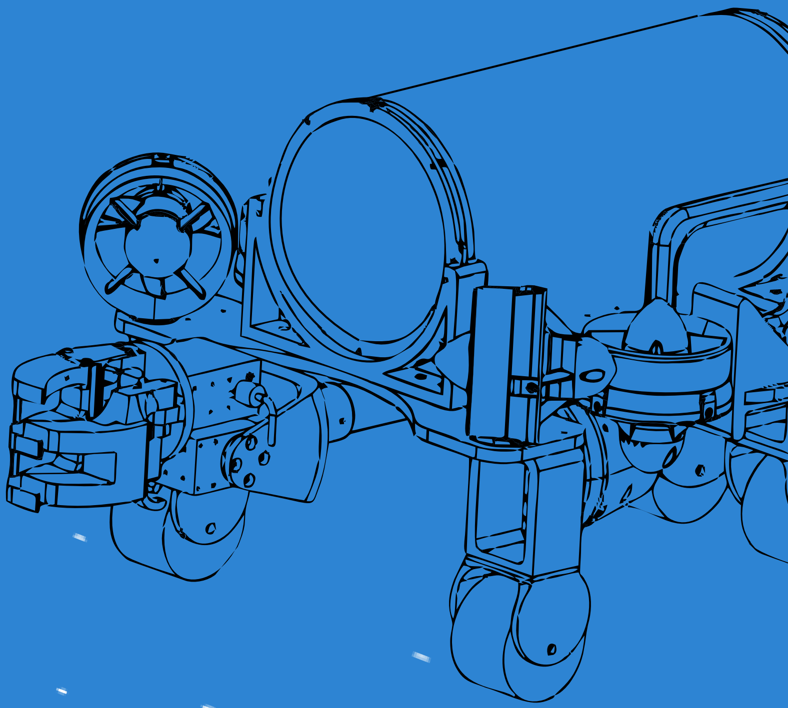
THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

TECHNICAL REPORT 2024 MATE ROV



Hong Kong

ENGINEERING ENTREPRENEURSHIP CLUB INC.

TEAM MEMBERS

Name	Job Title	Grade	Major
Leung Ming Fong	Chairman of EEC	Year 4	EIE
Ng Chun Yin	Chief Executive Officer	Year 4	EE
Leung Kam Ho	Chief Technical Officer	Year 4	EIE
Tam Ching Yuen	Chief Operating Officer	Year 4	COMP
So Wai Pang	Chief Financial Officer	Year 4	EIE
Lee Tsz Kin	Lead Engineer	Year 3	EE
Tsoi Ting Wai	Electrical Engineer	Year 4	EE
Zhang Kin Hang	Software Engineer	Year 2	EIE
Chung Tak Yu	Mechanical Engineer	Year 2	EE
Zou Mingyang	Mechanical Engineer	Year 2	EE

SUPERVISORS

Prof. Tam Hwa Yaw
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MENTORS

Mr. Cheuk Chi Ming
Mr. Lo Long Yin
Mr. Tam Hei Shek, Anson
Mr. Tsang Wai Ho

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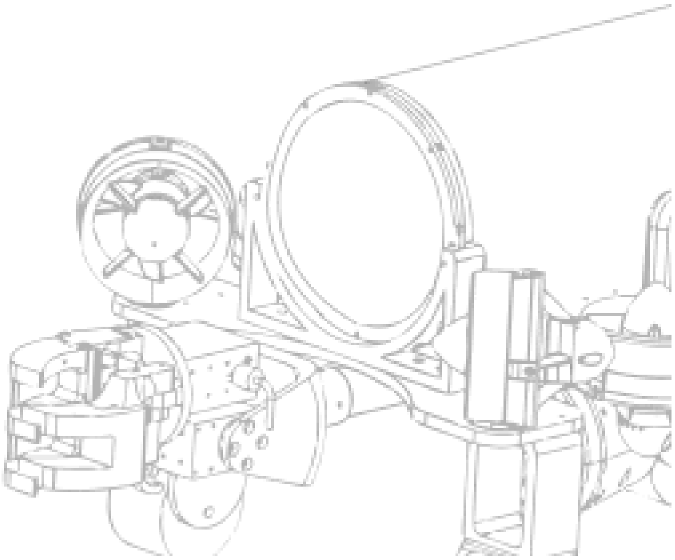


1. Abstract

Figure 1.1 Team Photo

Figure 1.2 Photo of Manta Ray

The Engineering Entrepreneurship Club Inc. ("EEC") is comprised of ten engineering students from The Hong Kong Polytechnic University who are enthusiastic about constructing reliable and cost-effective robotic systems to resolve various real-life problems, particularly in a marine environment.

This year, EEC is dedicated to preparing our remotely operated vehicle (ROV) named "Manta Ray" to contribute towards achieving the United Nations' sustainable development goals and the Ocean Decade Challenges for collective impact. Our focus areas include expanding the Global Ocean Observing System, protecting and restoring ecosystems and biodiversity, and unlocking ocean-based solutions to climate change.

To ensure the "Manta Ray" performs at its best, the EEC has made significant upgrades to enhance its capabilities compared to the previous model, particularly in stability and durability during underwater operations. These upgrades include using high-quality materials, reinforced components, and a flexible frame to withstand harsh underwater conditions, improving the ROV's reliability and ability to perform complex tasks consistently.

In addition to the ROV, the EEC also has a vehicle called "Float", joining for Climate Action, equipped with sensors to collect data on the impact of climate change on the ocean. The EEC is excited about the potential impact their projects can make towards achieving UN sustainable development goals and is committed to promoting sustainable engineering practices.

2. Teamwork

2.1. Company Structure

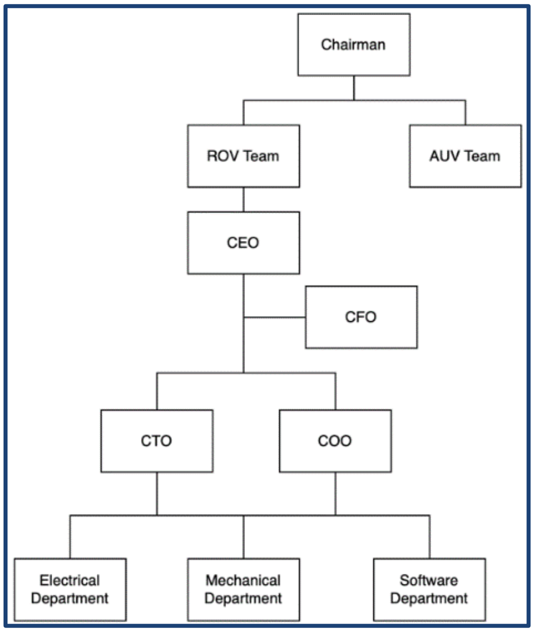


Figure 2.1.1 Company Structure

This project has been broken down into three major parts – project management, software, and hardware. Workload has also been allocated to different departments of our organization. Refer to Figure 2.1.1 for further information about the company structure. This work breakdown structure was extensively used to create mini-tasks, which were created from a larger sub-project that was divided. Doing so makes allocating jobs much more manageable and traceable.

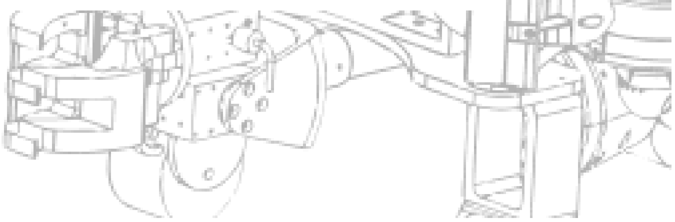
EEC comprises three departments: the Mechanical Department, the Electrical Department, and the Software Department. The Mechanical and Electrical Departments are responsible for designing and handling technical issues of the hardware components, including developing the circuits, choosing suitable components, soldering electronics onto circuit boards, and waterproofing the main electronics chambers. The Software Department programs Raspberry Pi, the Manta Ray's central processor, and designs algorithms to calculate the dimensions that were discussed in detail above.

2.2. Work Allocations and Project Schedule

In terms of project management, the CEO of the EEC has the role of overseeing the company's operation and the project's progress, like designing the Gantt chart to monitor working progress and ensure the project stays on track with the ideal schedule. Please refer to Figure 2.2.1 for the Gantt chart of EEC. The CTO is responsible for the overall design and operations of ROV, and he is also the head of the software team. The CFO is responsible for managing the company's financial status; they will manage the company's funding and prepare the financial statements, such as making a budget plan.

	September, 2023	October, 2023	November,2023	December, 2023	January, 2024	Feburary, 2024	March, 2024	April, 2024
Briefing and Workshop	🟪	🟪						
Design of ROV	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Frame	🟩	🟩	🟩	🟩				
Robotic Arm				🟩	🟩	🟩	🟩	🟩
First Prototype	🟩	🟩						
Second Prototype			🟩	🟩	🟩	🟩	🟩	🟩
Design of Float	🟥	🟥	🟥					
First Prototype	🟥							
Second Prototype		🟥	🟥					
Electrical	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Component Intsallation	🟦			🟦				
Digital Camera	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Software	🟨	🟨	🟨	🟨	🟨	🟨		
OpenCV						🟨		
Control Interface	🟨	🟨	🟨	🟨	🟨			
Task Practice					🟧	🟧	🟧	🟧

Figure 2.2.1 Project Schedule

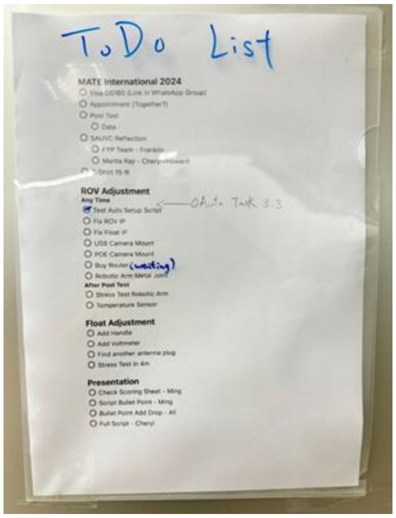


2.3. Resources, Procedures, and Protocols

The timeline of Manta Ray can be categorized into four stages, which include planning, designing, constructing, and testing. To ensure communication and flow of information in the team, regular team meetings were held to discuss team progress and upcoming arrangements on the timeline (Figure 2.2.1, 2.3.1). When EEC received the mission description, we first broke down the tasks and labelled any specific mission requirements that needed more attention on the design or new components (Figure 2.3.2). For instance, a temperature sensor and an individual float are required in the mission this year, and 2-dimentional movable gripper would be advantageous for many placing tasks. Then, we further brainstorm strategies and difficulties in different approaches to completing the missions. Mentors will join our meetings to advise on our design ideas and strategies. Subsequently, the company shifts towards the designing and construction phase. The team is split into three integral components - electronic and electrical, software, and mechanical - and collaborate in designing and creating prototypes.

