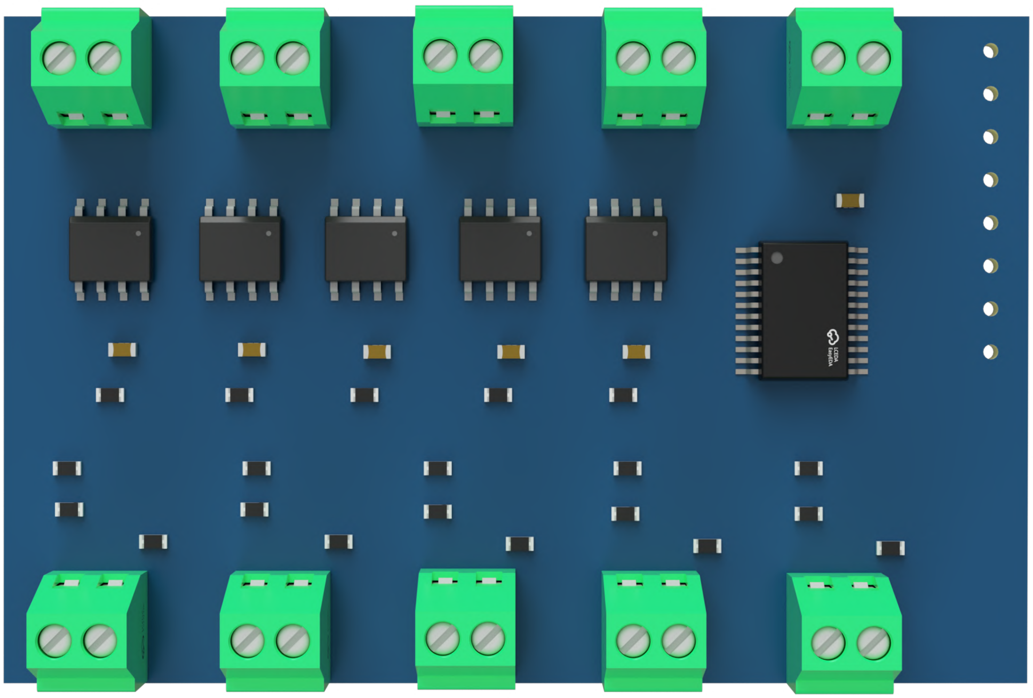


Fig. 20: Power Monitoring Board PCB Layout for Duburi 4.5

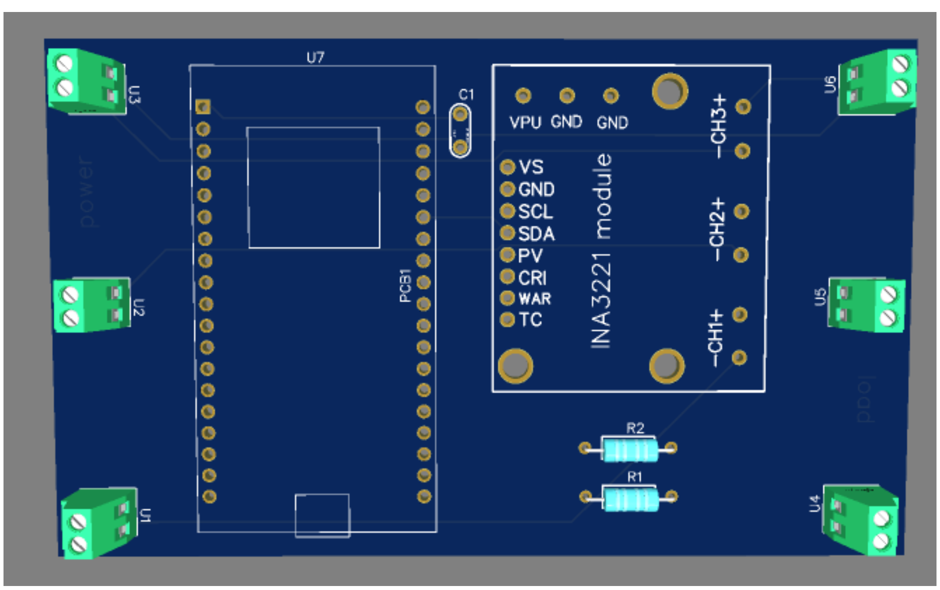


Fig. 21: Power Monitoring Board PCB Layout for Dubomini 2.0

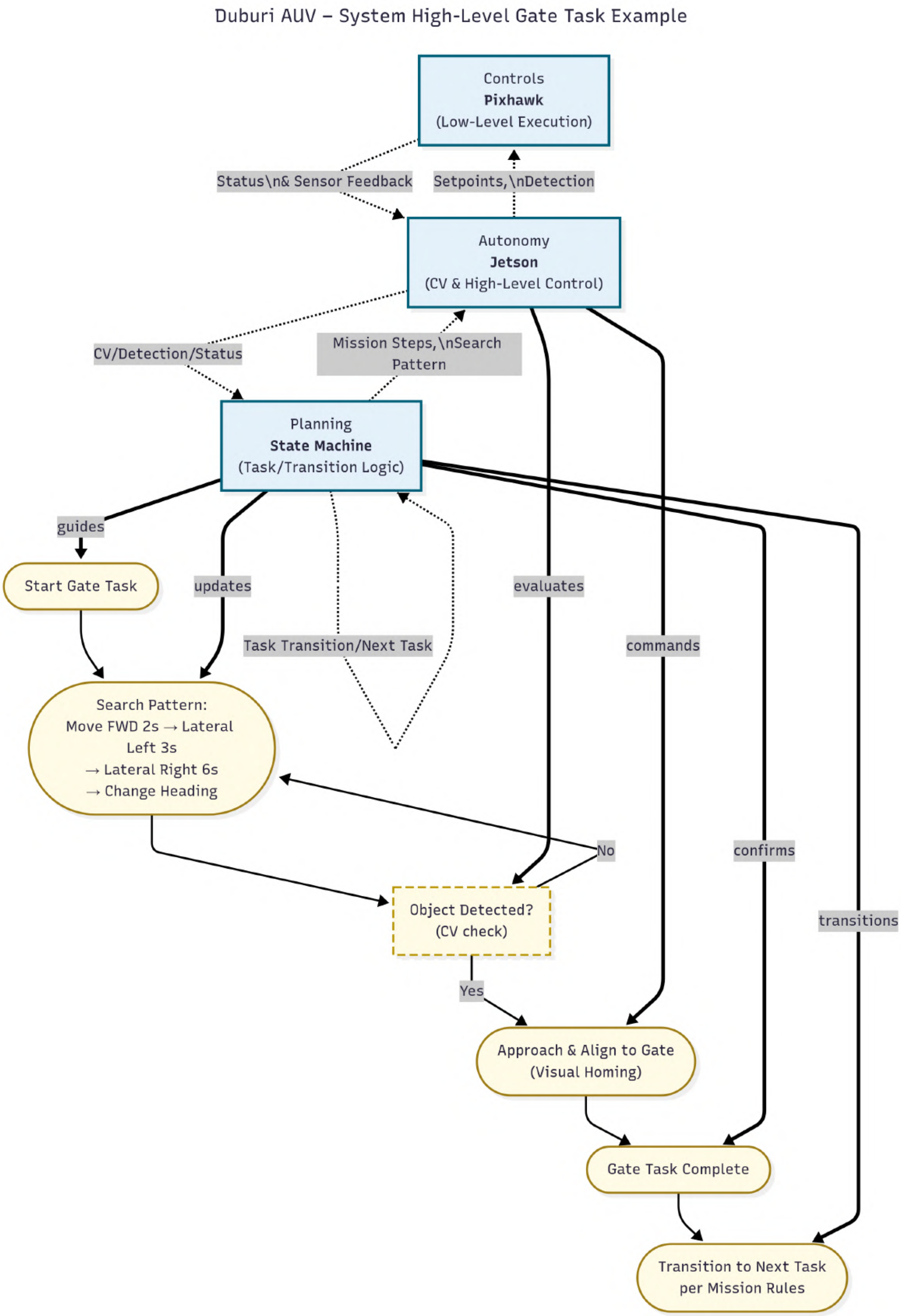


Fig. 22: Search Pattern

Appendix C: Testing Box

Primary Components

- Duburi 4.5
- Dubomini 2.0
- 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: Testing Strategy & Validation Plan

For both Duburi 4.5 and Dubomini 2.0, the team treats testing not as a terminal verification stage but as a continuous engineering discipline interwoven through every phase of the development lifecycle. Each subsystem, spanning mechanical, electrical, software, communication, and mission autonomy, is progressively validated under operating environments of increasing fidelity, advancing from isolated bench characterisation toward end-to-end mission execution.

