保良局顏寶鈴書院
Po Leung Kuk Ngan Po Ling College

HONG KONG, CHINA

Aquamarine Ranger Class

2025 MATE ROV Competition

Technical Report

Team instructor	Mr. Chan Sung Chun, Boby
Mentors	Mr. Ching Ho Yin, Ian
	Mr. Chim Man Chung, Bob

CEO, Software and Research Head	Ho Tsz Shing, Jason
CFO, Electrical & Electronics Head	Krishna Bagale
Mechanical & Designs Head	Ching Ho Long, Brian
Mechanical & Software Engineer, R&D, Pilot	Fang Sen, Jeff
Mechanical & Electrical Engineer, R&D, Co-pilot	Luo Miu, Maurice
General Engineer, Secretary	Cheung Ka Hei, Charles
Mechanical Apprentice, Electrical Engineer	Chen Jia Kang Bo, Jacob

TABLE OF CONTENTS

ABSTRACT

Aquamarine is an underwater robotics company specialising in the design and development of remotely operated vehicles (ROVs). Comprised of 7 passionate and highly skilled engineers, Aquamarine is committed to pioneering innovative solutions in the field of ROV technology.

Hydra is Aquamarine's 3rd generation ROV, our newest and most advanced product tailored to address the 2025 MATE ROV Competition's theme of tackling climate change impacts on freshwater ecosystems. Learning from previous unsuccessful attempts, Hydra integrates all critical components — power distribution, signalling sensors, and cameras — into an upgraded electronic enclosure. This sleek approach enhances mobility to greater approach challenges by simply minimising the ROV's size.

Throughout the development process, countless challenges were faced. Instead of giving up, we treated every challenge as an opportunity to strengthen our abilities, ultimately pushing us forward, which ended in creating such a solid product. With the ultimate aim to facilitate the collection of vital data on shipwrecks and assessing the effects of climate change, such as rising water temperatures and invasive species, Hydra reflects our total commitment to sustainability and the preservation of cultural resources. Moreover, it aligns with the United Nations Decade of Ocean Science for Sustainable Development, inspiring innovation and action to protect aquatic ecosystems for a healthier planet.

TEAMWORK AND PROJECT MANAGEMENT

COMPANY PROFILE

Mechanical and Designs
This sector is responsible for the structure of Hydra, creating payloads and tailoring task-specific tools.

Software and Research
This sector is responsible for Hydra's software, as well as research and development for the ROV, with a focus on the control system.

Electrical and Electronics
This sector manages the electronics of Hydra, creating the electronics box for housing components and designing the circuitry and wiring.

Administrative and Management
This sector handles administrative duties, including public relations, documentation, and financing. It is directly under the CFO's management.

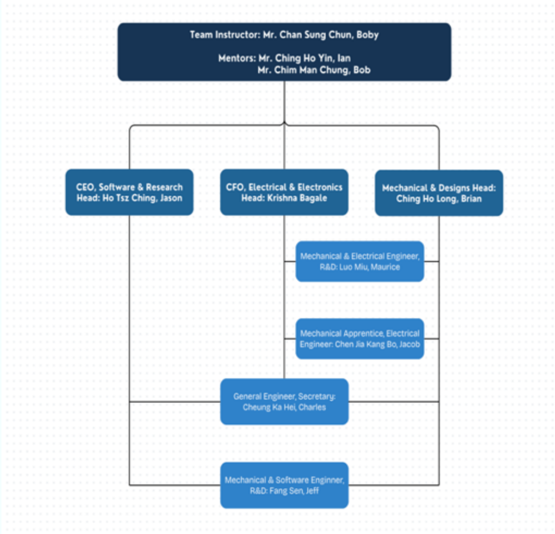


FIGURE 1: COMPANY TREE DIAGRAM

FIGURE 2: PICTURE OF OUR MEMBERS

PROJECT MANAGEMENT

To guarantee constant progress being made, weekly meetings have been conducted on Saturdays ever since September of 2024. To account for team members who could not attend, a summary would be posted in the team's group chat to ensure everyone is on the right track at any time. Meetings usually start at 10 in the morning and could last up to two hours, depending on how much is on the table.

To ensure everyone is working on Hydra efficiently and effectively, all departments are required to do a presentation on their respective current process during these meetings. This usually consists of what the departments have done, issues encountered, and what they learned. This demonstrates the commitment of our team members, as well as their gain of knowledge for future endeavours.

Despite the frequent meetings held throughout the semester, team members are encouraged to update our common repository – Notion – for information sharing. It acts as an easy way for departments to share their recent works and progress without needing to communicate in person. This greatly enhances the efficiency and work ethic in Aquamarine. Below are snippets of our Notion file, where each department's tasks and their respective progresses are listed for referencing.

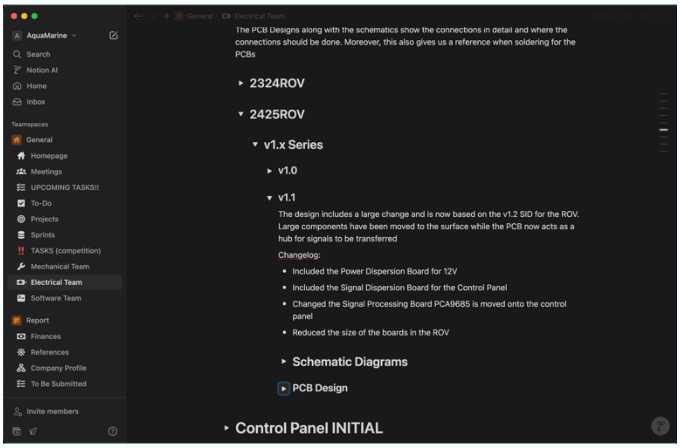


FIGURE 3: DOCUMENTATION OF ELECTRICAL TEAM

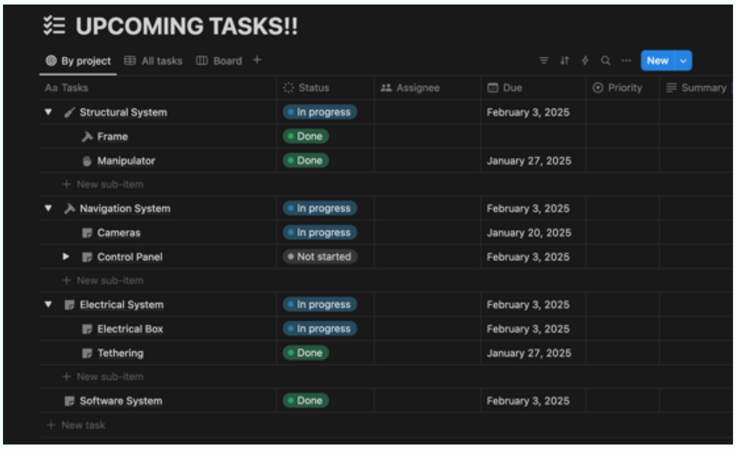


FIGURE 4: TASK LIST AND TIMELINE FOR MEMBERS TO VIEW

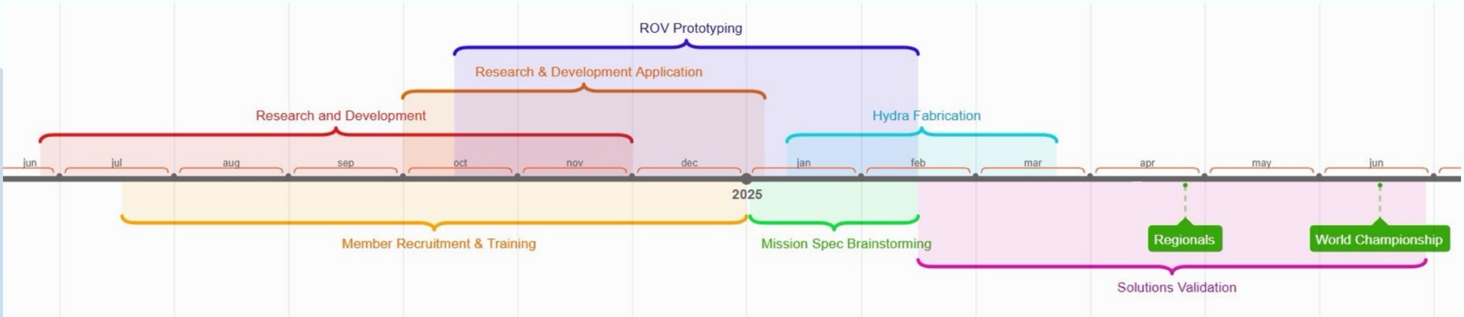


FIGURE 5: TIMELINE FOR MEMBERS TO FOLLOW

DESIGN RATIONALE

DESIGN EVOLUTION

Aquamarine has undertaken a comprehensive reassessment of the ROV's design, undergoing significant enhancements and re-designs following our participation in the 2024 competition. Besides completely revamping the structure and design, the two major issues of Hydra's predecessor, Triton, were our main targets when designing Hydra. Triton's bulkiness and water leakage posed a huge problem when traversing the waters.

