Team Bath Hydrobotics

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2025 Technical Report

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UNIVERSITY OF BATH

Table of Contents

1. MESSAGE FROM OUR CEO

ABDULLAH ALI

CEO, TBHy 2024-2025

This project has been an incredible learning experience. I have gained valuable insight into underwater robotics, led a multidisciplinary team, and had the pleasure of working alongside dedicated, like-minded individuals. The Plymouth event at Fugro was highly insightful, and we are truly grateful for the opportunity to attend the World Championships in Alpena, Michigan.

Despite months of hard work, late nights, design reviews, payment complications, and manufacturing delays, every challenge was worthwhile. This journey has reignited my passion for robotics and its potential to solve real-world problems.

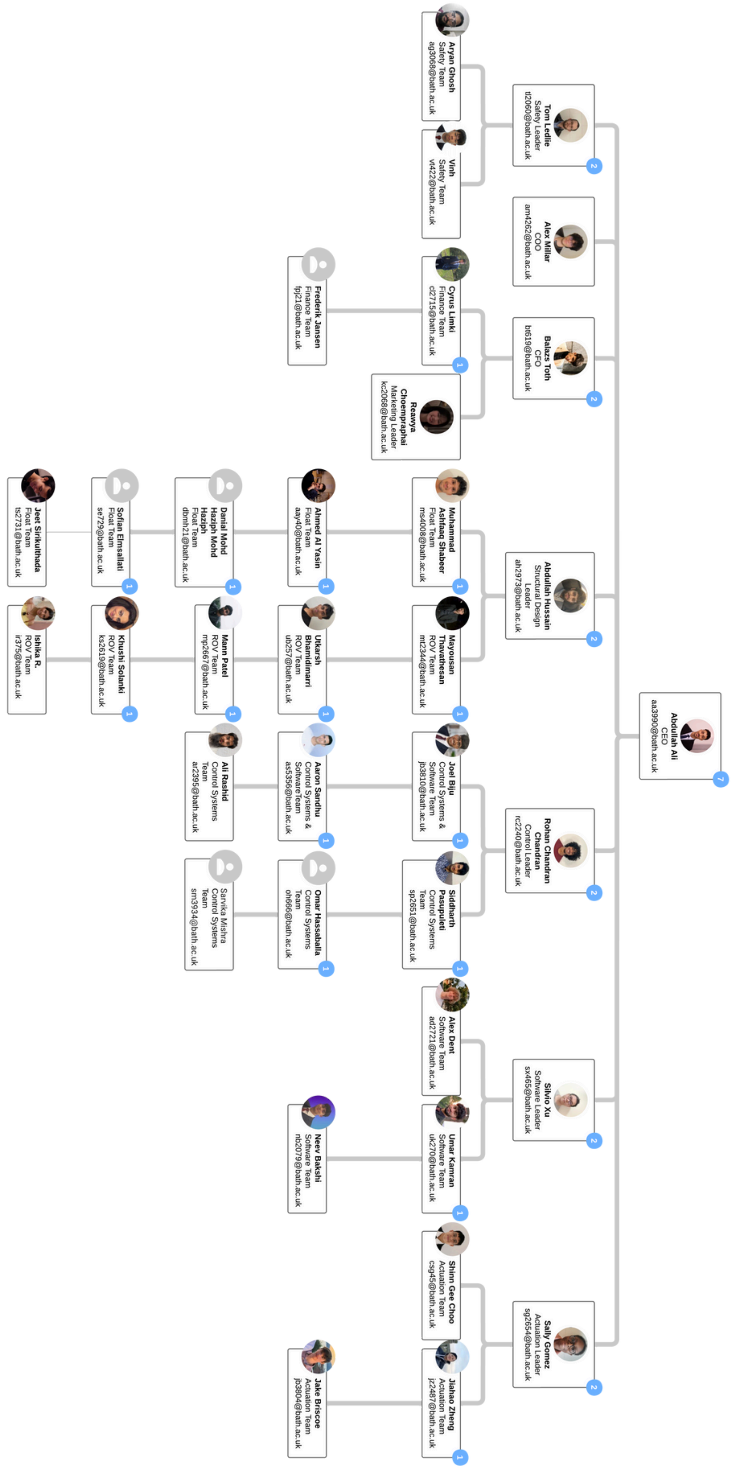
Regardless of the outcome, we are just getting started. We will return stronger, better prepared, and ready to develop even more effective solutions.

2. ABOUT US

The beginning

Team Bath Hydrobotics was established in 2022 under the supervision of Dr. Tareq Assaf, whose research focuses on robotics and bio-inspired systems. Created to bridge the gap between theoretical study and practical application, it is the University of Bath's only marine robotics team. The team brings together students from a wide range of disciplines to explore innovative, cost-effective approaches to underwater vehicle design. It also encourages both STEM and non-STEM students to pursue careers in robotics and marine engineering by applying technology to real-world problems.

3. Organisational Chart



4. Project Management

4.1 Team Structure and Workflow:

The team was split into sub-teams focused on mechanical design, electronics, software/UI, and operations. Communication was maintained via Discord for daily coordination and Microsoft Teams for document sharing and meetings. Weekly in-person or remote sessions were used for updates and collaborative planning.

4**.2 Task Distribution and Tracking:**
We used Trello for agile project management and tracking deliverables. Team leads maintained a Gantt chart to visualise milestones and manage dependencies. Trello cards were categorised by deadlines and tagged by team member responsibilities.