Four engineering principles anchor the validation philosophy:

- **Progressive Validation**: Systems are qualified incrementally, beginning with isolated component tests and culminating in complete mission runs.
- **Subsystem Isolation**: Each module is independently characterised before integration so that any anomaly can be traced to a known origin.
- **Repetition**: Every test is documented and reproducible under controlled conditions to ensure consistent, comparable outcomes.
- **Fault Tolerance**: The vehicle is engineered to retain controllability, operational safety, and recoverability under partial subsystem failure, whether sensor degradation, communication loss, or intermittent hardware faults, preventing single-point failures from cascading into total mission loss.

To enforce disciplined validation, all testing activities are partitioned into four major stages:

1) Bench-Level Subsystem Validation
2) Dry Integration Testing
3) Controlled In-Water Testing
4) Full Mission Validation

1. Mechanical Subsystem Testing

1.1 Hull Watertightness Verification

The pressure hull is the most safety-critical mechanical element of the vehicle. Loss of hull integrity translates directly into catastrophic damage to onboard electronics and immediate mission termination. Validation is therefore approached with redundant, overlapping checks before any wet deployment.

Validation Process:

- Preliminary vacuum testing at 10 to 15 kPa below atmospheric pressure
- 12-hour vacuum hold monitoring
- Soap-bubble leak detection inspection
- Wet submersion testing with internal moisture indicators

Validation Criteria:

- No measurable pressure decay across the hold window
- No visible air bubbles during immersion
- No internal moisture ingress
- All absorbent indicators remain dry post-recovery

1.2 Thruster Configuration and Stability Testing

Each T200 thruster is independently characterised for ESC behaviour, thrust polarity, current draw, and telemetry integrity prior to integration. Once installed, pool-based qualification assesses hover stability, heading control, translational response, and station-keeping under both quiescent water and induced disturbance.

1.3 Vision-Guided Torpedo Validation

Torpedo system validation proceeds along the full perception-to-actuation chain rather than the launcher in isolation:

- Camera pipeline verification
- Vision alignment testing against the target
- Pose estimation stability under varying range and orientation
- Dynamic launch testing under simulated disturbance

1.4 Grabber Manipulation Testing

Grasp repeatability and retention are characterised by presenting target objects under varying lateral offsets, orientations, and partial occlusion. The custom grabber is required to maintain a secure hold across the full envelope of approach conditions encountered during mission tasks.

1.5 Solenoid Marker Dropper Testing

Repeated submerged actuation cycles are run on the marker dropper to validate timing consistency, electrical stability, and resistance to electrolytic degradation of the solenoid housing and contacts.

Test Area	**Validation Method**	**Expected Outcome**
Subsystem Functionality	Operational testing	Stable and repeatable operation
Fault Injection	Controlled failure simulation	Safe recovery behaviour
Performance Validation	Continuous monitoring	Operational stability

2. Electrical Subsystem Testing

2.1 Power Distribution Board Validation

The PDB is exercised across the full operational envelope to confirm that downstream rails remain within tolerance even during transient or fault conditions. Test scenarios include:

- Idle compute load
- Full operational load
- Rapid transient changes
- Fault injection conditions
- Simultaneous ESC startup

Acceptance Criteria:

- Voltage rails remain within ±2% of nominal
- Recovery time below 50 ms
- Fault isolation within 100 ms

2.2 Kill Switch and Safety Validation

Emergency shutdown behaviour is exercised while the vehicle is under active propulsion, with the requirement that thruster output terminates immediately while telemetry and compute remain available for post-event diagnosis.

2.3 Power Monitoring and Telemetry Validation

The power monitoring chain is verified end-to-end against the following criteria:

- Real-time voltage and current monitoring across all rails
- Telemetry reporting stability over extended operation
- Visibility of sensor and subsystem status to the base station
- Automatic fault indication during abnormal operating conditions

2.4 Inter-Vehicle Communication (IVC) Testing

Synchronisation reliability between Duburi 4.5 and Dubomini 2.0 is evaluated alongside fallback FSM behaviour, with deliberate interruption of the IVC link to confirm that each platform reverts cleanly to its independent operating mode.

Test Area	**Validation Method**	**Expected Outcome**
Subsystem Functionality	Operational testing	Stable and repeatable operation
Fault Injection	Controlled failure simulation	Safe recovery behaviour
Performance Validation	Continuous monitoring	Operational stability

3. Software Subsystem Testing

Software validation is organised along four progressively higher levels of abstraction, beginning from raw driver behaviour and culminating in deterministic mission-level state management.