The main source of bulk in Triton was its 3 different electronic enclosures for components. This year, Hydra adopts a single enclosure system to house all critical electronics, while other components, like power dispersion, can be managed outside of the enclosure by potting different wire nuts. This reduction in bulk also facilitates easier waterproofing and potting, thereby reducing problems of leakage. The other source of bulk was the unnecessarily large frame used to hold the ROV, which resulted from a miscommunication between the mechanical and electrical team. Time constraints did not allow for a redesign of the frame, so the team had to use what they were given. This year, better project management systems were put into place, as mentioned previously. All of these improvements come together to create a sleek and compact design that is Hydra.

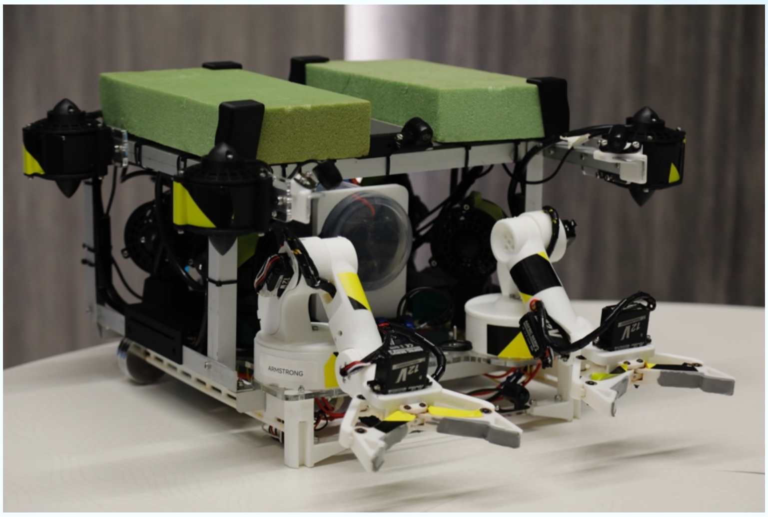


FIGURE 6: HYDRA

DESIGN PROCESS

When designing Hydra, Aquamarine's engineers remained firmly guided by our core developmental principles, known as **CUES**: Cost-effectiveness, User-friendliness, Efficiency, and Safety.

For example, ever since the earliest stages of development, the team prioritised the implementation of a self-balancing, auto-orienting system to enhance the piloting experience. As a result, the number and placement of thrusters were carefully engineered with self-balancing and orientation capabilities in mind. Throughout the project, every member was committed to upholding the principles of CUES, ensuring that Hydra stayed true to Aquamarine's vision.

To minimise time lost in prototyping and redesigning, Hydra and all its components were first modelled using 3D CAD software, enabling precise 1:1 scale visualisation. This approach allowed us to identify and resolve potential issues early, greatly reducing resource consumption and development time. For designs involving complex moving parts, rough sketches were initially created to guide the 3D modelling process, ensuring clarity and efficiency throughout. Figure 7 shows the initial sketch of the manipulators of Hydra.

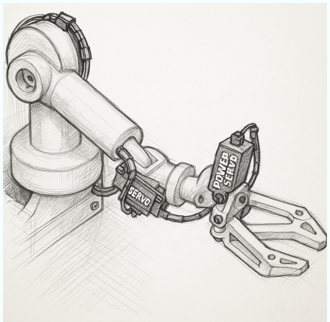


FIGURE 7: INITIAL SKETCH OF MANIPULATOR

MECHANICAL AND STRUCTURE

Structure and Frame

Continuing from last year's design, Hydra uses L-shaped aluminium strips for its frame. This lightweight yet sturdy metallic frame is 523 mm in length, 429 mm in width, and 230 mm in height. The frame was designed to optimise centre of mass and propulsion, providing increased stability when piloting. (Reference ***Buoyancy and Ballast*** for more details) This was achieved by mounting the electronic enclosure near the centre of the ROV, while thrusters were positioned at the same horizontal plane as the centre of gravity, minimizing any unnecessary pitch movement. This ties into our developmental principle of CUES – user-friendliness.

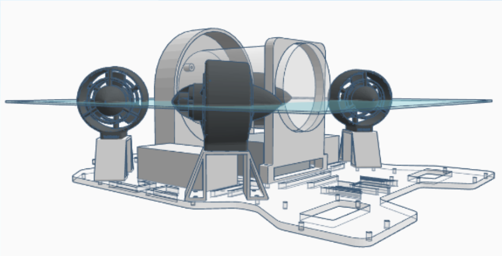


FIGURE 8: VISUALISATION OF LAYERING

A laser-cut acrylic base serves as the main board to centralise all elements into a cohesive unit. This 5 mm thick acrylic provides exceptional stability and strength to house different components (Mitsubishi Chemical America, 2018). Openings were added to the base in order to make it permeable, creating less resistance underwater (especially for vertical movement). This makes the ROV more stable and less prone to unwarranted rotations, further enhancing the piloting experience and aligning with our principles of CUES.

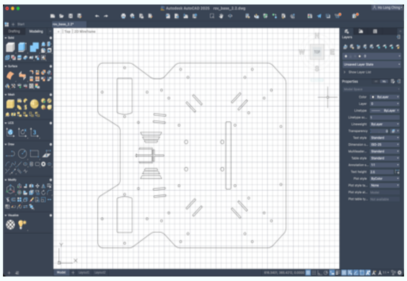


FIGURE 9: ACRYLIC BASE DESIGNED IN AUTOCAD

Electronic enclosure

Hydra uses a cylindrical food storage container as its electrical enclosure. A 3D-printed housing secures the lid of the container onto Hydra, where the body of the container can hence be locked onto Hydra. This housing also gives space for cables to exit the enclosure and connects to components. Only the lid is potted, this ensures a water-tight seal while also providing the ability to twisted open the container. Compared to ROV-specific alternatives (e.g. acrylic tubing), food storage containers are easier to waterproof – a simple twist, while having strong waterproofing capabilities that rival ROV-specific alternatives on the markets. This is one of the most innovative solutions implemented in our ROV, solving the issues of waterproofing the enclosure presented in past years. (Reference ***Innovation*** for more)

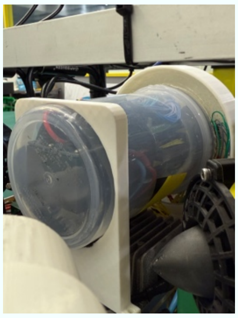


FIGURE 10: ELECTRONIC ENCLOSURE

Thrusters

This year, 8 ApisQueen U2 Mini thrusters were used instead of the 6 BlueRobotics T200 used for our previous ROVs. Following a comprehensive analysis made by our mechanical engineers, it was collectively decided that the U2 Mini offers an optimal balance of performance and stability. The T200 drastically exceeds the power limitations: this industrial-grade, high cost thruster was deemed unwarranted by the team. The U2 Mini also has a factory-potted ESC (electronic speed controller), meaning that our team need not spend time waterproofing the ESCs like our previous designs. In adherence to the IP20 safety standards for thrusters, custom thruster guards with a maximum aperture of 8.2mm were designed and installed to prevent intrusion of small objects, preventing potential harm to aquatic wildlife and plant life.

Thruster	Max. Force	Voltage	Max. Current	Price (USD)
T200	36.4N (12V)	10-20V	17A (12V)	Free (re-use) (Market cost: $200)
U2 Mini	8.8N (12V)	12-16V	8A (12V)	$32.00

FIGURE 11: COMPARISON OF THRUSTER TYPES U2 MINI AND T200

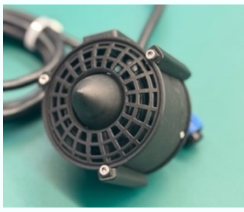


FIGURE 12: THRUSTER GUARDS FOR U2 MINI

Propulsion

Four vertical thrusters are positioned at the outermost edges of the ROV to maximize torque. This arrangement ensures that, even with additional load, the thrusters can generate sufficient torque to lift Hydra underwater. The four horizontal thrusters are anchored at 45° angles, compared to previous designs of 35° anchors. This arrangement allows for agility for both axis of translational movement and yaw rotations, instead of favouring translational movement in the x-axis. (Figure 13)

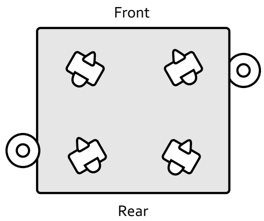
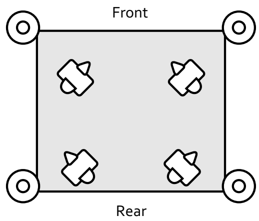
Triton (ROV 2024)	Hydra (ROV 2025)
	
✗ Thrusters are anchored at 35°, only favouring translational movement in x-axis.	✓ Thrusters are anchored at 45°, agility in all axes of lateral movement and rotation.
✗ Only 2 thrusters for vertical propulsion, leading to poor balancing.	✓ 4 thrusters for vertical propulsion, allowing self-balancing using IMU.
✗ Vertical thrusters are close to the device's centre of gravity, generating low torque.	✓ Vertical thrusters are placed at the outmost edges, maximising torque and lift.