Our team uses Fusion 360 for mechanical design for resource management. Manta Ray's robotic arm, omni wheel levelling platform, and the inner frame of the Manta Ray are designed throughout the team space we created in Fusion 360. With the team space, members can review and edit the design, whether it is finished or not. We can keep tracking the progress of our design, brainstorm ideas, make different versions of one component, and make comparisons.

Prototypes test out potential design problems and compare different innovative ideas to find the optimal one. Once the designs are confirmed, the sub-teams will start integrating modules together and ready for water testing. Our team emphasized an agile development cycle, in which we focus on rapid testing and modification. To document the process, meeting notes and debriefings were made after each water test to keep recording the problems and solutions.



ToDo List

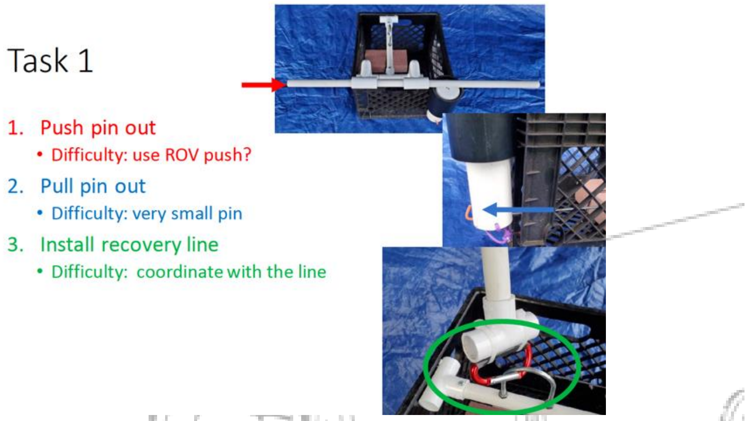
MATE International 2024
○ Visa DS160 (Link in WhatsApp Group)
○ Appointment (Together?)
○ Pool Test
  ○ Date:
○ SAUVC Reflection
  ○ FYP Team - Franklin
  ○ Manta Ray - Cheryl+Howard
○ T-Shirt [illegible]

ROV Adjustment
Any Time
☑ Test Auto Setup Script ← Auto Task 3.3
○ Fix ROV IP
○ Fix Float IP
○ USB Camera Mount
○ POE Camera Mount
○ Buy Router (waiting)
○ Robotic Arm Metal Joint
After Pool Test
○ Stress Test Robotic Arm
○ Temperature Sensor

Float Adjustment
○ Add Handle
○ Add Voltmeter
○ Find another antenna plug
○ Stress Test in 4m

Presentation
○ Check Scoring Sheet - Ming
○ Script Bullet Point - Ming
○ Bullet Point Add Drop - All
○ Full Script - Cheryl

Figure 2.3.1 Team Progress and Upcoming Arrangement



Task 1

1. Push pin out
   - Difficulty: use ROV push?
2. Pull pin out
   - Difficulty: very small pin
3. Install recovery line
   - Difficulty: coordinate with the line

Figure 2.3.2 Tasks Requirements Breakdown & Brainstorming Ideas

3. Design Rationale

3.1. Engineering Design Rationale

The total size of Manta Ray is 85cm x 41cm x 33cm (Length x Width x Height), and its weight is 16.1kg. It consists of a laser-cut and 3D print hybrid designed frame, a two-degree-of-freedom robotic arm, eight thrusters, an electrical component chamber with a Raspberry Pi 4B microcontroller, two front cameras for straight front view and seafloor view, 30m long neutral buoyancy tether, Omni-wheel levelling platform and signal communication with LAN cable. The peripherals include the Float for performing vertical profiling, a display monitor, and a Xbox controller (Figure 3.1.1).

Safety is a high priority in EEC and is one of the considerations during the design of Manta Ray. Precautions from physical injuries or electric shock during the operation of ROV are taken with protections like thruster shrouds, tether strain relief and eye-catching labels on movable parts. Fuses are included to protect the ROV electrical system. More importantly, the kill switch is easily accessible with clear labels in an emergency and needs immediate ROV shutdown.

We also take into account maintenance for our modular design. Many parts have the advantage of switchable and interchangeable designs. During our development and testing phases, it is beneficial for quick repairs and trying out different prototypes.

Regarding the missions, we would like to highlight our robotic arm and float. The robotic arm design is strongly task-oriented. ROVs in the field are required to handle many complex tasks, leading to the gripper being the most crucial part of interacting with the environment. We aim to develop a robotic arm that is highly flexible and a multi-function gripper for various shapes of objects. We also add friction tape to ensure a tight grip on items and prevent mission failure. The Float is dedicated to plotting the vertical profile with remote control. The control is simple, and a detailed data log is created.

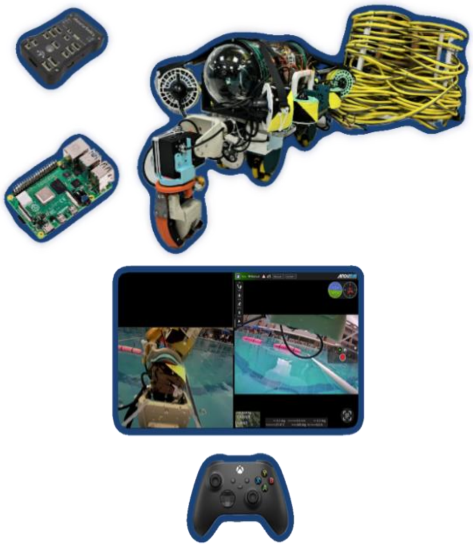


Figure 3.1.1 System of Manta Ray

3.2. Innovation

3.2.1. Oil Waterproofing and Cooling

Traditional waterproof servos only provided static waterproofing, failing to protect against water ingress during operation, as shown in Figure 3.2.1. To overcome this limitation, our team implemented an innovative solution. We created a dynamic barrier by filling the servo interior with oil (Figure 3.2.2). The oil prevents water from entering the sensitive components and improves servo cooling during operation. This cost-effective solution makes the servo more reliable and has a longer lifetime.

Figure 3.2.1. Waterproof Servo Motor Leaking Water

Figure 3.2.2 DIY Waterproofing by Adding Oil to the Servo

3.2.2. Anti-fog System and Microprocessor Cooling

Besides oil waterproofing, we addressed two other key challenges for underwater robots with a single, innovative solution. To prevent fogging on the front viewport and ensure optimal Raspberry Pi performance, we implemented a dual-purpose thermal management system, as shown in Figure 3.2.3. This system utilizes a strategically placed snail fan to create targeted airflow within the ROV chamber. The fan effectively circulates warm air, preventing condensation on the viewport during cold-water dives. Simultaneously, this airflow cools the Raspberry Pi, promoting stable operation and maximizing processing power. This unique design eliminates the need for complex, separate anti-fog and cooling solutions, resulting in our ROV's streamlined and efficient thermal management system.

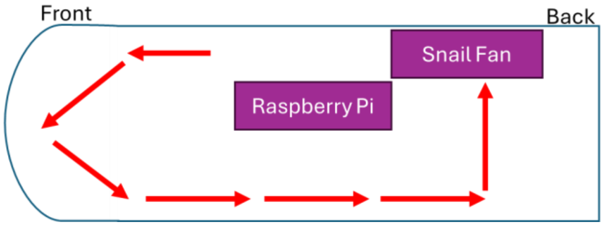


Figure 3.2.3 Snail Fan Circulation Explain

3.3. Problem-Solving

Since our ROV electronic chamber is warm during operation, there will be a small temperature difference compared with the surroundings. Fog will then form on the front window, which makes it difficult to see underwater (Figure 3.3.1). We first tried to fix this using an anti-fog gel you can buy in stores. However, this only worked briefly (2-3 tests), and we had to reapply it often. We accidentally learned something important while drying a wet part with a hairdryer one day. We noticed that blowing air on a dry surface prevented fog from forming. This gave us an idea for a new way to stop the fogging problem on Manta Ray for good.

We installed a small "snail fan" next to the camera, which blows air directly to the front cover (Figure 3.3.2). This solved the problem completely, and there was no more fogging. By carefully observing the problem, trying different solutions, and thinking critically, we were able to fix a major issue with our ROV and invent a new and effective way to prevent fogging.

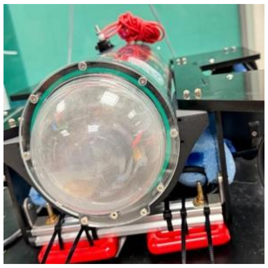


Figure 3.3.1 Fog Due to Condensation

Figure 3.3.2 Snail Fan Installed on the Camera

3.4. System Approach

Manta Ray's design follows a system approach, where all subsystems work together to achieve efficient underwater exploration. This collaborative approach focuses on:

1. **Integration**

Seamless communication and data exchange between subsystems like the Raspberry Pi controller, cameras, thrusters, and sensors. This ensures smooth operation and real-time data acquisition.

2. **Interoperability**

Compatibility between hardware and software. The chosen software should effectively utilize the ROV's hardware capabilities (cameras, thrusters, robotic arm) for optimal performance.

3. **Maintainability**

Modular design with easily interchangeable parts allows for quick repairs, upgrades, and testing of different configurations during development and future operations.

