MEGATRON

2024 MATEROV Technical Documentation

Explorer Class

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Introduction

Team Mission

To design and test rugged, safe and intelligent vehicles by fostering innovative interdisciplinary collaborations.

Team Vision

Leveraging marine robotics to enhance and streamline data collection methods for environmental research.

Project Timeline

Before work began on constructing a new AUV/ROV from scratch, overall team leads thoroughly discussed and surveyed existing vehicles on the market to arrive at the final capabilities for the vehicle which would be suitable for a variety of missions, and how the entire hardware and software architecture should be integrated. Once a consensus was established, the team focused on parallel development strategies to allow hardware and software sub-teams to build up capabilities independently of each other.

The project timeline can be broken down into four phases (Figure 1). Phase I (Oct-Dec 2023) focused on validating a new 6-DOF thruster configuration and testing the ArduSub control framework, allowing the hardware team to design a new external frame and make necessary modifications. Phase II (Jan-Feb 2024) focused on the production of the official vehicle to be used for competitions. Phase III (March 2024) transitioned to intensive autonomous software integration and validation so that the vehicle would be ready for an AUV competition on April 5th. After this, the team took a hiatus to prepare for final examinations and began work for MATEROV in May 2024.

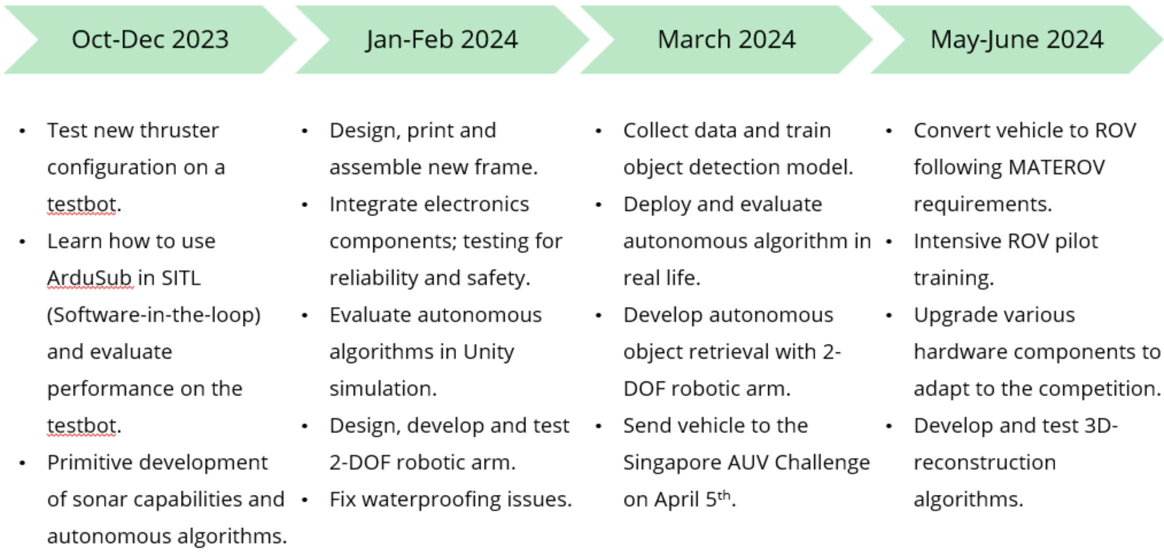


Figure 1: Overall project timeline

Teamwork

Resource and Progress Management

Mecatron conducts fortnightly meetings for all members to update major announcements, report on overall progress and find solutions to any issues. During these meetings, members from both hardware and software sub-teams are updated on the progress and challenges on each side, enhancing collaboration across domains. To allow the team to be on track for competitions, we employ the Scrum methodology - a progress management strategy extremely popular in software development. Scrum emphasises incremental progress by breaking large tasks into smaller deliverables with regular meetings to set and negotiate new deliverables. Following this methodology, we divide our timeline into smaller iterations - each spans three weeks and includes a number of deliverables for all personnels - and use Github Project (Figure 2) to track iterations, assignees, and log reports. In using a centralised platform, all members are clear on what they have to do and what has been done. After each iteration, sub-teams meet again in-person to discuss what is feasible in the next iteration and resolve any current issues.

