epoxsea

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Technical Report

MATE ROV Competition 2024

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

INTRODUCTION

Abstract

EPOXSEA's most recent Remotely Operated Vehicle (ROV), WAHOO, represents an innovative solution engineered to execute operations such as the repositioning of Coastal Pioneer Array nodes, the installation of intelligent cabling, marine surveillance, and the monitoring and preservation of coral health.

EPOXSEA (Figure 1), is a diverse company of 29 employees, comprising 7 women and 22 men, hailing from over 5 countries, with 13 years of expertise in the design, manufacture, and operation of ROVs. EPOXSEA's well-structured organization and clear departmental hierarchy enable the efficient transformation of ROV concepts into cost-effective products.

Adhering to the development standards of safety, efficiency, affordability, and user-friendliness, EPOXSEA has spent years in research, development, and debugging. EPOXSEA self-developed ROV control framework, the ROV system, has been incorporated into WAHOO, rendering it the most capable ROV in our lineup.

WAHOO is characterized by its modularity, speed, serviceability, ease of maintenance, reliability and lightweight design. EPOXSEA is pleased to disclose the design rationale, safety measures, management strategies, critical analysis, and accounting.

WAHOO represents the future of ROVs, encapsulating approximately 1200 work hours over a year. Its innovative features include an open structure, an eight-thruster configuration, underwater omni-wheel propulsion, and versatile manipulators.

This document will delineate the planning process, prototyping stages, and challenges that EPOXSEA encountered, to contribute to the global ROV community. It is our hope that other companies can learn from the experiences to construct more advanced ROVs in the future.

(234 words)

Figure 1 EPOXSEA Company Photo

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LEUNG, Chun Yin: Our mentor, for the guidance and technical assistance throughout the design process of WAHOO.

Design Rationale

Design Overview

EPOXSEA has undertaken a comprehensive reassessment of the ROV's design, adhering to the development principles of safety, efficiency, cost-effectiveness, and user-friendliness. Leveraging 13 years of research experience in ROV technology, the most recent iteration of the ROV, WAHOO, based on 2023 ROV Model Marlin, has been integrated with the newly developed ROV System. This integration enhances functionality and ease of use, effectively catering to customer requirements.

The ROV System encompasses Code Repositories, Robot Operating System 2 (ROS2), Electrical Systems, versatile claw-like manipulator design and a modular, lightweight frame. EPOXSEA intends to adopt the ROV System as a foundation for future development, implementing iterative enhancements rather than annual code rewrites as previously practiced, thereby augmenting engineering efficiency and mitigating risk.

Safety remains paramount within the ROV System, with EPOXSEA mandating strict adherence to safety design standards by all employees. Building upon the safety standards of the previous year, EPOXSEA has introduced additional measures, such as the development of a ROV simulator and monitoring software.

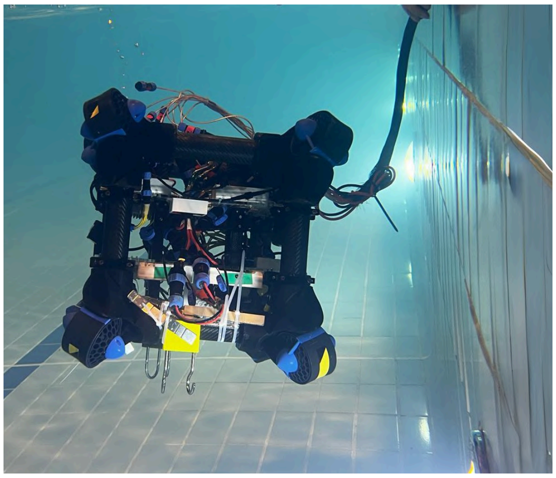


Figure 2 WAHOO underwater in action

This simulator is utilized for preliminary testing of the ROV's hardware, software, and mechanical components prior to actual manufacturing, thereby enhancing efficiency and reducing costs. Additionally, WAHOO incorporates numerous safety features. These include thruster guards, which safeguard the ROV and minimize potential injury risks for the deck crew.

Epoxy is consistently employed to ensure the protection of the electronic components. Epoxy withWAHOO's open structure design is a perfect match of electonic system which allows fast repairing time.