4. **Safety**

Prioritizing safety throughout the system. This includes features like thruster guards, tether strain relief, clear labelling, emergency kill switch, and fail-safe mechanisms within the electrical system protected by fuses.

5. **Human-machine interface (HMI)**

Designing an intuitive and user-friendly control system using the Xbox controller and the dual camera view. This allows for efficient pilot control and minimizes training time.

3.5. Vehicle Structure and System

Using underwater robots or remotely operated vehicles (ROVs) has become increasingly popular in marine exploration, oil and gas exploration, and oceanographic research. These robots can perform various tasks, from collecting samples to performing complex operations at great depths.

The total size of Manta Ray is 85cm x 41cm x 33cm (Length x Width x Height), and its weight is 16.1kg. The cost of the ROV is around 3300 USD. Underwater robots must operate in harsh environments, including extreme pressure, saltwater, and corrosive substances. The combination of acrylic for the frame structure and 3D print for the module mounting (Figure 3.5.1) for an underwater robot provides a list of advantages, including strength, durability, and affordability, that is well-suited for the harsh underwater environment. All materials can be easily customized and fabricated into complex shapes and designs, making them an ideal choice for the construction of underwater robots.

Trade-off

We originally planned to use carbon fibre plates instead of acrylic plates, which are lighter and stronger. However, carbon fibre is more expensive and complicated to manufacture. On the other hand, we can laser cut the acrylic in the school lab, which is easier to manufacture. Therefore, we use the acrylic plate as the ROV frame.

Modularity

The ROV Frame uses an acrylic plate as an ROV base, which is designed to mount modular units such as thrusters and Omni wheel modules (Figure 3.5.2). It contains mounting holes for different modules. It can support different modules and different thruster configurations. For our final ROV design, omni wheel modules, thruster mounts, chamber mounts, and robotic arm modules are mounted on the frame. A highly flexible ROV frame allows quick and easy configuration change or module placement. For example, they change between six and eight thruster configurations, move the robotic arm, and switch out thrusters.

Material

We chose acrylic because it is a versatile and widely used type of plastic known for its transparency, durability, affordability, and versatility in various applications. It acts as the main body of the ROV, providing promising protection to the electrical components and keeping the ROV cost reasonable. We also use 3D printing materials for mounting between components and the frame. It can be printed in different shapes with significant strength for the ROV module. Also, it is flexible, can print the parts in hours for testing, and can be easily replaced with new printed parts.

Mission Oriented Modification

The design of the Manta Ray followed an iterative process to meet the demands of specific missions. Originally equipped with a single USB camera, the ROV required an upgrade to handle object retrieval from the seabed. An omni-wheel levelling platform was integrated to address this challenge, allowing the ROV to maintain stability on the seafloor during manipulation tasks. However, this modification created a visibility issue for the front camera, making it difficult for the operator to assess the robotic arm’s grip on objects. To rectify this limitation, a waterproof Power over Ethernet (PoE) camera was introduced (Figure

3.5.3). This new camera offered a fresh perspective for the operator and, conveniently, did not necessitate changes to the control software system due to its compatibility with the existing LAN protocol.

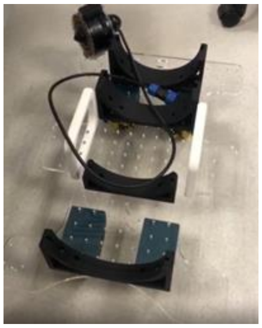


Figure 3.5.1 Acrylic Plate & 3D Print

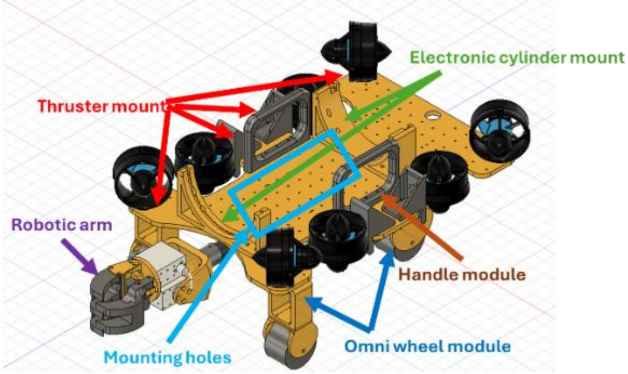


Figure 3.5.2 ROV Frame and Modular Components

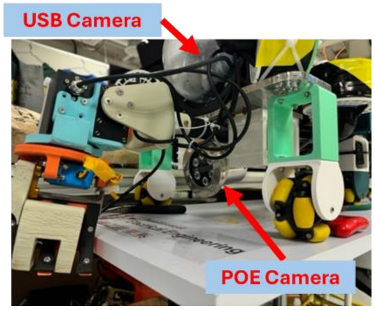


Figure 3.5.3 PoE Camera Placed Behind the Robotic Arm

3.6. Electrical System

3.6.1. Overview

The underwater robot system utilizes a modular design for efficient power distribution and management. We uses mutiple DC-DC converter to steps down the voltage levels to meet the specific needs of different components. Electronic speed controllers regulate the speed and direction of the robot's thrusters, cameras provide visual feedback for navigation and situational awareness. A Raspberry Pi 4B serves as the robot's main computer, processing data from sensors and controlling Manta Ray. The Pixhawk flight controller provides additional processing power and functionalities specifically designed for autonomous vehicles. Finally, a tether supplies power and communication to the robot from the surface station. This tether connection allows for real-time monitoring and control of the underwater robot.

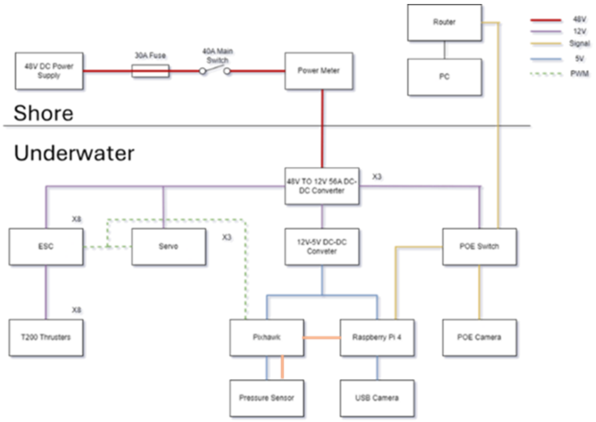
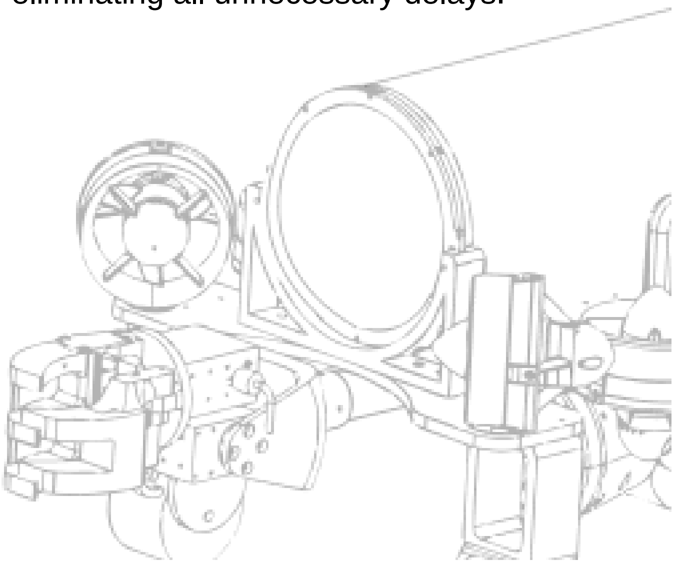


Figure 3.6.1 Connection of the ROV Electrical System

3.6.2. On Boards Computers

We uses Raspberry Pi 4B as the Single-board computer "SBC" and Pixhawk as the flight controller, which holds a significant role in managing the functionalities of ROV. With the processing power of Raspberry Pi 4B, we can analyze different sensor data in real-time. We can also run an underwater robotics system at 100hz, eliminating all unnecessary delays.



3.6.3. Electronic Speed Controllers (ESC)

The underwater robot utilizes Electronic Speed Controllers (ESCs) to ensure precise and efficient movement. ESCs receive control signals from the Pixhawk flight controller. Based on these signals, they regulate the speed and direction of the robot's thrusters. This allows for smooth manoeuvring and precise positioning underwater. Also, it incorporates safety features like overcurrent protection, which safeguards the thrusters from electrical overload during operation. Moreover, ESCs can filter electrical noise from the power supply or tether, ensuring clean and reliable signals for accurate motor control.

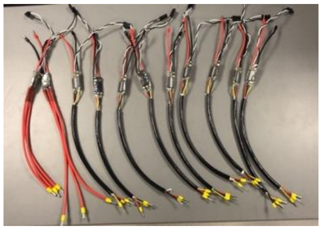


Figure 3.6.2 ESC for Eight Thrusters

3.6.4. Power Distribution

Our power distribution system has three 48-12V DC-DC converters, which mainly support eight thrusters and three servo motors (Figure 3.6.3). Each 48-12V DC-DC converter can support up to 56A output current capable of 3 thrusters with full thrust. The other components will be allocated to converter 3, which has only two thrusters and relatively low current consumption.