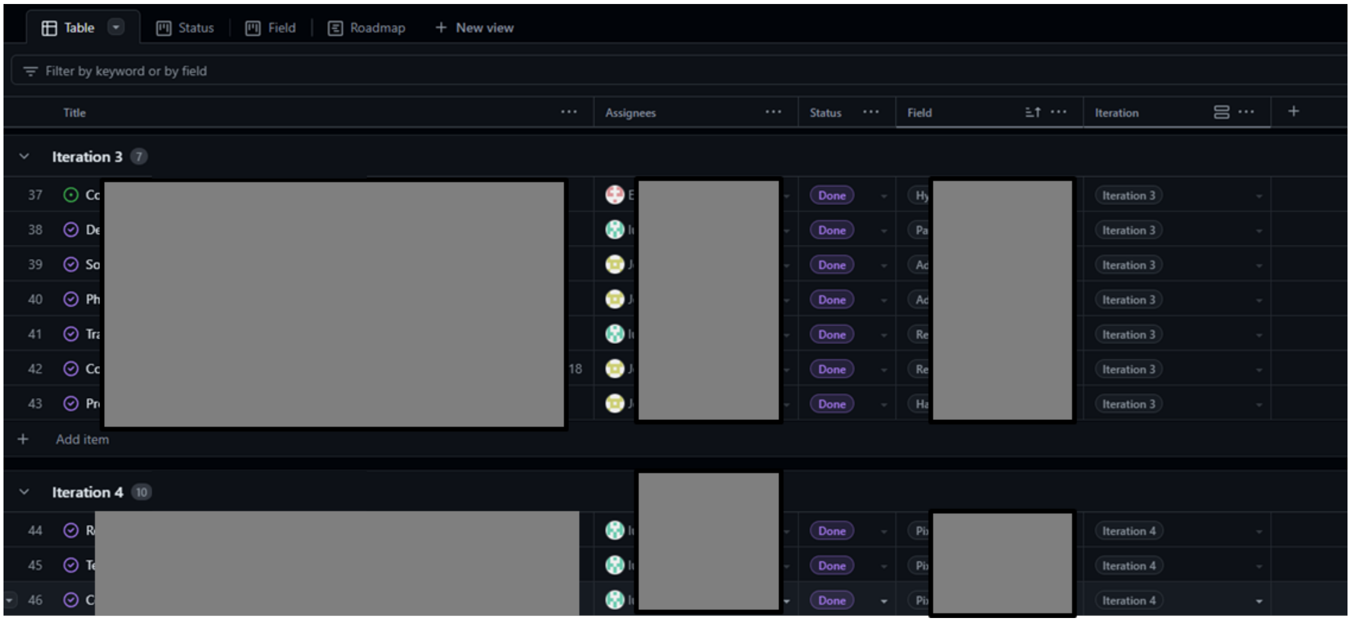
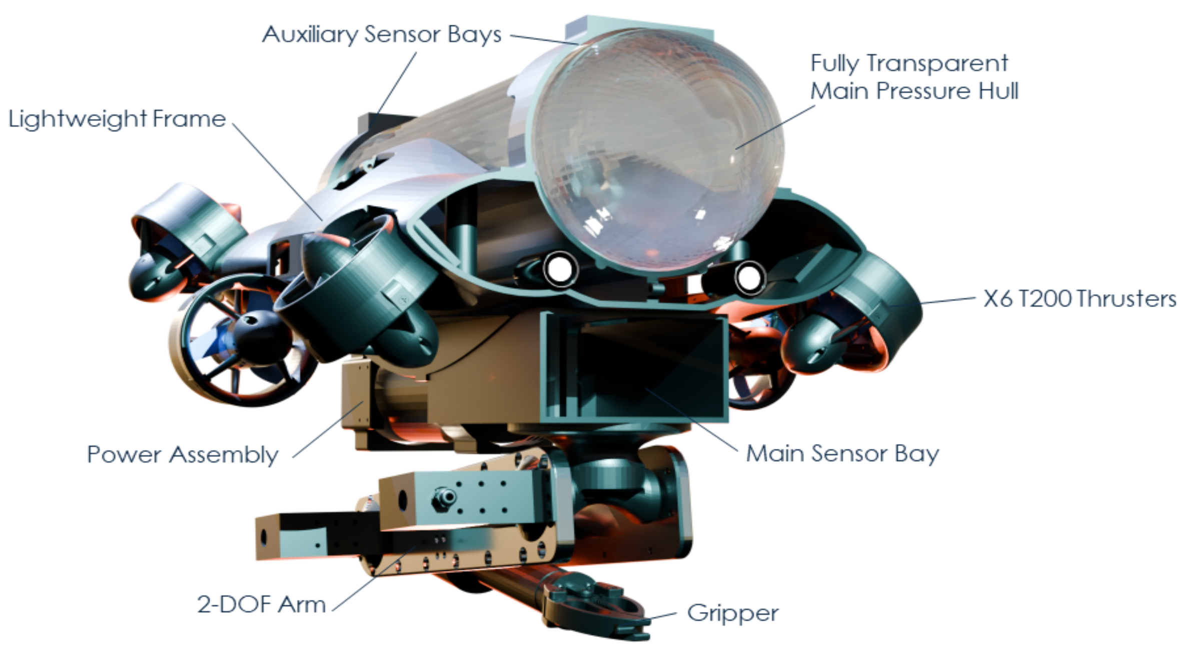


Figure 2: Illustration of Github Projects used for our progress management

Design Rationale

Engineering Design Rationale



Turtleboi was designed with a few goals in mind. First, the vehicle needs to be multi-mission type capable, meaning it must be able to perform in MATEROV missions and beyond. This meant that the vehicle needed to be modular to accommodate the frequent changes in sensor configurations and power configurations. Secondly, the vehicle must allow for easy troubleshooting. This is particularly important due to the tight timeline of our development program. Lastly, the vehicle must have adequate safety features to minimise harm to personnel and to the vehicle. In the following sections we will demonstrate the steps taken to achieve these goals.

Innovation

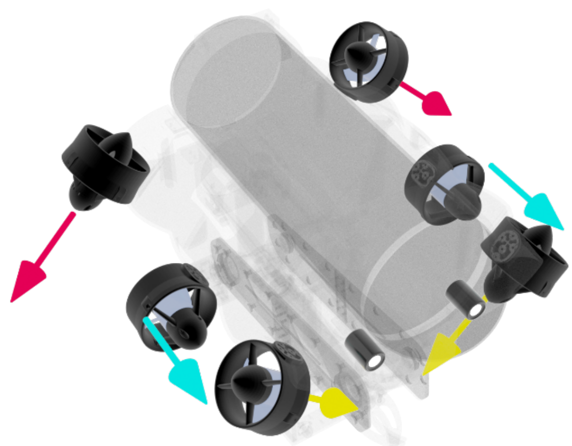


Figure 3: Turtleboi's custom thruster configuration

One of the most important design considerations was how to arrange thrusters to achieve stable and energy-efficient 6 DOF motion control so that the vehicle can perform lateral and active roll/pitch control, as well as maintain depth and attitude even in the presence of external perturbations such as water currents or payload imbalance. Existing configurations by ROV companies such as BlueRobotics, VideoRay and Oceanbotics often use more than 6 thrusters to achieve 6 DOF control, potentially using more energy. Understanding that the typical horizontal vectored configuration is most versatile for lateral, forward and yaw motion, we flipped this concept around and asked the question: "What if we do a vertical vectored configuration?" This arrangement would enable true 6 DOF control and minimise energy consumption. After researching that ArduSub allowed custom frame configuration out-of-the-box and few ROVs on the market used this configuration, we proceeded to experiment with this setup on our testbot before deciding that the performance was satisfactory to be implemented on our official vehicle Turtleboi.

Problem Solving

Our initial waterproofing strategy for the AUV involved using superglue to seal cable penetrators, making the cables non-removable, and employing a metal plate cover, which failed to provide an adequate seal, resulting in water leaks. To address these issues, we conducted a series of brainstorming sessions, gathering inputs from hardware team members to explore the various alternatives. We utilized a rational process, to evaluate each option based on criteria such as durability, ease of maintenance, and reliability. Through further research, we discovered that an acrylic cover would offer a smoother surface and a more reliable seal. Based on the trade study results, which indicated superior performance and easier implementation, we decided to replace the superglued penetrators with Blue Robotics penetrators, known for their robustness and maintainability, and to substitute the metal cover with an acrylic cap. Although this comprehensive solution required additional time and caused delays, it effectively resolved the waterproofing issue.

Turtleboi is now reliably protected against water ingress, and the new penetrators facilitate easier maintenance and future upgrades. This strategic shift from makeshift fixes to a well-researched and systematically evaluated approach has significantly improved the AUV's operational reliability and longevity.

Systems Approach

Turtleboi's development strategy was designed in such a way as to accommodate multiple development paths and allow the hardware and software teams to understand how to coordinate development plans. As such, development began with the construction and deployment of a test bot (figure 4). This vehicle allowed the software team to experiment with thruster configurations and understand their propulsion control algorithms. At the same time, the hardware team was able to develop the full scale vehicle based on these learnings in tandem with testing.