In contrast to its predecessor, Marlin, which employed 12 distinct manipulators for mission execution, the latest version of the ROV, WAHOO, with the multifunctional manipulator design, utilizes a versatile claw-like manipulator design. This design enables the execution of multiple mission tasks, resulting in rapid deployment and cost efficiency.

Furthermore, WAHOO has been enhanced pilot user-friendliness, with an Inertial Measurement Unit (IMU) [1] , capable of measuring orientation and angular velocity. This allows WAHOO to perform dynamic matrix movements, as opposed to relying on a static matrix. Consequently, it can achieve linear motion by automatically adjusting the differential force of the thrusters.

The continued application of modular design principles to WAHOO has proven beneficial, particularly when integrating manipulators and executing mission tasks from various orientations.

In the past, EPOXSEA predominantly employed passive manipulators, valuing their simplicity and dependability. However, our engineers identified a limitation in their flexibility. This year, in initiative, WAHOO has transitioned to exclusively using active manipulators. These active deices aims to enhance not only operational speed but also the proficiency and research development of our engineering team.

Design And Manufacturing Process

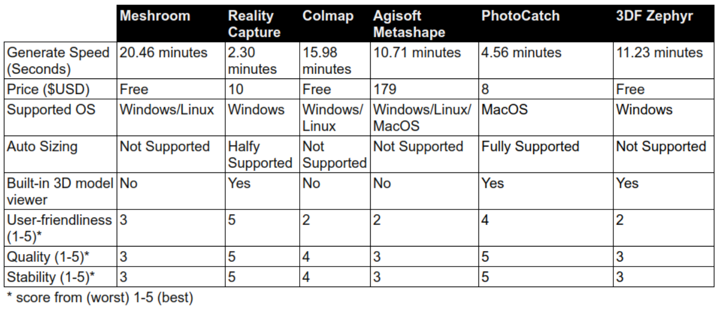
EPOXSEA's mechanical engineers employ an aligned design process to optimize design and manufacturing, facilitating a step-by-step approach to mechanical design and production. At the inception of the design phase, all team members convene to discuss potential improvements and elements to retain from the previous year's design.

For instance, the ROV frame from the previous year was deemed excessively large, prompting the mechanical engineers to downsize the frame. Additionally, the hardware engineers discovered that the 3D printed Polylactic Acid (PLA) electronic housing would deteriorate and turn brittle over prolonged exposure to water, mechanical engineers decided to change the 3D printing materials to Polyethylene terephthalate glycol (PETG). [2][3]

EPOXSEA engineers adhere to a Plan, Develop, Test, and Production cycle, in conjunction with the aligned design process, to minimize the disruption of other departmental developments. Initially, the mechanical engineers develop a dual independent layout of hardware components placing boards for the electronic components and better cable management, enabling the hardware engineers to plan accordingly. Subsequently, the mechanical engineers utilize SolidWorks, a 3D CAD Design Software System, to develop the frame, allowing software engineers to conduct tests in a simulated environment. Following the completion of the initial design, revisions were made during meetings to discuss cost optimization, tool placement, and the reduction of size and weight. Upon finalizing the design revisions, the components for the frame were procured and the final product was manufactured.

Decision and trade-offs Process

EPOXSEA has implemented a new decision-making process, enabling cross-departmental comprehension and participation. This approach fosters superior budget management and ensures the efficacy of each decision. The Knowledge Base (KB) has evolved into an open platform for storing documents and files, enhancing transparency. This year, we instituted a policy that has transformed EPOXSEA into a highly transparent company, thereby boosting productivity and fostering a sense of belonging among employees. For example, software engineers employed a trade-off matrix to determine the appropriate photogrammetry software for their requirements (Figure 3).