3.1 Sensor Driver Validation

- ROS2 publishing stability across extended operation
- RViz frame alignment with the physical vehicle
- Timestamp synchronisation across sensor streams
- Communication dropout handling at the driver layer

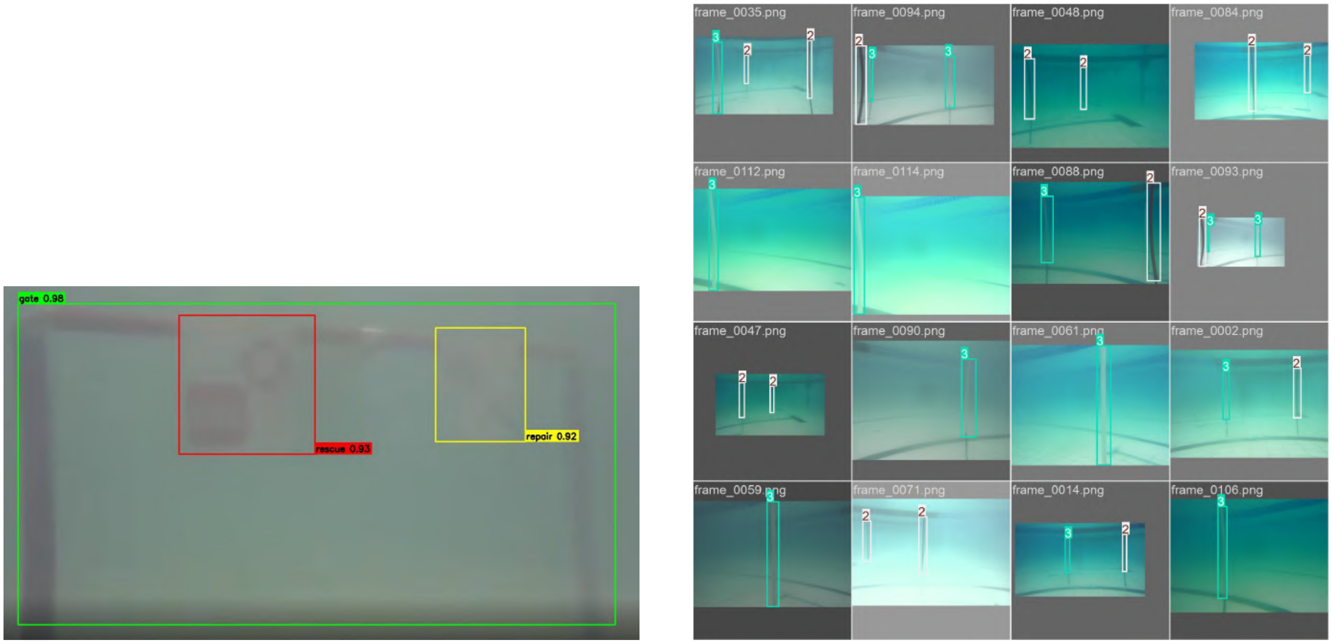
3.2 Localization Validation

- Pixhawk AHRS output verification
- BNO085 IMU bias and drift characterisation
- DVL-based heading estimation
- EKF fusion stability under degraded sensor inputs

3.3 Autonomous Perception Testing

Perception is validated against curated datasets and live pool footage, with attention to the failure modes most frequently encountered in competition pools:

- Offline dataset testing across annotated mission props
- Evaluation in reflection-heavy environments
- Occlusion handling under partial target visibility
- ByteTrack and Kalman filter validation for persistent tracking



(a) Gate detection under turbid water.

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

Fig. 23: Representative perception results across core RoboSub tasks: (a) Gate and (b) Slalom. Each demonstrates detection robustness under real-world variations in lighting, occlusion, and class similarity.

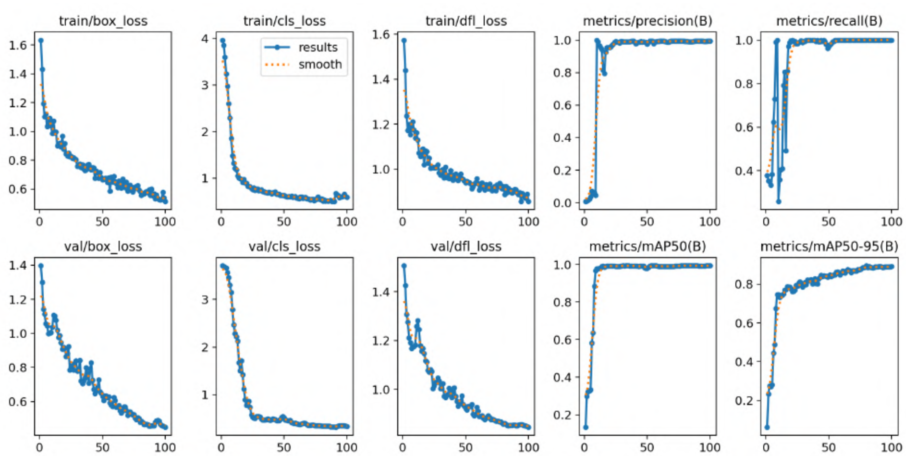


Fig. 24: Detection model performance analysis: loss, precision, recall, and mAP progression over training epochs.

