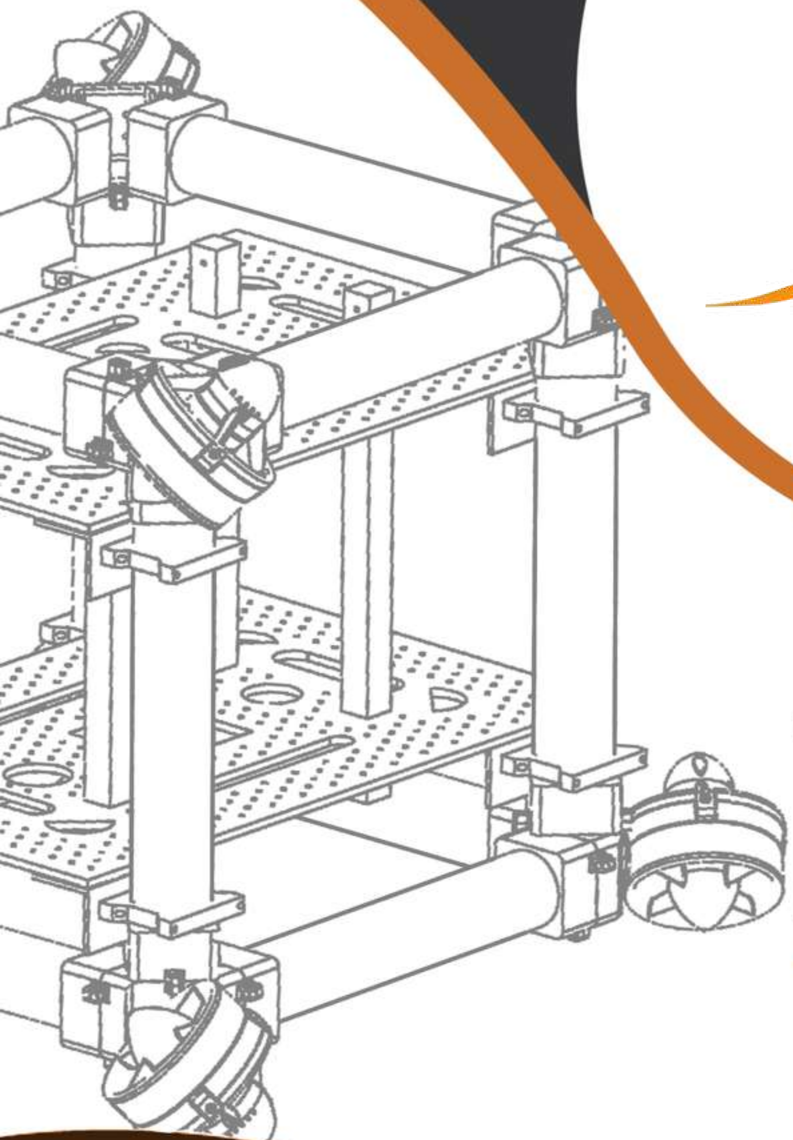
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY
香港科技大學

epoxsea



# TECHNICAL REPORT

## 2023 MATE ROV Competition

**Chief Executive Officer**

| | | |
|---|---|---|
| LEUNG, Ka Chun | Year 2 | Dual Degree Program |

**Chief Financial Officer**

| | | |
|---|---|---|
| CHAU, King Tsun | Year 2 | Computer Engineering |

**Chief Technical Officer**

| | | |
|---|---|---|
| YU, Ho Chun | Year 2 | Physics |

**Mechanical Engineers**

| | | |
|---|---|---|
| LAM, Chun Ho | Year 2 | Mechanical Engineering |
| CHAN, Ho | Year 2 | Integrated System Design |
| CHAN, Leong Ip | Year 1 | Dual Degree Program |
| CHEUNG, Chun Wai | Year 1 | School of Engineering |
| CHIN, Jonathan Kiu Fung | Year 1 | School of Engineering |
| HUI, Kan Lap | Year 1 | School of Engineering |
| LEE, Ting Yan | Year 1 | School of Engineering |
| MUI, Jessye | Year 1 | School of Engineering |
| TAI Chun Ho Ryan | Year 2 | Civil Engineering |
| WONG, Kin Hang | Year 2 | Mechanical Engineering |

**Electronic Engineers**

| | | |
|---|---|---|
| KUO, Chen Chieh | Year 2 | Electronic Engineering + Computer Science |
| CHEUNG, Yan To | Year 2 | Electronic Engineering |
| HUNG, Ka Ho | Year 2 | Physics + Mathematics |
| SONATA, Joshua Elnathan | Year 2 | Electronic Engineering |
| NG, Ji Yan | Year 4 | Ocean Science |
| TAM, Siu Ho | Year 1 | School of Engineering |

**Software Engineers**

| | | |
|---|---|---|
| KAO, Ka Ho | Year 3 | Computer Engineering |
| CHI, Ting Hsuan | Year 2 | Computer Science + Electronic Engineering |
| LI, Xin Wei | Year 1 | School of Engineering |
| LI, Chi Kin | Year 1 | School of Engineering |
| TSAI, Yiu Ki | Year 1 | School of Engineering |
| WONG, Hoi Chun | Year 2 | Computer Engineering |
| WONG, Wing Him | Year 2 | Electronic Engineering |
| YIP, Chi Ho | Year 1 | School of Engineering |
| ZHANG, tin yau | Year 1 | School of Engineering |

**Supupervisor**

Dr. WOO, Kam Tim

**Mentor**

LEUNG, Chun Yin

Hong Kong

# CONTENT


Figure 1.1 : group photo of Epoxsea with Marlin

# ABSTRACT

Epoxsea is a Hong Kong company consisting of 5 female and 23 male employees from a diverse range of nationalities, including but not limited to Canada, China, Indonesia, Taiwan, and more. Marlin, the newest invention from Epoxsea, is a remotely operated vehicle(ROV)that excels at duties such as monitoring the circulation, chemistry, biology, and condition of bodies of water. Aside from signature hydrodynamic features that improve overall operability, Marlin is outfitted with mission-specific components that allow it to accomplish a variety of underwater tasks, for example inspecting and creating 3D models of coral heads, comparing seagrass recovery, monitoring endangered Lake Titicaca giant frogs, and removing biofouling from underwater equipment. This includes a self-designed robotics float, in support of the GO-BGC Project, financed by the National Science Foundation (NSF). Across countless days and nights, our engineers have developed the necessary skills and experience to produce an ROV that can adapt to numerous diverse environments and high safety standards. Marlin is the result of extensive planning, researching, prototyping, and testing carried out in accordance with strict safety regulations. It is an embodiment of serviceability, speed, power efficiency, and maneuverability. This report will cover Marlin's technical specifications, ability to accomplish mission-specific features, and the development process leading up to Epoxsea's most iconic product to date. Illustrations and images are included to support explanations visually when appropriate.

(225 words)

# DESIGN RATIONALE

## Design Evolution

Epoxsea is a company that consistently prioritizes excellence and continuous improvement in the development of its ROVs. By focusing on functionality and performance, the company has successfully built upon previous experiences and incorporated new technical innovations to create its latest ROV, the Marlin.

Before designing the Marlin, Epoxsea's engineers meticulously examined the strengths and weaknesses of previous ROVs and other commercial ROVs in the market. We aimed to achieve four primary objectives: improving agility, enhancing maintainability, increasing flexibility, and reducing weight while ensuring stability. These goals led to the innovative "Dice-shaped Frame" approach, which is implemented in the 8-thruster propulsion system.

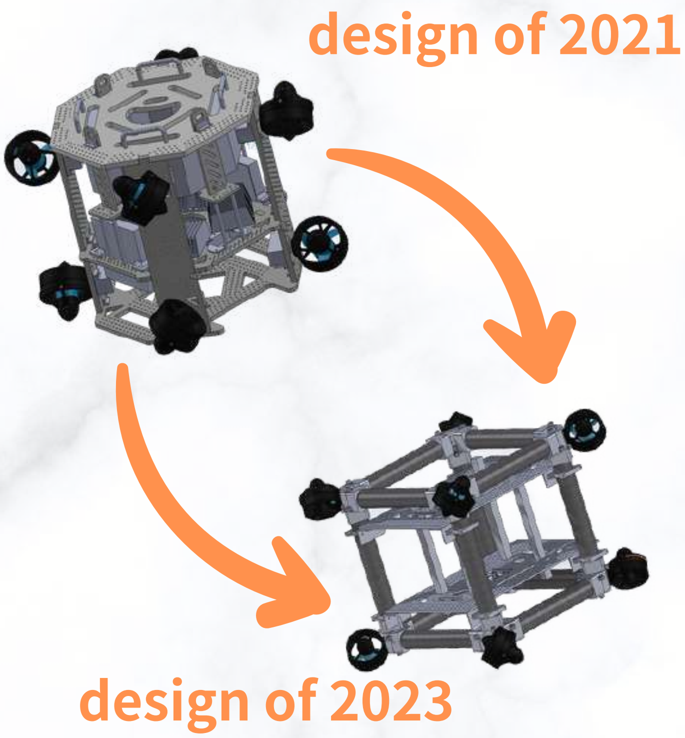



Figure 2.1 : Redesigning the ROV

The "Dice-shaped Frame" concept significantly improves Marlin's agility. As the name suggests, this approach entails a cubic core frame structure. When viewed as a cube, each thruster is installed at one vertex, allowing for movements with four degrees of freedom. This innovative design, inspired by existing market ROVs, results in higher functionality at a reduced cost. Additionally, Epoxsea switched to P75 thrusters, which provide greater thrust than the BlueRobotics T200 thrusters. These thrusters enhance Marlin's swiftness in all directions without significantly increasing the overall cost.
Addressing the primary objective of increasing flexibility, Epoxsea implemented a modular design strategy for the Marlin ROV. This approach allows for easier customization and upgrading of the ROV's components, making it adaptable to various mission requirements. Our engineers can easily swap out or add new sensors, cameras, and manipulators depending on their specific needs.