With the goal of developing this vehicle into a multi-mission type capable vessel, hardware development of the final vehicle was designed to accommodate rapid changes in sensor and power configurations as required by the software team. The vehicle frame is mounted with numerous, easy to use sensor bays where cameras, sonars and manipulators can be attached and removed as needed. At the same time, the software team developed their programs under the Robotic Operating System (ROS) which allows for seamless communication and processing of sensor data from multiple sources. The use of ROS allows the software team to quickly change their programs to accommodate changes to sensor configurations on the hardware side. Such changes are made easy as ROS is organised into nodes and topics with each sensor or process occupying a node and can communicate through topics. Hence changes can be made quickly through addition or removal of nodes and topics. This ability of the software and hardware teams to quickly adapt and respond to each other allows Mecatron to build and test along multiple concurrent pathways and arrive at an engineering solution that best suits our goals.

Figure 4: Turtleboi's Testbot

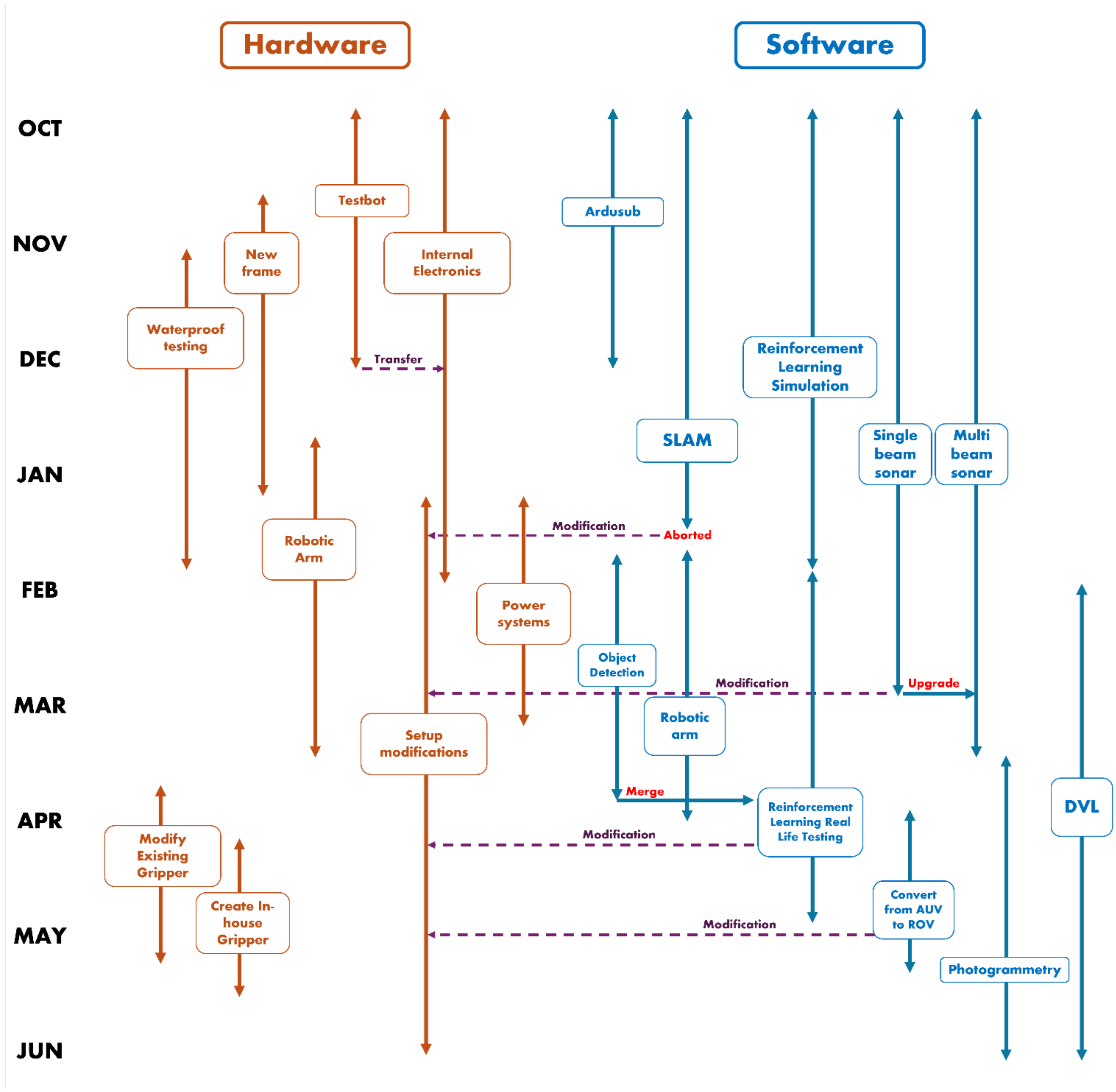


Figure 5: Turtleboi's Development Pathways

Vehicle Structure and Systems

Vehicle Frame

Turtleboi's structure closely follows the structure of a sea turtle, with an outer shell protecting the vital systems of the vehicle. The outer shell is a lightweight but highly durable frame manufactured with PC-ABS using 3D-printing. It is compact with a dimension of 690 x 490 x 420 mm. This outer shell serves not just as a protective layer, but also to improve the hydrodynamic properties of the vehicle. It also serves as a mount for the propulsion systems, sensors and manipulators of the vehicle. The many sensor bays available on the frame allows for quick additions or removal of sensors based on mission requirements.

The frame material was chosen based on an ordered list of material properties as shown in figure 6. Available materials were ranked based on advertised material properties weighted against their priority to derive their desirability score. Due to cost constraints, PC-ABS was selected despite being 3rd on the list. The frame is further reinforced with epoxy resin to increase strength and also acts as a layer of UV protection.

Parameter	Priority
Flex Strength	4
IZOD	3
Elongation	2.5
Tensile Strength	1

Material Score	
Weighted	Pos
DIRAN 410MF07	3
Nylon CF10	2.779068
PC-ABS	2.222926
ABS-M30	2.119504
ASA	1.89255
PLA	1.83475
ABS ESD7	1.699495
ABS-CF10	1.545618

Figure 6: Material selection scores

Main Pressure Hull

At the center of the frame rests the main pressure hull. It consists of an acrylic cylinder that is 5mm thick with a spherical dome at the front. This hull contains all of the key electronics of the bot, including the onboard computer, Pixhawk flight controller and Electronic Speed Controllers (ESCs). The components are secured to an acrylic plate which separates the hull into two halves, maximizing the available space within the cylinder. These electronics are cooled by a central cooling spine which pipes heat towards the metallic ends of the pressure hull, which are exposed to the cooler waters outside.

Power Systems Pressure Hull

A key safety feature in the vehicle design is the separation of the power systems from the main electronics. At the back of the vehicle rests a secondary, smaller acrylic cylinder which holds the power systems of the vehicle. These can be reconfigured between battery power and tethered power for Autonomous and Manual modes. This separation minimizes the risk of damage to the core electronics should the power systems suffer a destructive failure and also allows for frequent inspection without disturbing the main cylinder.