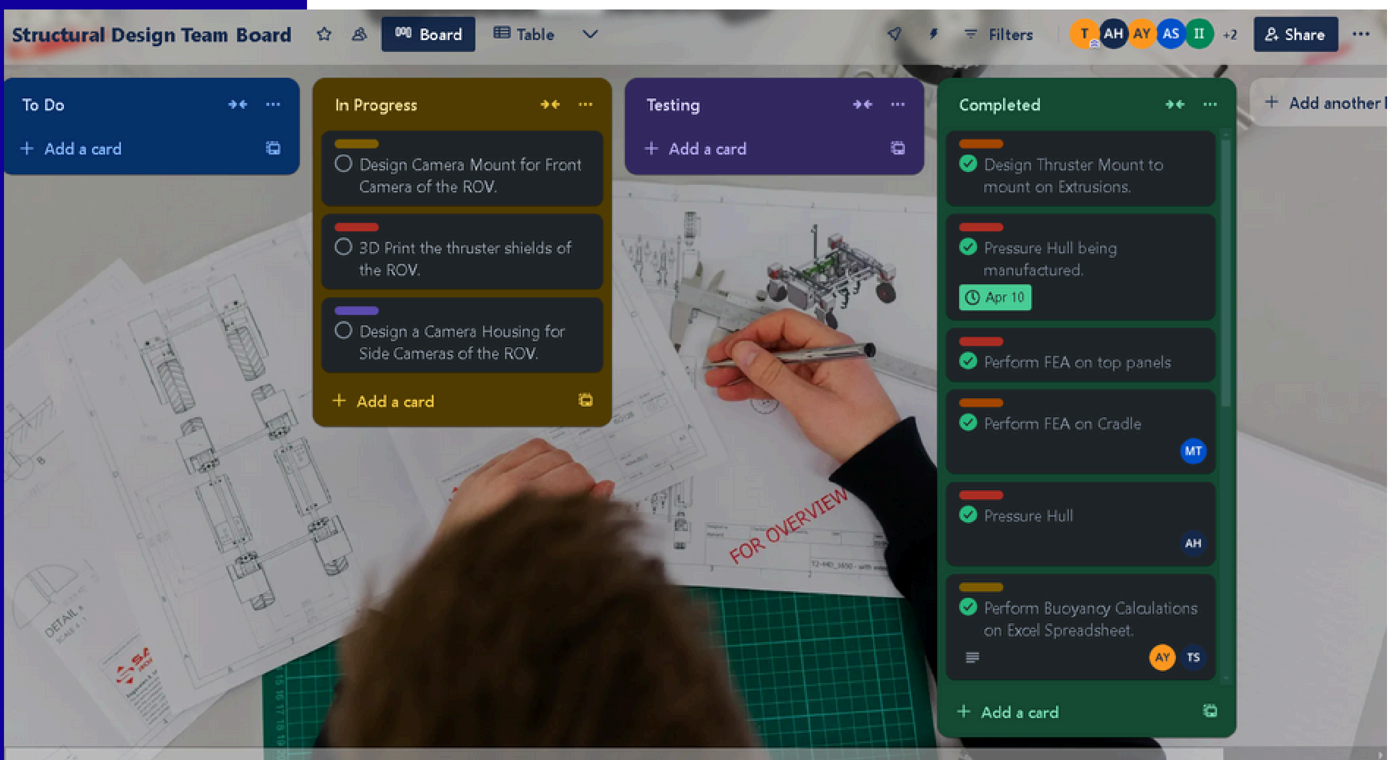


Figure 1: *Structural Design Team Trello Board*

5. Float Structure

Design & Operation

The float integrates a vertical profiling system and internal electronics within a cylindrical ABS hull, chosen for uniform pressure resistance and mechanical durability. End caps are sealed with nitrile O-rings and joined by a 3D-printed flange with threaded rods to improve sealing integrity and lower the centre of mass.

Buoyancy is regulated by a 750N linear actuator driving a 500ml syringe, displacing water to adjust volume and depth. Limit switches at both ends of the stroke ensure controlled, repeatable actuation.

The actuator is powered by 8 AA alkaline batteries in series for simplicity and field availability. A centrally mounted Blue Robotics Bar02 sensor provides accurate depth feedback. ABS landing gear protects the float during impact and ensures stability throughout buoyancy transitions.

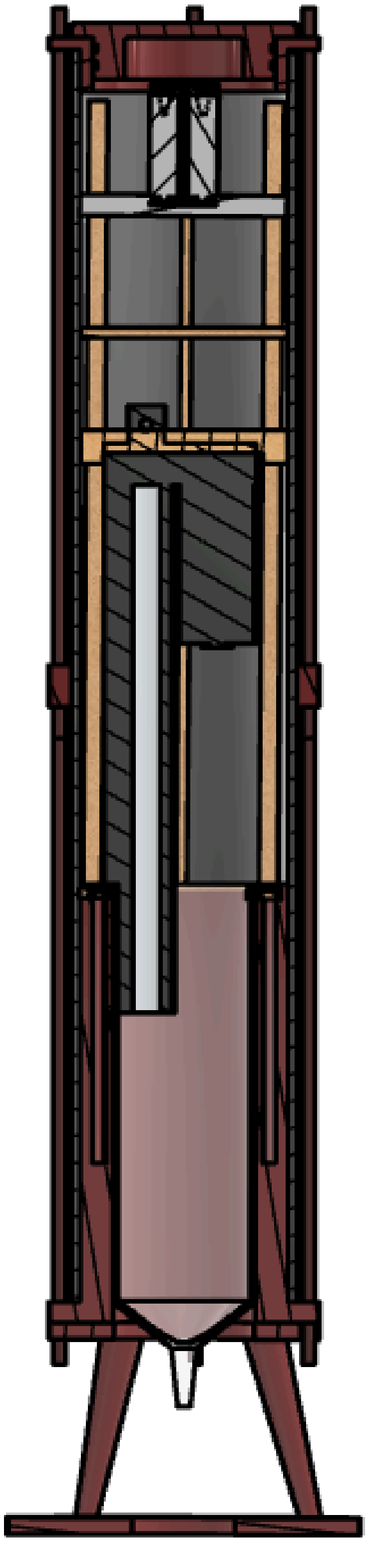


Figure 2: Cross section of the float showing 500ml syringe and controlled with a linear actuator, with a landing cushion to protect against impact.

6. ROV Frame Outline:

Modular Performance Frame: A lightweight structure combining core composites for strength and aluminium for thermal efficiency. The electronics bay uses precision-cut plywood within a sealed aluminium pressure tube, balancing durability with eco-conscious, adaptable engineering.

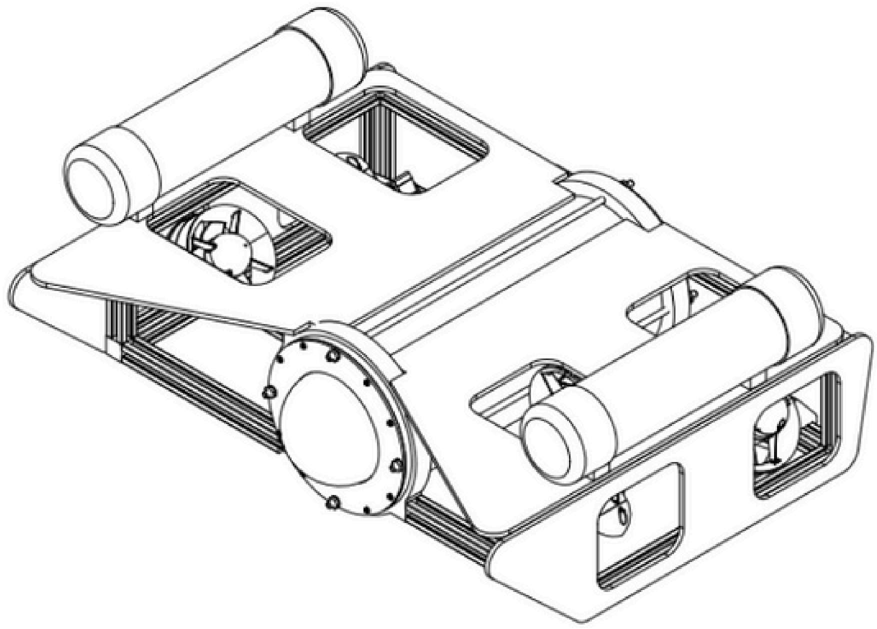


Figure 3: *ROV Frame with Buoyancy Tubes*

Stable & Reliable Control System: Our control software integrates PID control to ensure smooth ROV control for 6 Degrees of Freedom, whilst also being able to control the robotic actuator for performing maintenance procedures simultaneously.

Sensor Suite: Includes pressure, temperature, and water-leak sensors for real-time data gathering, leak warnings, and environment monitoring.