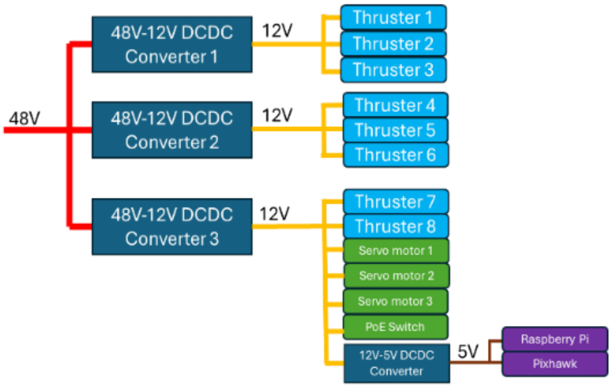


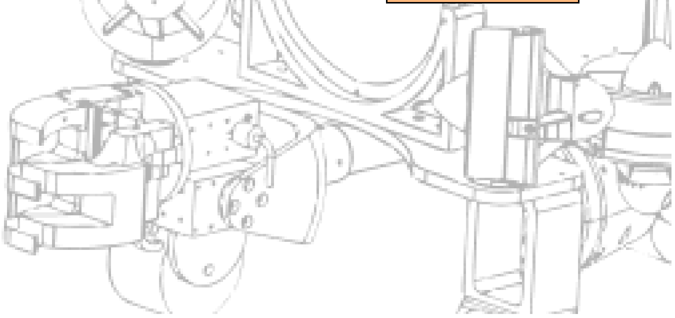
Figure 3.6.3 Power Distribution of ROV

3.6.5. Power Calculations

We created a spreadsheet to track the ROV's total power consumption for our power calculations. It contains power draw and efficiency loss estimates linked to automated calculations. The spreadsheet is readily accessible by all employees and has a user guide to explain how to use, test, and update the calculations (Table 3.6.1).

Table 3.6.1 Power calculations for Manta Ray operating at maximum power.

System	Power Draw	
Provided MATE Power Supply	30A@48V	+1440W
Sensitive Electronics	1*Raspberry Pi 4: -6 W 1*USB Camera: -2 W Power Loss due to Converter Inefficiency:12%	-9.09W
12V Servo Motors + PoE Camera	3*Servo Motor: 4.3A@12V=51.6W 1*PoE Camera: 2A@12V=24W Power Loss due to Converter Inefficiency:12%	-85.9W
12V T200 Thrusters	8*T200: -864W Power Loss Due to Converter Inefficiency:12%	-981.8W
The remaining margin for efficiency losses and future additions:		363.33W



3.6.6. Electronic Enclosure

We use an acrylic chamber with an O-ring cap to hold all electronics, such as ESC, DC-DC converters, Raspberry Pi, and USB cameras. (Figure 3.6.4) Compared with using epoxy to do waterproofing, the epoxy method is more costly since the entire module needs to be changed even if only one component inside is broken. An acrylic chamber with an O-ring cap method can locate and replace the broken components instead of changing other functional elements. Therefore, it is more cost-effective and money-saving.

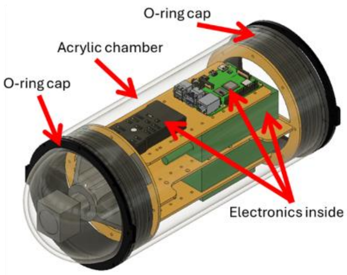


Figure 3.6.4 Electronic Enclosure

3.6.7. Tether design and Management

The ROV's tether support signals and power are connected to the control station (Figure 3.6.5). A pair of 12 American Wire Gauge (AWG) DC power cables are used to supply 48V to the ROV. Also, there is a LAN cable for ROV control and PoE camera signals. We prioritize safe and efficient tether operation through a comprehensive protocol. This protocol emphasizes four critical practices:

- Pre-deployment Inspection: A thorough pre-dive examination identifies potential issues such as fraying, kinks, or damaged electrical connections.
- Dynamic Tether Management: Tether length is carefully monitored during operation to ensure sufficient slack. This prevents excessive tension on the ROV while avoiding unnecessary slack that could create entanglement hazards.
- Proper Storage: When not in use, the tether is stored in a controlled environment – clean, dry, and with regulated temperature. This protects it from environmental damage and extends its lifespan.
- Coiling Techniques: Appropriate techniques are employed to avoid sharp bends or kinks during storage or deployment, minimizing potential damage. (Figure 3.6.6)

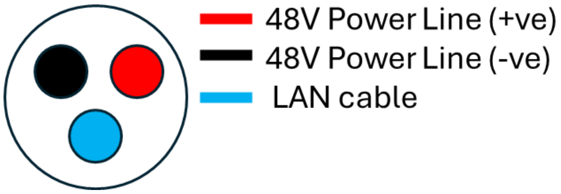
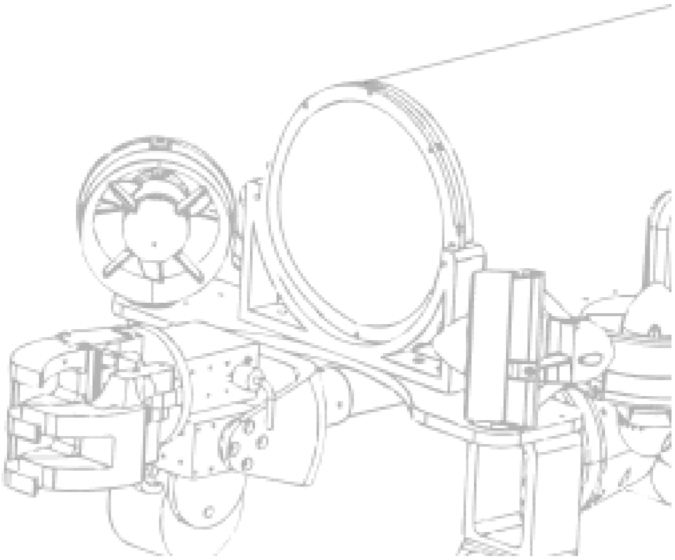


Figure 3.6.5 Cross-section of the Tether

Figure 3.6.6 Tether Coiling System

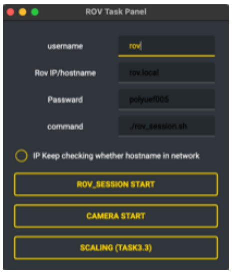


3.7. Control System

3.7.1. ROV Connection

We can set up Manta Ray by connecting a laptop to the router, which offers wired and wireless LAN connections for adaptability. The wireless network enables communication with and data download from our Float. Once both the computer and Manta Ray are connected to the LAN, a custom application, as shown in Figure 3.7.1, will automatically detect and establish connections to the PoE and USB cameras, displaying the live video feed on the laptop screen. This application further facilitates communication between the Raspberry Pi and Pixhawk flight controller, allowing control of the Manta Ray through QGroundControl, a popular open-source software program for drone control. Finally, a Bluetooth controller can be paired with the laptop, providing a conventional interface for the pilot to manoeuvre Manta Ray (Figure 3.7.2).

In the previous year, we used a keyboard as the interface to control the ROV, but it limited the control of the whole computer. The keyboard is locked, and other tasks (such as switching windows or plotting graphs) cannot be performed on the same computer while the program runs. Thus, we switch to using a joystick controller.



username: rov
Rov IP/hostname: rov.local
Passward: polyuef005
command: ./rov_session.sh

○ IP Keep checking whether hostname in network

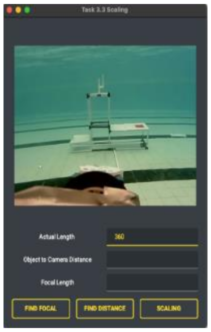
Figure 3.7.1 Custom Application developed by our team

Figure 3.7.2 Dual Camera Control System

3.7.2. Software Developed for Completing Tasks

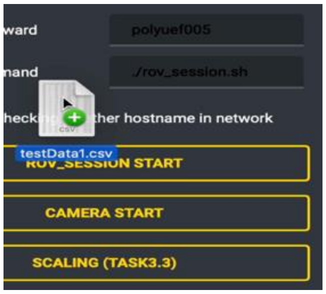
For task 3.3, estimating object length and 3D modelling is essential. We developed an application so that the user can calculate the scale of display pixels to the actual length of the target and apply it to other sides. The estimation error is capped under 5 cm. The user first inputs a frame of the camera footage and the given length of the coral restoration area via the panel (Figure 3.7.3). Then, draw the reference line along the given side in the frame for the program to calculate the scaling. To find the length of the target, draw along the sides, and the estimation is labelled near the lines with the scaling (Figure 3.7.3). Afterwards, the user may create the 3D model with Fusion360 using the estimated dimensions from the program.

In task 3.4, we will receive a CSV file after recovering the acoustic receiver using the same application we designed. As in Figure 3.7.4, we can drag and drop it to the UI, pipeline the data plotting action, plot the data as in Figure 3.7.5, and determine the highest number of sturgeons detected.



Actual Length: 360
Object to Camera Distance:
Focal Length:

Figure 3.7.3 Scaling Panel



ward: polyuef005
nand: ./rov_session.sh
heck ther hostname in network

Figure 3.7.4 Drag & Drop the File to the Application

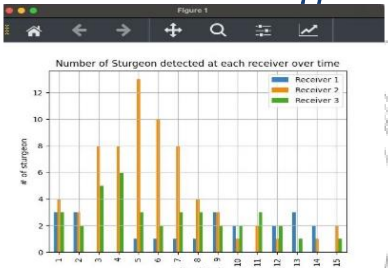


Figure 3.7.5 Data Visualization

3.8. Buoyancy and Ballast

For optimal stability, an ROV meticulously balances its components. Weight and specially designed plastic forms are strategically positioned on the frame to fine-tune its centre of gravity and buoyancy (Figure 3.8.1, 3.8.2). This meticulous balance ensures the ROV remains level underwater, enabling smooth task execution without uncontrolled sinking or floating. This approach reflects a profound grasp of buoyancy principles, resulting in a streamlined and efficient design.

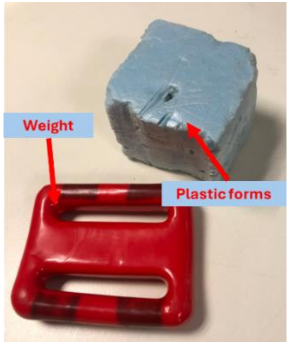


Figure 3.8.1 Plastic Forms and Weight for the ROV

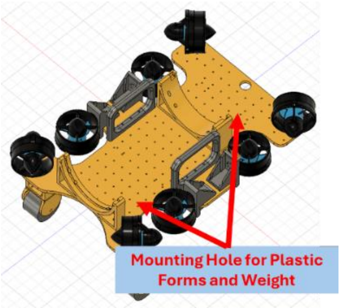


Figure 3.8.2 Mounting Holes on ROV for Buoyancy and Ballast

3.9. Propulsion

Eight thrusters are used to control both the transversal and rotational motion of the ROV. The Blue Robotics T200 motor is selected for its reasonable cost and excellent performance. The propulsion system consists of four horizontal thrusters in a vector configuration and four vertical thrusters. This configuration allows the Manta Ray to be manoeuvrable with six degrees of freedom in the water, as shown in Figure 3.9.1, while maximizing propulsion forces and torque. Assuming the effects produced by the four propellers are identical, by calculation, the angle of each horizontal motor should be set to 45° for the frame, optimizing both resultant force and torque.