Propulsion Systems

The propulsion system on Turtleboi consists of 6 BlueRobotics T200 thrusters arranged in a configuration capable of stable and manoeuvrable 6 DOF motion (refer to Innovation subsection on how this configuration is optimised for a variety of missions). The firing order of these thrusters is determined by the Ardusub firmware in the Pixhawk flight controller which takes inputs from the joystick controller. Each thruster is equipped with a 3D-printed, epoxy-coated IP2X guard to ensure user safety.

Buoyancy and Ballast

The buoyancy of Turtleboi is strictly static with changes made using stainless steel weights secured inside of the frame to balance the vehicle. The buoyancy statistics of the bot are shown below.

Turtleboi Volume	0.014629245 m3
Turtleboi weight above water	13.2 kg
Buoyancy	14.629245 kg
Turtleboi weight underwater	-1.429245kg

For MATEROV, Turtleboi is naturally highly buoyant. This is disadvantageous as more power is wasted on pushing the vehicle down and holding it at constant depth. This also creates a highly turbulent environment around the vehicle which makes it difficult to complete the more intricate tasks in the competition. To combat this, we have used flat steel ballasts placed around the inside of the frame to increase the vehicle's weight, as well as balance the vehicle. The final buoyancy of the vehicle is such that only 2 cm of the vehicle is above water. This allows the vehicle to not only easily move to deeper waters, but also float to the surface should the electrical systems fail, enabling quick recovery.

Control and Electrical Systems

Power Delivery and Conversion

Our circuit uses two converters to step down voltage and create a separated parallel circuit. For enhanced safety, all converters are equipped with individual fuse protection. The circuit features an open-architecture design, allowing for seamless integration of industry-standard components, facilitating maintenance, and enabling future upgrades without complex modifications. One key highlight of our circuit is that the main current-carrying wire passes through a power module connected to the Pixhawk 6C, enabling us to monitor real-time voltage and current consumption. Another key highlight of our circuit is the dual parallel circuit design. This allows us to perform an emergency stop by cutting power to the thrusters while keeping other main components powered. The connection of both parallel circuits ensures that the thrusters are only powered when the main control is active, guaranteeing they operate only under controlled conditions. Additionally, the separation prevents large voltage drop due to thrusters operation from affecting sensitive electronics such as the Jetson Orin Nano.

Topside Control Unit (TCU)

The surface control system consists of a Wifi router broadcasting to users' personal laptop(s). This laptop serves as the mission control centre, offering a user-friendly Graphical User Interface (GUI) for operators to visualise the ROV's camera feed and exercise precise control.

An emergency stop (E-stop) system is integrated into the topside control system, allowing operators to quickly shut down the ROV in case of an emergency.

Tether design

Our tether consists of 3 separate cables - power, ethernet and E-stop - bound together by zip tiles at regular 1m intervals. The power cable is a 4-core (16 AWG each) cable used to deliver up to 18A of current with minimal energy loss. Cat6e Ethernet cable enables networking between the TCU and our vehicle. The E-stop cable is a 2-core (18 AWG each) cable used to open a relay and cut the power to the thrusters' sub-circuitry in case of an emergency. The total length of the tether is 25m with a strain relief mechanism attached to the vehicle side to ensure the tether is always securely connected to the vehicle.

Tether Management

Managing a long tether involves careful organization and protection to ensure stable and reliable communication and power supply. During operation, the tether is fully laid out in an uncoiled and untangled arrangement for fast deployment of tether into the water. After each deployment, the tether is coiled into a cable reel for easy management and prevention of tangles and kinks. We have ensured that connectors are secure and waterproofed for our application. Regular inspections for wear and tear are done to ensure smooth operation. Strain reliefs at both connection points have been implemented to prevent disconnection. There is always a dedicated team member handling cable management during operation to avoid snagging and ensure smooth operation.

Control System

The Control system on the Turtleboi consists of a Jetson Orin Nano and a Pixhawk 6C flight controller. Jetson Orin Nano is a single-board computer with an energy-efficient ARM-based CPU and powerful NVIDIA GPU, making it suitable for machine learning and complex mission planning while drawing only 15W of power. On the other hand, Pixhawk 6C is a powerful microcontroller capable of controlling ESCs (electronic speed controllers) and servos, interfacing with sensors such as leak and pressure sensors, as well as performing PID control (Proportional- Integral-Derivative) for depth and attitude control of the vehicle.

Pixhawk's open-source firmware, Ardusub, offers a depth-hold mode that allows the pilot to keep the ROV at a constant depth and attitude if no pilot input is given, using Inertial Navigation Filter (EKF) and autopilot feedback control (PID). To actively maintain orientation and heading despite load imbalance or perturbations, the Pixhawk module takes inputs from built-in IMU (inertial measurement unit) and compass to estimate its current state and perform the necessary feedback control. Maintaining depth is done with depth input from the Bar30 pressure sensor and vertical acceleration readings from the built-in IMU. This mode is advantageous for our operation because the ROV pilots can focus on getting to the target depth and heading without having to actively maintain the vehicle at the desired state.

Depth-hold mode also enhances control when manipulating the 2DOF robotic arm for pick-and-place operations. The 2DOF robotic manipulator is controlled by three servos, which are actuated via commands from a teleoperation keyboard interface. Each servo is assigned specific keyboard keys to regulate its rotational direction. The rotational angle of each servo per key press has been precisely calibrated to ensure seamless and smooth arm movements.

Communication

Pixhawk 6C is connected to the Jetson module via USB port, allowing it to be interfaced with Pymavlink (a set of Python libraries designed for Pixhawk flight controllers) directly from the Jetson module for Python scripting. This connection can also be forwarded to the topside computer(s) via UDP (User Datagram Protocol), enabling the Pixhawk to be controlled from the topside ground station (QGroundControl in this case). Thus, there can be parallel control of the Pixhawk module, one from a joystick connected to topside computer(s), and another one from a Python script running on the Jetson module. During the competition, the joystick controller would be generating control signals for the thrusters, while the software program would be used to generate the control commands for the robotic arm. This software program, despite running on the Jetson, can take inputs from the topside computer because of SSH connection (Secure Shell Protocol) between the onboard Jetson module and topside computer.

	Advantages	Disadvantages
ROS Networking	Long-term solution for multi-machine development.	Hard to debug given the time constraint.
TCP (Transmission Control Protocol)	Reliable delivery of data.	Higher latency than UDP.
UDP (User Datagram Protocol)	Low latency and fast data transmission.	Some data packages can be lost in transmission. However, this is acceptable as not all data packages

	UDP is the **default implementation** for Pixhawk and QGroundControl.	are critical (such as video frames).