	Meshroom	Reality Capture	Colmap	Agisoft Metashape	PhotoCatch	3DF Zephyr
Generate Speed (Seconds)	20.46 minutes	2.30 minutes	15.98 minutes	10.71 minutes	4.56 minutes	11.23 minutes
Price ($USD)	Free	10	Free	179	8	Free
Supported OS	Windows/Linux	Windows	Windows/ Linux	Windows/Linux/ MacOS	MacOS	Windows
Auto Sizing	Not Supported	Halfy Supported	Not Supported	Not Supported	Fully Supported	Not Supported
Built-in 3D model viewer	No	Yes	No	No	Yes	Yes
User-friendliness (1-5)*	3	5	2	2	4	2
Quality (1-5)*	3	5	4	3	5	3
Stability (1-5)*	3	5	4	3	5	3

* score from (worst) 1-5 (best)

Figure 3 Comparison of which model to use for photogrammetry

In the initial phase of WAHOO's development, both mechanical and hardware engineers employed a systematic approach, scrutinizing the WAHOO innovation design. All pertinent information and research findings were consolidated and uploaded to the Knowledge Base (KB). A comparative analysis was conducted, evaluating various factors such as current usability, availability of products or materials, cost, and future applicability. Upon completion of the preliminary design, modifications were implemented during collaborative sessions. EPOXSEA has determined that this year's primary innovation objectives encompass the design of an open structure, multifunctional manipulators, omnidirectional propulsion, and a carbon fiber frame.

The decision-making process is not confined to the initial design phase; it is a continuous practice implemented throughout the ROV development lifecycle. For instance, a manipulator was decommissioned (Figure 4) due to its instability and fragility. Following deliberations among the mechanical engineers, it was substituted with a more robust design, enhancing its grip strength. Mechanical engineers routinely design multiple manipulators, provide mutual feedback, and record performance during pool tests to ascertain the superior design.

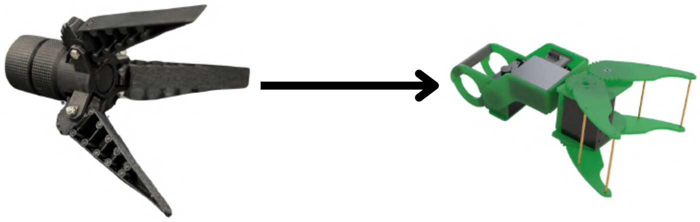


Figure 4 Change of claw design from left to right

Vehicle Structure

This year, WAHOO utilizes an open structure, as conventional electronic enclosures, despite their ubiquity, present a time-consuming repair process. With our open design, a malfunctioning component merely requires removal from water, identification of the defective part, disconnection, replacement, and reconnection to restore functionality.

WAHOO has three main sections. The central section is primarily dedicated to electronic components and cable management. The top and bottom carbon fibre tubes are designated for camera installation, while the side and bottom tubes are reserved for manipulator installation. This configuration eliminates blind spots in component installation, allowing manipulators to be installed from any angle for swift position switching and efficient mission execution. The manipulators and cameras are affixed to WAHOO using a plug-in design principle, as opposed to traditional ROV embedded design, enabling effortless positional modifications. This design permits attachment to any carbon fibre tube, providing engineers with the flexibility to alter the positions or even replace new manipulators and cameras during mission execution. Furthermore, it facilitates rapid replacement of these components when necessary. The current dimensions of WAHOO are 400 mm in length, 400 mm in width, and 500 mm in height (Figure 5.1), with a total weight of 17.95 kg, signifying a 32% reduction of size, as previous year contained superfluous space that did not contribute to functionality. The decision for these specifications was made after a trade-off analysis with the previous year’s model. Engineers found that the prior model was excessively large for certain mission tasks. A smaller model, such as the current one, permits greater maneuverability, reduces the cost of vehicle construction, and the lightweight design allows for easy deployment by two employees for mission operations.

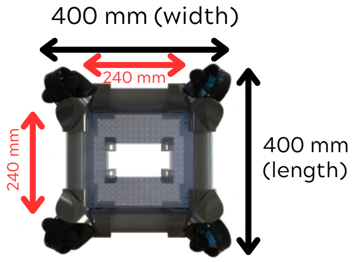


Figure 5.1 Dimension of WAHOO

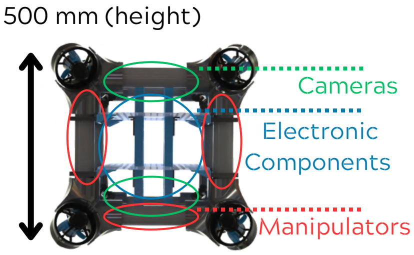


Figure 5.2 Layout of WAHOO

The weight of a single carbon fibre tube is 0.07 kg, while a thruster and a 3D-printed Polyethylene terephthalate glycol (PETG) thruster mount weigh 0.44 kg and 0.3 kg respectively. Consequently, the total mass of the frame, inclusive of thrusters, is approximately 6.76 kg. This represents a substantial reduction of 32% compared to the previous year’s weight of approximately 10 kg. This improvement underscores our commitment to efficiency and innovation.