Thrust Calculation

The ROV has four vertical thrusters (Figure 3.9.2). Each thruster produces 3.71 kg thrust at 12V and 17A. The total thrust for the ROV payload will be 4x3.71=14.84kg, capable of carrying all the props on the mission.

Trade-off

Manta Ray prioritizes manoeuvrability by utilizing an 8-thruster system. Compared to the 6-thruster configuration AUV, the 8-thruster provided additional pitch control, offering superior control and stability in all directions, allowing Manta Ray to perform tasks requiring stabilization and patience. However, as shown in Figure 3.9.3, this comes at the cost of a weight and dimension increase. While the AUV only weighs 6.7kg in air, the Manta Ray weighs 16.1kg, and the size of the Manta Ray is also 60% larger than the AUV.

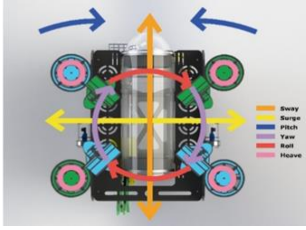


Figure 3.9.1 Six Degrees of Freedom

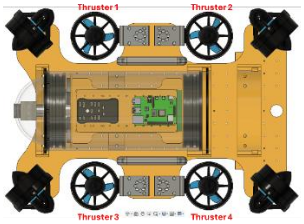


Figure 3.9.2 Four vertical thrusters in ROV

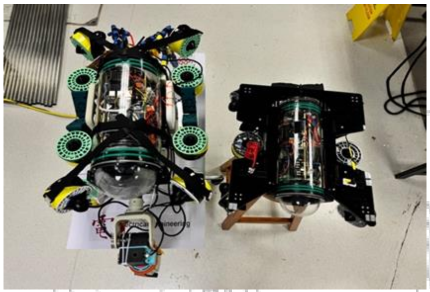


Figure 3.9.3 Size Comparison of 8 Thruster Manta Ray Vs 6 Thruster AUV

3.10. Payload And Tool

3.10.1. Robotic Arm

The 2-degree-of-freedom robotic arm, as shown in Figure 3.10.1, consists of 3 servo motors with a custom-designed gripper for the mission made with 3D printing material. It can tilt and pan in a wide range, which allows the gripper to interact with items at different heights. The gripper has five fingers with frictional material, enabling it to grip most items tightly, such as different-diameter pipes and sediment samples.

In tasks 1 to 3, most of them are related to retrieving and placing items, such as "Triggering" the multi-function node and installing a power connector. With friction tape on the fingers, the gripper can hold items more tightly, so the gripper will not lose items during a mission.

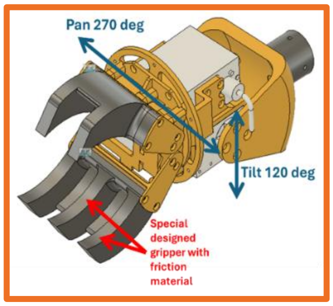


Figure 3.10.1 Robotic Arm 3D model

3.10.2. Multifunctional Hook

The multifunctional hook (Figure 3.10.2) allows the ROV to transport heavy objects (such as the irrigation system in Task 3.1) (Figure 3.10.3) and transport multiple items from the poolside at the same time (such as the recovery line in Task 1 and the ACDP in Task 3.4) (Figure 3.10.4). The tilting servo motor can control the multifunctional hook. It prevents the servo motor from overloading since the heavy items will create large torque to the servo arm due to the long moment arm. It also allows the ROV to pick at most two items simultaneously to reduce the round trip time and improve efficiency.

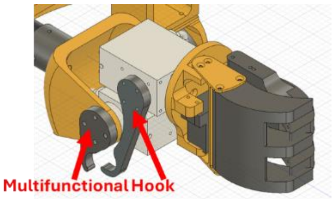


Figure 3.10.2 Multifunctional Hook 3D model

Figure 3.10.3 Multifunctional Hook Carrying Irrigation System

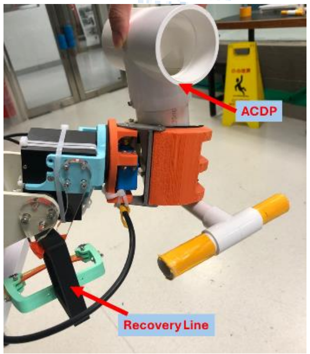


Figure 3.10.4 Multifunctional Hook Carrying Multiple Items

3.10.3. Omni Wheels Module

Most tasks are on the seafloor, such as recovering a sediment sample (Task 3.4) and installing the AUV power connector (Task 2). The ROV may become unstable because of the water current, making it hard to constantly stay at one position or level. Also, when performing the tasks, the bottom of the ROV has a high chance of physical damage by scratching or collision with objects. Thus, we installed the omni wheels on the ROV (Figure 3.10.5) to provide stable motion on the seafloor and simultaneously prevent scratching with the seafloor.

During our test runs, we discovered an issue with the control of picking up objects from the floor. The props on the seafloor have differences in height, such as the sediment samples are on the ground, and the activator of the irrigation system is raised 8cm above the seafloor. Using ROV depth hold to do these tasks will be difficult and unstable. Using Omniwheel with lifted height allows the ROV to walk on the seafloor with stability. We adjusted the robotic arm position height, allowing ROV to do both tasks (Figure 3.10.6, 3.10.7) while walking on the seafloor smoothly without using depth hold mode.

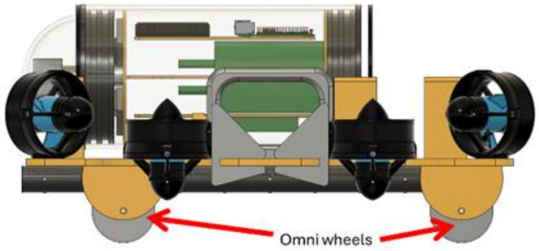


Figure 3.10.5 Omni Wheel Leveling System

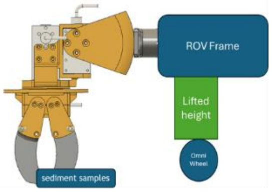


Figure 3.10.6 Demonstration of collecting sediment samples

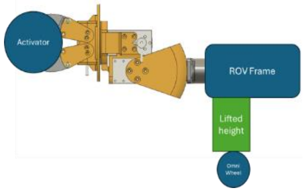


Figure 3.10.7 Demonstration of activating of the irrigation system

3.10.4. Camera Position

Two cameras are mounted on Manta Ray (Figure 3.10.8): a 120-degree HDR USB camera and a 90-degree waterproof PoE camera.

USB camera is placed above the robotic arm, at the centre of the camber. It can provide footage with a wide field of view and high resolution, which is suitable for any image processing task. However, it requires encoding and then streaming to an on-shore computer via LAN cable.

On the other hand, the waterproof PoE camera can be placed outside the camber of the Manta Ray and provide close-up footage of the robotic arm. The PoE is an IP camera that will establish an image stream once connected to a LAN network, simplifying the setup procedure.

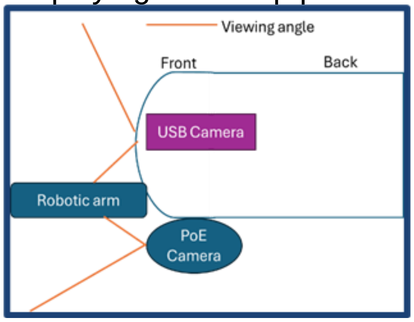


Figure 3.10.8 Camera Install position and viewing angle

3.10.5. Recovery line

The recovery line is designed to attach to the bale of the multi-function node. The recovery line handle is specially designed to attach to the ROV multifunctional hook. The carabiner is easy to attach to the bale and does not require large force. It has a secure connection when attached to the U-bolt bale. It ensures that it will not loose and fail the task.

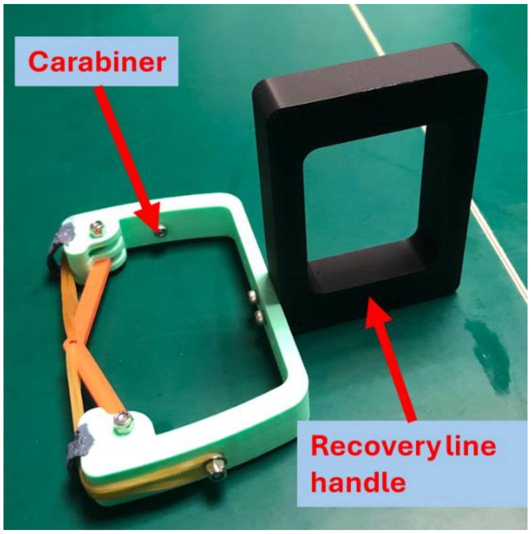


Figure 3.10.9 Recovery Line

3.10.6. Float

For task 4, the vertically deployed Float is designed to conduct vertical profiling (Figure 3.10.10). The device can sink or float by controlling the syringes to absorb or expel water. The obstacle avoidance sensor is activated when it sinks, and the control system expels water to bring it back to the surface. It comprises three key modules: a buoyancy engine for maintaining position, a transmission module for data relay, and a system for visualizing collected data. These modules integrate cutting-edge sensor technology and payload tool compatibility, guaranteeing the Float's efficient functionality. AA alkaline batteries power it.