Manipulator Arm: Custom-built for precision tasks such as retrieving samples, placing objects, and interacting with the environment.

HD Vision System: implementing the use of synchronised cameras and a calibrated 160-degree fish-eye lens with real-time streaming, allowing our pilots to gain clear visibility for the pilot.

6. ROV Structure

The main ROV chassis is constructed from 11mm thick core composite panels using a rotary cutting tool, offering a lightweight yet rigid framework capable of withstanding underwater stresses. These panels are paired with aluminium extrusions, which were selected for their simplicity and adaptability during assembly. The extrusions allowed us to easily mount and reposition internal components and brackets without re-manufacturing structural parts. Although this added some additional weight, the cost-effectiveness and modularity they offered were essential during iterative development.

The pressure hull, machined from 6082 aluminium by the university due to strict university policy that students cannot use the CNC machines due to the danger it imposes on students, and it being a very expensive machine, served as the central housing for sensitive electronics. Aluminium was selected due to its higher thermal conductivity, which enabled passive heat dissipation and helped prevent component overheating in a sealed environment. The cylindrical shape of the hull was chosen specifically for its ability to evenly distribute external hydrostatic pressure, reducing stress concentrations and increasing the depth rating of the vessel. This made it ideal for underwater deployment where external pressures rise significantly with depth.

To ensure a water-tight seal, dual O-rings were used at both ends of the pressure hull. The acrylic domed end cap allowed for optical clarity and offered durability under pressure. Neutrally buoyant foam was mounted to the frame to improve stability and reduce the load on the thrusters, keeping the ROV horizontally balanced in the water.

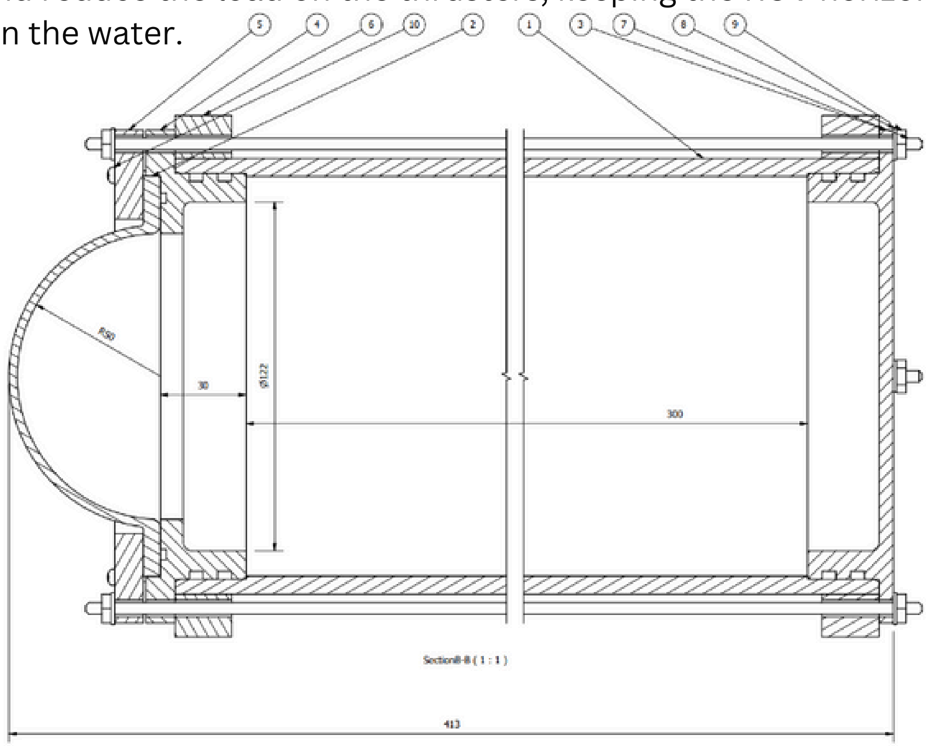


Figure 4: *Sectional View of the ROV Pressure Hull Assembly*

7. Thruster Allocation

The ROV uses a total of six thrusters to achieve full six-degree-of-freedom (6DOF) control. Four T200 thrusters are mounted at 45-degree angles on the horizontal plane, enabling precise control over heave, sway, roll, and yaw through vector-based thrust mixing. Two horizontally oriented T100 thrusters provide dedicated control over surge and contribute to pitch stabilization. This configuration ensures that the ROV can translate and rotate independently in all axes, allowing it to perform complex manoeuvres such as station keeping, rotation during photosphere tasks, and fine adjustments during object manipulation. The selected layout provides a good balance between mechanical simplicity, control authority, and energy efficiency.

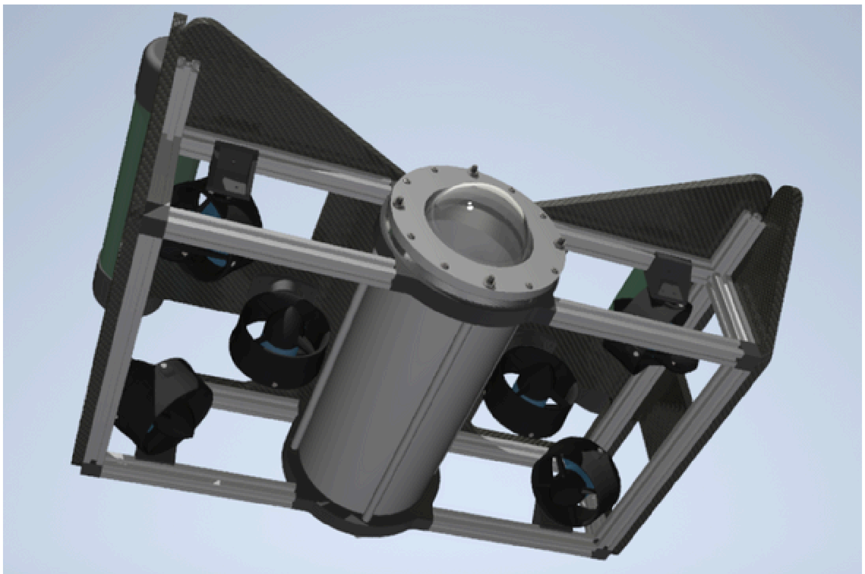


Figure 5: *Thruster allocation displayed using bottom side of the ROV*

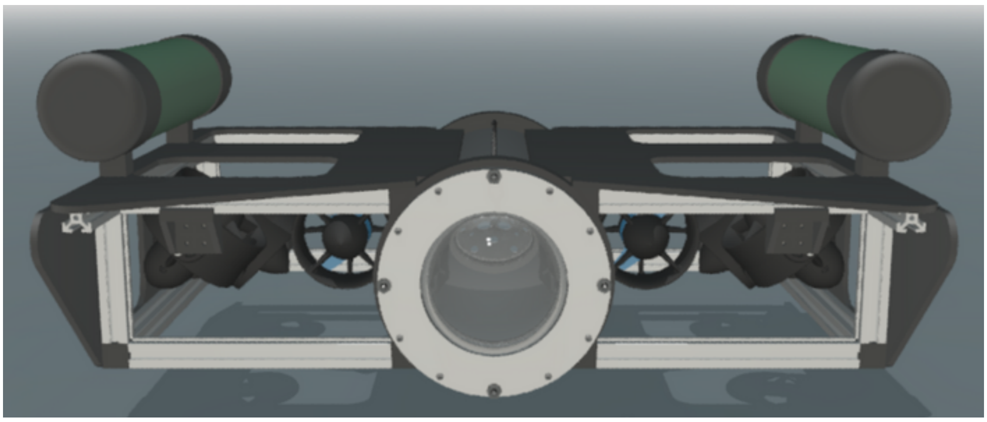


Figure 6: *Thruster allocation displayed using front side of the ROV*

8. Tether Design

01

Power and Data Transmission

The tether integrates power and data transmission while maintaining neutral buoyancy. The power cable uses 4mm² CSA copper conductors rated for 32A, safeguarded by a 30A fuse. The signal cable consists of a 9-core Ethernet line to support UDP video and telemetry.