In terms of maintainability, Marlin's structure is designed for easy access to electronic components. Based on challenges encountered during the building and testing of the 2022 ROV, Epoxsea opted for an open structure approach. This decision addresses the issue of densely-packed structures, further reducing costs by simplifying maintenance and repair activities. Two polypropylene boards, consisting of numerous mounting holes, are positioned at the lower part of Marlin to lower the center of gravity and increase stability. Carbon fiber tubes and 3D-printed thruster mounts form the cubic structure, continuing the "buoyancy as frame" concept from previous ROVs. By sealing the carbon fiber tubes on both sides with epoxy, the air is trapped inside, providing buoyancy and eliminating the need for bulky floatation modules. This innovation results in a more compact ROV, achieving higher functionality at reduced costs.

| | Design of 2021 | Design of 2023 |
|---|---|---|
| Max no. of manipulators | 6 | 12 |
| Mean time to repair | 5.5 mins | 2 mins |
| load capacity | 12.14 kg | 41.2 kg |
| overall cost | USD$ 6143 | USD$ 4274 |

Table 2.1 : comparison of old and new design

# System Interconnection Diagram

The following diagram and table are the System Interconnection Diagram (SID) and the fuse calculation respectively.

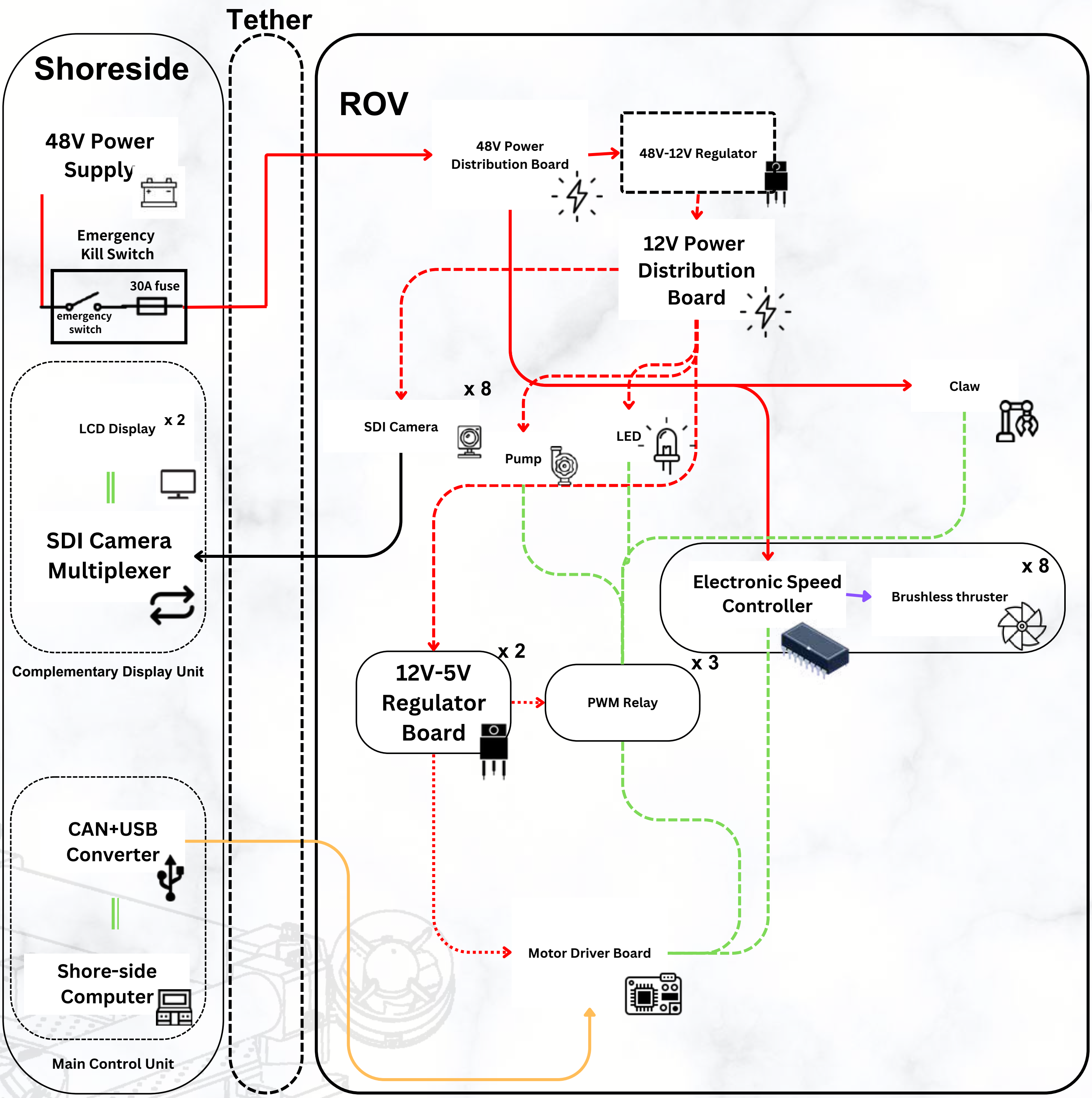
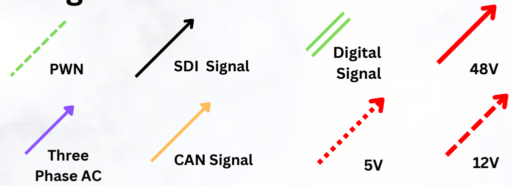



Figure 2.2 : system interconnection diagram

## Legend




| Component Name | Qty | Working Voltage [V] | Average Current [A] | Total Current Drawn [A] | Max Power Per Unit [W] | Max Power [W] |
|---|---|---|---|---|---|---|
| Electronic Speed Controller + Thruster | 8 | 48.00 | 2.00 | 16.00 | 96.00 | 144.60 |
| PWM Relay | 3 | 5.00 | 0.01 | 0.03 | 0.05 | 0.15 |
| Motor Driver | 1 | 5.00 | 0.20 | 0.20 | 1.00 | 1.00 |
| Serial Digital Cameras | 8 | 12.00 | 0.42 | 3.36 | 5.04 | 40.32 |
| Claw | 1 | 48.00 | 4.50 | 4.50 | 216.00 | 216.00 |
| LED Light | 1 | 12.00 | 0.05 | 0.05 | 0.60 | 0.60 |
| Pump | 1 | 12.00 | 1.50 | 1.50 | 18.00 | 18.00 |

Table 2.2 : fuse and power calculator for each component

| | |
|---|---|
| Total Current Drawn by System [A] | 30.94 |
| ROV Maximum Power Consumption [W] | 1452.07 |
| Total Current Drawn by System at 48V [A] | 20.68 |
| 150% Overcurrent Protection [A] | 31.02 |

Table 2.3 : overall fuse and power calculation

# Vehicle Core System Mechanical

## FRAME

The "Dice-shaped Frame" approach was selected for the Marlin ROV due to its capability of balancing between cost, dimensions, and mass. Comprising 12 carbon fiber tubes, the frame assumes the form of a cube enclosing two layers. Carbon fiber tubes were chosen based on their excellent strength-to-weight ratio, rendering them an economical option for generating a sturdy lightweight frame. Each polypropylene board incorporates numerous mounting holes and hollowed areas to accommodate manipulators and enhance stability against hydrodynamic resistance. The lower board serves as a platform for mounting hardware and selected manipulators, while the upper one functions as a strain relief mechanism, connecting the ROV to the poolside through a tether. Polypropylene was favored for its affordability and resistance to the underwater environment.

Throughout the planning and design process, various materials were assessed for their suitability in constructing the ROV's components. In the end, stainless steel mounts were preferred over 3D printed alternatives due to their significantly increased durability and superior ability to endure greater stress and pressure. This choice resulted in a more dependable and long-lasting mounting solution without considerably augmenting the overall cost of the ROV.

## BUOYANCY

In the past, our approach to flotation involved covering several cut-up pieces of styrofoam with carbon fiber cloth and epoxy, and attaching them directly inside the ROV for convenience. However, we recently explored alternative solutions for flotation, leading to the implementation of carbon fiber tubes as the main buoyancy source.

| | |
|---|---|
| buoyancy force of each carbon fiber tube | 18.7N |
| number of tubes | 12 |
| boyancy fine tuning | -8.4N |
| total boyancy force | 216.0N |

Table 2.4 : calculation of buoyancy force

Figure 2.4 : explosion diagram of the frame edge

unlike previous designs, Marlin's frame doubles as its buoyancy system, simplifying the overall design by providing structural integrity and flotation force simultaneously. The ROV's framework comprises of 12 carbon fiber tubes, which serve as the primary buoyancy source. To prevent water leakage and maintain trapped air inside the tubes, epoxy is applied to seal the edges.

To achieve neutral buoyancy, the ROV's total weight is carefully balanced against the buoyant force provided by the carbon fiber tubes. This balance ensures that Marlin remains stable in the water, allowing it to execute tasks smoothly without sinking or floating uncontrollably. This innovative approach to the buoyancy system demonstrates a deep understanding and practical application of buoyancy principles, resulting in a more streamlined and efficient design.

## PROPULSION

The propulsion system of Marlin consists of eight P75 thrusters to ensure the reliability and durability of the performance. Each thruster is mounted at 45 degrees elevated along diagonals towards the center on both the front side and the backside of Marlin. Compared to the previous designs, the 6-thrusters propulsion system mainly focuses on moving along the x- and z-direction, while the renewed design generally enhances the thrusting force in the linear motion of all three axes. It provides higher mobility in traveling to different locations underwater and high accessibility by adjusting its movement for using the manipulators mounted on different faces in Marlin. In addition to the three rotational degrees of freedom toward the x-y-z axes, six degrees of freedom can be provided so that Marlin can perform most of the movements and orientations for achieving the tasks.

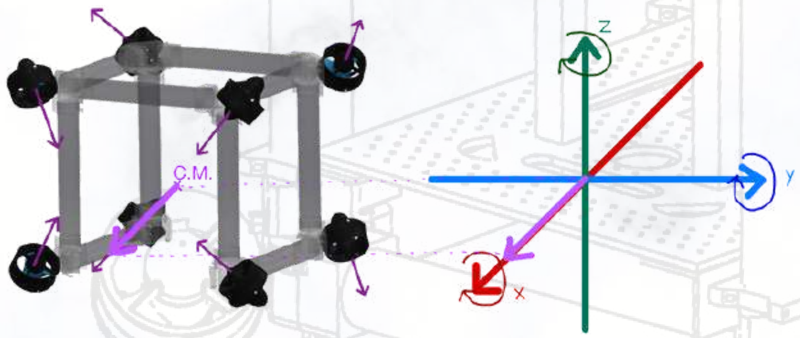



Figure 2.5 : diagrams illustrating the coordinated movement of 8 thrusters

This increased flexibility enables the ROV to perform a wide range of movements and orientations necessary for completing tasks. During the design process, trade-offs were considered to balance power consumption, cost, performance, and mission requirements. The P75 thrusters, while cheaper and more powerful, do consume more power and can sometimes draw too much current. However, the improved mobility and task efficiency offered by the 8-thruster system justify the trade-off. Careful consideration of the overall power management system and current protection measures can help mitigate the risk of excessive current draw.