Figure 3.10.10 Float

Buoyancy Engine

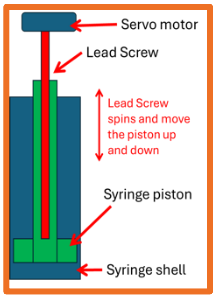


Figure 3.10.11 Diagram of Float

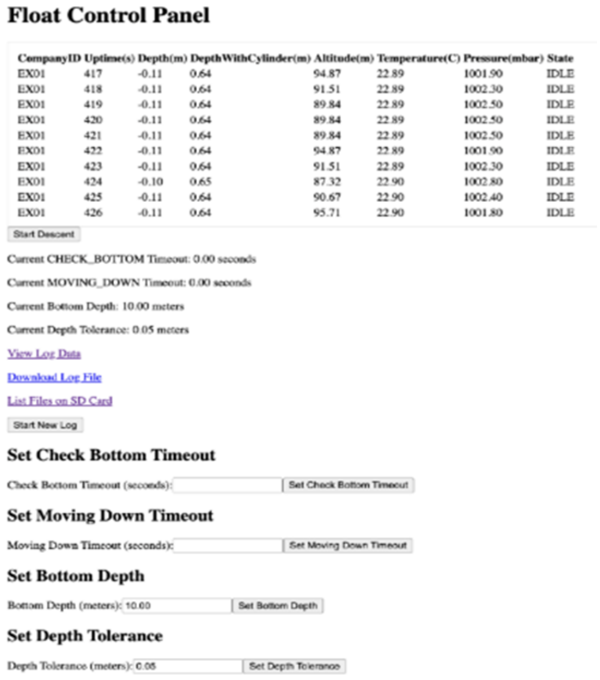
To make a buoyancy engine, we need to change the float density, such as increasing its mass (more water inside) [1]. Therefore, we used a servo motor with a lead screw, which acts as a linear actuator (Figure 3.10.11), to pull and push the syringe piston to get and release water. As the Float sinks, the water will flow into the syringe until it reaches its maximum volume. The limit switch will signal the ESP32 to automatically switch to the ascent mode and return the Float to the surface.

Transmission Module

Regarding the communication and transmission of data between the float and control station, ESP32 is used. The ESP32 is a powerful microcontroller and system-on-chip (SoC) designed and manufactured by Espressif Systems. It is widely recognized for its versatility, performance, and low-power capabilities, making it a popular choice for a wide range of embedded applications. The ESP32's built-in Wi-Fi and Bluetooth capabilities suit the mini-ROV well. An antenna is added at the top of the Float to strengthen the signal transmission as well. It ensures the transmitter can be maintained high enough above the surface of the water to communicate with the mission station. When the computer sends the signal to the Float to sink, it will do a complete vertical profile once. When the Float reaches the shore, it will send the data in its SD card to the station computer.

Visualisation of Data

A Float Control Panel (Figure 3.10.12) is developed to create the vertical profile so that the operator can conduct vertical profiling and review the data log easily. The data for vertical profiling is stored in the SD card embedded in the Float. The data collected includes the company number, the float time since the recording of the log, depth of Float, attitude, temperature of surroundings, pressure and float status. The operator can download a .csv data log file and plot graphs with the Python library Matplotlib. Data is graphed as depth by time. (Figure 3.10.13)



Float Control Panel

CompanyID	Uptime(s)	Depth(m)	DepthWithCylinder(m)	Altitude(m)	Temperature(C)	Pressure(mbar)	State
EX01	417	-0.11	0.64	94.87	22.89	1001.90	IDLE
EX01	418	-0.11	0.64	91.51	22.89	1002.30	IDLE
EX01	419	-0.11	0.64	89.84	22.89	1002.50	IDLE
EX01	420	-0.11	0.64	89.84	22.89	1002.50	IDLE
EX01	421	-0.11	0.64	89.84	22.89	1002.50	IDLE
EX01	422	-0.11	0.64	94.87	22.89	1001.90	IDLE
EX01	423	-0.11	0.64	91.51	22.89	1002.30	IDLE
EX01	424	-0.10	0.65	87.32	22.90	1002.80	IDLE
EX01	425	-0.11	0.64	90.67	22.90	1002.40	IDLE
EX01	426	-0.11	0.64	95.71	22.90	1001.80	IDLE

Current CHECK_BOTTOM Timeout: 0.00 seconds

Current MOVING_DOWN Timeout: 0.00 seconds

Current Bottom Depth: 10.00 meters

Current Depth Tolerance: 0.05 meters

Set Check Bottom Timeout

Check Bottom Timeout (seconds):

Set Moving Down Timeout

Moving Down Timeout (seconds):

Set Bottom Depth

Bottom Depth (meters): 10.00

Set Depth Tolerance

Depth Tolerance (meters): 0.05

Figure 3.10.12 Float Control Panel

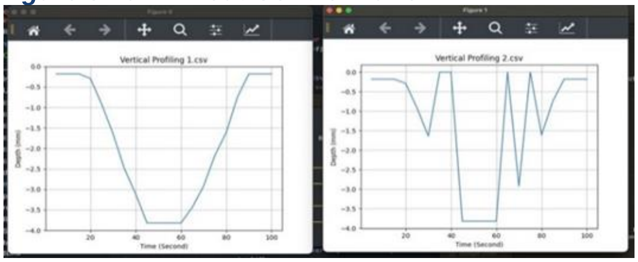
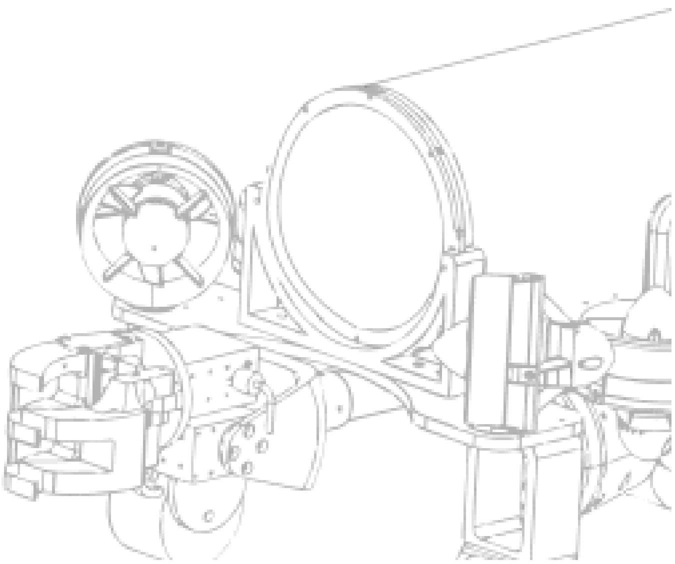


Figure 3.10.13 Graphs of vertical profiles



3.10.7. Sensors

For precise underwater navigation, especially in pool environments, we rely on the Blue Robotics Bar30 depth sensor. This high-resolution sensor measures water pressure, providing accurate depth readings down to 300 meters. This allows for safe and controlled autonomous operations within a pool for various tasks. Bar30 is installed in the Manta Ray and the Float (Figure 3.10.14). It will enable Manta Ray to perform depth hold mode, easily operating at the seafloor or midwater and getting the pool's actual depth with the Float. Moreover, the DS18B20 temperature sensor is installed on the Manta Ray, allowing it to measure the smart cable temperature in task 2 accurately.

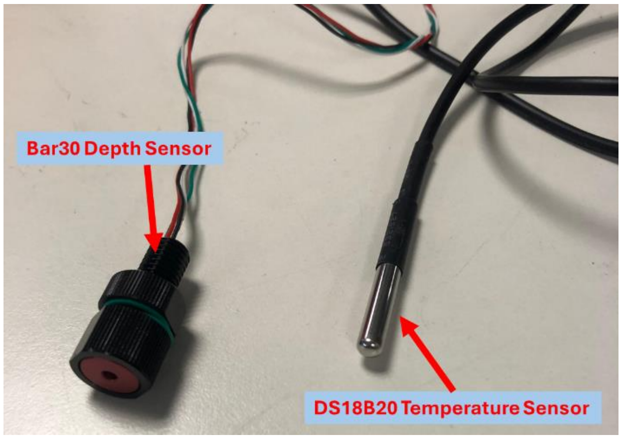
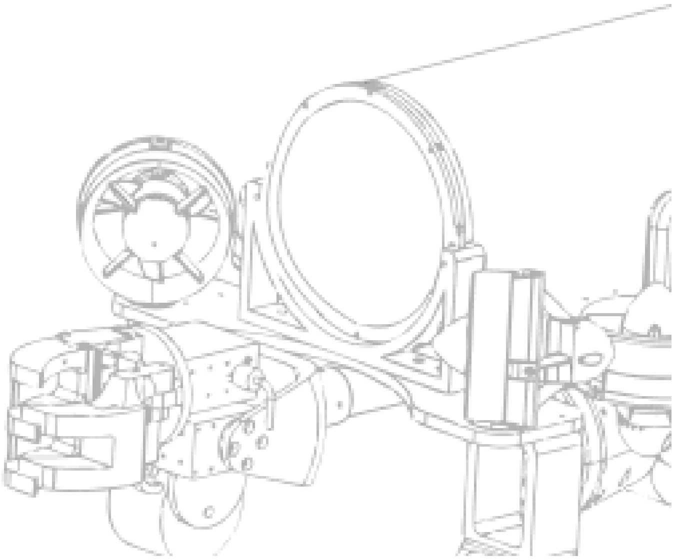


Figure 3.10.14 Sensors in ROV and Float



4. Safety

4.1. Company Safety Philosophy

EEC's highest priority is safety during the construction, testing, and deployment of Manta Ray. Numerous strict regulations regarding safety precautions have been implemented so that all EEC members manage to conduct various practices in a safe environment.

4.2. Lab Safety Protocol

EEC always puts safety as its highest priority. All new members are well-trained with necessary safety precautions such as watching demonstrations concerning practical soldering work and having introductory meetings about some common toxic materials used, all of which are conducted by our senior members.

Figure 4.2.1 Job Safety

EEC requires all members to at least abide by the safety checklists prepared by both the Industrial Center in the University and MATE. Members are required to work in pairs when they are handling soldering work and energizing electric circuits. Protective personal equipment (PPEs) is compulsory depending on the tasks that must be completed (Figure 4.2.1). To exemplify, wearing masks and protective gloves throughout the process is obligatory when members conduct works that produce lethal substances, such as cutting carbon-fibre material and mixing epoxy, a toxic substance. Members must also wear safety goggles with different specifications using a laser cutter and bench drilling machine. The EEC provides other specific PPEs, such as hearing protectors, for its members to use on demand.