02

Connector Limitations and Sealing Improvements

Due to space constraints and connector unavailability, Farnell IP68-rated 3-pole plugs (SP2112/P3/1C and SP2110/S3II/1C) were used initially. However, they became a major failure point, with water ingress traced back to flexible silicone O-rings. We replaced them with nitrile O-rings and applied marine sealant and Plumber's Mait to improve reliability.

03

Cable Bundling and Buoyancy

Cables were bundled Foam tubing was zip-tied at calculated intervals to maintain near-neutral buoyancy, minimising drag and improving control stability, avoiding costly custom sheathing. The tether terminates in waterproof penetrators with ground bonding on the plates to avoid potential difference buildup and electrolysis.

9. Control System

9.1 Software Architecture

Control logic was first developed in MATLAB Simulink as observed in Figure 7 to model six degrees of freedom and derive the thruster mixing matrix. Open-loop control mapped Xbox controller input through this matrix to generate PWM signals sent to the ESCs. Closed-loop control layered PID feedback on top, using IMU and pressure sensor data to correct orientation and depth errors. This output was also passed through the thrust mixer, enabling precise control for tasks like photosphere capture and manipulation.

9.2 Sensor Fusion

The ROV integrates two IMUs: the BNO055 and BNO085. Sensor fusion using a Kalman filter provides accurate orientation data, compensating for individual sensor drift. Pressure data from the BlueRobotics Bar30 feeds into PID control loops to maintain target depths.

A water leak sensor inside the hull monitors moisture and triggers emergency procedures if activated.

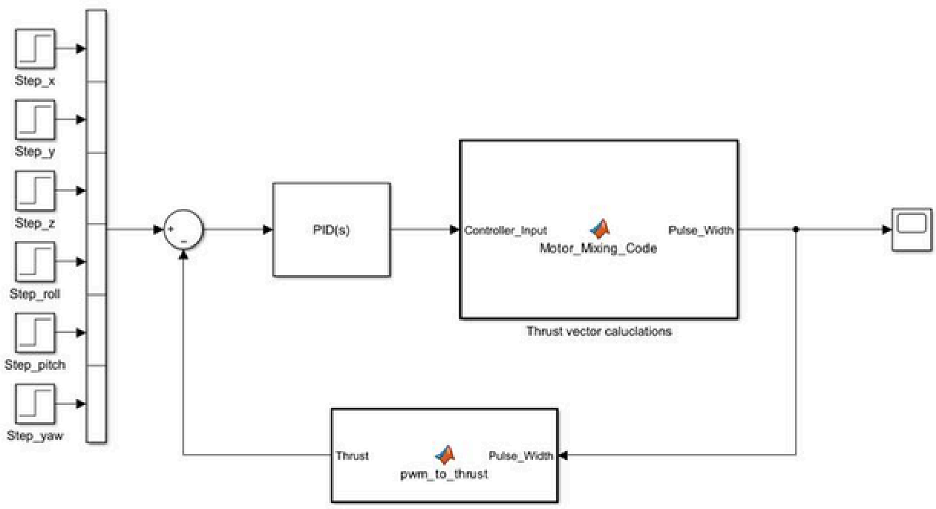
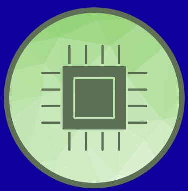


Figure 7: *MATLAB Simulink control diagram for 6 DoF*

10. Electronics and Control Interface



10.1 Microcontroller Integration

The electronics stack includes a central Arduino ESP32 for real-time control, interfaced with the pressure sensor, IMUs, and leak detector. Power regulation and motor drivers are housed in a modular electronics tray within the aluminium pressure hull.

All cabling is routed through WetLink penetrators. The power board is isolated, with fuse protection and bonded ground for safety.

10.2 Xbox Controller Interface

Manual control was implemented using a wired Xbox Series X controller. A Python-based driver script using pygame collects real-time input from the controller and transmits it to the ROV using UDP. The choice of UDP reduces latency and enables smoother piloting without significant packet buffering.

The control scheme includes mapping of analog sticks to translational motion, bumpers for vertical movement, and triggers for yaw. Hat switches were used to control peripherals such as lights and the buoyancy engine.