FIGURE 13: COMPARISON BETWEEN TRITON AND HYDRA

Owing to the limitations on electrical current, Hydra's current cannot be larger than 25A. It is crucial to find the balance between thrust and current. Through calibration processes (Appendix I), each thruster a set digital limit of 3.8A, giving a maximum thrust of 20N. Each horizontal thruster will provide a maximum component thrust of 20N × cos(45°) = 14.1N, giving a maximum translational thrust of 14.1N × 4 = 56.4N. The maximum lift thrust will be 20N × 4 = 80N. These values were chosen based on Hydra's terminal speed under the effects of water resistance after conducting digital simulations in SOLIDWORKS (Figure 15) and calculations (Figure 14). Hydra is programmed in a way that the total current of all thrusters will not be able to exceed 16A at any given time. Power will be digitally distributed to the thrusters to fit these constraints, where a digital failsafe will be triggered once the current drawn by thrusters is larger than 18A, temporarily shutting down all thrusters.

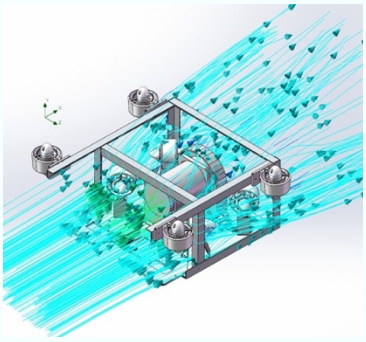


FIGURE 14: SOLIDWORKS SIMULATION OF FLUID RESISTENCE

Terminal speed is reached when $F_{net} = 0$:

$$F_{drag} = F_{thrust} \rightarrow \frac{1}{2}\rho v^2 C_d A = 56.4N$$

From simulations and measurements:

Drag coefficient (C_d) = 75.74,
Cross sectional area = 0.6313 m^2

Terminal velocity = 1.54ms^{-1}

FIGURE 15: CALCULATION OF TERMINAL VELOCITY

Buoyancy and Ballast

In a water tank, the displacement method was used to find the exact volume of Hydra, determining Hydra's initial buoyant force. Marine grade buoyancy foam was used as the extra buoyancy required to keep Hydra as close to neutrally buoyant as possible. Figure 16 shows the calculations done. These foam blocks were locked onto the structure of Hydra using custom 3D-printed mounts shown in Figure 16.

To keep the centre of mass and buoyancy at the centre of Hydra's structure. Slotted masses are fit into a slider to fine tune the centre of mass and buoyancy shown in Figure 18.

Initial net buoyancy:

$$\rho V g - mg = (997 \times 0.00480 - 9.2) \times 9.81 = -43.305\ N$$

Net buoyancy provided by foam blocks:

$$\rho V g - mg = (997 \times 0.00447 - 0.042) \times 9.81 = +43.307\ N$$

Final net buoyancy = $+0.002$ N

FIGURE 17: CALCULATION OF NET BUOYANCY

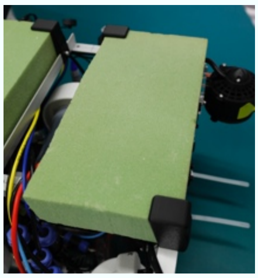


FIGURE 16: BUOYANCY FOAM & MOUNT

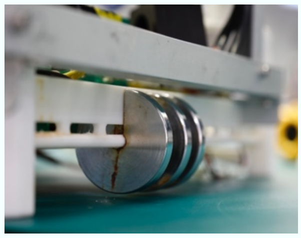


FIGURE 18: SLIDING MASS

Topside Electronics — INITIAL

Everything starts at the INITIAL, our control panel, housing all control and video systems of Hydra.

This year, to create a more capable system, a Raspberry Pi 5 was used due to its high versatility and computational power, optimal as the central controller for the ROV. Compared to previous designs which used the Arduino Mega 2560, the Raspberry Pi 5 does not require any additional host shields for USB human interface devices (HIDs), making it a favourable choice when needing to connect multiple USB HIDs into one system.

Following previous designs, the *Logitech Extreme 3D Pro Joystick* has proven itself to be the most suitable input device and is used to control Hydra. This joystick was meant for flight simulations, making it a favourable option for ROV control, due to both the same degrees of freedom. An addition to our system is a *Logitech F710 Gamepad*, which is used to control the manipulators. Having to use multiple USB devices, it gave us more reason to switch to the Raspberry Pi 5.

FIGURE 19: INITIAL

The INITIAL has an acrylic board which covers the internal electronics, providing protection of the electronics against water splashes from the poolside. This acrylic board hosts all the plug connections to all components. RJ-45 plugs are used for all signals, and Radiall Banana Plugs are used for power. A small custom PCB was created to manage the signal wires in the INITIAL.

A 24" monitor is used for viewing the main cameras. It is connected to a 4-channel DVR (digital video recorder). Two portable monitors are plugged externally onto the control acrylic, where panel mounts connect them to their respective components. One is connected to another DVR for task-specific cameras, while another connects to the Raspberry Pi 5, serving as a GUI display.

The Tether

The team determined that 25 metres will be most suitable length for the tether. It is plugged into the acrylic panel of the INITIAL and has 5 main parts. A cable reel is used to for the poolside operator to easily manage the release/retraction of the tether.

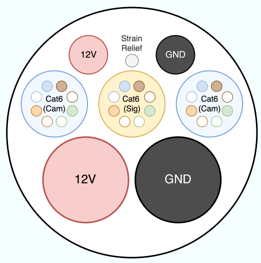


FIGURE 20: CROSS-SECTION OF TETHER

Two 6-AWG wires are used to transmit 12V and ground (GND) across the long tether. The use of a low AWG is to minimise the power loss from the long distance travelled across the tether. Previous designs had too much power loss across their 12-AWG power wires, hence a balance was found in the bulkiness of the power cable and the power loss across the cable.

One Nissen Cat6 cables wire is used to transmit the signals between the Raspberry Pi and the components underwater – 2 pairs of wires transmit signals using the RS-485 protocol, while the rest are responsible for resetting the Arduino Mega 2560 Pro and Mini Maestro (RST) and common grounds (GND). Two additional Nissen Cat6 cables are used for the camera vision system (Ref. Vision System). Twisted pair cables were specifically chosen this year, as the twisted pairs would improve data transmission by reducing the electromagnetic interference (EMI) generated (BYJU'S, n.d.).

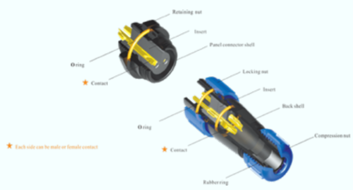


FIGURE 21: SP-21 EXPLODED VIEW

The tether is attached by Radiall Banana Plugs — Safety Series on the topside, acting as a safer version of the generic banana plugs due to the retractable sleeve protecting it from water damage. The SP21 waterproof plugs by WEIPU on the bottomside make the tether detachable from the ROV while providing IP68 to the connection point, ensuring the safety of the connection. The tether being detachable provides the ability to move the ROV and tether separately.

Bottomside Electronics — ULTIMO

As we learnt from the previous ROV, the use of I2C to communicate across long distances is unstable and has high latency across long distances. Thus, a secondary communication device, an Arduino Mega 2560 Pro is put inside Ultimo, providing the ability for low latency communication between sensors which is very important for real-time processing.

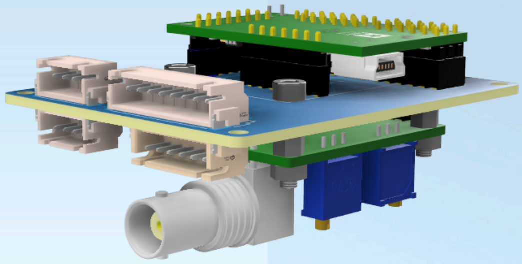


FIGURE 22: 3D MODEL OF "INPUT PCB"

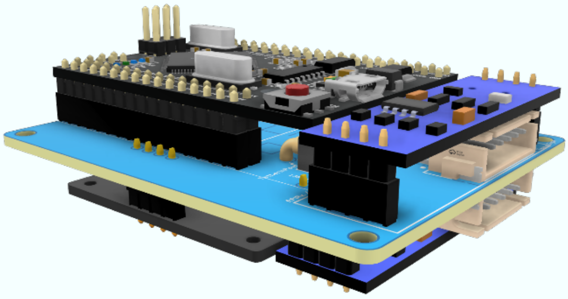


FIGURE 23: 3D MODEL OF PROCESS PCB

The Pololu 18-channel Mini Maestro was used as the microcontroller for the ROV to provide PWM for the 8 thrusters and 8 servos. In contrast to the Adafruit PCA9685, the Pololu Maestro allows for easy processing of errors due to the ability to generate an error code through its servo controller.

Other sensors such as an IMU and pH module are also included in the PCB, providing more information for actions such as PID, or act as task-specific tools. (Details in ***Payload Tools and Sensors***).

Thus, unique PCBs are created. The "Input" PCB (Figure 22), hoisting the Arduino Mega 2560 Pro, where the signals received from the tether; The "Process" PCB (Figure 23), hoisting the Polulu 18-channel Mini Maestro, acting as the PCB for the output of all PWM signals for all ROV components. These PCBs allow for easier debugging as the schematic of the PCB can be referred for any and all troubleshooting, allow for reusable components as they can be taken off the PCB, and also easy wire management inside the electrical enclosure as connections are completed in the PCB entirely.