### THRUST CALCULATION

The maneuvering system of the ROV consists of 8 thrusters, each positioned at one corner of the cubic chassis. Taking three perpendicular edges of the cube as the x-y-z axes, each thruster is angled so as to be 45 degrees offset from every axis. Thus, all thrusters can be utilized simultaneously regardless of the axis of movement or rotation, reducing the load put upon any singular unit.

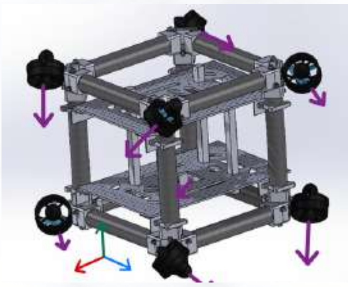


Figure 2.6 : photo of thrust directions

Each thruster produces 6.8kg of thrust at 24V and 22.6A when rotating clockwise, and 7.8kg at the same voltage with 25.2A when spinning counterclockwise. By considering the mounting board as a plane of reference, we can see that the thrust is directed 45 degrees off the z axis. Thus, we can multiply the vector thrust by sin(45°)to get following formula:

$$6.8 \times \sin(45^{\circ}) = 4.8kg(clockwise)$$
$$7.8kg{\times}\sin(45^{\circ}) = 5.5kg(anticlockwise)$$

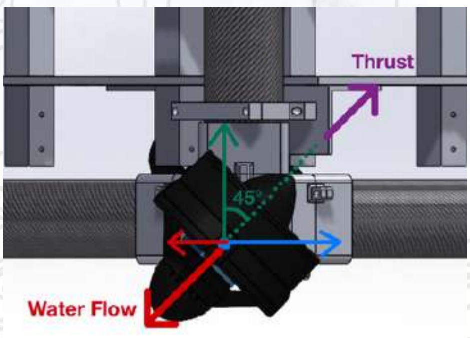



Figure 2.7 : vector decomposition of thrust and water flow

Combining all eight propellers present on the ROV, we achieve the below amount of vertical lift:

$$4.8kg \times 8 = 38.4kg$$
$$5.5kg \times 8 = 44.0kg$$

With multiple thrusters and high thrust power, Marlin can move in any direction, rotate on its axis, and perform complex movements while maintain high stability in water. In additions, Marlin can achieve higher speeds and cover more area in a shorter amount of time.

# Electronics

### CAMERA

For this year, Marlin is equipped with eight digital cameras to provide a comprehensive and clear visual coverage for controlling the robot to tackle different challenges and tasks. The decision to use eight cameras was made to ensure an all-around view and minimize blind spots, enabling the team to effectively navigate the ROV and carry out mission-critical tasks. The cameras were strategically placed around Marlin to maximize their field of view and provide comprehensive coverage of the underwater environment.

Each camera is connected directly to the shoreside control unit via an RG316 cable. A Digital Analog Video Converter converts the received signals from the cameras into video displayed on the control unit's screen. This setup optimizes the video output to 2048x1080 pixels with consistent 10-bit RGB color output. The high-quality image resolution allows for responsive image processing and enables the team to carry out tasks stated in this year's competition manual, such as creating 3D models and scanning the sea bed.

### TETHER

The tether supports the signals, power, and pneumatics function of the ROV by connecting with the offshore control units.

A pair of 12 American Wire Gauge (AWG) DC power cables are used to supply 48V to the ROV. Among the 11 transmission cables, there is 9 coaxial camera SDI signal cables, 1 CAN transmissions signal cable

With a 50Ω impedance of the coaxial cables, long-range video transmission can be maintained. The tether is protected with an elastic PET braided cable sleeve to increase the durability of the tether, and with a strain relief cable inside to maintain a stable connection and provide a rigid connection point between the tether and the ROV.

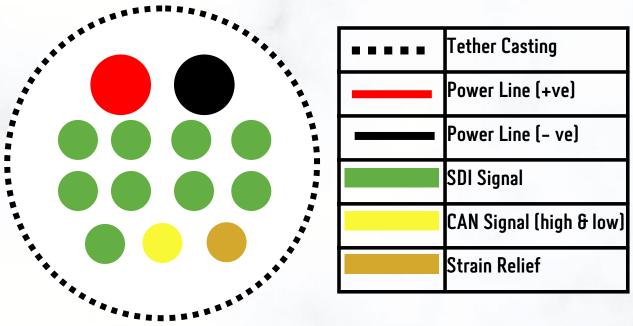



Figure 2.8 : cross section of the tether

To ensure the efficient and safe operation of the tether, Epoxsea has developed a tether management protocol, which includes the following:

1. Before each deployment, thoroughly examine the tether for signs of wear or damage, such as fraying, kinking, or compromised electrical connections.
2. Carefully manage the tether's length during operations, ensuring sufficient slack to prevent tension on the ROV while avoiding excessive slack that could lead to entanglement or snagging hazards.
3. Store the tether in a clean, dry, and temperature-controlled environment when not in use to protect it from the elements and prolong its lifespan.
4. utilizing appropriate coiling techniques and avoiding sharp bends or kinks.

## CONTROLLER AREA NETWORK (CAN)

CAN protocol acts as the communication protocol between the ROV and the control box. The centralized CAN is connected to USB to the CAN adaptor and every board in Marlin. Due to the high baud rate of up to 1.25Mbps, Marlin enables rapid message exchange between the components by the USB to CAN adaptor. CAN signals will be sent to the different components through the adaptor from the computer.

Thus, it can control a set of MCU that execute various functions, ranging from adjusting motor thrust.

### Boards

The team uses STM32F103 as the microcontroller unit "MCU" due to its reliability and flexibility. Signal control holds a major role in managing the features of the ROV, hence the MCU's qualities benefit the team. Overall, we have seven boards, which consist of three 48V power distributions, two 12V power distributions, one motor driver, and one CAN board. The boards' dimensions are between 40mm and 80mm in both height and length. The motor driver board has its own MCU for its respective usages. Each of the boards is equipped with LEDs to indicate whether they are functioning well or not. The power distribution boards, which consist of 12V and 48V, have sixteen and five outputs subsequently.

## ELECTRONIC ENCLOSURE

Epoxsea has always adhered to the tradition of using epoxy as a means of waterproofing the ROV robot, since their first participation in the competition. Epoxy has been identified as the best option for providing superior waterproofing capabilities, and its use ensures the elimination of the risk of water leakage into critical electronics, thus preventing the danger of short circuits. Additionally, epoxy reinforces the electronics by settling into a solid when dried, providing additional strength and protection to the electronic boards and wires from mechanical impacts. Our engineers have also discovered that wires directly connected to the boards may pose a weakness, given that twisting and pulling can cause the strands of the soldered wire to come loose, which poses a significant risk to the lifespan of the electronic circuit board, due to its small size. Therefore, epoxy can come in handy in such situations. It also serves as a physical barrier, preventing short-circuiting of the PCB, which is pivotal for the optimal functioning of the ROV.

Figure 2.9 : picture of PCB covered in epoxy

### POWER DISTRIBUTION

Our power distribution system consists of three 48V boards. These boards include a main input board that receives the 48V power from the tether, and two extension boards that distribute the power to the various components of the ROV.

One significant change we have made from previous years is the use of eight 48V thrusters to power the Marlin. This decision has several benefits, including a reduction in weight and increased power effectiveness. To ensure that the claw, four relays and 12V regulator receive power, they will be linked to the 48V boards, with the components receiving power from the 12V regulator. The motor driver board will be connected to the 12V-5V regulator boards. To meet the needs of the components, the motor driver board will further convert the power to 5V and 3.3V. Additionally, the 48V power will be used directly to power the claw.

To enhance safety, each power distribution board features a self-recovery fuse. This fuse is triggered when the current exceeds a safe level and automatically resets once the current returns to normal. These safety features are crucial for ensuring the longevity of our equipment and the safety of our team. Overall, our power distribution system is optimized for efficiency and reliability, with safety as a top priority.

## Software

### GRAPHICAL USER INTERFACE (GUI)

To facilitate seamless interactions between Marlin and the drivers and support the various manipulators and sensors on the robot, our software department developed an integrated Graphical User Interface (GUI) using Python along with the PyQt5 library. Python was chosen for GUI development because of its reliability, and convenience, and it is better compatible with other software task programs that are also developed in Python. The camera output panel and the multimedia management system allow the driver to effortlessly manage photographs and videos captured from the robot for the forthcoming tasks. Also, the checkbox, the automatic score calculator, and the timer component help with drivers' time control, which could ensure that they are able to accomplish all required tasks within the time limit. Besides, the direct connection between the robot and the controller makes it such that there is little or no delay between the drivers' commands and the software packages' responses.

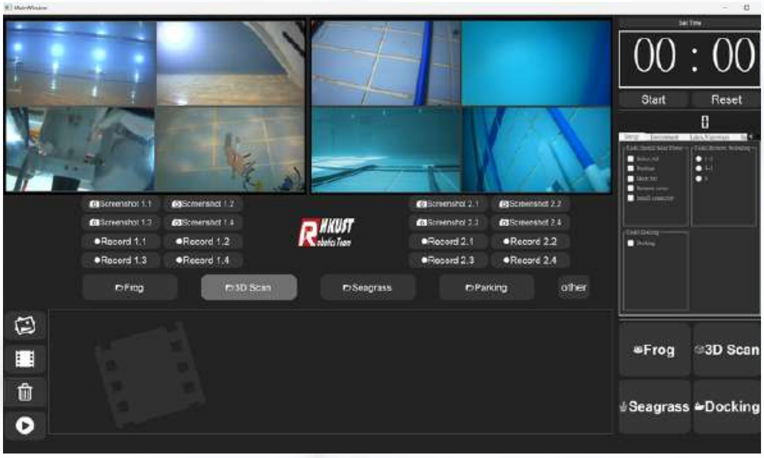



Figure 2.10 : screenshot of the GUI

### EVENT-DRIVEN ARCHITECTURE

The Event-Driven Architecture (EDA) paradigm, which enables the development of large systems with various interacting components, serves as the foundation for the Marlin's software architecture. An event bus is employed to implement EDA, allowing packages to publish events that other packages can access. Due to the decoupling of various program components and the ability of numerous receiving packages to handle incoming events asynchronously, this strategy is more adaptable and scalable than other architectures.