4.3. Manta Ray's Safety Features

Manta Ray contains plenty of safety features to keep our personnel, the ROV, and the working environment safe and healthy. Extra safety measures are required for the electrical and electronic divisions mentioned below. Motor shrouds (Figure 4.3.1) are used to cover the thrusters. Fuses must be installed in live wires, and no Tee-joint is allowed ahead of the fuse. Moreover, various waterproofing techniques are applied to ensure no water leakage occurs.

Figure 4.3.1 Thruster Shrouds & Eye catching labels

<u>Eye-catching labels on moving or hazardous objects</u>

Eye-catching tape is installed on the hazardous object, as in Figure 4.3.1. Noticing any nearby operator helps operators easily identify potential dangers, increasing awareness and minimizing the likelihood of accidents

Emergency Kill Switch

The emergency kill switch (Figure 4.3.2) allows us to cut off the ROV power when there is an emergency issue, such as when an unexpectedly high current is drawn, the ROV is out of control, and the ROV has physical damage. It prevents the ROV from damaging the environment and itself. The kill box ensures the safety of the underwater creatures and the ROV.

Figure 4.3.21 Kill Switch

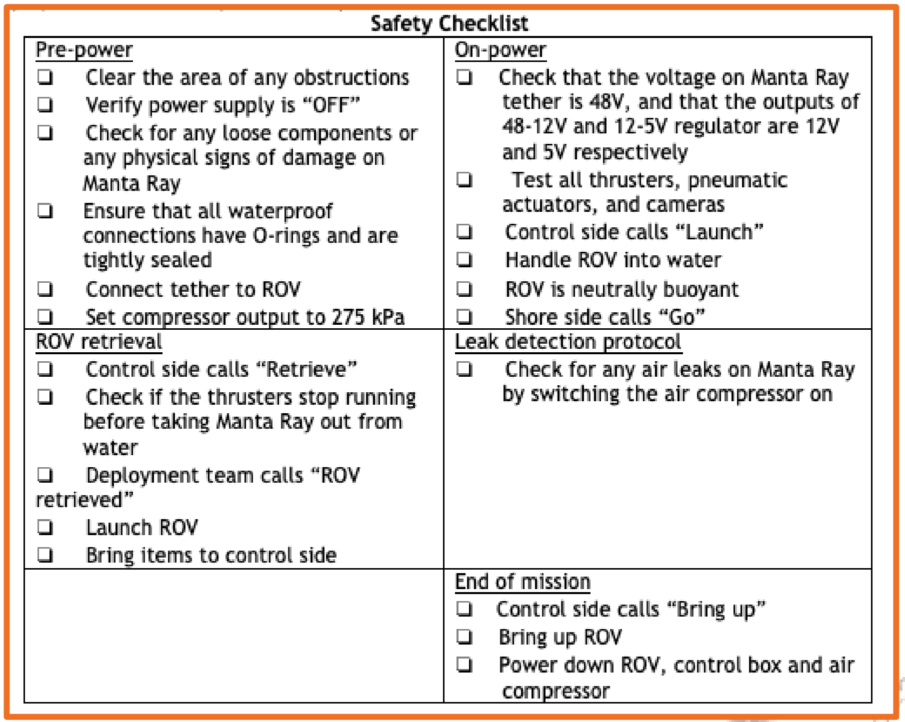
Tether Strain Relief

On a mechanical level, the tether on both the shore and the underwater ends are locked with a buckle (Figure 4.3.3), relieving any strain acting downright on the tether as the tether is a communication unit rather than a supporting structure.

Figure 4.3.3 Tether strain relieve system

4.4. Safety Procedures

EEC's safety checklist dictates operational safety protocols in terms of pre-power, on-power, ROV retrieval, and leak detection protocol. These protocols are closely followed before and after the deployment of Manta Ray. Some are presented in Figure 4.4.1.



Safety Checklist

Pre-power ☐ Clear the area of any obstructions ☐ Verify power supply is "OFF" ☐ Check for any loose components or any physical signs of damage on Manta Ray ☐ Ensure that all waterproof connections have O-rings and are tightly sealed ☐ Connect tether to ROV ☐ Set compressor output to 275 kPa	On-power ☐ Check that the voltage on Manta Ray tether is 48V, and that the outputs of 48-12V and 12-5V regulator are 12V and 5V respectively ☐ Test all thrusters, pneumatic actuators, and cameras ☐ Control side calls "Launch" ☐ Handle ROV into water ☐ ROV is neutrally buoyant ☐ Shore side calls "Go"
ROV retrieval ☐ Control side calls "Retrieve" ☐ Check if the thrusters stop running before taking Manta Ray out from water ☐ Deployment team calls "ROV retrieved" ☐ Launch ROV ☐ Bring items to control side	Leak detection protocol ☐ Check for any air leaks on Manta Ray by switching the air compressor on
	End of mission ☐ Control side calls "Bring up" ☐ Bring up ROV ☐ Power down ROV, control box and air compressor

Figure 4.4.1 Safety Checklist

5. Testing and Troubleshooting

Testing and fixing problems are essential steps in building something great. Testing makes sure everything works right, performs well, and is safe to use. Fixing problems helps us identify and address any issues that come up so things run smoothly. In short, both testing and fixing are vital to a project's success.

5.1. Waterproof testing

To test the quality of waterproofing, EEC implemented air leakage testing, measuring the air loss through leaks in the electronic chamber. Using a manual air pump, set the air pressure inside the chamber to 50 kPa.

Figure 5.1.1 Waterproof testing

If the reading (Figure 5.1.1) of the pump does not change after 10 minutes, the electronic chamber is proved to be airtight. Otherwise, the testing verifies a risk of leakage in the chamber. Manta Ray has been confirmed to have passed the air leaking test.

5.2. Camera Calibration

A series of camera tests were performed (Figure 5.2.1) to ensure that Manta Ray captures clear and comprehensive visuals during its underwater operations. These tests were designed to evaluate two critical aspects: field of view and image quality.

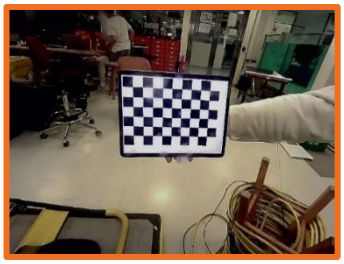


Figure 5.2.1 Camera calibration

We carefully adjusted the camera angles during testing to achieve the best field of view. This included capturing footage from various angles and simulating real-world scenarios that Manta Rays might encounter underwater. The ideal angle would provide adequate coverage while reducing blind spots.

Calibration was an essential part of camera testing because the front cover of the ROV can cause distortions in the captured images. This process corrects optical aberrations caused by the ROV's cover, ensuring the camera produces precise, undistorted images. As shown in Figure 5.2, the calibration procedure requires taking images of a special calibration grid from various perspectives. Specialized software then examines these images to determine the degree of distortion and calculates correction factors. We can ensure the accuracy and reliability of Manta Ray's underwater imagery by applying these corrections during image processing.

5.3. Wet Run

After all the tests mentioned above, our vehicle can operate smoothly and conduct missions. The team progress to the next testing stage: wet run testing. The stage is divided into trials in the laboratory-controlled environment (Figure 5.3.1) and full system trials in open water (Figure 5.3.2, 5.3.3).

The laboratory pool environment provided a controlled setting for Manta Ray to perform a series of trials for individual tasks. This approach allowed us to closely monitor and evaluate the performance of each function separately. It also helps to narrow down the testing area and conduct testing more systematically. The controlled environment reduced external variables, making it ideal for isolating and troubleshooting performance inconsistencies.

After completing the individual task trials, we moved on to a full-scale pool test in a larger pool. This environment provided a more realistic setting and better simulations of open water conditions, which the Manta Ray would encounter during the competition. The test runs aim for the crew to get familiar with the on-shore operation and discover potential problems with the vehicle during a longer running time. Testing in open water enabled manoeuvres that required more space, such as sharp turns and high-speed movements. We recreated the entire competition run, allowing the crew to hone their communication, coordination, and task execution skills in situations similar to the actual event.

This progressive approach of pool testing builds confidence in the Manta Ray's capabilities. It allowed for systematic identification and resolution of issues and refinement of crew procedures in a controlled environment. This ultimately prepared both Manta Ray and the crew for the challenges in the competition.

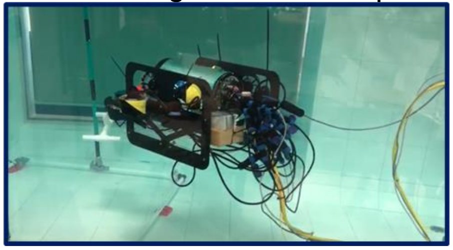


Figure 5.3.1 Trial run in lab pool With Prototype 1

Figure 5.3.2 Footage of Pool Test 1

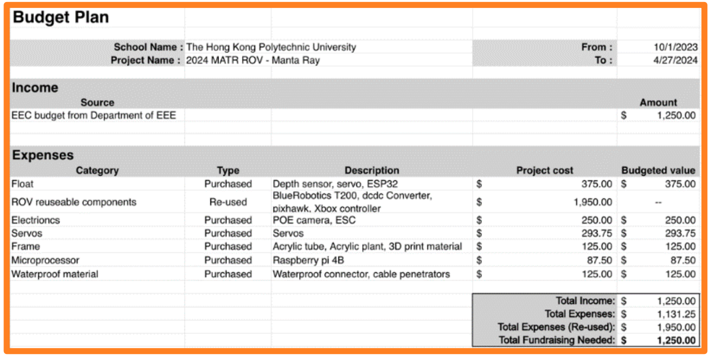
Figure 5.3.3 Footage of Pool Test 2

6. Accounting

6.1. Budget

The Department of Electrical and Electronics Engineering allocates this year's budget. The total budget for the project is USD$1250, and the estimated expenses are USD$1311.25 (Figure 6.1.1).