Cameras are connected to the Jetson computer via USB and streamed to the ground station via UDP. In general, for communication between the onboard systems and topside station, UDP is the preferred method after performing a comparison matrix with other methods.

Payload and Tools

Cameras

Turtleboi has 2 pinhole cameras which live streams images from the vehicle perspective. One camera is mounted on the robotic arm to make it easier for the ROV pilot to accurately actuate the arm, retrieve, and manipulate the desired objects. This camera is positioned such that the gripper and the space in front is within view. The second camera is placed at the dome of the main pressure hull, providing a clear front view from the vehicle perspective, giving the pilot crucial information about the vehicle's surroundings. This camera is adjustable, allowing real time changes to the camera view depending on mission conditions.

Robotic Arm

The robotic arm used on Turtleboi is a 2-DOF arm controlled by 2 servos. The arm is custom made, save the 2 servos. Manufactured using 3D printing with PETG, the arm was designed to be lightweight, yet durable enough to lift basic items. The servos used are from ROV maker and are rated for up to 40Kgcm of torque. They are underwater safe and allow for precise positioning, a crucial capability for reliable arm movements.

The servos are all placed along the centreline to reduce the additional angular moment and keep the centre of mass near the centre plane of the arm assembly. This minimises the bending strains applied on the arm links as well as normal strains on the arm joints, extending the lifespan of the robotic arm.

Build vs Buy, New vs Used

The decision to build, buy or reuse is based on how well existing components in the market meet our operational needs, the risk of an old component or a custom made component failing and its impact on our operations. However, due to limited existing components available to us, most components were custom made or bought. The table below highlights how each system on Turtleboi was evaluated in this regard.

System/component	Built/Bought or Reused	Reason
Propulsion	Reused	Blue Robotics' T200 underwater thrusters provide more than enough thrust for our operation. We were able to obtain a set from our University
On Board Computer	Bought	Turtleboi requires high processing power and Mecatron does not have capabilities to create a custom Single Board Computer. Hence a Jetson Orin was purchased since it has the required processing power and operating system.
Flight Controller	Bought	Being able to use ArduSub would save our time in developing a control system software.
Heat Management	Built	Unique shape and arrangement of internal electronics required a custom heat management spine which was designed and machined by Mecatron and our home University
Power Management	Built and Bought	Risk of a fully custom made power management system was significant but market solutions did not fully meet our power and safety requirements. Hence a mix of custom made power buses, energy monitoring and outsourced converters, fuses were used to meet our needs.
Robotic Arm	Built and Bought	Waterproof 2 DOF robotic arms were very costly. As such, apart from the servos, the robotic arm was made in-house using a mix of machining and 3D printing. The existing gripper that we had was extremely old and the risk of failure was high. As such the gripper was also custom made with an added turning capability.
Cameras	Bought	Existing camera solutions in the market meet our requirements in terms of cost, resolution and FPS.
External Frame	Built	Manufacturing capabilities in Mecatron are sufficiently advanced to construct a custom external frame. This also gave us more

		control over the design of the frame and decreased the time between iterations.
Pressure Hull	Built and Bought	Pressure Hulls available in the market fit our specifications but required some modifications such as additional outlets and reinforcements which were done in-house
Tether	Bought	Market options fit our requirements in terms of length, transmission speeds and strength
Strain Relief	Built	Integration of strain relief to the vehicle required a custom solution as market options did not meet dimensions required. A custom strain relief and attachment pieces were manufactured in-house using 3D printing

Safety

Construction

Designing a ROV entails extensive safety considerations, including waterproofing, pressure resistance, thermal management, and electrical insulation. Through the build process, key notes would be secure wiring, robust seals and thorough check for leaks is crucial. Additionally, implementing emergency fail-safes and following the safety standards minimise risks during operation and maintenance. Safety measures during development are crucial, such as wearing goggles when drilling, using gloves and masks when handling epoxy, and ensure proper ventilation or exhaust fume extraction when soldering. These precautions help protect the team and ensure a safer and more reliable ROV.

Personnel and Equipment

Safety is a key priority for Mecatron. Before joining Mecatron's activities, new members are required to complete compulsory online modules on fire safety, emergency procedures, lab and equipment protocols. These modules provide in-depth knowledge on hazard identification, risk assessment, and proper response, ensuring everyone is well-prepared for potential incidents. New members using equipment for the first time are always supervised by Team Leads in the lab. Because of our small team size, Leads also provide 1-to-1 training for new members to ensure safety in equipment handling. Additionally, the Dyson-NTU Studio, where we are housed, features secure access to prevent unauthorised entry, protecting our equipment and our vehicle. Finally, after every lab session, Team Leads ensure that equipment is organised and stored properly after use, preventing equipment losses and maintaining a conducive working environment.

Pool Tests

Before every pool test, the safety checklist (**Appendix**) was reviewed, and a five-minute dunk test was performed before powering the ROV. All employees are aware of the Job Site Safety Analysis and will follow the mitigating procedures to minimize potential hazards involved in pool tests.

Critical Analysis

Testing & Troubleshooting

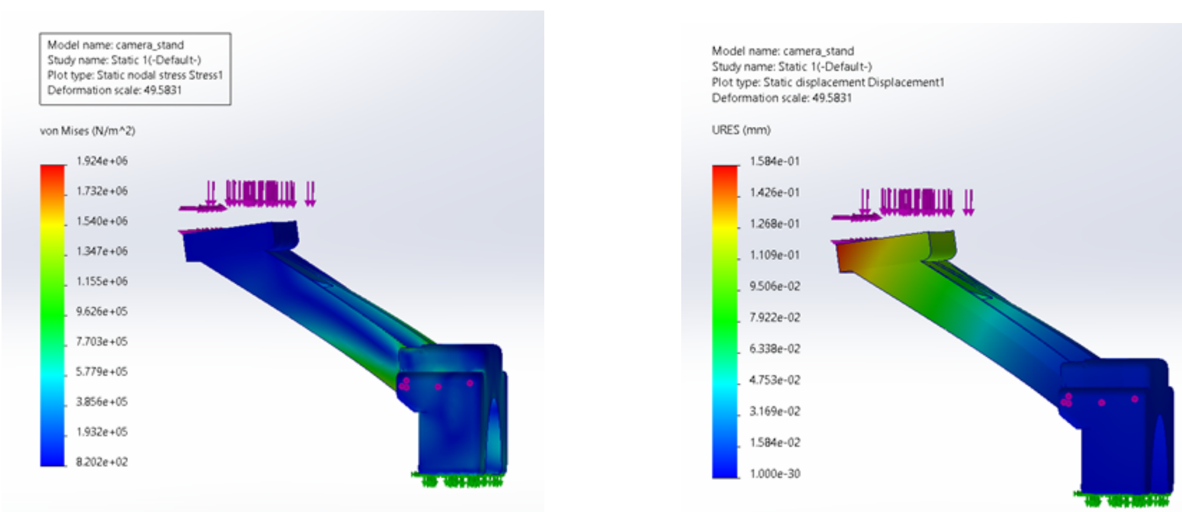


Figure 7. Finite Element Analysis test on the camera mount to the arm (stress & displacement analysis)

The testing methodology for the ROV involved using a digital twin and iterative optimization through rapid prototyping. Since we built the entire vehicle from scratch, many parts and assemblies were designed and printed using 3D printers. Consequently, material strength, size accuracy, and surface finish had to be verified during the manufacturing process. To achieve this, we used a digital twin, creating a model in SolidWorks to test geometric validation, theoretical strength and ultimate strength of the parts through finite element analysis as shown in **Figure 7**.