Frame

WAHOO’s frame characterized by its high strength and rigidity. The frame (Figure 7) is engineered using carbon fibre tubes that exhibit high resistance to fatigue. We deliberated over the use of aluminum tubes as an alternative, after a comprehensive comparison of both materials, we concluded that the superior tensile strength and density of carbon fibre made it the optimal choice, rendering the switch to aluminum unwarranted [4]. These tubes are interconnected by PETG Thruster Mounts. PETG is selected as Thruster Mount material stems from extensive comparative testing with alternatives such as ABS and PLA. These tests, which included a 100-hour water immersion test and drop tests, only PETG remains well condition (Figure 6), demonstrated that PETG offers superior durability, compared to PLA and a more environmentally friendly printing experience than ABS, without the production of any toxic gases.

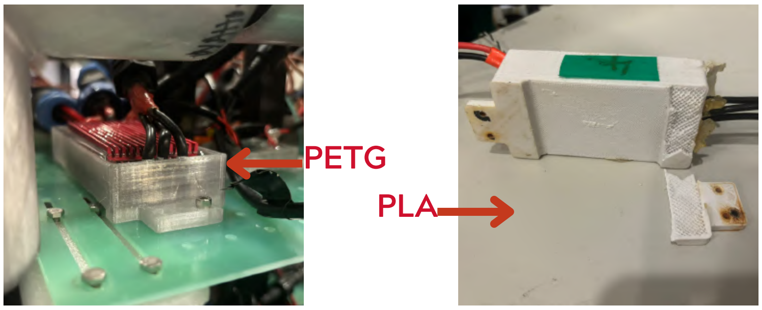


Figure 6 PETG and PLA hardware housing condition after 100 hours water test

Two glass fibre boards are installed on the middle of the frame, firmly held in position by metal tube clip fixture clamps (Figure7) and four central carbon fibre tubes, thereby enhancing the load capacity for electronics without compromising the integrity of the boards.

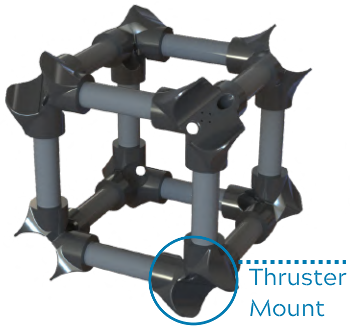


Figure 7 WAHOO frame

Figure 8 Metal tube clip fixture clamp

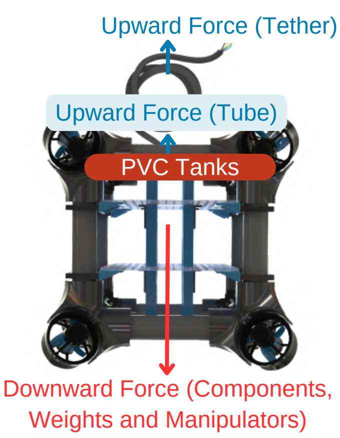
Vehicle Cost

The financial details of the vehicle are delineated in the Accounting section. This year, EPOXSEA has judiciously utilized a smaller budget compared to the previous year. This is largely attributable to the development of the ROV System, which facilitates preliminary testing prior to the manufacturing process. This strategic approach has proven to be cost-effective.