Marlin's control system design is built upon this flexible and modular software architecture. The control system consists of multiple subsystems responsible for specific tasks, such as navigation, manipulation, and communication. These subsystems interact through the event bus, exchanging information and responding to events in real-time to ensure the proper functioning of the Marlin.

As a result of the substantial use of EDA in Marlin's overall software architecture, services are easily replaceable and modifiable, which enable a quick and non-blocking development cycle. By avoiding dependencies and blocking concerns, Marlin's software can be built and improved rapidly and effectively.

# MISSION SPECIFIC FEATURE

## TASK 1: Marine Renewable Energy

### MAGNET DRIVEN CLAW

Our team has created a custom multipurpose claw for completing task 1.1 and task 1.2. One of the purposes is to grab the three mooring connectors and the power connector, connecting them to the appropriate anchors (U-hooks or the middle power source). The claw will initially clamp onto one of the mooring connectors or the power connector, then the ROV will move to within the three wind turbines. Once the solar panel array is within the three wind turbines, the ROV will submerge and disconnect the mooring connector from the array, dragging it down to clip with the U-hooks below. We repeat this process for the other two connectors. After clipping the third connector, the ROV will use the claw to remove the power port cover, before going to grab the power connector (attached to the solar panel array). Finally, the claw clamps onto the power connector, and the ROV moves to connect it to the power port. The power port cover will presumably be moved to the side of the pool.

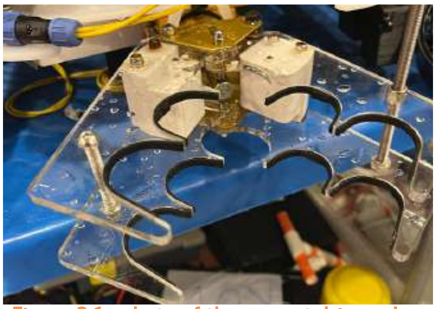


Figure 3.1 : photo of the magnet driven claw

Similar to task 1.1, our team will mainly be relying on the claw to complete this task. For the pipe cleaner biofoulings, the claw will simply clamp around the loops, or the driver can utilize the claw's curved structure to pull out the pipe cleaners. For the red cross biofoulings, the claw will clamp around them, and the ROV will move in reverse to detach them from the wind turbines.

By constructing the claw ourselves, we were able to fine-tune its functionality, dimensions, and compatibility with our ROV, ensuring seamless integration and dependable performance throughout the event. In comparison, outsourcing the claw would have necessitated extensive research to find a product that might still fall short of meeting the specific mission requirements.

### AUTO PILOT CONTROL

In task 1.3 of the ROV mission, the robot is required to navigate into a docking station and press a button located at the back of the station. This task can be accomplished either manually or autonomously. Our team devised a program to maximize our score by utilizing OpenCV to obtain a mask of the red button from the video feed captured by the camera. To ensure accuracy, multiple filters were implemented to reduce background noise and ensure a consistent performance. This enabled us to obtain a clear image of the red button, and accurately determine its position in the camera feed. We then converted the distance between the center of the screen and the midpoint of the red button into a set of coordinates that were used to control the ROV's motion, specifically its surge, sway, and heave motion. Once the image of the red button was centered on the screen, the ROV moved forward until it made contact with the button at the end of the docking station.

## TASK 2: Healthy Environments from the Mountains to the Sea

### FISH TRAP

A rotatable disk is installed inside the transparent circular container which acts as a gate to let the fry out. After the ROV has stayed in the safe release area for the set period, it will move vertically downward until the T-shaped stick collides with the bottom of the pool, activating the gate and releasing the fry.

Figure 3.2 : photo of the fish container

## SEAGRASS COUNTING ALGORITHM

The ROV first obtains an underwater image of the distribution of seagrass in order to calculate the seagrass blocks. A green color mask is introduced to identify areas with green seagrass. This extracts the green color pixels from the image. The noise cancellation algorithm is applied to enhance the information in the processed image. The result contains only green areas in the image. Furthermore, the square-counting algorithm detects squares by connecting contours in the image and calculates the correct number of seagrass blocks. We perform a check to ensure that all detected areas are parallelograms and exceed a certain size in order to minimize error.

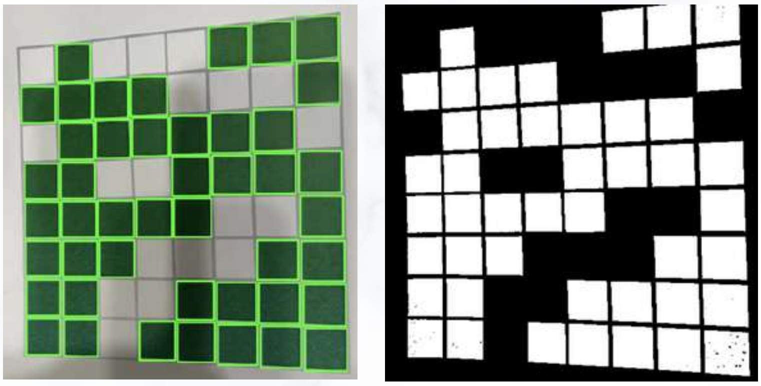


Figure 3.3 : seagrass identified by the computer program

## 3D MODEL BUILDING PROCEDURE

Constructing a 3D model of a coral head requires expertise in photogrammetry and strategic camera positioning. To address the mission requirements, our software engineering team first considered the option of developing a 3D construction pipeline from scratch. However, they recognized that doing so would be highly complicated, time-consuming, and might not yield the same high-quality results as existing APIs or libraries.

With this in mind, the team evaluated various options for both 3D model creation and visualization software applications, including Colmap, Mashroom, Apple Reality API, and OpenCV built-in functions. After rigorous testing and comparison, the team concluded that the Apple Reality API provided the best results and performance. By opting to use an existing software solution rather than developing one in-house, the team could allocate more resources to refining the robot's photographic trajectory and algorithm, ensuring efficiency and quality.

With the software selected, we devised a plan for the robot's photo-capturing path to ensure comprehensive coverage of the target object. They formulated an algorithm that involved circumnavigating the object and completing four revolutions while capturing images. For each revolution, the robot's orientation was incrementally modified to capture images from various angles. combined with the rigorously tested methodology, it resulted in a 3D model with a level of detail and accuracy essential for analysis.

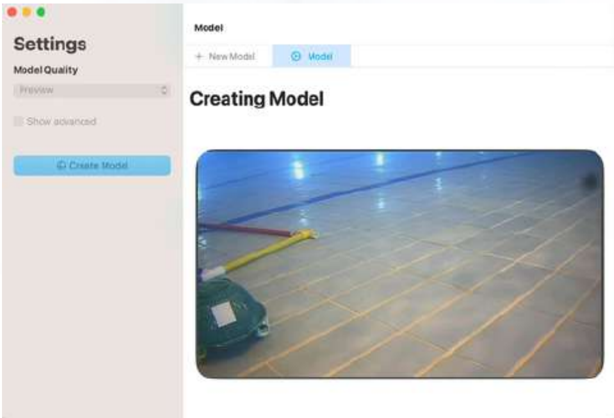



Figure 3.4 : screenshot of a program developed with Apple Reality API

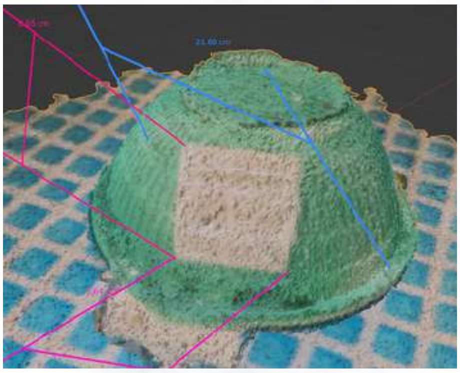


Figure 3.5 : screenshot of dimension measurement

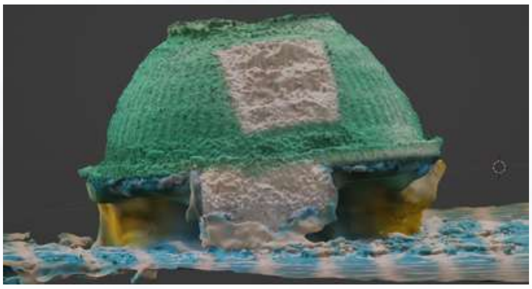


Figure 3.6 : side view of the model

## WATER SAMPLE EXTRACTOR

We are required to extract a water sample from a container suspended inside a 2-gallon bucket. Marlin employs a water pump for extracting water sample from containers to examine its composition. The water pump consists of a water inlet and a water outlet. The water inlet is connected to a pillar used for aiming and penetrating the plastic wrap, while the outlet is connected to a 50ml empty container fixed on Marlin. When the pillar is aimed into the water sample container, the pump can extract the water sample to our container.

# TASK 3: MATE Floats! 2023

The vertical float, designed to meet mission requirements, consists of two primary components: a buoyancy module and a transmission module. These modules feature innovative sensor and payload tool integration, ensuring the float's effective operation.

## BUOYANCY MODULE

This module comprises a water inlet at the float's bottom, a linear actuator, and a syringe. The actuator is powered by a battery case, each containing 6 AA alkaline batteries, which provide high voltage and current to the motor for strong suction force. The output power and direction of the linear actuator are controlled by the PWM signal generated by the Arduino Nano board, enabling seamless water intake and discharge. When the actuator moves up, water flow into the syringe due to the negative pressure difference, and vice versa when the actuator moves down. By controlling the volume of water in the syringe, the buoyancy module allows the float to rise or sink in the water with ease, meeting specific mission requirements for depth control.

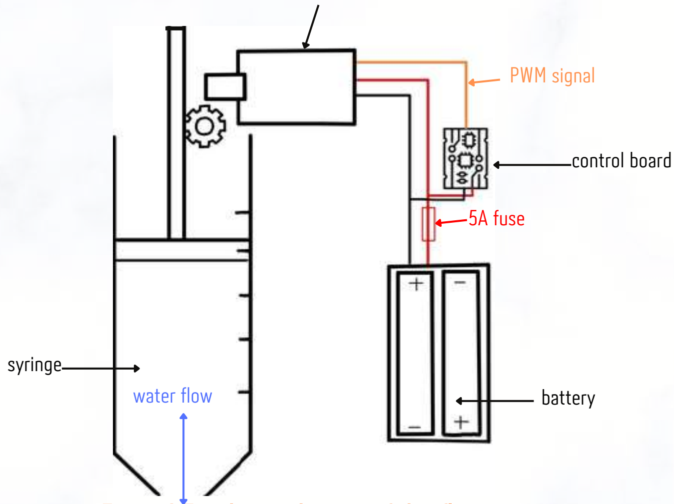


Figure 3.7 : physics diagram of the float

## TRANSMISSION MODULE

Designed to meet the mission's communication needs, this module employs a radio signal transmitted through an RF transmitter module installed on the vertical float. The signal, which contains information about the current time and company number, is sent when the float reaches the water level. An RF receiver module, located in the control box, picks up the signal, displaying the data on the monitor.