A 12V boost converter was used to provide power to the thrusters, and servos. In previous years, the voltage loss when going through the tether was neglected. A boost converter is used to ensure the input voltage of the components is at its nominal voltage rating to avoid damaging components. The boost converter is required to compensate for the loss of 0.67V, providing adequate voltage to meet the nominal voltage of components. An additional 5V bump converter was used for IMU and Arduino Mega 2560 Pro, and a 3.3V bump converter for the camera system.

Voltage In	Current	Resistance	Voltage Loss	Voltage Out
12.0V	24.67A	0.064Ω	−0.67V	11.33V

FIGURE 24: VOLTAGE CALCULATION

SOFTWARE AND COMMUNICATION

As mentioned previously, the RS-485 protocol was used to transmit data from the INITIAL to Hydra. The choice to use the Rs-485 protocol is due to its stability for high-speed, long distance transmissions (Simon, 2024). For our design, the balance between speed and stability was found at a transmission speed of 5.76kb/s. This contrasts our previous design of using I2C extenders, which is unfavourable for long distances and has a high-latency when used. The data packets transmitted to Hydra from the INITIAL are 16 PWM values, while the values received by the INITIAL from Hydra are 3 angular values from the IMU and 1 pH value. The INITIAL RaspberryPi connects to a portable monitor for GUI display. Using the PyGame library, the pilot can view the speed of each thruster, the status of the manipulators, sensory values, etc. This further supports our developmental principles of CUES, as it allows the pilot to have a graphical view of all different processes at the same time. It also serves as the display for the data from our buoyancy engine, ***Dolphin***. (Refer to the ***NRD Design Document***)

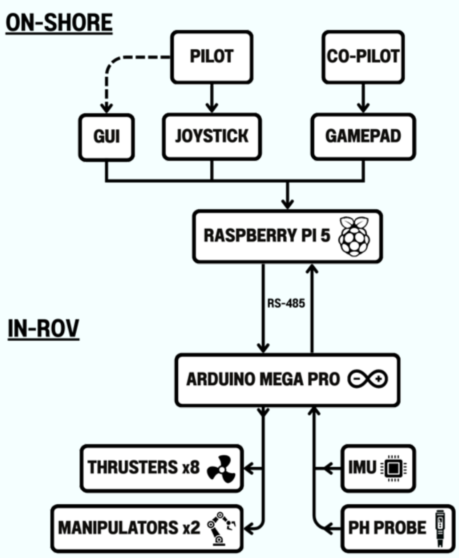


FIGURE 25: LOGIC FLOWCHART

PAYLOAD TOOLS AND SENSORS

Vision system

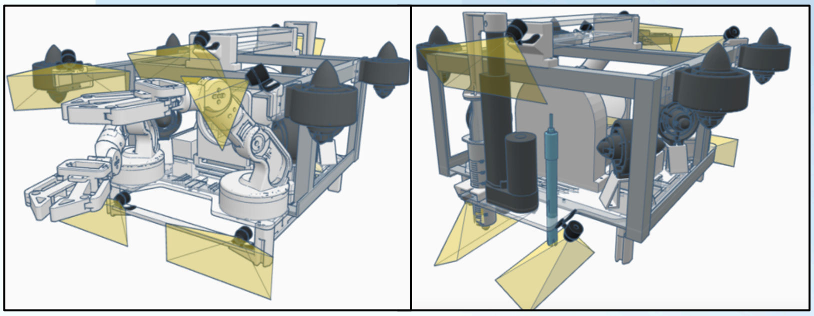


FIGURE 26.1 & 26.2: PLACEMENT OF CAMERAS (CAD VISUALISATION)

8 wide-angle rear-view car cameras (170°) were used as for the vision system of Hydra. This new video system allows for double the amount of cameras to be used simultaneously compared to previous designs. These cameras are connected to 2 passive camera baluns (4 each) and is linked to shore using CAT6 cables, which are connected to another set of baluns. A set of 4 cameras is connected to a digital video recorder (DVR) in the INITIAL: two are used to look at the front and rear of Hydra, while two look at the manipulators (refer to ***Twin Manipulator System***). Another 4 were used for task-specifics: two were used for the sample extractor (refer to ***Sample Extractor***), while two were used for shipwreck measurements (refer to ***Shipwreck Measurements***). Figures 26.1 and 26.2 show the placement of cameras on Hydra. The cameras used were analogue cameras, which when compared to digital ones, cost less, offer lower latency and longer transmissions. Also, these cameras come with an IP68 rating, making it even more favourable. The team did not see a strong reason to use digital cameras, since the effect of them can be achieved by using capture devices.

Shipwreck Measurements

For measuring the size of an object, Hydra adopts a stereo camera system. The two cameras create a depth disparity and allows for the software to compute the distance from an object and its size of an object. The cameras are connecting to a computer using a dual HDMI capture device. Using OpenCV, the software takes data from both cameras and masks out the target object. It then computes the size using trigonometric algorithms (For more details, see Appendix III). With an average uncertainty of ±2.8cm, this system can accurately measure a distant object and complete the requirements of ***Task 1.1 Shipwrecks***.

360° Photosphere

To create the photosphere required in ***Task 1.1 Shipwrecks***, the independent sensor used was an *Insta360 OneX*. The device itself is not waterproof, so a custom made waterproof casing was used. It is attached to a custom-fitted base, so Hydra can use its manipulators to place the sensor into the designated area. Adhering to MATE's safety standards, the on-board battery was removed. Instead, a long power cable was used to power the device (Reference ***SIDs***). After scanning its surroundings, the device would save the data onto its on-board micro SD card, which the poolside operator can retrieve and give to the control station personnel for analysis. Due to the limited development time, our team deemed the opportunity cost of developing a custom sensor to be too high and not worth the time and cost required. Using a commercial grade product lead to lower R&D costs and ensures quality without needing to spend a lot of time developing a custom independent sensor for this task.

Sample Extractor

The sample extractor consists of three components: the linear actuator, syringe, and pH sensor. They are fixed in position on the acrylic base at the back of Hydra, which allows us to balance the weight contributed by the twin manipulator on the front of Hydra. A tailor-made 3D model connects the waterproof linear actuator with the syringe. The pH sensor is positioned right next to the extraction system for in-situ sample testing. To function, the pilot has to manipulate Hydra such that either the syringe, or pH sensor is inserted into the sample underwater.

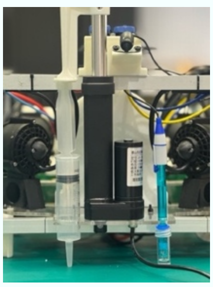


FIGURE 27: SAMPLE EXTRACTOR

Twin-Manipulator System

Each manipulator has three degrees of freedom (DOFs) (Figure 28). Having this many DOFs facilitates more precise operations for different tasks. Instead of moving the entire ROV to complete tasks, the pilots can utilize the dexterity of the manipulators, allowing them to accomplish tasks without repositioning the entire ROV. This improves the accuracy and efficiency of Hydra, enhancing the user-friendliness and thus aligns with our principles of CUES.

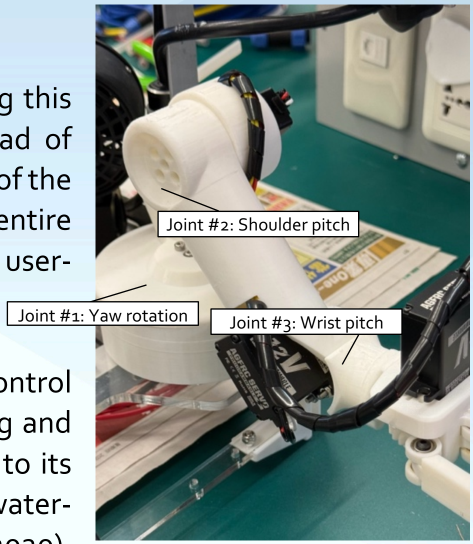


FIGURE 28: DEGREES OF FREEDOM

Four of the SA75CVSW-V2 high-torque waterproof servos were used to control each manipulator, with 3 controlling its DOFs and 1 controlling the opening and closing of the mechanical gripper. These coreless servos were chosen due to its high overload capacity, excellent heat dissipation (further enhanced by water-cooling underwater), and high torque-to-weight ratio, etc (Servotechnica, 2020). The combined weight of the servos, along with the length of each arm segment, generates a significant amount of torque. To relieve the servo's stress, almost all components of robotic arm are 3D printed using PETG – a light-weight yet strong material (except for small gears and servo horns, which use aluminium alloy). Additionally, since each servo contributes substantial torque to the system, the self-rotating "roll" axis of the gripper was sacrificed, as no tasks strictly require such rotating mechanism.

At the same time, two identical robotic arms were installed on the robot to enable two-handed interaction, similar to humans. A number of tasks require replacing old, broken equipment with newly refurbished ones. With a single manipulator system, valuable time would be wasted if the ROV needs to approach the surface for replacement every time a broken piece of equipment is retrieved. In contrast, a twin-manipulator system allows for greater efficiency: one arm can hold the new equipment while the other removes the broken component, facilitating a seamless replacement in a single motion. This approach significantly enhances operational efficiency and aligns with our principles of CUES.