Buoyancy

In line with the prior “buoyancy as frame” design principle, we employ epoxy-sealed carbon fibre tubes filled with air, because this methodology effectively facilitates rapid adjustment of buoyancy during the preparatory phase. This approach opens up space that was previously consumed by large flotation modules, thereby providing additional locations for manipulator mounting. EPOXSEA employs the PVC Buoyancy Add-On System (PBAS), a mechanism designed to facilitate rapid buoyancy adjustments by modifying or supplementing the volume of air in PVC tanks. These tanks, available in three capacities 0.001 m^3, 0.002 m^3 and 0.0005 m^3, are affixed to the side. During mission operations, our engineering team can utilize the PBAS to accomplish buoyancy alterations within a timeframe of 1-2 minutes.

The tether of WAHOO also contributes to its buoyancy, ensuring that it typically floats on water (Figure 9). EPOXSEA is committed to maintaining the center of gravity at the WAHOO's midpoint to avoid interference and ensure smooth movement. Our engineering team has developed a computational model to determine the volume of air required in the PVC tanks.



$$F_b = -pgV_{rov}$$

ROV weight = 17.95 kg
ROV Density = 84.5 kg/m^3
Buoyancy = 67.6 N
*Volume of ROV = 0.4*0.4*0.5*
g = 9.81 ms^{-2}

Force Needed for netural buoyancy:
B = 84.5(0.4*0.4*0.5)*9.81 - 17.95 = 47.9732 N*

$$B = Q \times V_{air} \times g$$

Volume of Air Needed:
*47.9732/(1000*9.81)*
= 0.00489 m^3

Figure 9 Buoyancy Calculation on WAHOO

Topside Electronic

In the previous year, EPOXSEA made a significant investment to upgrade the control box computer to an Intel NUC 11 mini PC. Upon evaluation, the computer continues to deliver robust performance and meets our computational needs, thus negating the need for further investment in a new computer. The case of the control box is a JS-16 waterproof protective case, equipped with two 40cm monitors; the lower monitor is dedicated to the display of four bottom cameras directly (Figure 10.1) through the signal combiners to reduce the latency of using OpenCV, the upper monitor is utilized for the Graphical User Interface (GUI) and operation of WAHOO. EPOXSEA's policy for control box upgrades prioritizes computational requirements; if these are met satisfactorily, upgrades are deferred to optimize budget utilization. All hardware components, including computers, signal input receivers and signal combiners are neatly housed within the lower compartment of the control box (Figure 10.2). This arrangement ensures efficient setup, tidy cable management, and protection against inadvertent water splashes. Control signals are transmitted via the USB port and converted to CAN signals through a USB-to-CAN wire converter. The control box is equipped with a power supply and an emergency button for rapid shutdown of WAHOO. The control box employs a straightforward signal reception port design (Figure 11), wherein each port is dedicated to a single SDI or CAN cable. This design facilitates swift cable connections without disrupting the cable management in the lower compartment.

Figure 10.1 Control box displays

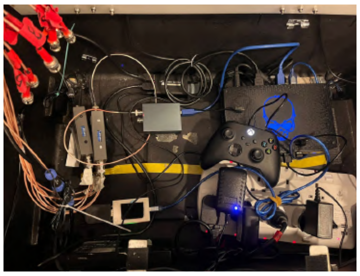


Figure 10.2 Lower compartment of Control box

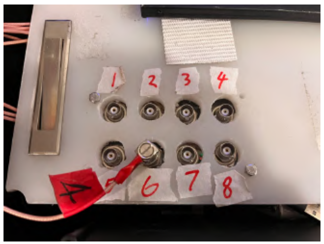


Figure 11 Signal reception ports on Control box

Bottomside Electronics

The WAHOO onboard hardware system is a tripartite structure, encompassing the Propulsion System, the Camera System, and the Manipulators and Sensors System.

EPOXSEA's electronic design standard is predicated on the principle of preventing a single point of failure from causing a system-wide breakdown. All systems are engineered with an emphasis on reliability, durability, serviceability, minimal assembly times, reduced component lead times, and operational stability.

The microcontroller utilized by WAHOO is the STM32F103CBT6, which is comprised of primary electronic components. These include motor driver boards, 12V and 48V power distribution boards, Electronic Speed Controllers (ESC), a 48V-12V Regulator, a 12V-5V Regulator, a Sensor Board, a Claw Board, and a CAN Board.