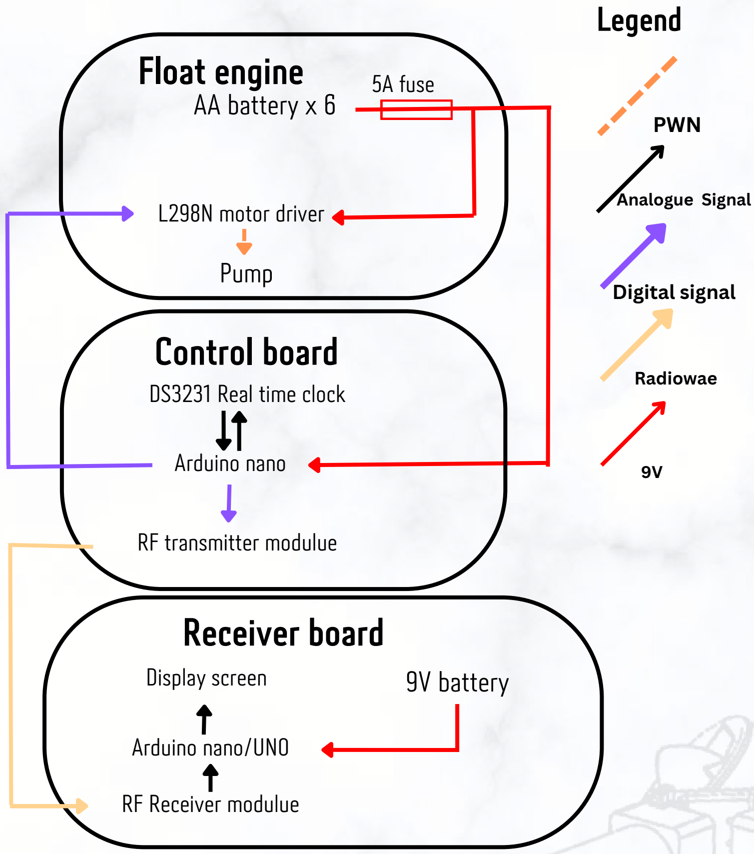


Figure 3.8 : Interconnection diagram of the float


Figure 3.9 : photos of the float

# SAFETY

## Philosophy

Our company prioritizes employee safety, believing that their well-being is crucial to Eposea's operation. We are committed to providing a secure environment in which employees can maximize productivity while remaining protected. This philosophy has guided the manufacturing process of our ROV, and we have implemented various measures to uphold these principles.

## Safety Training

In January 2023, we conducted peer-to-peer advanced safety training for new employees. This training aimed to familiarize them with the tools, equipment, and safety protocols involved in building the ROV, including electricity and fire safety, and proper apparatus usage. Senior employees demonstrated safe tool handling and supervised new employees as they practiced using the equipment, ensuring all team members adhere to necessary safety guidelines.

## Laboratory safety

We strictly implement our laboratory safety measures to protect employees while they work with tools, machinery, and hazardous materials. To ensure the well-being of our team, we provide safety goggles and hearing protectors for employees to wear when operating machinery or powered tools. Additionally, gloves and protective clothing are available for handling chemicals or materials that may cause skin irritation or injury.

To safeguard against health risks posed by solder fumes and epoxy resins, an exhaust ventilation system is utilized during soldering and epoxy handling processes. Workstations are designed with proper ergonomics, ensuring comfortable and safe working environments that reduce stress and fatigue.

Employees are expected to remain vigilant and focused when using components, minimizing the risk of injury to themselves or others. They should also follow proper procedures for handling and disposing of chemical materials

First aid kits are readily available in case of accidents, and employees are responsible for returning used components to their designated storage locations. Regular safety inspections are conducted to assess and maintain optimal lab conditions.

## Vehicle Safety Feature

Epoxsea strictly follows MATE safety requirements every year to ensure Marlin is up to standard in terms of design, manufacture, and operation. As the result, our philosophy of safety is integrated into ROV design.

To minimize the risk of harm to our crew mates, our company has removed all sharp edges from Marlin and marked other parts that might be dangerous. The wires have been carefully arranged so that people won't trip over them while they are at the poolside. The insulation on the wires and boards has also been waterproofed to prevent shorting out if exposed water touches it. In case of emergency, a kill-box with an inline fuse and an emergency stop button has been installed to cut off the  power supply.

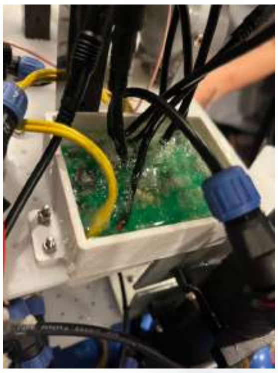


Figure 4.1 : waterproofed wire and board

Figure 4.2 : photo of the kill box

## Equipment Safety Assignment

Employees are required to use tools and equipment safely and appropriately, following proper operating procedures and guidelines. Regular training sessions and refresher courses are provided to keep employees up-to-date on safe practices and any changes in equipment usage.

In case of malfunction, damaged tools, or potential hazards, operations should be halted, and the issue reported to the appropriate supervisor or safety officer. Employees are responsible for conducting pre-use inspections of tools and equipment to identify any defects or issues that may pose a risk during operation.

Team members are encouraged to clean their workspace, tools, and equipment after use to maintain an organized working environment that reduces the likelihood of accidents caused by clutter or misplaced items. Furthermore, employees are instructed to store tools and equipment properly to prevent damage and ensure their availability when needed.

Figure 4.3 : photo of employee in safety training

## Testing Protocols

Every year, improvements are made to the testing protocols used to guarantee the operational safety of the Epoxsea's ROV. Routine dry runs of every operation are accomplished before any tests are carried out in water. All crew members must consistently and rigorously commit to the Job Safety Analysis Checklist and the Operational Checklist. Clear communication protocols, such as the use of "Kill" and "Launch" signals, must be used between engineers on the shore and those operating the ROV. As a result, any physical harm due to the improper activation of the ROV's manipulators or thrusters could be eliminated. These communication signals have proven to be very helpful in ensuring that the ROV is not operated while crew members are performing maintenance or to immediately shut down in case of emergencies.

# TESTING AND TROUBLESHOOTING

## Vehicle testing methodology

To ensure the performance and reliability of Marlin, our team employs a comprehensive testing methodology that involves multiple stages. First, we conduct an in-air dry test to assess the power supply unit's functionality and propellers, while also identifying possible leaks in the connection wiring. Following this, Marlin undergoes a neutral buoyancy test to ensure its stability and mobility in water. Finally, the ROV is tested for its ability to perform mission-specific tasks, which are evaluated through pre-determined success criteria.

## Troubleshooting Strategies

The intricate structure of Marlin motivates employees to meticulously troubleshoot any issues that arise during testing. Our team employs various strategies and techniques, such as brainstorming, root cause analysis, and iterative problem-solving, to address challenges from different perspectives. Employees are encouraged to collaborate and share their expertise, fostering a problem-solving culture that promotes innovative solutions.

## Prototyping and Evaluation

In the hardware department, digital multimeters are utilized during electronic testing to confirm the appropriate connectivity of the circuit boards. Waterproof materials are applied to the circuit boards before conducting underwater testing to ensure optimal performance in aquatic environments.

In the mechanical department, our company uses rapid prototyping to evaluate design options for the chassis and manipulators. We first establish a proof of concept through 3D printing, which allows us to test the feasibility and effectiveness of our designs. Once the design is refined, we proceed to create a prototype, followed by stress testing to ensure the component's durability and robustness.

# PROJECT MANAGEMENT

## Organization Structure, Planning, and Procedures

Epoxsea specializes in developing advanced ROVs for underwater exploration and research. Our company emphasizes inclusive culture, prioritizing team cohesion and seamless integration of new members through team-building activities and workshops. These initiatives promote smooth transitions for newcomers, enhance cross-cultural understanding, and strengthen the team's problem-solving abilities.

The Marlin project exemplifies the benefits of Epoxsea's inclusive culture, as diverse perspectives improve the ROV's adaptability in handling unexpected situations. By cultivating a supportive and harmonious work environment, Epoxsea ensures success in both the Marlin project and other initiatives.

Epoxsea fosters transparent communication, self-management, and collaborative decision-making. Gantt charts are utilized to outline project timelines, keeping team members informed of tasks and deadlines. Weekly meetings are held to assess progress, set short-term goals, and address challenges faced by divisions.

## Company Management

The leadership team of Epoxsea often includes a CEO, CFO, CTO, and Safety Officer. The CEO is responsible for the overall success of the organization and manages its operations and growth strategy. The CFO manages the company's financial actions, including financial planning and risk management. The CTO has a specific responsibility to ensure that the development of the ROV complies with the requirements of the MATE ROV Competition 2023. This is an important role in ensuring that Epoxsea is able to successfully participate in the competition. The Safety Officer oversees workplace activities to ensure compliance with safety regulations and policies. Together, these executives work to ensure the successful operation and growth of Epoxsea.

At Epoxsea, each department has a leader who plays a vital role in managing their team and ensuring its success. These leaders are responsible for setting and achieving departmental objectives, overseeing the department's budget and resources, leading and supervising personnel, collaborating with other departments and leaders, and representing their department in meetings and discussions. By effectively carrying out these responsibilities, department leaders contribute to the overall success of Epoxsea.