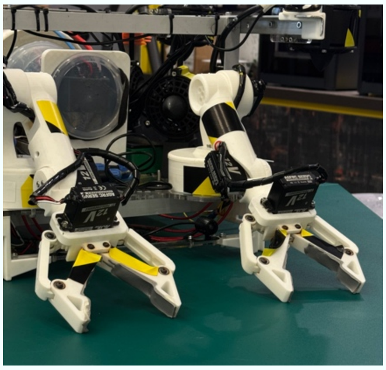


FIGURE 29: TWIN MANIPULATOR

In order to complete different tasks, a custom 3D printed different "adapters" were made. These "adapters" allows us to quickly install and replace the required equipment for different tasks, instead of installing additional task-specific tools, which simplifies the design of the entire robot and reduces the weight of the overall robot.

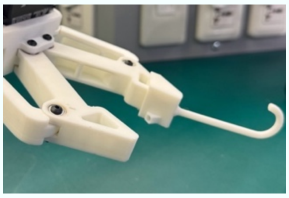


FIGURE 30: HOOK ADAPTER

Inertial Measurement Unit (IMU)

The twin-manipulator system mentioned above contributes to a large amount of weight, and together with its movement, creates an unpredictable imbalance of weight. To solve this, an IMU is required for real-time adjustments. The Hiwonder IM10A Inertial Navigation Module was used in the system to maintain balance within Hydra. By computing the roll, pitch and yaw values using its in-built accelerometer, gyroscope and magnetometer, a closed-loop control system is created. The on-board Arduino Mega Pro acts as a PID controller, auto-levelling Hydra at all times. The effects of auto-heading can also be achieved with the same principles. This would allow for easier steering for the pilot and lets Hydra maintain its stability even after picking up items using its manipulators. This IMU is placed along the centre of the axes of Hydra to reduce vibrations and hence reduces fluctuations in measurements. The accuracy and flexibility of this 10-axis IMU makes it a favourable choice over other alternatives. This enhances the user-friendliness and aligns with our principles of CUES.

SAFETY

SAFETY PHILOSOPHY

Safety is of paramount importance in our company and cannot be ignored under any circumstances. Aquamarine believes that all accidents can be prevented through the strict implementation and enforcement of safety measures designed to protect all members. Drawing on our experiences from previous years, we have developed and enforced comprehensive safety protocols to ensure a secure working environment, providing peace of mind for everyone at work.

VEHICLE SAFETY MEASURES

Safety is an elemental aspect of Hydra's design, with our engineers actively working to incorporate all necessary safety features to ensure user protection. They cautiously polish all sharp edges and corners to eliminate potential hazards. Moving parts, such as thrusters, are clearly marked with hazard labels, and all thrusters are shrouded and equipped with guards to prevent unsuitable objects from entering. Additionally, a kill box is installed between the tether and power supply, featuring a 25-amp inline fuse near the Anderson power connectors, as well as a 50V 2200 µF capacitor in parallel with the on/off switch to enable immediate system shutdown if needed. These measures allow a safer operating environment for users.

LAB SAFETY PRACTICE

All members of Aquamarine are required to strictly adhere to safety protocols while working in the laboratory. Personal protective equipment, such as safety goggles and hearing protectors, are provided, and masks are issued for individual use. Safety goggles and hearing protectors must be worn at all times when handling machinery and power tools. Members whose work generates particulates, such as when working with epoxy or fibres, are required to wear masks and protective gloves throughout the task. Additionally, air ventilation systems are employed when using the laser cutter to mitigate the toxic gases produced during the process, protecting members.

At Aquamarine, all new members undergo rigorous peer-to-peer training before engaging in any laboratory tasks, ensuring that everyone is familiar with safety protocols. Members are encouraged to remind and assist one another in addressing potential safety hazards, such as turning off unused tools and helping with heavy lifting. Furthermore, all members are invited to proactively update safety protocols when necessary to minimize the risk of dangerous situations.

FIGURE 31: WEARING SAFETY GLOVE AND GOGGLES WHILE SANDING

TROUBLESHOOTING

TESTING PROTOCOL

Inevitably, bugs and issues will come forth when testing software and electrical systems. This is the nature of engineering and is unavoidable. In previous years, a significant of time was wasted when testing and troubleshooting unnecessary items. To reduce the time wasted, the following troubleshooting protocol was developed. It is designed to systematically identify and resolve issues within software systems, where the steps are organised in a logical order: from most likely to fail and easiest to debug to least likely to fail and most complex to debug. Team members are strongly advised to adhere to this troubleshooting protocol.

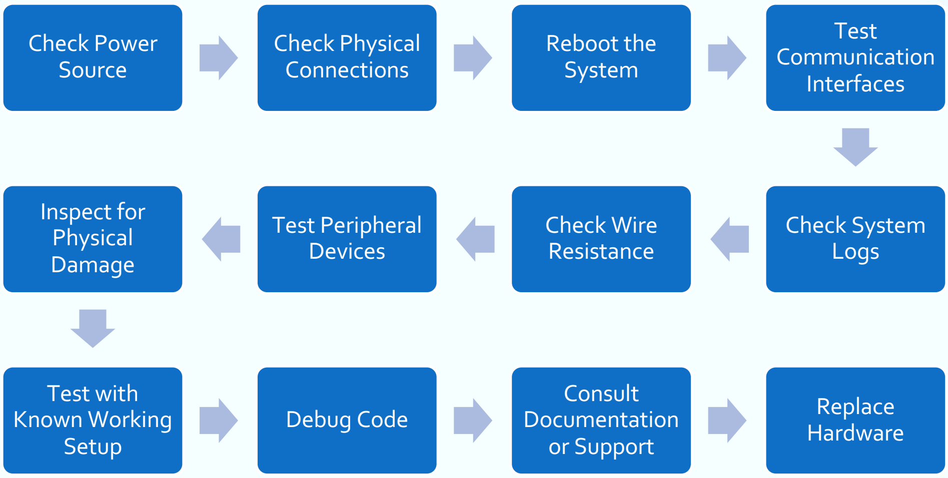


FIGURE 32: TROUBLESHOOTING PROCEDURE

TESTING & TROUBLESHOOTING TECHNIQUES

Throughout the development of Hydra, we have demonstrated a comprehensive approach to creating not just a reliable, but also an effective underwater robot. The troubleshooting procedures we had developed to avoid past mistakes make emphasis on trial and error, which allows us to ensure that before integration, each module would have already been rigorously tested, and refined, which leads to an overall enhanced performance of the system. Whenever errors rose during the testing, we would follow the protocol and debug accordingly.

With numerous engineers equipped with limitless creativity, we often come up with numerous designs for one singular object. To utilise the best design out of the proposed designs, we print out a prototype of all the designs and let them undergo what they will be functioning as in Hydra while factoring in other elements such as cost, durability, efficiency, and such, ultimately choosing the best design. Often times it takes numerous failures before a design works flawlessly. Figure 33 and 34 show the prototypes of components in Hydra.

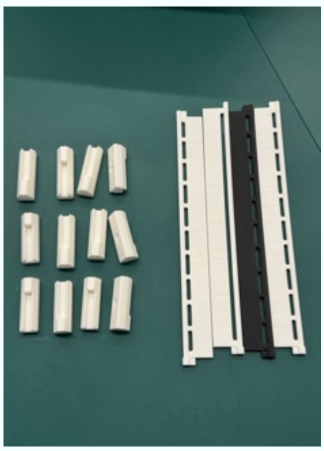


FIGURE 33: PROTOTYPES OF SLIDING MASS POLE AND BASE

FIGURE 34: PROTOTYPES OF MANIPULATOR COMPONENTS

CHALLENGES AND SOLUTIONS

TECHNICAL CHALLENGES

CABLE MANAGEMENT

Cable management is one of the most important factors when it comes to engineering, and Hydra is no different. For previous designs (including Triton and the prototype in October), we focused on the general functionality instead of the workmanship – we only needed it to work. However, this lead to a lot of different issues, like poorly designed outlets from the electronic box, useless stretches of electrical cables, etc. This resulted in concerns regarding efficiency, maintenance, and safety. For Hydra, although it was not easy to have good cable management, we still tried our best to map out where the wires should go in order to minimise the wasted wire length. Also, we tried to include as much labelling as possible in order to make debugging and maintenance easier. All in all, the cable management situation was improved significantly since our designs.

PRECISE MANIPULATION

Achieving precision in manipulation is critical for completing various tasks effectively. The manipulator acts as the robot's hand; thus, the more precise it is, the greater its capabilities. To enhance precision, we aimed to incorporate multiple rotational axes to allow for detailed movements. However, this was not a straightforward task due to our lack of experience. Despite extensive research and development, we struggled to finalize the design. Ultimately, we decided to leverage third-party resources available online, which led us to a well-built manipulator arm capable of executing complex motions. This solution not only provided us with a compact design but also reduced the need for an excessive number of mission-specific tools.