WAHOO does not have a Main Electronics Housing (MEH). WAHOO's unique innovative open structure (12.2) significantly reduces both repair time and costs. The operational procedure involves simple replacement and reconnection, eliminating the extensive labor associated with managing a MEH. Each circuit board within the 3D printed housing (Figure 12.1) is meticulously sealed with epoxy for waterproofing and wires protection.

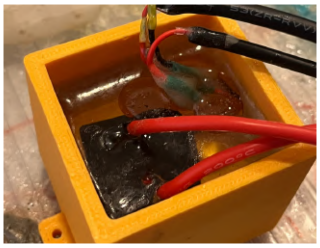


Figure 12.1 3D Printed Electronic Housing

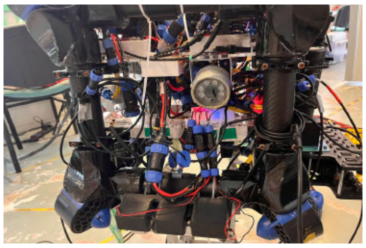
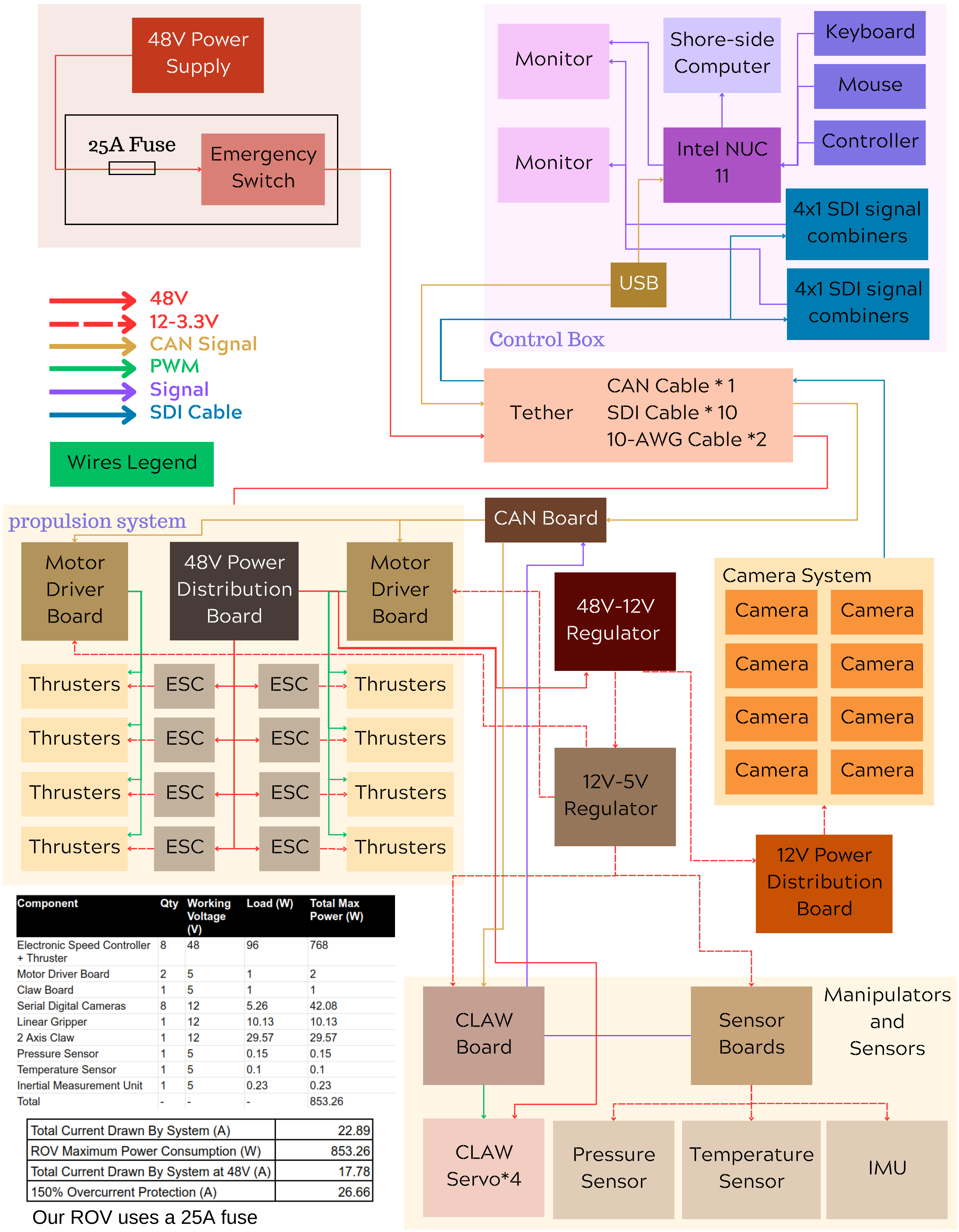