3.4 FSM Validation

- DVL dropout testing to confirm dead-reckoning fallback
- Perception loss recovery and re-entry into search patterns
- Manipulator stall handling
- Deterministic state transitions across the full mission graph

Test Area	**Validation Method**	**Expected Outcome**
Subsystem Functionality	Operational testing	Stable and repeatable operation
Fault Injection	Controlled failure simulation	Safe recovery behaviour
Performance Validation	Continuous monitoring	Operational stability

4. Integration Test Plan

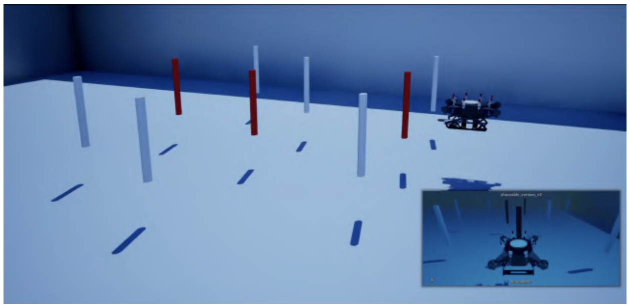
Full-system integration testing exercises the vehicle as a single, coupled platform, validating that all subsystems operate simultaneously under realistic computational and electrical load. The intent is to surface cross-domain failure modes (thermal, electromagnetic, or timing-related) that remain invisible under isolated bench validation.

Validation Areas:

- Battery power-up behaviour
- Voltage rail stability under combined load
- Sensor availability across the full stack
- Camera operation and frame integrity
- DVL connectivity and bottom-lock acquisition
- Thruster response across the command envelope
- CAN heartbeat integrity
- Kill switch functionality during active operation

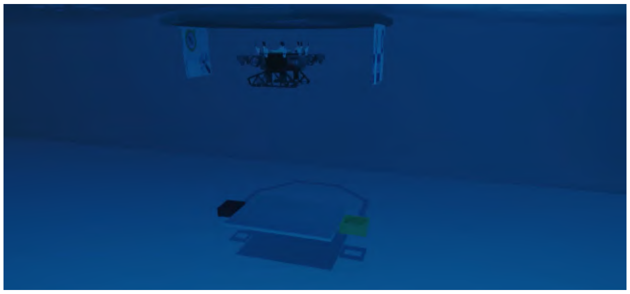
Dry integration runs precede every wet deployment. These confirm thermal stability and communication integrity outside the water, ensuring that no avoidable fault is carried into the pool.

(a) Gate Task



(b) Slalom Navigation

(c) Torpedo Launch



(d) Octagon Surface

Fig. 25: Simulation-based integration testing in Unreal Engine: (a) Gate task execution, (b) Slalom navigation, (c) Torpedo launch, (d) Octagon surfacing.

Test Area	Validation Method	Expected Outcome
Subsystem Functionality	Operational testing	Stable and repeatable operation
Fault Injection	Controlled failure simulation	Safe recovery behaviour
Performance Validation	Continuous monitoring	Operational stability

5. Pool Test Operations and Safety Procedures

Pool operations are conducted under a fixed role assignment so that responsibility for each safety-critical function is unambiguous throughout every test run.

Operational Roles:

- **Safety Operator:** Maintains exclusive authority over emergency kill switch activation.
- **Electrical Monitor:** Tracks battery telemetry, voltage stability, and electrical anomalies.
- **Software Monitor:** Observes ROS2 telemetry, node health, and communication status.
- **Mechanical Observer:** Detects physical instability, leaks, or abnormal mechanical behaviour from the deck.

Post-Test Review: Every test concludes with a structured debrief covering:

- Log archival
- Failure categorisation
- Root-cause analysis
- Design modification tracking

Test Area	Validation Method	Expected Outcome
Subsystem Functionality	Operational testing	Stable and repeatable operation
Fault Injection	Controlled failure simulation	Safe recovery behaviour
Performance Validation	Continuous monitoring	Operational stability

6. Graceful Degradation Testing

Graceful degradation testing deliberately introduces representative failures while the vehicle is in active operation, with the aim of confirming that the autonomy stack reacts predictably rather than catastrophically.