FIGURE 35: MANIPULATOR

NON-TECHNICAL CHALLENGE

TIME MANAGEMENT

As the team progresses to senior forms, especially with many members in Grade 11, the workload has significantly increased, particularly with the impending closing date of the final examinations. Balancing academic responsibilities with non-academic commitments, such as this competition, has become increasingly challenging. Finding an equilibrium between work life, school life, and personal life is difficult, as we need to dedicate time to excel in competitions to enhance our portfolios and acquire valuable skills. At the same time, we must prioritize our academic performance for our future while ensuring we allow ourselves sufficient time to rest amidst the pressures we face.

Navigating these hardships has not only made us more resilient individuals but has also helped us develop high-quality work habits and efficiency. We've learned to manage our time effectively, setting clear priorities that allow us to juggle multiple responsibilities. This experience has taught us the importance of self-care and the need to recharge, as burnout can hinder productivity. By supporting each other and sharing strategies for success, we've created a collaborative environment that fosters growth. Overall, these challenges are shaping us into well-rounded individuals, preparing us for the demands of both academic and professional pursuits while maintaining a healthy lifestyle.

INNOVATION

Throughout the development of Hydra, the team has devised innovative solutions to overcome challenges in a cost-effective yet sophisticated manner. One notable example is the improvement in waterproofing techniques. Previously, the standard practice was to completely fill the electronics enclosure with AB glue. While this method ensured a watertight seal, it permanently fixed all internal components in place, making maintenance, upgrades, and troubleshooting almost impossible. The glue in the enclosure needed to be taken apart and re-sealed if upgrades or changes were required. It also created bulk, making the ROV more difficult to manoeuvre.

To address this, the team introduced the use of waterproof cables (Figure 36), allowing external devices to be connected to the internal systems and without compromising the enclosure's seal. Furthermore, the AB glue now only covers the lid of the enclosure, allowing the enclosure to be easily twisted open for in-depth maintenance. This new system not only maintains reliable waterproofing but also allows for efficient access to internal components, greatly enhancing Hydra's maintainability and enabling in-depth debugging when necessary.

FIGURE 36: WATERPROOF TYPE-C CABLES

LESSON LEARNED

Rearrangement of Working Protocol

From previous competitions, we recognized that effective communication is key to our success. In the past, team members had little to no knowledge of each other's work, which led to major integration challenges. One significant issue was the poor planning and construction of the ROV, resulting from a lack of collaborative information sharing.

To improve this situation, weekly meetings were held to foster better communication. Members were also required to use Notion, a centralised document system for members to publish their tasks and progress between integration between sectors. As a result, team members became more aware of each other's progress and could offer assistance, leading to enhanced efficiency and integration. This year, these changes significantly boosted our overall progress and collaboration.

Importance of R&D

Previous competitions have taught us that a lot of mishaps can be unforeseen during the development of a robot. Something that we may have spent much of our time developing only to learn that the system is faulty due to the lack of understanding behind the processes of the ROV. A large portion of the time was only spent on the development into a faulty system, but no time was spent in doing research to understand the system.

This year, a large portion of time was spent in the researching and testing of new systems such as different communication protocols. Initially, we explored the RS-232 protocol, but it took us a while to realise that it was practically unusable due to its limited range. This oversight resulted in a significant amount of wasted time, as we have already developed systems around this protocol, which ultimately proved itself unsuitable for our application.

After conducting thorough research, we decided to switch to RS-485. This protocol offered better distance capabilities and greater reliability for our needs. The transition to RS-485 allowed us to enhance our communication system significantly, enabling more efficient data transmission over longer distances. However, we had to change our PCBs and modify a lot of our designs to fit this new design, which resulted in more time wasted. This showed us the importance of R&D, which we previously overlooked.

FUTURE IMPROVEMENTS

User Interface

Developing a web-based user interface that prioritizes responsiveness, user experience, and security is essential for enhancing mobility and convenience across various devices. This approach allows users to access the interface seamlessly from smartphones, tablets, and desktops, thereby improving overall engagement and satisfaction.

To achieve this, it is crucial to implement responsive design principles, ensuring that the layout adapts fluidly to different screen sizes and resolutions. Utilizing frameworks like Bootstrap or Tailwind CSS can facilitate this process, making it easier to create a visually appealing and functional interface.

User experience should also be at the forefront, with intuitive navigation and accessibility as key considerations. This not only helps in attracting a diverse user base but also ensures that individuals with disabilities can interact effectively with the platform.

Moreover, integrating robust security measures is vital to protect user data and build trust. Implementing secure authentication methods and adhering to best practices for data protection will enhance user confidence in the system.

While the transition to a web-based interface presents challenges, such as the need for additional web design knowledge and potential integration complexities, the long-term benefits—such as increased user engagement, improved accessibility, and a more modernized approach—make it a worthwhile investment. By continually seeking user feedback and utilizing analytics to refine the interface, you can create a dynamic platform that evolves alongside user needs and technological advancements.

Operating System

Hydra currently runs on a simple RaspberryPi and Arduino bidirectional network. It is simple and robust, but not easily expandable and will be slow as more and more components are added. Future improvements for the next generation of ROVs could be the use of the Robot Operating System (ROS).

Using ROS could focus on enhancing autonomy, communication, and system efficiency. Developing a custom control system could streamline operations while incorporating AI-based object recognition and navigation would improve autonomous decision-making. Upgraded communication systems, such as high-bandwidth acoustic modems, could enable more seamless data transfer. Optimizing power management through smart systems or energy-harvesting methods would extend mission durations. Expanding the sensor suite, including sonar, temperature, and salinity probes, would provide a deeper understanding of the environment. A modular design would make future upgrades easier, while a more intuitive operator interface would enhance real-time control. Advanced fault detection and predictive maintenance could help prevent critical failures. Additionally, incorporating hybrid propulsion systems for increased manoeuvrability and underwater charging stations would improve operational capabilities and reduce downtime, making the ROV more versatile and reliable for extended missions.

REFLECTIONS

CHING HO LONG, BRIAN (Head of Mechanical and Designs)

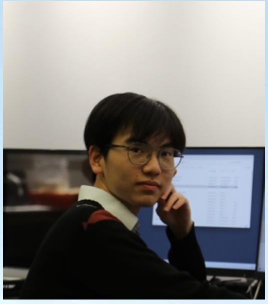


FIGURE 37: CHING HO LONG

As I approach my final year participating in these challenging yet enjoyable competitions, I find myself reflecting on the invaluable lessons I've learned along the way. This experience has taught me essential skills in engineering, time management, organization, and maintaining a healthy work-life balance. Confronting various challenges has been crucial to my personal development, pushing me to become a better individual.

Over the past three years, these competitions have fostered my ability to self-motivate, engage in self-directed learning, and set meaningful goals. As a result, I have not only enhanced my technical skills but also grown significantly as a person. I'm grateful for the journey and the opportunities it has provided to refine my abilities and prepare for the future.

CHEUNG KA HEI, CHARLES (Secretary)


FIGURE 38: CHEUNG KA HEI

As a newcomer to the MATE competition, I find these tasks extremely interesting, on one hand, it truly puts teams from all around the world up to the tasks, utilising engineering skills, from CAD design to assembling the piece. I found each of the processes to have its challenging spots, but also its uniqueness and fun, which makes them worth the time and effort. Ultimately, not only have I improved my engineering skills, but also my communication, commitment, and so many other attributes that are not limited to the engineering nature of ROVs.

HO TSZ SHING, JASON (CEO, Head of Software and Research)


FIGURE 39: HO TSZ SHING

Over the past three years, I have learned so much. From the very first day of forming this team, we have watched each other grow—from being inexperienced novices to competent individuals capable of designing complex systems from scratch. Personally, I started off as "the software guy", but I quickly expanded my skillset, delving into both electrical and mechanical design. This journey has been an incredible learning experience.

Beyond technical skills, I have also grown as a leader. Guiding a team of people is never easy, especially when you feel just as clueless—if not more—than everyone else. Amidst all the confusion, I learned the importance of staying calm and composed, assigning tasks that align with each team member's strengths. My mentor, Mr. Chan, has been instrumental in shaping my leadership abilities. He once told me:

"What separates a good leader from the rest is their ability to make use of their team members—leveraging everyone's strengths while helping them identify and improve their weaknesses."

This marks my final year of participating in the RANGER class of the MATE ROV competitions. It's been an unforgettable journey, and while I don't do well with goodbyes, I take comfort in knowing the growth and memories we've shared will stay with me forever.

Thank you to my parents and teachers who have supported me throughout this journey, and thank you to my teammates who have been at this project since day 1. We have come a long way, and I can't wait to see what's in store for us in the future!

FINANCES

COST PROJECTION AND BUDGETING

The Cost Projection and Budgeting shows the financial advances made at the start of the preparation for ROV. Deciding on how the budget should be spent for each component of our ROV.