11. Graphical User Interface

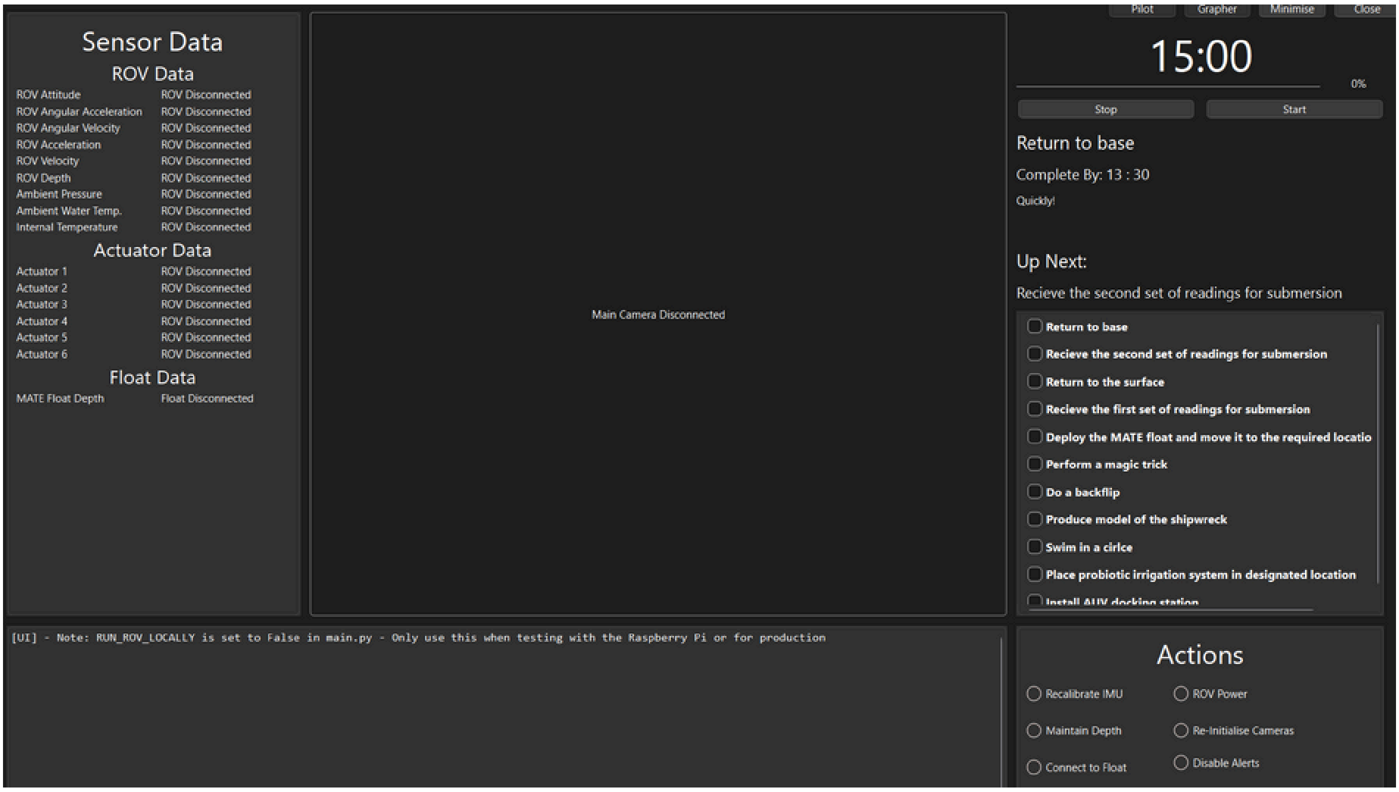


Figure 8: *Main Graphical User Interface (GUI) Display for ROV Operations*

The ROV's GUI, built in PyQt5 and designed using Qt Creator, supports real-time monitoring and control through a multithreaded architecture using QThread. It features separate views for the Pilot and Copilot, displaying live video feeds, telemetry (depth, IMU, leak status), mission checklists, and actuator data. The interface follows PEP8 standards and uses type hints for maintainability.

UDP is used for low-latency video and data transmission. Camera feeds are displayed as JPEG streams, and the GUI includes error alerts for sensor faults or disconnections. Photosphere generation is supported post-mission. Panoramas can be visualised using sphere_viewer.py by specifying the image path. Feature-based stitching is handled via HUGIN, though limited underwater texture can cause stitching failures. To streamline this, we implemented a script using HUGIN’s CLI that automatically stitches images captured during ROV rotation. A second, IMU-based method was also developed, using sensor data to position images without relying on visual features, though it is still undergoing calibration and can be switched whichever is most appropriate.

Figure 9: *Demonstration of photosphere conducted using hugin.*

12. Video Transmission

The ROV streams video using UDP for low-latency performance. Three ports (52524–52526) are dedicated to video feeds from different cameras. Video packets are transmitted as JPEG frames with heartbeat and re-synchronisation protocols for robustness.

A 12.3MP stereo camera bundle with a CS lens from Arducam is mounted on a Raspberry Pi. This system enables 360-degree photospheres by rotating the ROV in 30-degree increments in closed-loop mode due to it's low FOV of 65°. It also supports object dimensioning. A calibrated fisheye lens (160° FOV) or a wide-angle USB camera was used for wide pilot visibility, independent to the stereo-cameras ensuring the pilot can view the environment for easy ROV control and task completion.

Figure 10: *Arducam 12.3MP*2 Synchronised Stereo Camera Bundle Kit with CS Lens for Raspberry Pi*

13. Safety and Risk Management:

13.1 Safety Protocols

All members underwent lab safety training. The lab environment was structured with maximum occupancy limits, PPE protocols (EN166 eye protection, EN388 gloves, EN ISO 20345 boots), and hazard signage. A Job Safety Analysis (JSA) was performed at each build and test stage. Emergency stop buttons and power isolation switches were installed for thruster testing.

13.2 Equipment Safety

Leak detection was regularly verified before deployment and thrusters were shrouded for every use. The aluminium hull was grounded to avoid electrolysis, with all modules subjected to insulation resistance tests.
The buoyancy engine in the float was tested in isolation before being integrated, and safe syringe travel limits were enforced via limit switches.

13.3 Team Communication and Operations

Roles were divided into pilot, copilot, and technician. Daily coordination happened via Discord. Teams managed files and meeting documentation on Teams. Dedicated sub-channels and pinned posts helped maintain clarity.
The surface station operator maintained oversight on all diagnostics and monitored sensor dashboards, providing redundancy in fault detection during live runs. Safety was prioritised from top to bottom level.

14. TESTING AND TROUBLESHOOTING

14.1 Design Validation with FEA:

Throughout the design phase, Autodesk Inventor used Finite Element Analysis (FEA) extensively to validate structural performance under expected operational loads. Side and top panels of the ROV frame were simulated under static pressure loads to assess stress distribution and failure modes. In particular, the 3D-printed interlocking rings that hold the aluminium extrusions in place were a focus of analysis, ensuring they could withstand dynamic loads without material fatigue while carrying the ROV. Thermal simulations were also conducted to evaluate passive heat dissipation through the water-tight aluminium pressure hull. This analysis enabled a design that was tested and refined before manufacture saving time and costs.

14.2 Electrical Testing and Debugging:

During development and integration, digital multi-meters and oscilloscopes were used to verify electrical signal continuity, detect shorts, and monitor power regulation under load. Multi-meters were essential for continuity checks across solder joints and for identifying incorrect connections during troubleshooting. These tests became especially important when we had to join up the power-supply from the mains safely under supervision with a technical staff. Oscilloscopes helped diagnose PWM signal integrity between the Arduino, ESCs, and thrusters which allowed us to confirm that control signals were clean and correctly timed. This equipment was also used to validate communication integrity over the tether, especially during UDP transmission testing, ensuring that controller signals and video streams arrived with minimal packet loss and lower latency. Ground bonding continuity was also checked across the entire electrical chassis to ensure no potential differences were present between conductive surfaces, which could otherwise lead to galvanic corrosion or electrolysis underwater.

14. TESTING AND TROUBLESHOOTING

14.3 Float's & ROV Mechanical System Testing

Mechanically, the buoyancy engine (750N linear actuator and 500ml syringe) was tested independently before integration. Its stroke limits were validated with limit switches, and displacement volume was confirmed via a controlled immersion test. The actuator's force output was sufficient to adjust buoyancy. We validated the syringe system's repeatability and sealing performance over repeated actuation cycles in a 61cm pool and risky attempts in deep lake conditions, as it was possible to lose it, which meant the control system needed to be reliable. Whereas, the ROV pressure hull seen in Figure 11 was conducted in the university's swimming pool to identify water seepage during the mechanical test ensuring no electronics were present or any power provided to the hull.