Failure Scenarios Exercised:

- Target occlusion
- Sustained perception loss
- DVL dropout
- IMU drift accumulation
- CAN packet loss
- IVC interruption
- Voltage sag conditions

Expected Recovery Behaviour:

- Re-entry into search patterns upon target loss
- Dead-reckoning fallback during DVL dropout
- Alternate heading source selection when primary AHRS degrades
- Safe surfacing when recovery becomes infeasible

Core Validation Principles:

- Repeatability
- Fault isolation
- Incremental integration

- Recoverability
- Safety under failure

Test Area	Validation Method	Expected Outcome
Subsystem Functionality	Operational testing	Stable and repeatable operation
Fault Injection	Controlled failure simulation	Safe recovery behaviour
Performance Validation	Continuous monitoring	Operational stability

Taken as a whole, the validation framework spans every major engineering domain of both platforms, covering mechanical integrity, electrical stability, software determinism, integrated operation, deck-side safety, and graceful degradation, ensuring that no class of failure is left uncharacterised before competition. The methodology established for Duburi 4.5 and Dubomini 2.0 is built around a single objective: high reliability, operational safety, and mission robustness under realistic underwater conditions. Through disciplined subsystem isolation, progressive integration, controlled fault injection, and exhaustive operational verification, every engineering decision remains traceable, reproducible, and grounded in measured system behaviour. All logs, test outcomes, and design revisions are archived and cross-referenced against this validation framework, preserving long-term engineering accountability and supporting continuous system improvement across development cycles.

Appendix E: Outreach activities

Outreach has been part of BRACU Duburi's identity for many years, evolving alongside the team itself. What began as informal school visits has matured into a sustained, multi-year programme spanning STEM education, gender inclusion, alumni mentorship, environmental engagement, and the broader development of Bangladesh's robotics ecosystem. The sections that follow describe the present state of that programme, but they are best understood as continuations of a long-standing commitment rather than as isolated initiatives.

1. The Origins of Our Mission

The defining shift came after RoboSub 2023. Travelling across Bangladesh and meeting students from communities far removed from elite institutions, the team was confronted with a clear reality: scientific curiosity is widely distributed across the country, but the opportunities to act on it are not. Many of the students we met were sharply capable and visibly hungry for technical fields, yet had never been shown that disciplines like underwater robotics could be available to them. Our outreach mission was redefined around that gap. The objective is no longer simply to demonstrate the AUV, but to expand the population of young people in Bangladesh who consider engineering a viable path for themselves.

2. School Visits and Public Engagement

Over the past year, members of Duburi visited more than ten schools and participated in six major outreach events across Bangladesh. At each of these, the AUV was presented not as a finished artefact but as a working system whose design choices, failures, and revisions could be openly discussed with students. The intent is to move beyond admiration toward genuine technical interest. A moment that has stayed with the team came from a young student encountering the vehicle for the first time and asking, "Is this a boat?" The question captured the precise gap our outreach exists to address, the gap between what students have seen and what they could one day build. A number of students from these visits have subsequently reached out about pursuing science and engineering, with several already orienting their early studies toward robotics.

(a) Members of Duburi engaging visitors at an institutional science fair.

(b) A young visitor examining the AUV during a hands-on outreach session.

Fig. 26: Duburi's public engagement work, bringing the vehicle and the discipline into direct contact with the wider community.