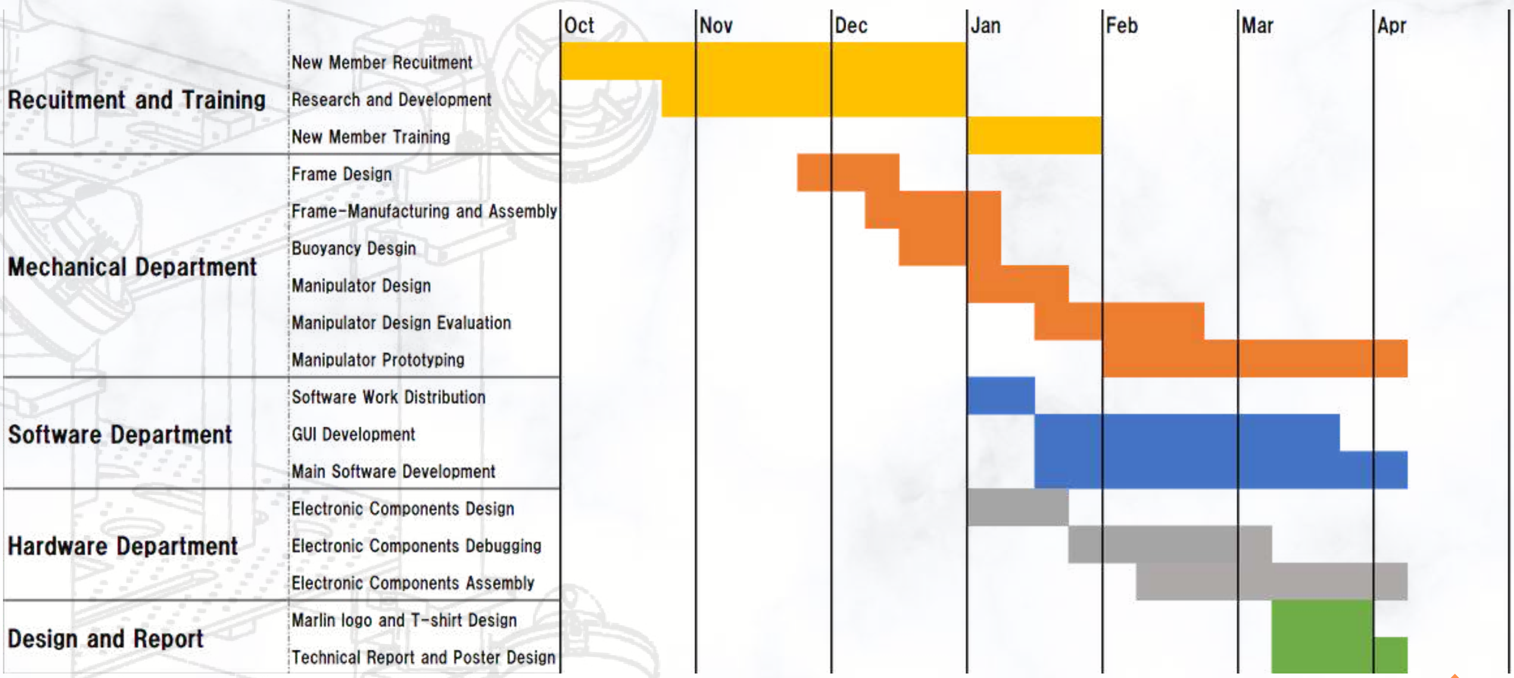



Figure 6.1 : Gantt Chart

## Mechanical Pipeline

Epoxsea remains dedicated to nurturing the professional growth of its mechanical engineers, emphasizing the development of dependable manipulators and the enhancement of teamwork. Engineers collaborate in pairs, jointly conducting research and design processes, exploring alternative solutions, and presenting their findings to the division. This strategy fosters a harmonious team environment while facilitating the early identification of potential issues, mitigating the squandering of time and resources.

Leveraging resources such as Dropbox's cloud-based file storage system, Epoxsea streamlines the co-working experience and ensures version control of mechanical designs. This platform permits design access and modification without constraints of time or location, directly supporting the achievement of mission objectives by expediting the development process.

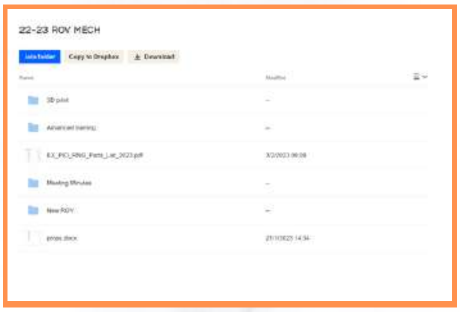



Figure 6.2 : A screenshot of the DropBox interface

To guarantee and refine manipulator performance, each device undergoes field testing to evaluate driver friendliness and operability. Engineers obtain feedback from drivers after each trial, pinpointing areas of improvement and augmenting the manipulator's performance to ensure mission readiness and reliability.

Figure 6.3 : Small Scale On-shore Testing of the Water Sample Collection Mechanism

## Software Pipeline

The software department concentrates on crafting reliable software, incorporating essential controls and mission-specific functionalities. The software architecture enables engineers to work on distinct modules concurrently without interference, directly contributing to mission objectives by facilitating efficient development and integration.

The software pipeline serves to consolidate and maintain up-to-date software versions throughout water testing. This multi-staged testing approach yields highly reliable and mission-ready software, satisfying all requirements and exemplifying a commitment to quality and excellence. The pipeline ensures that only the most refined and robust software versions advance to the deployment phase, bolstering the successful completion of mission objectives.

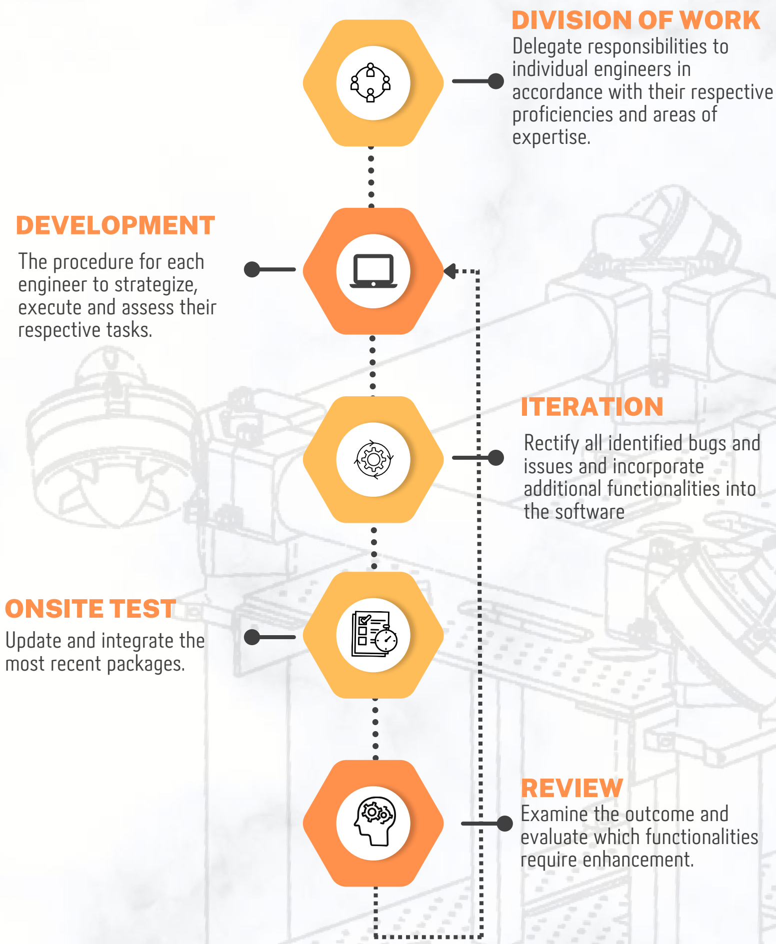



Figure 6.4 : Software Pipeline Flowchart

# CHALLENGES

## Non-technical Challenges

### TIME MANAGEMENT

Any robotics project requires excellent time management because the crew must finish their work within a set deadline. However unplanned occurrences like vacations, supplier delays, or component shortages have interfered with our project schedule, resulting in additional delays and putting more strain on the team. Unfortunately, the Chinese New Year break in late January resulted in delays of more than a month after our team ordered components from China. The crew finished the prototype later than expected as a result of the delay, endangering the project's success. To address the above problem, our company incorporated a buffer into the project timeframe to account for unforeseen circumstances in order to reduce this risk.

### RESOURCE MENAGEMENT

Robotic projects can be expensive, involving large expenditures on hardware, software, and supplies. Yet, when the team needs to purchase components rapidly, cash flow issues can occur. To take advantage of a supplier's discount on components, for instance, the team might need to deposit thousands of dollars. As a result, team members may experience financial hardship and run the danger of project delays if they are unable to buy the necessary components in time. To solve this issue, our company created backup plans and look into alternative sources of funding, such as increasing sponsorship, to reduce the likelihood of such hazards.

## Technical Challenges

### THRUSTERS FINE-TUNING

In order to effectively integrate Marlin's design and optimize the controller's driving experience, a continuous adjustment of each thruster's motor input is necessary. This entails the provision of additional speed modes to enhance the overall smoothness of driving. One of the most intricate tasks to accomplish is the development of an automatic docking system. Unlike a straightforward following line task, this task requires the 3-dimensional movement of the ROV, thereby presenting significant challenges in the coding process. Multiple iterations of fine-tuning the code are essential to ensure the successful execution of this task.

### FLOAT CONSTRUCTION

Our company also faced several challenges when building the vertical profiling float. One of the challenges was cable management. The wires that were used in the float engine were fragile and prone to breaking. This made it difficult to ensure that the connections between the carious components were secure and reliable.

Apart from cable management, component layout also was a great challenge. This was particularly difficult because the float had to be thin to minimize drag and improve its performance in the water. Additionally, many of the components that needed to be included inside the float was bulky and difficult to fit into the limited space available. To deal with this difficulty, our engineers carefully planned out the placement of each component and design custom mounting brackets to hold them well in place.

# FUTURE IMPROVEMENT

## Electronics

In the pursuit of refining Marlin's electronic components, we have delineated two primary areas of improvement that hold the potential to significantly enhance the system's performance and usability: Tether Simplification and PCB redesign for MATE Float.

First and foremost, reducing the number of wires in the tether that connects the underwater vehicle to the computer on the surface would streamline the overall design and mitigate tangling issues. The current tether utilizes 8 wires to transmit the video feed, which could be simplified by employing optical transmitters. By connecting 4 wires to an optical transmitter each, only 2 signal wires would be required to transmit the data. This approach would declutter the tether and ameliorate entanglement problems that could surface.

Secondly, redesigning the printed circuit board for the MATE Float could redound to a more compact and functional vehicle. The extant PCB incorporates an Arduino Nano to govern the logic and an L298N for motor control. However, the magnitude of the board renders it difficult to ascertain a suitable casing for the float. By engineering a new, smaller PCB, the dimensions of the board could be reduced, expediting the process of finding an appropriate enclosure for the MATE Float. The redesigned PCB would streamline the overall architecture and enhance the capabilities of Marlin's electronic components.