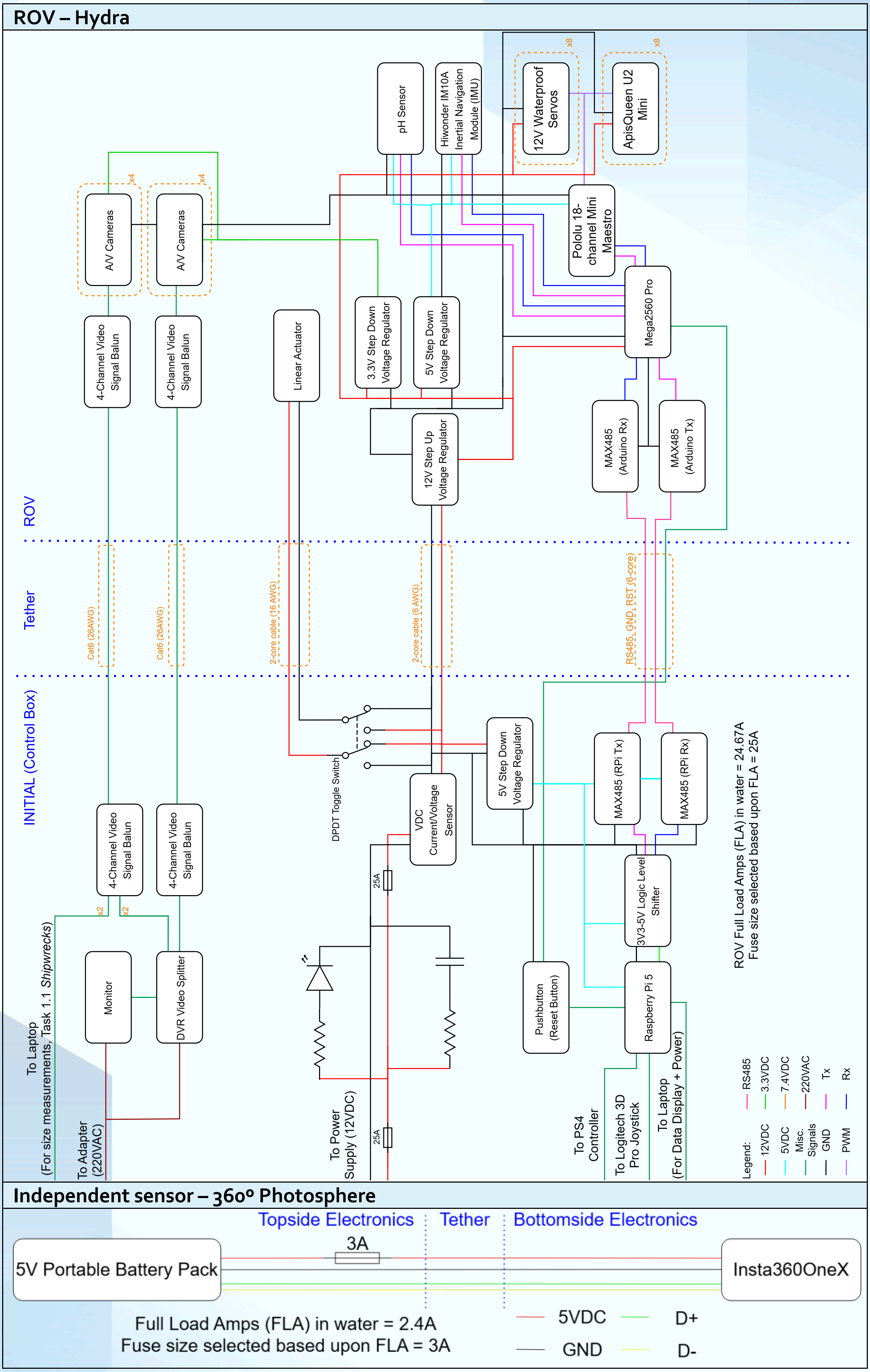
	Value (US$)	Net Cost (US$)	Description
Income			
School Funding	2578.85	2578.85	Our school, PLKNPLC, gives us funding for development
Personal Funding	4000	4000	For airfare, accommodation and research side-projects
Mechanical Expenses			
All Purchased	300	300	Electronic Enclosures, Acrylic Boards, Screws
All Inventory	500	0	Aluminium Strips (Frame), 3D Printing Filament
Electrical Expenses			
All Purchased	350	350	PCBs, Switches, Wires for other uses, Voltage Regulators
All Inventory	200	0	XT, XH2.54, Headers, Anderson, Banana Plugs
All Reused	300	0	Signal Wires, 10AWG Wires (For Power), Strain Relief
Hardware Expenses			
All Purchased	800	800	Task Specific Tools, IMU, MAX485 Modules, Servos
All Inventory	500	0	Raspberry Pi5, Thrusters
All Reused	200	0	Arduino Mega Pro, Mini Maestro
Travel Expenses			
Transport of ROV and Competition Equipment	150	150	Minitruck Fee for ROV and Equipment
Transport Fee for 7 Team Members	3500	3500	Airfare and accommodation fee for team members
ROV Competition			
Cost of Regional Competition	520	520	
MATE Fee	270	270	

FINANCIAL REPORT

The financial report shows the total expenses of the actual ROV. This includes developmental and transportation costs.

	Value (US$)	Type	Net Cost (US$)	Description
Income				
School Funding	-	Income	2578.85	Our school, PLKNPLC, gives us a set amount of funding for development
Personal Funding	-	Donation	3699.45	Members spent their own money to provide resources for the team
Additional Funding	-	Donation	967.74	After having a shortage of funds, we applied for additional funding from the school board
Mechanical Expenses				
Electronic Enclosure	4.94	Purchased	4.94	Waterproof Twistable Containers
Aluminium Strips	120	Inventory	0	L-shaped and Flat Aluminium Strips
3D Printing Filament	338.3	Inventory	0	BambuLab PLA Basic, BambuLab PETG-HF
Acrylic Boards	97.88	Purchased	97.88	White/Transparent 1m*1m*0.05m
Screws and Screwdrivers	47.74	Purchased	47.74	Hexagonal Screwdrivers and Screws (M2-M5)
Electronic Expenses				
PCB Fabrication	20	Purchased	20	5 Custom PCBs fabricated by JLCPCB
Purchased Wires	181.98	Purchased	181.98	6, 16 AWG Power (2-core Tether) and Nissen Cat6 Signal Cables
Re-used Wires	250	Reused	0	26 AWG Signal Wires, 10 AWG Power, Steel Wire (strain relief)
Plugs	100	Inventory	0	XH2.54, XT30, Headers, Anderson, Banana, Panel Mounts
Boost/Bump Regulators	60	Purchased	60	10V → 12V (Waterproof); 12V → 5V, 12V → 3.3V
Switches	30	Purchased	30	SPDT (power), DPDT (linear actuator), Emergency and Reset Buttons
Hardware Expenses				
Thrusters	256	Inventory	0	ApisQueenU2 Mini
Servos	633.52	Purchased	633.52	AGF SA75CVSW-V2
Mini Maestro	49.07	Reused	0	Mini Maestro 18-Channel USB Servo Controller (Assembled)
pH Sensors and Module	9.99	Purchased	9.99	N/A
IMU	89	Purchased	89	10-axis IMU Inertia Navigation Module (Without Shell)
Analog Cameras	120	Purchased	120	N/A
Arduino Mega Pro 2560	16.56	Reused	0	N/A
Raspbery Pi5	80	Inventory	0	2GB RAM
Miscellaneous Developmental Expenses	-	-	489.2	Estimation of costs during the development process
ROV Competition				
Cost of Regional Competition	-	-	520	
MATE Fee	-	-	270	
Travel Expenses				
Transport of ROV and Competition Equipment	-	-	150	Minitruck Fee for ROV and Equipment
Transport Fee for 6 Team Members	-	-	3000	Airfare and accommodation fee for team members (only 6 members are going to Internationals)
Total Cost	**2504.98**		**5724.25**	
ROV Competition Fee			790	
Balance			**731.79**	

SYSTEM INTEGRATATION DIAGRAM (SID)



REFERENCES

BYJU'S. (n.d.). *Faraday's Law*. Retrieved April 2, 2025

Hodanbosi, C. (1996, August). *Buoyancy: Archimedes Principle*. (J. G. Fairman, Editor, & NASA) Retrieved Janurary 08, 2025

Servotechnica. (2020, November 12). *What are the coreless motors?* . Retrieved Janurary 25, 2025

Simon, B. C. (2024, March 21). *What is RS485 Pinout, 12 Key Advantages & FAQs*. Retrieved from eTechnophiles.

ACKNOWLEDGEMENTS

Aquamarine would like to acknowledge the following for their support in giving us the chance to develop Hydra and to expand our knowledge.

MATE ROV - for organising the competition.

The Institution of Engineering and Technology (IET) and MATE Hong Kong - for organising the Hong Kong regional round, allowing Aquamarine to advance to Internationals.

All Adjudicators, staff, members, and volunteers - for their continuous support and advice.

City University of Hong Kong – for providing us valuable insight on engineering design.

Po Leung Kuk Ngan Po Ling College - for providing the development venue, financial support, equipment, and such.

Principal CHAU Chor Shing - our esteemed school principal, for providing us with financial support and skills training needed to develop and refine our designs.