Figure 11: *Pressure Hull mechanical test checking for water-seepage in University's 2m swimming pool.*

15. Procurement & Innovation

15.1 Build vs Buy / New vs Used:

All major hardware and electronics in this system were newly purchased and integrated in-house, except for two T100 thrusters generously donated by our technical supervisor, Alan Hunter. Our decision to use newly sourced components was driven by the need for compatibility, traceability, and reliability, especially as this was our first complete ROV build with no inherited hardware.
We purchased an off-the-shelf 48V to 12V buck converter rated for 100A to safely supply power to all six thrusters (four T200s and two T100s). Although the thrusters would not be run at full throttle continuously, each T200 draws up to 20A, and each T100 around 10A. This overspecification provided thermal and electrical headroom. Building a high-current converter in-house would have introduced significant design risk, including managing PCB trace width, thermal dissipation, transient protection, and isolation for safety, which was impractical within our timeframe and experience level.

We also opted to use Blue Robotics Electronic Speed Controllers (ESCs), which are specifically designed for their thrusters and include features like soft-start, overcurrent protection, and easy integration with PWM control. Attempting to design and program our ESCs would have added unnecessary complexity and posed significant failure risks underwater.

While many small components, such as wires, crimp terminals, and connectors, were kindly donated by the university's electronics lab, all wiring, soldering, component integration, and system testing were carried out by our team. Technical staff were only involved in high-voltage or mains-level operations, such as safely wiring and testing the main bench power supply before connection to the mains. This ensured full student ownership while adhering to safety best practices.

15.2 Innovation:

While innovation was not the central focus, the team prioritised robust engineering and maintainable, modular systems that future teams could build upon. The development of a custom GUI and a Simulink-to-Arduino workflow reflected thoughtful design processes. Software innovation was evident through automated panorama stitching using the HUGIN CLI and the early development of an IMU-based image alignment system. Engineering rigour was upheld through FEA-guided iterations and comprehensive pre-deployment testing.

15.3 Software and UI Testing

All Python GUI modules were tested in isolation using unit test stubs, simulating sensor and video input. We created test payloads to validate real-time updates in the interface without needing the ROV to be physically connected. QThread operations were stress-tested under simulated load to prevent UI freeze or crash conditions. Internal debug logs and exception handlers were monitored using the stdout console to catch race conditions or socket failures. UDP communication protocols were validated using intentionally malformed packets and temporary dropouts to ensure reconnection logic and resynchronisation systems were robust. The heartbeat monitor ensured video feeds and controller inputs were automatically resynced without requiring a reboot.

15.4 Leak and Pressure Testing

Prior to each deployment, the aluminium pressure hull and float compartments were tested by pressing against the hull in a box of water to ensure watertight seals. before continuing testing it in a 61cm pool. Any pressure loss over a set duration indicated leaks or if the water-sensor indicates seepage, which were rectified using marine-grade nitrile O-rings, thread-locking adhesive, and WetLink penetrators with a warning on the UI to let the pilot know water got in. This test procedure formed part of our pre-mission checklist.

Figure 12: *Water leak sensor by dfrobot.*

15.5 Field Testing and Iterative Tuning

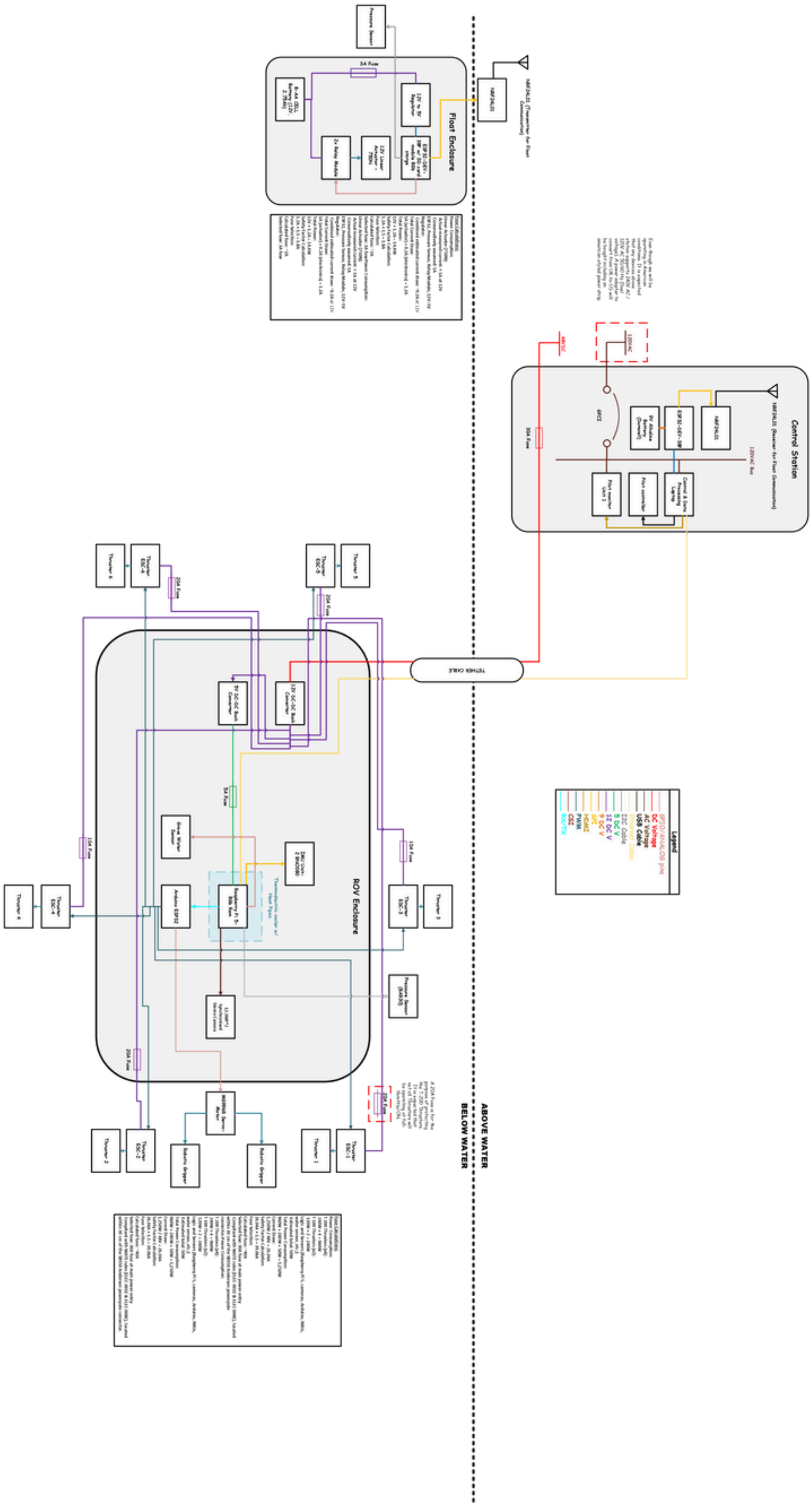
The ROV and float were tested in pool conditions to validate manoeuvrability, communication latency, and overall performance. Tests focused on tuning PID gains for depth and orientation control in closed-loop mode. Observed overshoot or instability was corrected through iterative adjustment and logged for version control. Vision system performance especially the stitching accuracy of the photosphere pipeline was evaluated under natural lighting but do require good quality photos. These results informed further image pre-processing and motion control refinement.