Before validating the digital twin, we printed a test piece to determine the actual uncertainty and shrinkage rate of the materials when printed by 3D printers. During this design phase, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), and polyethylene terephthalate glycol (PETG) were primarily used.

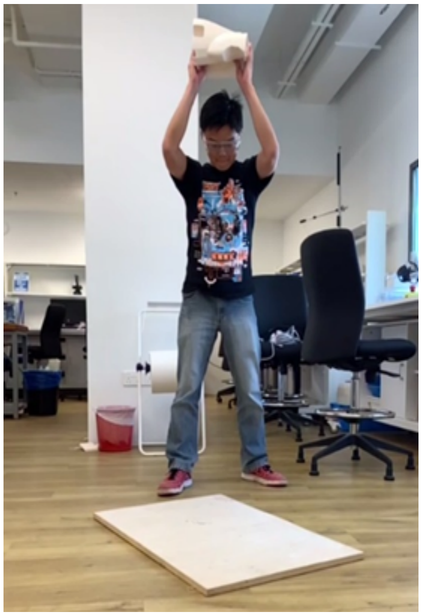


Figure 8. Simplified drop test of customised frame

A quick test sample printed in PLA was used first to validate the geometry and ensure it fit the constraints of the body cylinder and the frame of the ROV. The prototype parts were then printed in ABS and PETG, chosen based on their functional requirements and concerns about fatigue failure. Their strength was tested by conducting a simplified drop test, where the drop velocity was higher than the maximum velocity the ROV could reach (**Figure 8**).

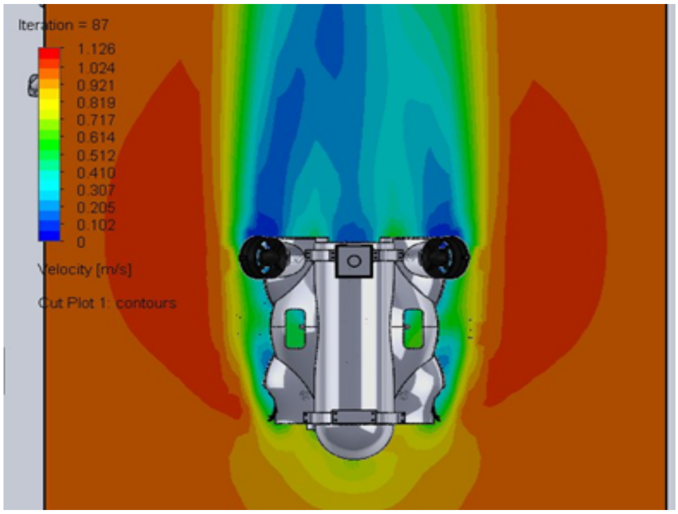


Figure 9. CFD analysis of entire ROV in Solidworks

For example, the frame of the ROV was initially designed in SolidWorks and subjected to computational fluid dynamics (CFD) simulation to determine its performance in fluid conditions as shown in **Figure 9**. Due to the limited print space of the printer, the frame was split into four parts and printed sequentially. After the drop test, all frame quadrants were printed and assembled.

Since we used a fused deposition modelling (FDM) printer, the surface finish was not smooth or anti-corrosive. Therefore, secondary processes such as filing, sanding, and applying epoxy were employed to reduce friction and improve the surface finish.

The high frequency of prototype iteration and validation supported the team in efficiently building the ROV hardware. Once assembled, the ROV was tested by the software team to verify and adjust the code, ensuring all manipulators and components functioned correctly before pool testing.

Once the ROV was fully functional, it was brought to a pool to practise mission tasks. During development, tools such as a multimeter, motor tester, and recorded video footage were used for troubleshooting if any components malfunctioned during testing.

Accounting

Budget

Income					
Source					**Amount**
Revenue from Fundraising Workshops					$ 3,703.70
Expenses					
Category	**Type***	**Sub-Category**	**Examples**	**Projected Cost**	**Budgeted Value**
Vehicle Development Expenses	Purchased	Hardware	Waterproof housing, O-ring flanges, endcaps	$ 148.15	$ 148.15
		Sensors	DWE exploreHD 3.0 camera, Arducam, ROVMAKER Bar30 pressure sensor	$ 481.48	$ 481.48
		Electronics	Jetson Orin Nano 8GB, Holybro Pixhawk 6C, tether wires	$ 740.74	$ 740.74
	Re-used	Electronics	T200 BR thrusters and ESCs, BR gripper, BR potted cable penetrators	$ 2,200.00	-
Control System Expenses	Purchased	Electronics	E-Stop	$ 7.41	$ 7.41
	Re-used	Electronics	WiFi router, Logitech F310 Gamepad Joystick	$ 74.07	-
Non-ROV Expenses	Purchased	Hardware	Waterproof housing, O-ring flanges, endcaps	$ 74.07	$ 74.07
		Sensors	Temperature probe	$ 3.70	$ 3.70
		Electronics	Raspberry Pi Zero 2W, 9V batteries	$ 37.04	$ 37.04
	Re-used	Sensors	BR Bar02 pressure sensor, BR potted cable penetrators	$ 100.00	-
Operational Expenses	Purchased	Lab Consumables	3D printing filament (i.e. PETG, PC-ABS)	$ 1,333.33	$ 1,333.33
		Equipment	600L water tank (small-scale testing), cart (portable workstation)	$ 370.37	$ 370.37
		Transport	2-way transport (Dyson-NTU Studio & NTU SRC pool)	$ 111.11	$ 111.11
Competition Expenses	Purchased	NIL	Competition registration fee, competition props	$ 650.00	$ 650.00
Travel Expenses	Purchased	NIL	2-way airfare (SG & USA), 2-way bot shipping fees, accommodation fees	$ 20,000.00	$ 20,000.00
*Items must fall into one of the following: Purchased – Items that will be newly purchased this year Re-Used – Items purchased in previous years (before 2018) by former robotics group				Total Income	$ 3,703.70
				Total Expenses	$ 26,331.48
				Re-Used Items Expenses	$ 2,374.07
				Total Fundraising Required	$ 20,253.70

As Mecatron was newly founded in August 2023, re-used components were “inherited” from a former robotics group that had been active before 2018 and most required components had to be newly purchased. Upon the formation of Mecatron, the budget was established in the table above. All values are stated in USD.