Most of the budget is spent on the frame of Manta Ray and purchasing electronic components.



Budget Plan

School Name : The Hong Kong Polytechnic University **From :** 10/1/2023
Project Name : 2024 MATR ROV - Manta Ray **To :** 4/27/2024

Income

Source	Amount
EEC budget from Department of EEE	$ 1,250.00

Expenses

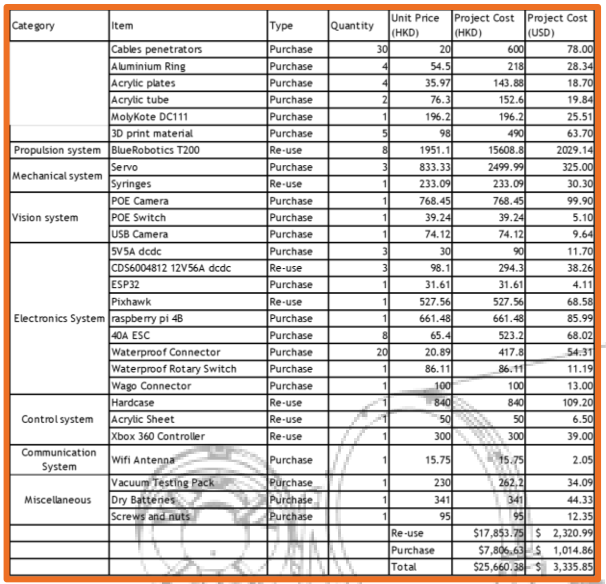
Category	Type	Description	Project cost	Budgeted value
Float	Purchased	Depth sensor, servo, ESP32	$ 375.00	$ 375.00
ROV reuseable components	Re-used	BlueRobotics T200, dcdc Converter, pixhawk, Xbox controller	$ 1,950.00	--
Electroncs	Purchased	POE camera, ESC	$ 250.00	$ 250.00
Servos	Purchased	Servos	$ 293.75	$ 293.75
Frame	Purchased	Acrylic tube, Acrylic plant, 3D print material	$ 125.00	$ 125.00
Microprocessor	Purchased	Raspberry pi 4B	$ 87.50	$ 87.50
Waterproof material	Purchased	Waterproof connector, cable penetrators	$ 125.00	$ 125.00

Total Income:	$ 1,250.00
Total Expenses:	$ 1,131.25
Total Expenses (Re-used):	$ 1,950.00
Total Fundraising Needed:	**$ 1,250.00**

Figure 6.1.1 Budget Plan

6.2. Cost Accounting

Based on the experience from the past competition, some of the essential components will be reused, such as the BlueRobotics T200 thrusters and controller. The detailed expenses are tabulated as shown in Figure 6.2.2.



Category	Item	Type	Quantity	Unit Price (HKD)	Project Cost (HKD)	Project Cost (USD)
	Cables penetrators	Purchase	30	20	600	78.00
	Aluminium Ring	Purchase	4	54.5	218	28.34
	Acrylic plates	Purchase	4	35.97	143.88	18.70
	Acrylic tube	Purchase	2	76.3	152.6	19.84
	MolyKote DC111	Purchase	1	196.2	196.2	25.51
	3D print material	Purchase	5	98	490	63.70
Propulsion system	BlueRobotics T200	Re-use	8	1951.1	15608.8	2029.14
Mechanical system	Servo	Purchase	3	833.33	2499.99	325.00
	Syringes	Re-use	1	233.09	233.09	30.30
Vision system	POE Camera	Purchase	1	768.45	768.45	99.90
	POE Switch	Purchase	1	39.24	39.24	5.10
	USB Camera	Purchase	1	74.12	74.12	9.64
Electronics System	5V5A dcdc	Purchase	3	30	90	11.70
	CDS6004812 12V56A dcdc	Re-use	3	98.1	294.3	38.26
	ESP32	Purchase	1	31.61	31.61	4.11
	Pixhawk	Re-use	1	527.56	527.56	68.58
	raspberry pi 4B	Purchase	1	661.48	661.48	85.99
	40A ESC	Purchase	8	65.4	523.2	68.02
	Waterproof Connector	Purchase	20	20.89	417.8	54.31
	Waterproof Rotary Switch	Purchase	1	86.11	86.11	11.19
	Wago Connector	Purchase	1	100	100	13.00
Control system	Hardcase	Re-use	1	840	840	109.20
	Acrylic Sheet	Re-use	1	50	50	6.50
	Xbox 360 Controller	Re-use	1	300	300	39.00
Communication System	Wifi Antenna	Purchase	1	15.75	15.75	2.05
Miscellaneous	Vacuum Testing Pack	Purchase	1	230	262.2	34.09
	Dry Batteries	Purchase	1	341	341	44.33
	Screws and nuts	Purchase	1	95	95	12.35
				Re-use	$17,853.75	$ 2,320.99
				Purchase	$7,806.63	$ 1,014.86
				Total	$25,660.38	$ 3,335.85

Figure 6.2.2 Project Costing

7. Acknowledgement

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8. References

[1] *What is buoyant force? (article) | fluids* (no date) *Khan Academy*. Available at: https://www.khanacademy.org/science/physics/fluids/buoyant-force-and-archimedes-principle/a/buoyant-force-and-archimedes-principle-article (Accessed: 06 April 2024).

9. System Integration Diagram(SID)

SYSTEM INTEGRATION DIAGRAM OF ROV

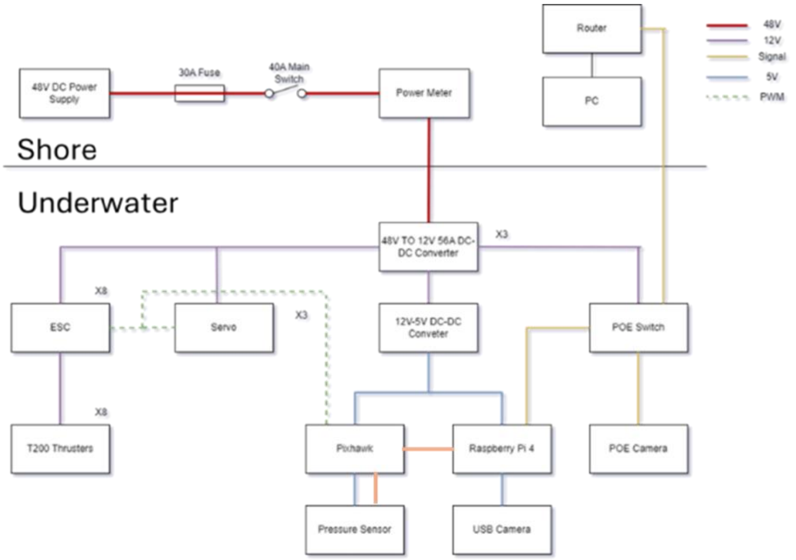
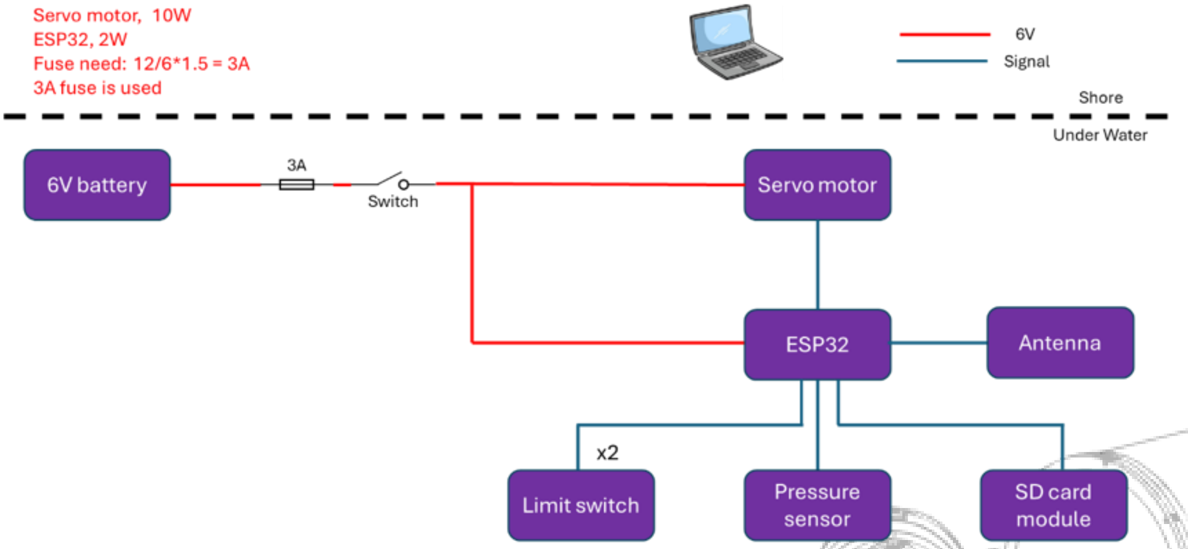


Figure 9.1 SID of Manta Ray

System	Power Draw	
Provided MATE Power Supply	30A@48V	+1440W
Sensitive Electronics	1*Raspberry Pi 4: -6 W 1*USB Camera: -2 W Power Loss due to Converter Inefficiency:12%	-9.09W
12V Servo Motors + POE Camera	3*Servo Motor: 4.3A@12V=51.6W 1*POE Camera: 2A@12V=24W Power Loss due to Converter Inefficiency:12%	-85.9W
12V T200 Thrusters	8*T200 : -864W Power Loss Due to Converter Inefficiency:12%	-981.8W
	Remaining margin for efficiency losses and future additions:	363.33W

Max Power:
= 9.09 + 85.9 + 981.8
= 1076.79W
Fuses Needed:
= 1076.79 /48V *1.3 = 29.16A
= 30A Fuse

SYSTEM INTEGRATION DIAGRAM OF FLOAT



Servo motor, 10W
ESP32, 2W
Fuse need: 12/6*1.5 = 3A
3A fuse is used

Figure 9.2 SID of Float