16. Acknowledgements:

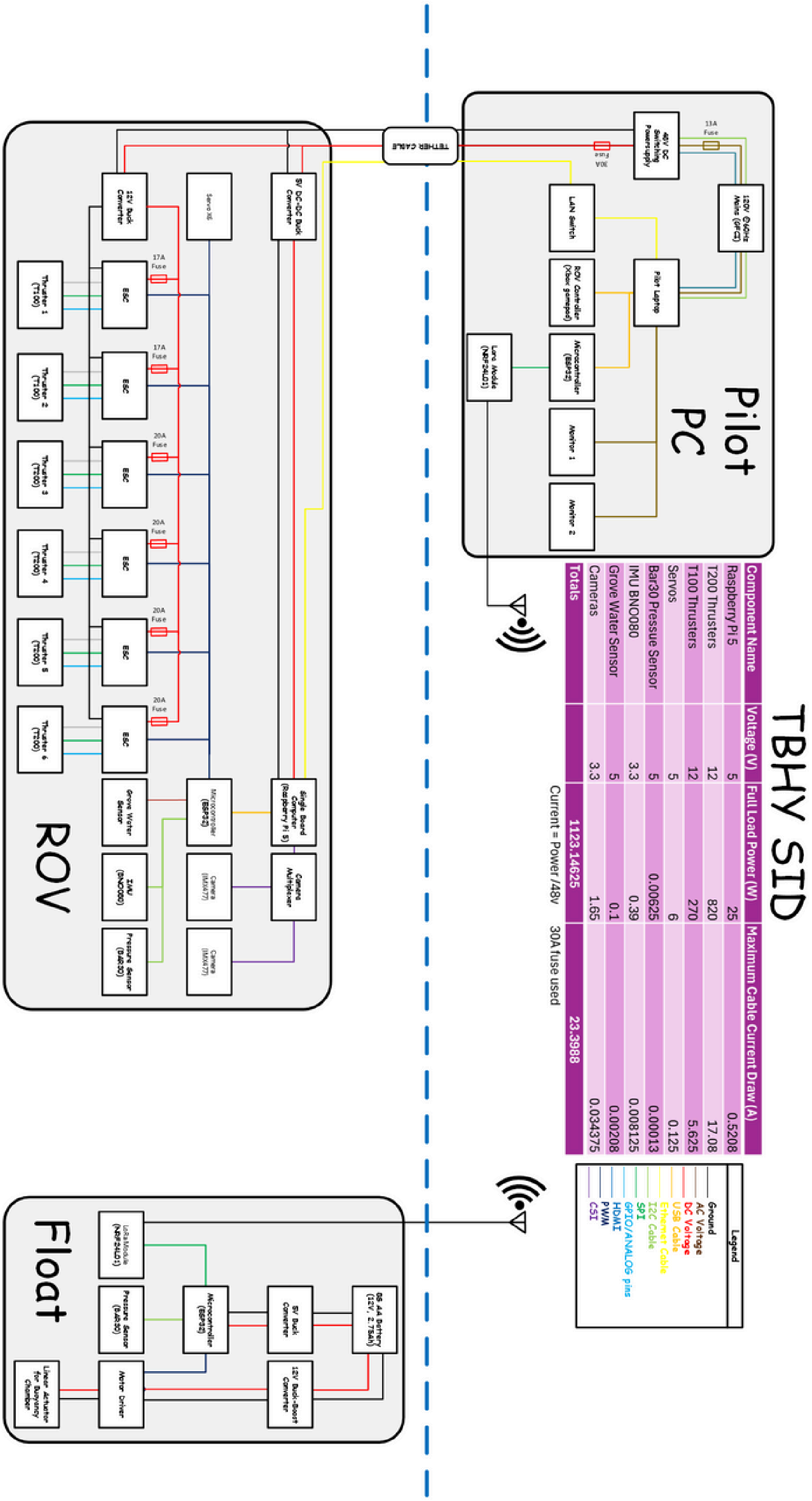
We thank the University of Bath faculty for their support in funding, resources, and workspace provision throughout the project. We are also grateful to the MATE ROV organisers for inviting us to the Plymouth event and for their valuable guidance and connections. Special thanks to Alan Hunter for donating two T100 thrusters and to Tareq Assaf for his consistent encouragement and early support, which kept us motivated during setbacks. We also appreciate the voluntary efforts of our team's hard work of up to 500 hrs to build and fix any potential issues, enabling the first ROV to be constructed in 3 years.

17. Appendix

A) ROV & Float System Architecture



B) Electrical SID



Component Name	Voltage (V)	Full Load Power (W)	Maximum Cable Current Draw (A)
Raspberry Pi 5	5	25	0.5208
T200 Thrusters	12	820	17.08
T100 Thrusters	12	270	5.625
Servos	5	6	0.125
Bar30 Pressue Sensor	5	0.00625	0.00013
IMU BNO080	3.3	0.39	0.008125
Grove Water Sensor	5	0.1	0.00208
Cameras	3.3	1.65	0.034375
Totals		1123.14625	23.3988

Current = Power /48v 30A fuse used

C) Budget and Cost Accounting

Income	**Budget**	**Type**	**Productions & Operations Budget & Costs Analysis**	**Project Cost**
Uni Of Bath Faculty Fundin	$ 6,715.82		Available Funds	$ 12,072.29
			Total Budget	$ 9,055.23
			Production Expenses	$ 6,511.03
			R&D Expenses	$ 214.91
			Operations Expenses	$ 5,525.38
Net Total Income	TBD		Total Costs:	$ 12,251.32
			Remaining Funds (Excluding Operations	$ 2,329.29
Production Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Chassis	$ 268.66	Purchased	Aluminium 6082 for CNC machined	$ 268.66
Thrusters	$ 1,500.00	Purchased	(6) T-200 Blue Robotics Thrusters	$ 1,468.34
Tether & Connectors	$ 600.00	Purchased	Tether & Cable Glands (IP68)	$ 537.32
Single-Board Computers	$ 700.00	Purchased	Nvidia Jetson Orin Nano & Raspbe	$ 664.94
Electronics & Wiring	$ 1,500.00	Purchased	(6) ECS For T-200 Thrusters & Electrical circuits + Power Supply	$ 1,443.30
Deckside Computer	$ 300.00	Purchased	Xbox Controller, Monitors	$ 283.57
Mission Tools	$ 500.00	Purchased	Cameras, Sensors, Claws.	$ 490.84
Raw Materials	$ 2,000.00	Purchased	Aluminimum, Epoxy, Fasteners, 3D printer filament, Consumables,Cored Carbon	$ 1,354.05
Subtotal Production Budget	$ 7,368.66		**Subtotal Production Costs**	$ 6,511.03
R&D Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Electronic Debugging tools & Equipment	$ 134.32	Purchased	ROV electronics for Software testing and essential tools.	$ 53.73
Materials	$ 200.00	Purchased	Fasteners, o-rings, cable grommets	$ 161.18
Subtotal R&D Budget	$ 334.32		**Subtotal R&D Costs**	$ 214.91
Operations Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Mission Props	$ 700.00	Purchased	MATE ROV mission props	$ 671.58
Mate Entry Fee	$ 650.00	Purchased	MATE ROV Entry Fee for Explorer	$ 650.00
Lab Supplies	$ 80.00	Purchased	PPE, Safety Signage , cable covers	$ 56.14
Printing	$ 50.00	Purchased	Poster and additional documents	$ 40.30
Lodging	$ 2,000.00	Purchased	Accomodation in College Park Apa	$ 1,250.00
Plane Tickets	$ 4,000.00	Purchased	Plane Tickets	$ 1,574.64
Shipping ROV To MATE	$ 300.00	Purchased	Shipping ROV & Float to Mate ROV	$ 402.95
Rental Cars	$ 671.58	Purchased	Rental Cars for 5 days	$ 402.95
eVISA UK	$ 141.03	Purchased	day American Visa to attend MATE F	$ 141.03
Competition Meals	$ 335.79	Purchased	Food allowance for each member fo	$ 335.79
Subtotal Operations Budget	$ 8,928.40		**Subtotal Operations Costs**	$ 5,525.38