Figure 12.2 View of Open Structure

System Interconnection Diagram



Component	Qty	Working Voltage (V)	Load (W)	Total Max Power (W)
Electronic Speed Controller + Thruster	8	48	96	768
Motor Driver Board	2	5	1	2
Claw Board	1	5	1	1
Serial Digital Cameras	8	12	5.26	42.08
Linear Gripper	1	12	10.13	10.13
2 Axis Claw	1	12	29.57	29.57
Pressure Sensor	1	5	0.15	0.15
Temperature Sensor	1	5	0.1	0.1
Inertial Measurement Unit	1	5	0.23	0.23
Total	-	-	-	853.26

Total Current Drawn By System (A)	22.89
ROV Maximum Power Consumption (W)	853.26
Total Current Drawn By System at 48V (A)	17.78
150% Overcurrent Protection (A)	26.66

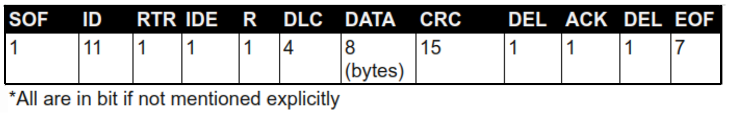
Our ROV uses a 25A fuse

Figure 13 System Interconnection Diagram

Controller Area Network

The WAHOO system employs the CAN protocol for onboard components, including thrusters and manipulators to communicate to each others within the same bus network, given its superior speed compared to the Local Interconnect Network (LIN). This year, WAHOO has fully integrated the CAN protocol to achieve more centralized control and expedited communication. The CAN protocol (Figure 14), with its high baud rate of up to 1.25 Mbps, facilitates efficient message exchange between the control box and WAHOO.

The CAN protocol, with its inherent error-checking and noise-resistant features, serves as an optimal communication protocol for a 20m tether. It facilitates direct node connections, eliminating the need for an onboard translator on the ROV, thereby reducing complexity and potential points of failure.



SOF	ID	RTR	IDE	R	DLC	DATA	CRC	DEL	ACK	DEL	EOF
1	11	1	1	1	4	8 (bytes)	15	1	1	1	7

*All are in bit if not mentioned explicitly

Figure 14 CAN protocol

CAN Board

The CAN Board handles all CAN signals from the tether, then it controls manipulators and thrusters through the claw boards and motor driver boards. It subsequently distributes these signals to the appropriate MCU based on the CAN protocol's identifier, thereby controlling specific components. Additionally, the CAN board is capable of transmitting signals back to the control box, it allows for immediate adjustments and responses, significantly enhancing the robot's adaptability.

Power Distribution

Within WAHOO, a 48V power distribution board (Figure 15.1) is utilized for power allocation. This board is interfaced with the tether's power cables, from which it derives power. The 48V board directs power to a 48V-12V regulator, eight Electronic Speed Controllers (ESC), and claws. Subsequently, the 12V board is responsible for powering eight cameras and LED lights.

Motor Driver Boards

WAHOO is equipped with two motor driver boards (Figure 15.2), strategically positioned on the top and bottom layouts. Each motor driver boards has four PWM outputs, to governs four ESCs. Upon receiving instructions from the CAN Board, the motor driver boards transmit signals to the ESCs, it is also capable of accommodating ST-Link input and output interfaces.