Cost Accounting

Mecatron's Standard Operating Procedure for procurement is summarized in the table below.

Purchasing Account	Request Raised		Purchased
	By	To	By
Mecatron Account	Mecatron members	Business Lead	Business Lead
Lab Account	Business Lead	CoE Staff	CoE Staff

The table below is a snapshot of the shared Excel sheet that all Mecatron members have access to, to request for equipment procurement. The excel sheet is restarted every month.

Purchase Details: To be filled in by members											Purchase Confirmation	
Request Date	Account	Item (with Purchase Link	Variant	Quantity	Unit Cost	Shipping Cost	Discount	Remarks (Purchase Justification / Discount Info)	Total Expenditure	Member	Approved? (Y/N)	Purchase Date
1/5/24	Lab Account	Ultimaker Print Core AA 0.40	NIL	1	$216.00	$0.00	NIL	Ultimaker printer is not functioning properly, the print core is damaged. Printer still can print but increasing number of issues due to wear and tear over time, need to fix the printer ASAP.	$216.00		Y	
1/5/24	Lab Account	Nozzle Seal S	NIL	1	$18.00	$0.00	NIL		$18.00		Y	
1/5/24	Lab Account	Ultimaker Cleaning Filament	NIL	1	$32.70	$0.00	NIL		$32.70		Y	
20/5/24	Mecatron Account	Copper Heat Pipes	Length 26mm, Height 2.5mm	12	$2.03	$0.00	NIL		$24.36		Y	21/5/24
20/5/24	Mecatron Account	ROVMAKER PMMA Pressure Hull	OD 160mm, Length 200mm	1	$88.00	$24.00	NIL		$112.00		Y	21/5/24

For financial auditing purposes, Mecatron submits budget spreadsheets (account statements) of the team's monthly expenditure and revenue to the NTU College of Engineering (CoE), for both Mecatron's own bank account (managed by the Business Lead; for Mecatron-specific purchases) and Mecatron's lab bank account (managed by CoE; for Mecatron's lab purchases). Weare unable to share the confidential monthly account statements, but the table shown below contains a snapshot representative sample of our cost accounting processes (hence, note that the final balance is inaccurate).

Funds							
Date	Type*	Category	Items	Description	Remarks	Amount	Running Balance
12/1/24	Purchased	Electronics	Jetson Orin Nano 8GB, Holybro Pixhawk 6C, tether wires	onboard computer, flight controller, tether for ROV	Used for Vehicle Development	-740.74	-740.74
12/1/24	Purchased	Hardware	Waterproof housing, O-ring flanges, endcaps	Main hull and power hull	Used for Vehicle Development	-250	-990.74
12/1/24	Purchased	Sensors	DWE exploreHD 3.0 camera, Arducam	Cameras for the ROV	Used for Vehicle Development	-520	-1510.74
31/1/24	Purchased	Equipment	600L water tank (small-scale testing), cart (portable workstation)	Mecatron's equipment for small scale testing and portability	Equipment can be kept for long-term use	-375	-1885.74
31/3/24	Re-used	Electronics	T200 BR thrusters and ESCs, BR gripper, BR potted cable penetrators	Underwater electronics from BR	Used for Vehicle Development	-2200	-4085.74
21/4/24	Cash donated	General	-	Fund donation from James Dyson Foundation via NTU CoE	Mainly used for ROV / non-ROV costs, excess used for tra	7777.78	3692.04
						Total Raised	7777.78
						Total Spent	-4085.74
						Final Balance	3692.04

As Mecatron was newly founded in August 2023 and the total fundraising amount required is very large, just for this first year, members have pooled their efforts to cover the bulk of their own travel costs (VISA, airfare and accommodation). In the meantime, Mecatron is still actively liaising with sponsors and will continue to conduct fundraisers, to reimburse members after the competition.

Acknowledgements

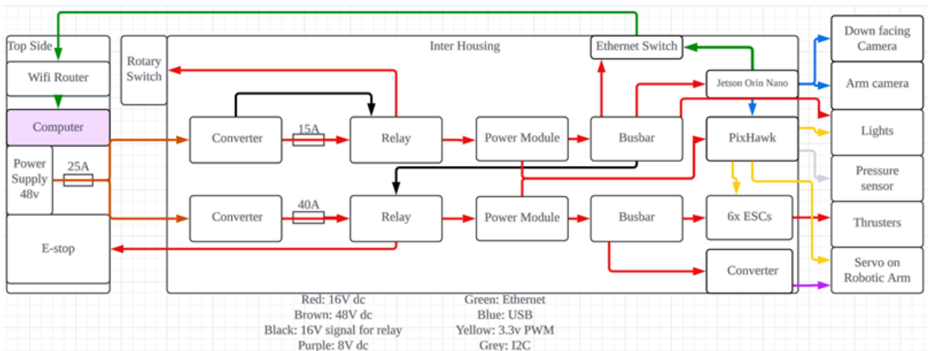
Mecatron is incredibly grateful for all the support we have received this year, which enabled us to build our ROV from scratch and travel to the USA to physically compete in the 2024 MATE ROV World Championship. We would like to thank the following people and organisations for their contributions:

- **NTU College of Engineering** for supporting our team through funding, supporting our team's outreach activities and providing us with laboratory space (Dyson-NTU Studio),
- **Asst. Professor Chan Wai Lee** for his unwavering support and continued advocacy for Mecatron as Mecatron's Prof. Advisor,
- **James Dyson Foundation** for funding support and for providing us with lab space and equipment through the Dyson-NTU Studio,
- **Zen4Blue** for financial support and continual support of our team
- **ROVMAKER** for their assistance in equipment testing and troubleshooting
- And **The MATE Center** & **Marine Technology Society** for organizing and sponsoring the annual MATE ROV Competition

Appendix

Systems Integration Diagrams

SID for Main ROV



Robotic arm	Peak current / A	Voltage / V	Power / W
2 high-torque servos	3.0	8.0	24.0
1 BR gripper	1.0	8.0	8.0
Total	-	-	32.0
Total at 90% efficiency for 16V-8V buck converter	-	-	35.6

Internal ROV	Peak current / A	Voltage / V	Power / W
Jetson Orin Nano	1.0	16.0	16.0
DWE underwater camera	0.3	5.0	1.3
Arducam camera	0.2	5.0	1.0
6 BR thrusters	40.0	16.0	640.0
Robotic arm (Table X)	-	-	35.6
Total	-	-	693.9
Total at 90% efficiency for 48V-16V buck converter	-	-	771.0