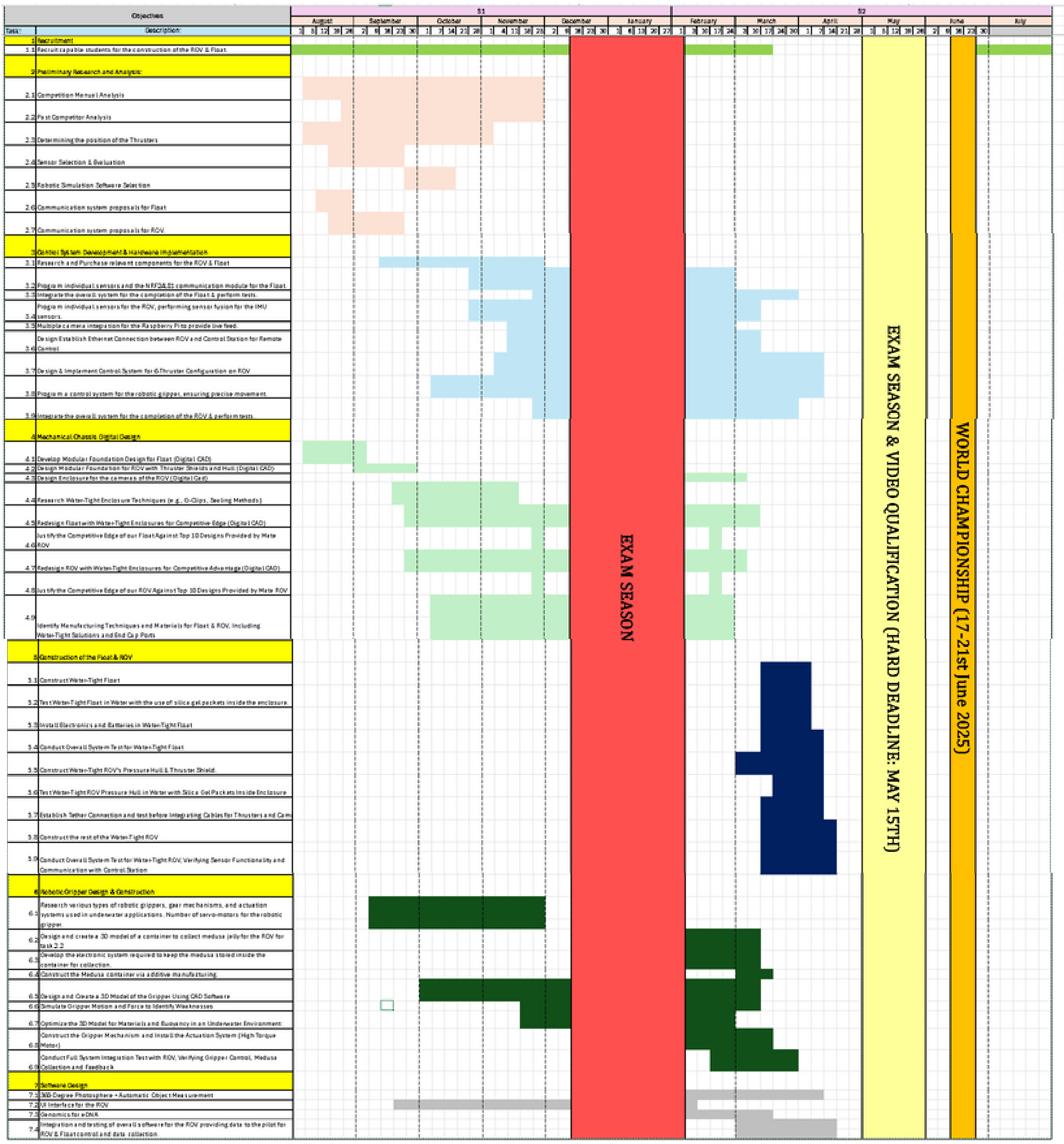
D) Lessons Learned:

The IP68-rated power and Ethernet connectors proved unreliable, with poor sealing that led to water ingress. A Blue Robotics penetrator would have been more suitable for Ethernet, and future designs should use multiple smaller power cables with individual glands. We have also realised the impact of custom PCBs as finding specific circuits have become drastically difficult and expensive.

We also emphasised the importance of checking all screws and acknowledging even minor leaks. While water was less conductive than expected, it still posed risks, reinforcing the need for tighter build checks and rated connectors.

Lastly, the university's restriction on electronics testing prompted us to secure a permanent on-site test pool, ensuring better support for future projects.

E) Build Schedule (TBHY 2025 Gantt Chart)



F) Safety Checklist

General Safety:

□ All team members present have completed lab safety induction.
□ Maximum lab occupancy (9 members) is not exceeded.
□ Proper PPE is worn by all personnel:

- □ EN166-rated safety glasses
- □ EN388-rated gloves
- □ EN ISO 20345-compliant safety boots

□ Emergency stop button is accessible and tested.

Electrical and Power Supply:

□ Only trained technical staff connect or modify any mains-powered equipment.
□ All 48V or high-power circuits are isolated before handling.
□ Ensure power supply is turned OFF before connecting or disconnecting any components.
□ Announce clearly before switching ON/OFF the main power supply (e.g., "Powering ON in 3, 2, 1...").
□ Use a digital multi-meter to verify no voltage present before handling.
□ Confirm all fuses are installed and rated appropriately.

Mechanical Integrity:

□ All external and internal screws are tightened and secured (torque-checked where applicable).
□ Propellers are free of obstructions and are properly shrouded
□ Pressure hull is fully sealed with O-rings inspected and properly seated.
□ Waterproof penetrators and connectors are tightened and sealed.
□ Syringe system and float actuator are locked and tested for stroke limits.

Pre-Deployment System Checks:

□ Controller input is tested and responsive.
□ Thrusters respond correctly to commands.
□ Depth , water-leak , and IMU sensor data is verified.

Post-Operation:

□ Power supply is turned OFF and disconnected safely.
□ Hull is depressurised and opened carefully.
□ All components are dried, logged, and inspected.
□ Tether is cleaned and recoiled.
□ Any faults or incidents are recorded for team debrief.