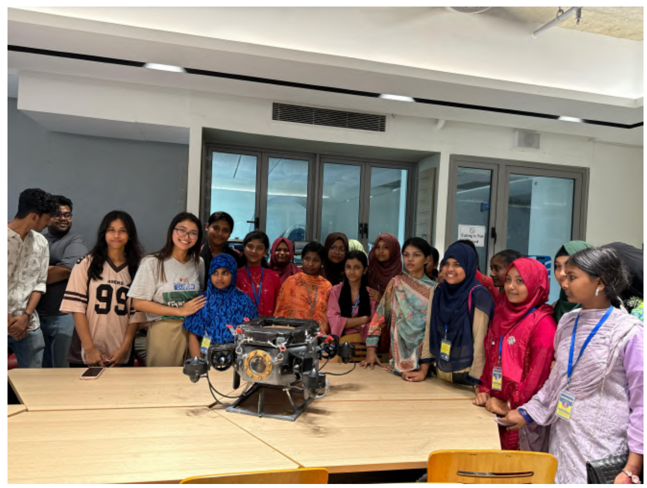
3. Gender Inclusion in STEM

A substantial proportion of Duburi's membership are women, who have taken on a leading role in the team's engagement with girls' schools across Bangladesh. The aim is twofold: to present working women engineers as a normal feature of the field, and to give young female students direct contact with peers who are only a few years ahead of them on the same path. The team draws from a wide disciplinary base, including computer science, electrical engineering, business, and biotechnology, which lets us communicate to students that underwater robotics is not the property of any one academic department. Members openly discuss the difficult parts of their journeys alongside the successful ones, in order to convey that progress in engineering is rarely linear. Sustaining a diverse team is, in our experience, not a separate goal from doing strong technical work; the two reinforce each other.

(a) An interactive session with girls' school students at our university laboratory.

(b) A Duburi outreach event focused on STEM engagement for young women.

(c) Young women working directly with the robotics platform during a demonstration.



(d) Closing a STEM engagement session for girls.

Fig. 27: Duburi's continued effort to widen participation for girls and young women in STEM, through engagement, demonstration, and sustained mentorship.

4. Alumni Network and Industry Partnership

Dubotech is the formal alumni network of Duburi, comprising former team members now working in industry, research, and graduate programmes both in Bangladesh and abroad. The network operates as a continuous bridge between the team and the professional world: members return as mentors, technical collaborators, and occasional partners on field projects. Dubotech organises industry seminars, opens access to professional events, and has represented Duburi at national platforms including the Bangladesh Investment Summit. This year, Dubotech was recognised as the "Best Startup of the Year," an acknowledgement of its work translating the team's research agenda into industrial underwater robotic solutions and a signal that the trajectory from student team to professional engineering practice is one that the broader ecosystem now sees as credible. The institutional memory carried forward by this network is one of the principal reasons that engineering decisions on the team are informed not only by current members but by years of accumulated experience.

5. Mentorship Across Geographies

Duburi's mentorship structure extends well beyond the university and beyond the country. Alumni based abroad contribute through online workshops, technical training sessions, and one-on-one guidance with current members. This distributed mentorship matters more than its scale suggests. The lessons most useful to a developing engineer, how to read a sensor datasheet under time pressure, how to triage a failure mode in the pool with thirty minutes left, are difficult to put into writing and are best transmitted through working alongside someone who has done it before. The international scope of the network gives current members access to working engineers across multiple disciplines and time zones.

6. A Conversation Across Disciplines

In 2025, the Robotics Club of BRAC University hosted an interactive session with NASA Chief Astronaut Joseph M. Acaba, attended by members of Duburi. Astronaut Acaba spoke about the operational realities of extended exploration missions, the discipline that international collaboration demands, and the role of perseverance in scientific research. Our team asked questions on robotics in extreme environments, on the interdisciplinary skills required at frontier engineering, and on the cognitive habits that allow engineers to recover from setbacks. The session reinforced something the team has long believed but rarely had the chance to hear stated by a working astronaut: that the engineering challenges in space and underwater are continuous with one another, and that the next generation of Bangladeshi engineers has a credible claim to working at both frontiers.