## Mechanical

Employees at Epoxsea consistently endeavor to enhance the capabilities of our remotely operated vehicle (ROV), Marlin, with the goal of increasing its effectiveness and reliability.
One key area of focus is corrosion, whose effects significantly compromise the strength, ductility, and dimensional integrity of mechanical components such as screws. This vulnerability to stress and damage necessitates preventative measures. To address this issue, Epoxsea personnel have evaluated two potential solutions: applying protective paint or epoxy resin to mechanical parts to prevent contact with water.

After deliberation, the application of epoxy resin has been determined to be the superior option as it not only mitigates corrosion but also precludes sharp edges and prevents water infiltration into electrical systems.

Another focal point is reducing stresses applied to carbon fiber tube connectors during the constant lifting operations of the ROV. The underlying cause of this problem would likely be remedied by distributing stresses throughout the ROV to fortify vulnerable junctions. However, due to shortcomings in the existing framework design, implementing such modifications mid-process proves more difficult. Despite these challenges, Epoxsea engineers remain steadfast in refining the present design and overcoming any hindrances to progress.

## Software

To ensure sustained performance and avoid impending obsolescence, the underwater vehicle needs to upgrade from the current Robot Operating System 1 (ROS 1) operating system to the newer Robot Operating System 2 (ROS 2) platform. Despite the challenges, migrating to a modern framework is critical for optimal functionality and longevity.

ROS 2 provides key benefits over aging ROS 1, including enhanced quality of service, real-time control, and cross-platform deployment. Although the transition will require systematically redeveloping software modules and will be time-intensive, the rewards of a nimbler, future-proof system make the investment worthwhile.

While the upgrade to ROS 2 will be an arduous endeavor, the transition to a modernized and maintained operating system is critical for sustained performance and currency. The robot needs to evolve with the latest technical advancements to operate at maximum efficacy and avoid incompatibility. The redevelopment of modules for migration to ROS 2 will require significant investments of time and resources. However, the rewards of enhanced functionality, versatility, and longevity will make the efforts worthwhile. It is essential to safeguard the robot against impending outdatedness and ensure its robust and reliable operation into the future.

# LESSONS LEARNED

## Using New Mangement Tools

Epoxsea gained invaluable insights in administration, particularly in project planning. This year, our company uses Asana to create a detailed project plan for building Marlin. Asana is a comprehensive platform for managing the project. It allows virtual communication and collaboration with team members and also tracks progress. Our company broke the whole development process into smaller, more manageable tasks and assigned them to team members with due dates. Asana's task management features allowed the team to track the status of each task and ensure that everyone knew what they were responsible for and when their work was due. In addition, Epoxsea also learned to keep track of the overall progress with the critical path method. We set milestones for the completion of each stage of the project, such as the completion of the design phase and the completion of the build phase. The milestones helped to keep the company focused on the big picture and provided a sense of accomplishment as the project progressed.

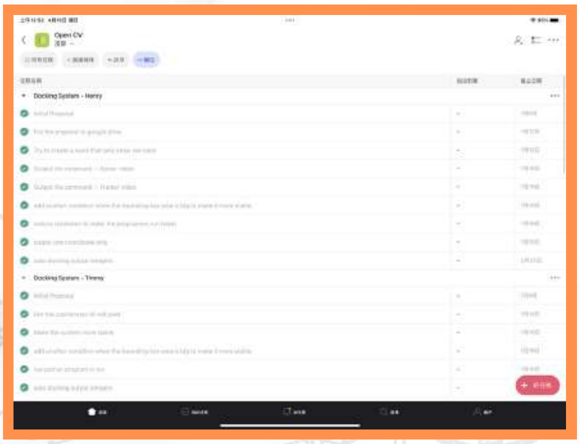


Figure 9.1 : screenshot of Asana

## Multi-field Collaboration

At Epoxsea, interdisciplinary collaboration has highlighted the value of effective communication, diverse perspectives, and teamwork. By embracing colleagues' expertise across disciplines, we've gained a deeper understanding of complex systems and fostered a collaborative environment, driving innovation and excellence in our industry.

## Mechanical Design

Beside, we have attained mastery in the domains of mechanistic, architectural design, and fabrication. In the realm of mechanistic, we have cultivated a profound comprehension of the theoretical precepts undergirding the laws of physics, which we artfully apply to conceive and fabricate an automated robotic system capable of operating efficiently in an aquatic environment. Our experience in design has inculcated in us the imperative importance of creativity, innovation, and problem-solving acumen to translate our conceptual ideas into pragmatic solutions apt for real-world applications. We have also forged skills indispensable for detail orientation and aesthetic finesse, ensuring that our robotic system achieves not only functionality but also visual appeal.

## Computer Vision Skills

As there are many tasks related to computer vision, our software engineers have explored OpenCV library, a open source computer vision library, in depth. OpenCV provided our engineers with access to a wide range of algorithms for tasks such as filtering, object tracking, 3D reconstruction and image processing. These algorithms and functions provided by OpenCV equip our software engineering the skills of applying computer vision in fields such as self-driving car, augmented reality, and not to mention robotics.

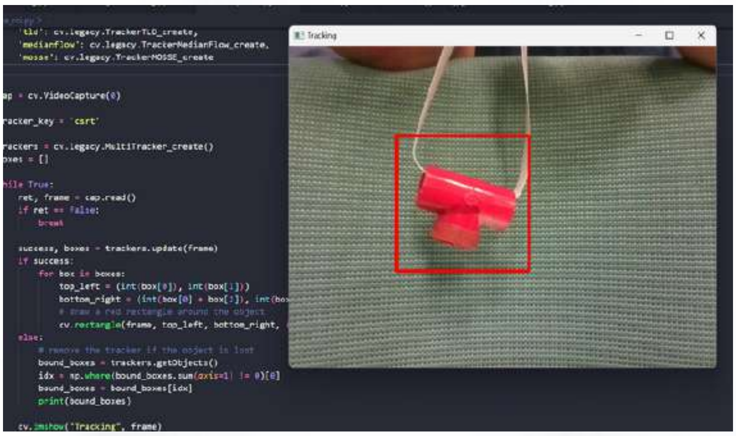


Figure 9.2 : photo of our software engineer experimenting with object tracking with CSRT Tracker in OpenCV

# SOCIAL RESPONSIBILITY

## Underwater Robot Competition

Last 2022 December, Epoxsea actively participated in the Underwater Robot Competition 2022 for youth to promote underwater robotics and STEAM (science, technology, engineering, arts, and mathematics) education. There were 16 primary schools and secondary schools. and over 100 teachers and students took part in it. As a company founded on the principle of social responsibility, we see this as a continuation of our tradition of providing technical support and knowledge-sharing with the community. We hope to inspire participants and ignite their passion for technology and innovation. Also, Exposea is eager to share our knowledge and experience with students and hobbyists alike to help advance their skills and interests.

Figure 10.1 : photo of our employee assisting in competition

Our employees volunteered as mentors and judge at the competition, providing guidance to participants on robot design and construction. We found that interacting with and supporting the next generation of robotics enthusiasts is rewarding and reinvigorates our own work. By giving back to the community in this way, Epoxsea is playing an active role in developing future talent in this exciting technical field. Through participating in community events such as this youth competition, we hope to spread technological knowledge, nurture talent, and ultimately drive progress in this field. Epoxsea remains dedicated to this goal as we continue developing innovative products and applications in the realm of underwater robotics.

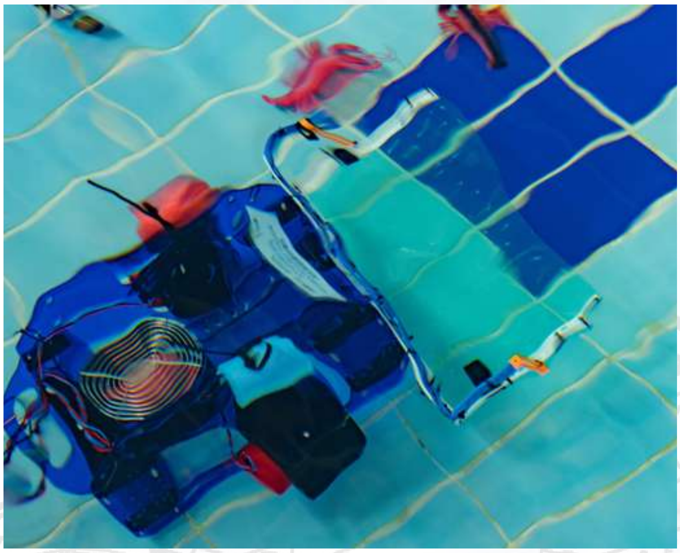


Figure 10.2 : photo of the participants' robot

## Laboratory Tour for Students

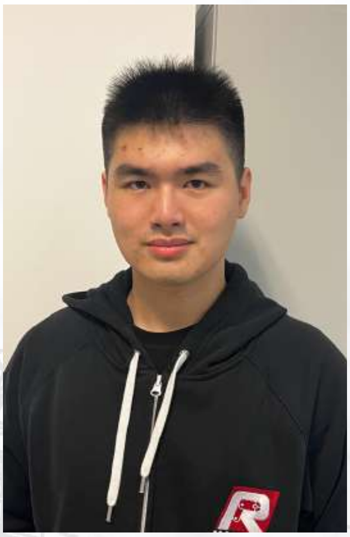
In April 2023, Epoxsea welcomed 10 secondary school students to our lab for a day of learning and discovery. The students explored the robotics workshop, electronics development lab, machine shop and ROV testing pool. They were fascinated to see the high-tech equipment and prototypes of underwater robots used for ocean exploration. Our employees gave demonstrations and explained how they designed, built and tested remotely operated vehicles.

Figure 10.3 : photo of our employee describing the basic design principles of underwater robots to students

# REFLECTIONS

As the CEO of Epoxea, I am incredibly grateful for the opportunities this role has afforded me. Through leading our team, I have been able to develop and sharpen my leadership skills, time management, and effective communication, which are crucial for enhancing overall productivity. Also being as a software senior, I have also gained a deeper understanding of managing timelines and milestones efficiently, which has been instrumental in ensuring the timely completion of tasks. Our journey has not been without its challenges, but we have always overcome them through collaboration and problem-solving. It is through our dedication and hard work that we have successfully developed Marlin, and the sense of accomplishment we feel is irreplaceable. Overall, this experience has been incredibly meaningful, and I am honored to be a part of Epoxea. I am grateful for the opportunities that this role has provided me and look forward to continuing to lead our team towards success.