Mr. Boby CHAN, Mr. Ian CHING, and Mr. Bob CHIM - our instructor and mentors, for sharing a lot of their experiences and insight during the design and construction process.

ORGANISERS AND SPONSORS

APPENDICIES

APPENDIX I – THRUSTER CALIBRATIONS

To accurately determine the current draw of the thrusters and the force provided at particular PWMs, a short experiment was conducted. A custom cross-shaped structure was constructed from PVC tubes. A thruster was attached to bottom end of the cross, while a *PASPORT Force Sensor* was hooked onto the top end. When the thruster provides a force, the force sensor experiences a pull/pushing force. This is repeated for every 0.50ms of PWM values, (measured using an CRO) where the particular force and current is recorded via the *SPARKlink Air Interface*. The values are then plotted into a graph for analysis:

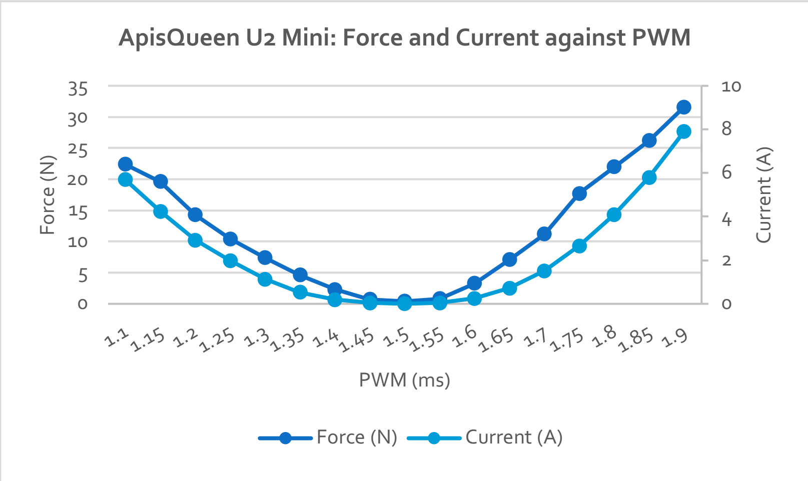


FIGURE 40: CALIBRATION GRAPH

FIGURE 41: CALIBRATION SETUP

APPENDIX II – POWER BUDGET

To account for the current allocation in the ROV, calculations are done to make sure the ROV does not go over-current.

Component	Voltage (V)	Max Current (A)	Quantity	Max Current Total (A)		Max Working Current	Max Working Current Total (A)
12V Inputs							
Apis Queen U2 Mini	12	8.0	8	64		3.8*	16*
Manipulator (AGF SA75CVSW-V2*4)	12	18	2	36		1.89	3.78
Linear Actuator	12	5.0	1	5		0.80	0.80
5V Inputs							
Arduino Mega 2560 Pro	5	1.0	1	0.42		0.40	0.17
Mini Maestro 18-Channel	5	1.0	1	0.42		0.050	0.021
MAX485 Modules	5	0.0050	4	0.0083		0.00030	0.00050
IMU	5	0.012	1	0.0050		0.012	0.0050
pH Module	5	0.0010	1	0.00042		0.0010	0.00042
3V3 Inputs							
Analog Cameras	3.3	0.010	8	0.022		0.001	0.0022
							20.78
Power Drops							
Power Drop to Tether	-0.67160198						
Power Drop to Boost Converter	11.328398	24.45		90% Conversion Efficiency			
Power Drop to Buck Converters	5	0.21		90% Conversion Efficiency			
	3.3	0.0024		90% Conversion Efficiency			
Final Full Load Amps		**24.67**					

*Thrusters do not operate at maximum simultaneously; hence the max working current total is at 16A (not 3.8A × 8)

The following equation can be used to compute the size of a distant object.

$$x = \sqrt{{d_{Rl}}^2 + {d_{Rr}}^2 - 2[d_{Rl}d_{Rr}\cos(\theta_{Rl} + \theta_{Rr})]}$$

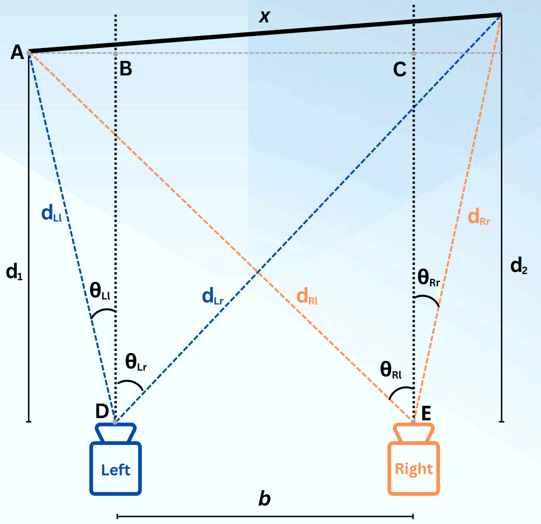


FIGURE 42: LABLED DIAGRAM OF STEREO CAMERA

Refer to FigureFigure. For a known FOV of a camera, the degree-per-pixel (dpp) is the quotient of the FOV (in degrees) and apparent on-screen pixel width of the camera feed.

Assume AB has an apparent pixel width of 380*px* on-screen, while the cameras have a dpp of *0.07°/px*, θ_{Ll} will equal to *26.6°*. Thus, the angular displacements are known and are denoted by the theta values.

The values of *d1* and *d2* are necessary to find the edge-to-camera distances (i.e. d_{Ll}, d_{Lr}, d_{Rl} and d_{Rr}). To find d_1:

$$\tan\theta_{Rl} = \frac{AC}{CE} \quad \tan\theta_{Ll} = \frac{AB}{BD}$$

And *CE* = *BD* = d_1, while b is the known distance between the cameras:

$$\therefore \tan\theta_{Rl} - \tan\theta_{Ll} = \frac{AC - AB}{d_1}$$

Therefore, d_1 can be expressed in following form. Subsequently, d_2 can be found in the same way:

$$d_1 = \frac{b}{\tan\theta_{Rl} - \tan\theta_{Ll}} \quad d_2 = \frac{b}{\tan\theta_{Lr} - \tan\theta_{Rr}}$$

Using values of d_1 and d_2, the edge-to-camera distances for the right camera can be found:

$$d_{Rl} = \frac{d_1}{\cos\theta_{Rl}} \quad d_{Rr} = \frac{d_2}{\cos\theta_{Rr}}$$

Finally, by using the law of cosines, we get:

$$x = \sqrt{{d_{Rl}}^2 + {d_{Rr}}^2 - 2[d_{Rl}d_{Rr}\cos(\theta_{Rl} + \theta_{Rr})]}$$

Using the edge-to-camera distances for the left camera can also give us another expression for x:

$$x = \sqrt{{d_{Ll}}^2 + {d_{Lr}}^2 - 2[d_{Ll}d_{Lr}\cos(\theta_{Ll} + \theta_{Lr})]}$$

The program would take the average of the two values from the two equations to give an accurate value.

The way this equation is set allows for the system to accurately compute the length of the shipwreck no matter its horizontal orientation: as shown in the figure, the equation still works despite the cameras not perfectly aligned to the shipwreck. However, it is limited in a way that orientations in the 3rd dimension (roll and pitch) cannot be accounted for, as 2 camera only account for depth disparity. This set-up, however, is easily expandable – by adding more cameras, orientations in the other axes can also be accounted for using the same mathematical principles.

APPENDIX IV – SAFETY CHECKLIST

Construction	Operation	
	Pre-power Test	In Water
□Keep the workspace clean and free of debris	□ Area safe (no tripping hazards, items in the way)	□ Check for bubbles, if large, pull ROV to surface
□Store materials properly to prevent tripping hazards	□ Verify switches and circuit breakers are off	□ Visual inspect for water leaks
□Use safety goggles or face shields when cutting and grinding	□ Tether flaked out on deck secured to ROV	□ Engage thrusters and begin operations
□Use appropriate gloves for handling materials	□ Strain relief connected to ROV	Loss Communication
□Inspect all machinery for any damage or wear before use	□ Electronics housing sealed	□ Cycle power on INTIAL to reboot ROV
□Ensure all guards and safety devices are in place and functioning	□ Visual inspection for damaged wires	□ If no communication, power down ROV
□Follow manufacturer's instructions and safety guidelines	□ Visual inspection for damaged wires	□ If communication is restored, resume operation
□Ensure all energy sources are properly isolated before servicing.	□ Thrusters free from obstructions	Pit Maintenance
□Store materials securely to prevent falls or spills	□ Power source connected to INITIAL	□ Verify thrusters are free of foreign objects
□Inspect electrical cords for damage before use.	□ INITIAL receiving 12V nominal	□ Visual inspect for any damage
□Ensure proper grounding of electrical equipment	□ Control station up and running	□ Ensure that all cables are neatly secured
□Disconnect power when changing accessories or making repairs	□ Ensure deck crew members are attentive	□ Verify tether is free of kinks
	□ Power on INITIAL	□ Visual inspect for leaks
	□ Verify thrusters are working properly	□ Test onboard tools
	□ Verify video feeds	□ Verify camera positions
		□ Washdown thrusters with water