Calculation for power cable resistance, assuming 25.0 tether length, 1.6 AWG ($1.5mm^2$) cable thickness, 4 cores (2 for positive and 2 for negative), copper material:

$$R = \frac{\rho \cdot L}{A} = \frac{(1.72 \times 10^{-8}) \times (25.0 \times 2)}{(1.5 \times 10^{-6}) \times 2} = 0.29\,\Omega$$

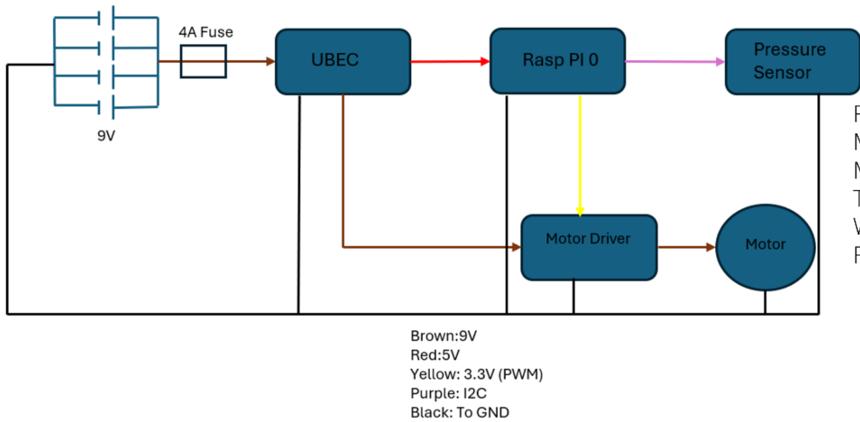
Total current drawn calculation, accounting for power cable resistance:

$$\frac{Power\ drawn\ by\ ROV}{Voltage\ at\ ROV} = I \ \Rightarrow \frac{771.0}{48.0 - 0.29\,I} = I \ \Rightarrow I = 18.0\ A$$

$$Current\ with\ 1.5\ Factor\ of\ Safety = 27\ A$$

Fuse used: 25 A

SID for Float



Fuse Calculation
Max Current to Raspberry Pi Zero: 2 A
Max Current to Motor: 0.4 A
Total Current = 2.4A
With 1.5 Safety Factor: 3.6A
Fuse Rating: 4A

Safety Checklists

ROV Disassembly:

- ☐ The power supply is Off
- ☐ The area around Pressure tube is Dry
- ☐ The Working Area is Clear of foreign articles
- ☐ Ensure a large enough working Area
- ☐ Pressure vent is fully opened
- ☐ Use pryers at two opposite positions on the cylinder hulls

ROV Assembly:

- ☐ Rov Is Powered OFF
- ☐ No loose wiring
- ☐ The wires are managed well on the control board
- ☐ The tube is dry and clean
- ☐ Ensure O-rings condition is good(greased and not cracked
- ☐ Before covering the control board with the tube, Pressure vent is open
- ☐ No wires pinched when closing
- ☐ Use clamps at two opposite positions on the cylinder hulls
- ☐ Ensure Pressure vent is fully closed once the pressure tube is closed

ROV Operation:

Pre-deploying:

- ☐ All wire and tether connections are secure
- ☐ The power supply dry, secure, and functioning. Verify voltage of supply is 48VDC
- ☐ Physical inspection all parts of the ROV are secure
- ☐ Visual inspection ROV not damaged
- ☐ Tether strain relief in place
- ☐ The pressure relief valve closed
- ☐ Tether is stretched out and not bundled or tangled
- ☐ Control Station all secure on a stable platform and connections secure
- ☐ The area in use is clear of any hazards
- ☐ Test ROV E-stop

Power-up:

- ☐ Ensure E-stop is pressed before turning on
- ☐ Control station laptop(s) running
- ☐ Close the rotary switch to turn on
- ☐ Verify that the voltage reading inside the main hull is 16-16.5V
- ☐ Visually verify that Jetson Orin Nano is running
- ☐ Visually verify that Pixhawk 6C lights are normal. No persisting red light (flashing red light is ok)
- ☐ Open the E-stop
- ☐ Check for any abnormalities in the starting-up sound of the thrusters
- ☐ Verify that the voltage reading on the other voltmeter is 16-16.5V

Deploying:

- ☐ Ensure all clear no water in ROV
- ☐ All parts of ROV secure
- ☐ ROV placed in water
- ☐ Perform ROV motion tests (forward, sideways, up-down, yaw)
- ☐ If the leak sensor sounds up in the topside laptop or there is water/steam in the hull at any time, shout out "Leak!" Proceed to Leak Detection Protocol

Leak Detection Protocol

- ☐ Abort Mission. Immediately press E-stop and shutdown Jetson Orin Nano
- ☐ Pull tether to get the ROV back urgently
- ☐ Lift the ROV out of the water
- ☐ Open the rotary switch to cut power to the entire vehicle
- ☐ Proceed to ROV Disassembly to remove water inside the hull(s)

Pre-Pool Test checklist

Before closing the cylinders,

- ☐ Check for damage on the 2 cylinders
- ☐ Are both cylinders completely dry?
- ☐ Are electrical connections completely dry?
- ☐ Are the fuses inserted and serviceable?
- ☐ Are there any visible short circuits in the internal electronics?
- ☐ Make sure main switch is open
- ☐ Check the polarity of the main power wires
- ☐ Briefly connect the power, close main switch and check if voltage supplied is correct(16-17V)
- ☐ Open the switch and disconnect the power

Close the cylinders.

- ☐ Are any wires in the 2 cylinders bent or in awkward positions?
- ☐ Is the main cylinder closed all the way with both O-rings inserted?
- ☐ Is the Power cylinder closed all the way with both O-rings inserted?
- ☐ Is the pressure relief valve tightened all the way
- ☐ Are there any exposed wires on the vehicle
- ☐ Are there any cracks on the external frame

Attach Tethers

- ☐ Check for damage on the E-stop cable
- ☐ Check for damage on the Ethernet cable
- ☐ Check for damage on the Power cable
- ☐ Are all connections tight?
- ☐ Attach the strain relief system
- ☐ Pull tether to check if strain relief is attached properly.
- ☐ Tether is laid out neatly with no knots

Conduct 5 min Waterproof Test

- ☐ Is the main switch still open?
- ☐ Lower vehicle into mini pool
- ☐ Observe for 30s if any water enters.
- ☐ Close the main switch and listen for thruster tones
- ☐ Observe if robotic arm moves and holds home position
- ☐ Fire the 6 thrusters one by one to verify serviceability.
- ☐ Can the vehicle move forward and backwards with controller?
- ☐ Can the vehicle rotate clockwise and anti-clockwise?
- ☐ Shut down power to the vehicle and open the main switch
- ☐ Leave for 5 minutes.
- ☐ Is there water in the vehicle?