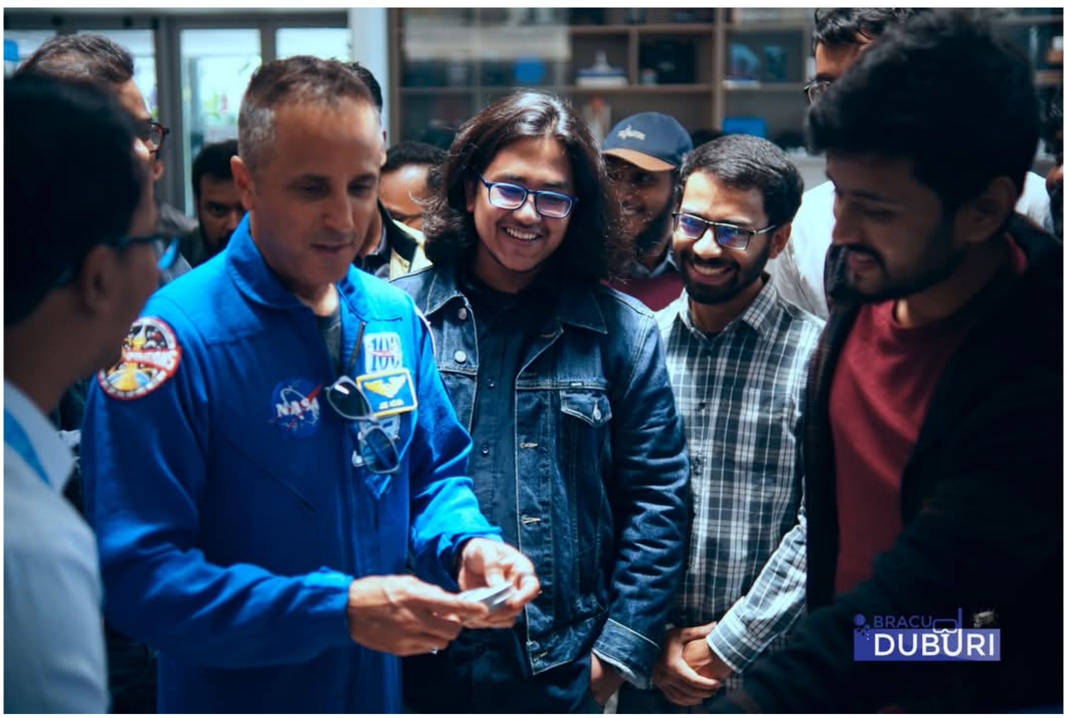


Fig. 28: Members of Duburi and Dubotech in conversation with NASA astronaut Joseph M. Acaba during the session hosted by the Robotics Club of BRAC University.

7. Documenting the Work

Communication is an integral part of the team's outreach. Duburi produces a regular podcast in which alumni discuss their entry into robotics, their professional trajectories, and the lessons accumulated along the way. The podcast also recognises the local technicians and machinists whose workshops the team has relied on for years; the precision skills they bring to the bench are an essential, often unseen, part of how Duburi's hardware comes together. Recording these contributions publicly is a way of acknowledging that the team's progress has always been a collective effort, distributed across a wider network than any organisation chart would suggest.

Fig. 29: A podcast session recorded by members of Duburi.

8. Contributing to a National Robotics Ecosystem

One of the most encouraging developments of recent years has been the emergence of new student teams and school programmes across Bangladesh taking up underwater robotics. The team views this not as competition but as the maturation of a national pipeline. Duburi actively shares technical material with these emerging groups, profiles their progress in our public communications, and engages with them at events. Following RoboSub 2025, this work extended into the country's wider innovation and deep-tech circuit. At BUET Innoverse, organised by Whiteboard Initiatives, the team presented its research programme and the development history of Bangladesh's first AUV platforms, holding extended technical conversations with students and researchers from outside the immediate underwater robotics community. The Broadband Expo provided a different audience entirely, where the discussion turned to applied use cases, marine exploration, underwater inspection of submerged infrastructure, and the role of autonomous systems in disaster response. Duburi also took part in Tech Diversity's "Hunger for Innovation" campaign, contributing to a broader conversation on youth-led innovation and the direction of engineering practice in Bangladesh. Across these venues the pattern was consistent: the questions raised were no longer only about how the vehicle works, but about how a domestic underwater robotics capability fits into the country's longer-term technological agenda. A national robotics ecosystem is a stronger position to operate from than a single isolated team, and the long-term ambition of the programme is for Bangladesh to develop a recognised standing in the field that no single institution could carry alone.

9. Toward an Applied Ocean Technology Agenda

Bangladesh's geography places it in a particularly direct relationship with water. The country's rivers, deltas, and proximity to the Bay of Bengal mean that underwater technology is not an abstract scientific pursuit but a matter of national consequence. Duburi's research and development efforts have begun to orient toward this reality, with active work on ocean monitoring, water quality assessment, and the use of autonomous underwater vehicles for environmental data collection. A recent field visit to Cox's Bazar brought the scale of the problem into sharp focus, where plastic pollution along the shoreline was observed to be affecting both marine ecosystems and the livelihoods of coastal communities. These observations have shaped the team's developing research agenda toward applications with direct local relevance, demonstrating that competitive robotics development and applied environmental engineering are not separate pursuits, but parts of the same long-term commitment to building engineering capability in Bangladesh that matters beyond the competition arena.

(a) Duburi members engaging with coastal communities at the Bay of Bengal on questions of underwater technology and ocean conservation.

(b) Field deployment of the AUV system as part of technical outreach at the water's edge.

Fig. 30: Duburi's field engagement in coastal communities, combining public demonstration with the early stages of applied ocean technology work.