~ CEO: LEUNG, Ka Chun Wesley (Year 2) ~



I am honored to be the hardware leader for the ROV team this year. Although this is my second year in ROV, it didn't stop me from learning new stuff and in fact, I had a much broader view of what the hardware department should do and how we should cooperate with other departments. As a hardware leader, I had to teach new skills and assign tasks to all my members according to their strengths and weaknesses as well as their conditions. Also, I learned how to collaborate with teammates from different backgrounds to deal with different situations which may give rise to all kinds of problems. Time management skills are also what I obtained during this time, as we have to complete our tasks before deadlines to make sure all the tasks are done before our scheduled date to test the robot. Finally, I want to thank the team because I had a fruitful experience working with people that are hardworking and passionate about their work.

~ Hardware Leader: KUO, Chen Chieh Chris (Year 2) ~

While I've only spent a few months as a junior mech employee of Epoxsea, I'm extremely grateful for the incredibly valuable experiences I've had up to this point as part of the team. As a hands-on learner and a first year with little engineering experience, I can't express how valuable it is to be taught mech skills (cadding, tool usage, etc.) and be given numerous opportunities to practice applying them. I've closely worked alongside other junior members in prop building sessions and designing mechanisms, while senior members from across divisions (mech, SW, HW) were always around to help answer any concerns I had. Whether it was being chased by the ROV during pool tests, brainstorming the optimal ROV layout, or just having lighthearted conversations between friends, the Epoxsea team has made me feel so at home alongside like-minded peers from all kinds of backgrounds. I truly look forward to working alongside this team.

~ Mechanical Junior: CHIN, Jonathan Kiu Fung (Year 1)~

# ACKNOWLEDGEMENTS

The following individuals and organizations have helped in the creation of Marlin, and Epoxsea would like to express our most sincere gratitude to them:

HKUST School Of Engineering — for providing persisting support, sponsorship and laboratories for Epoxsea
HKUST Center for Global & Community Engagement "GCE" — for supporting Epoxsea
HKUST Design and Manufacturing Services Facility "DMSF"— for providing technical advice and guidance to Epoxsea on mechanical design
HKUST Student Affairs Office "SAO" — for granting us permission to test Axolo at the university's swimming pool
Dr. WOO, Kam Tim— our supervisor, for his continuous consultation and advice that helped Epoxsea improve on both technical and non-technical aspects
LEUNG, Chun Yin— our mentors, for their guidance and technical help throughout the design process of Marlin
MATE Center — for organizing the international underwater ROV competition, providing a platform for the community to learn about marine technology, and promoting STEM education around the world by solving real life problems
The Institution of Engineering and Technology, Hong Kong "IET HK" — for organizing the Hong Kong/Asia Regional of the MATE International ROV Competition 2023 and educating the Hong Kong public on marine technology
RS Components Ltd. — for providing electronic components and funding for Epoxsea
The Milwaukee Electric Tool Corporation — for providing mechanical tools and funding for Epoxsea

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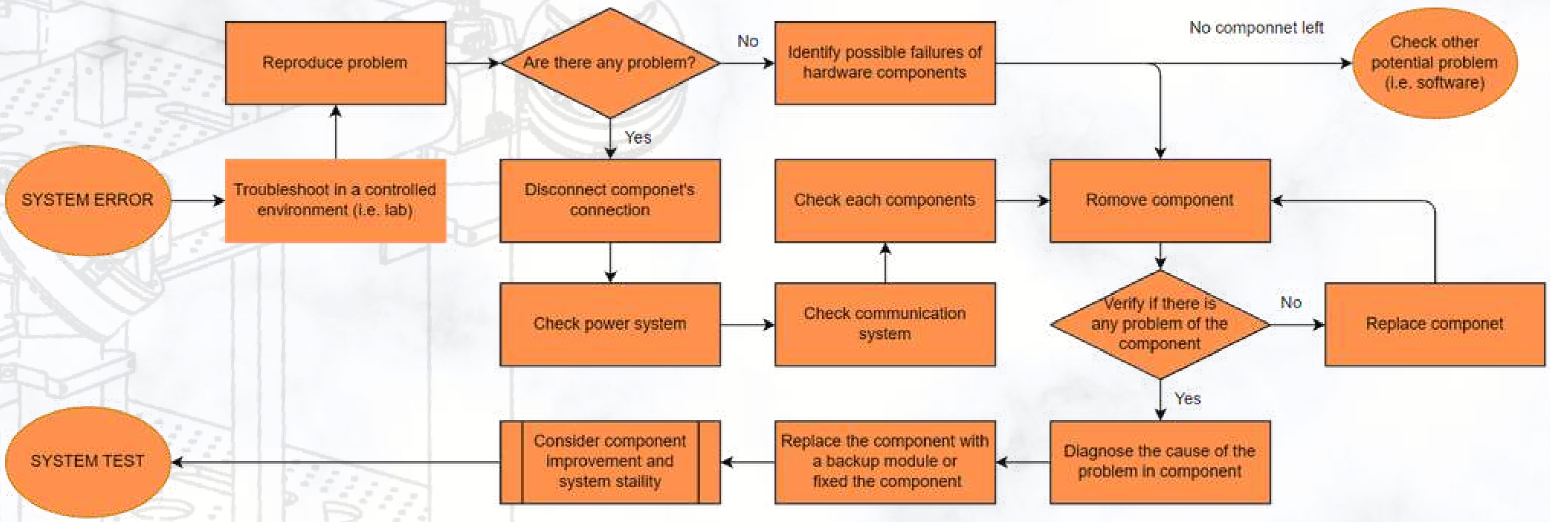
# APPENDICES

## Appendix A: Operational Checklist

| General | During Mission Run |
|---|---|
| ☐ No running at the pool.<br>☐ Only crew members are working on Marlin.<br>☐ Communication is loud and clear. | ☐ No bubbles are coming out.<br>☐ "Contact" is called when anyone touches Marlin.<br>☐ The status of Marlin is well monitored.<br>☐ The tether is not too tight or too loose. |
| **Construction** | **Protocol** |
| ☐ Ensure that the machinery/ tool is in good condition.<br>☐ Wear suitable protective equipment while working on cutting, drilling, etc<br>☐ Shut down all the electronic appliances when they are not used<br>☐ Perform soldering in a well-ventilated area or under a fume hood<br>☐ Put back all the tools to their designated position after using them.<br>☐Put on protective gloves and goggles to avoid direct contact while handling chemicals | ☐ "Kill" when the power is needed to be cut immediately<br>☐ "Contact" when anyone is going to touch Marlin<br>☐ "Launch" when the ROV is ready to be operated underwater<br>☐ "Release" when the shoreside crew triggers any manipulator |
| **Before mission run** | **After mission run** |
| ☐ All connections are secured and correctly connected<br>☐ No Camera is blocked<br>☐ Cables and tether are properly tightenedTether area has no obstruction<br>☐ Electronic and pneumatic systems are working<br>☐ No electronic components are exposed<br>☐ Nuts on manipulators are properly fastened and boltedDry test is completed | ☐ Ensure the power supply is turned off before disconnecting ☐ the tether<br>☐ Electronic parts remain dry during disconnectionController is not in contact<br>☐ The tether is kept tidily and neatly |

## Appendix B: Electronics Troubleshooting Checklist



# Appendix C: Proposed Budget

| Category | | | USD $ | USD $ | USD $ |
|---|---|---|---|---|---|
| Income | | | | | |
| University Fundng | The Hong Kong University of Science and Technology | | | | 3368 |
| Sponsorship | The Milwaukee Electric Tool Corporation | | | | 995 |
| Sponsorship | RS Components Ltd. | | | | 995 |
| Total Income | | | | | 5359 |
| Expense | | | | | |
| Hardware | Wiring | | | 191 | |
| | PCB printing | | | 51 | |
| | Components | MCU | 100 | | |
| | | others (mosfet capacitors, resistors, etc.) | 255 | 355 | |
| | Tools | | | 300 | |
| | Camera | | | 804 | |
| | Miscellaneous | | | 32 | |
| Hardware Total | | | | | 1733 |
| | | | | | |
| Mechanical | Frame | PP | 510 | | |
| | | connector | 38 | | |
| | | thrusters + speed controller | 651 | 1199 | |
| | buoyancy | styrofoam with coating | | 179 | |
| | pneumatic | connector | 100 | | |
| | | valve | 51 | | |
| | | pipe | 19 | 170 | |
| | Electromagnet | | | 89 | |
| | Control Box | frame | | 100 | |
| | 3D printing | repairment | | 31 | |
| | Tools | Stright die grinder | 153 | | |
| | | Drill bit | 40 | | |
| | | Driller | 89 | | |
| | | Impact driver | 70 | 352 | |
| | Miscellaneous | | | 402 | |
| | shipping | | | 102 | |
| Mechanical Total | | | | | 2624 |
| Software Total | | | | | 0 |
| Props | PVC | | | 51 | |
| | PVC connectors | | | 30 | 81 |
| Miscellaneous | | | | | 447 |
| Total | | | | | 4884 |
| | | | | | |
| | | | | | |

# Appendix D: Cost Projection

| Category | | | USD $ | USD $ | USD $ |
|---|---|---|---|---|---|
| Income | | | | | |
| University Fundng | The Hong Kong University of Science and Technology | | | | 3368 |
| Sponsorship | The Milwaukee Electric Tool Corporation | | | | 995 |
| Sponsorship | RS Components Ltd. | | | | 995 |
| Total Income | | | | | 5359 |
| Expense | | | | | |
| Hardware | Wiring | | | 255 | |
| | Computer for Control Box | | | 663 | |
| | Components | MCU | 64 | | |
| | | others (mosfet capacitors, resistors, etc.) | 32 | 96 | |
| | Header | | | 508 | |
| | SDI Camera | | | 510 | |
| | SDI Converter | | | 766 | |
| | LED lights | | | 4 | |
| | Miscellaneous | | | 26 | |
| Hardware Total | | | | | 2827 |
| | | | | | |
| Mechanical | Frame | PP | 30 | | |
| | | connector | 5 | | |
| | | thrusters + speed controller | 1134 | 1169 | |
| | buoyancy | styrofoam with coating | | 24 | |
| | pneumatic | connector | 16 | | |
| | | valve | 46 | | |
| | | pipe | 11 | 73 | |
| | Electromagnet | | | 29 | |
| | Water Pump | | | 13 | |
| | Claw | | | 38 | |
| | 3D printing | repairment | | 13 | |
| | Miscellaneous | | | 36 | |
| Mechanical Total | | | | | 1396 |
| Software Total | | | | | 0 |
| Miscellaneous | | | | | 51 |
| Total | | | | | 4274 |
| | | | | | |
| | | | | | |