Electronic Speed Controller

EPOXSEA consistently employs the Flycolor Magellan 5-14S80A Electronic Speed Controllers (ESCs) from the preceding year, given their pristine condition. The ESCs govern the operation of the thrusters. Each ESC board (Figure 15.3) is responsible for one thruster, modulating the thrust force through the use of Pulse Width Modulation (PWM) signals with clock frequency 84 MHz. It is 86.6x37.8x26 mm, operate in 80 A current. The rationale for employing one ESC per motor is to facilitate rapid response times in motor speed control. This approach also prevents the complete loss of thruster control, ensuring that if one ESC fails, the remaining ESCs can still maintain control, ensuring uninterrupted operation and enhancing overall system reliability.

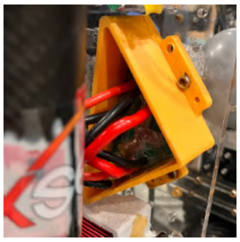


Figure 15.1 48V-12V Regulator

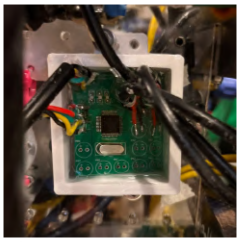


Figure 15.2 Motor driver board

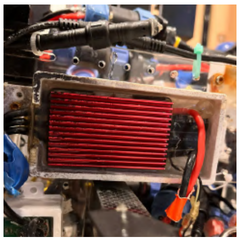


Figure 15.3 Electronic Speed Controller

Claw Board

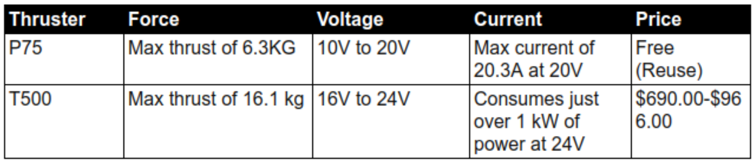
The Claw board is designed to facilitate up to three PWM signal outputs, powered by 5V. It incorporates a comprehensive H-Bridge Integrated Circuit, the DRV8251, which is renowned for its high efficiency, precision, and reliability in motor control applications. Equipped with an IP68 Waterproof Rotary Encoder, ensuring its optimal performance even in harsh underwater conditions. The board also accommodates both CAN and ST-Link input and output interfaces, enabling seamless integration with the robot's other systems.

Sensor Board

WAHOO is outfitted with three distinct sensors: a temperature sensor (DS18B20), a pressure sensor (MS5837), and a gyroscope (MPU9250). These are interfaced via an One-Wire Protocol (OWP) and employ the Inter-Integrated Circuit (I2C) protocol for communication. Our hardware engineers determined that the current methodology exhibits superior performance and stability compared to the Arduino-based design implemented two years ago. Also, the Sensor Board's use of the CAN protocol, with its inherent error-checking and noise-resistant features further enhancing the reliability and durability of the WAHOO.

Thrusters

The WAHOO model continues to employ the same eight P75 (MOT-P75-290) 48V thrusters, each being a 75 mm 4-blade variant, as used in the previous year's MARLIN ROV model. Upon evaluating the condition and performance of the P75 (Figure 16), which remains at the forefront of ROV technology, we initially contemplated upgrading to the T500 thrusters.



Thruster	Force	Voltage	Current	Price
P75	Max thrust of 6.3KG	10V to 20V	Max current of 20.3A at 20V	Free (Reuse)
T500	Max thrust of 16.1 kg	16V to 24V	Consumes just over 1 kW of power at 24V	$690.00-$96 6.00

Figure 16 Comparison of thruster types P75 and T500

However, we denied as we discerned that the power output of the T500 exceeds our requirements. Following a comprehensive analysis by our mechanical engineers, it was determined that the P75 thrusters offer the optimal balance of stability and performance. Furthermore, considering the higher cost of the T500, it was deemed an unwarranted upgrade. In adherence to safety standards for thrusters, we prioritize the protection of wildlife and plant life. To this end, we have installed hexagonal guards with a maximum aperture of 0.8 mm to prevent the intrusion of small objects into the thrusters. This year, we have also re-engineered the thruster mount (Figure 17) to enhance fluid dynamics and prevent entanglement with the tether. This redesign aims to improve operational efficiency and reliability.

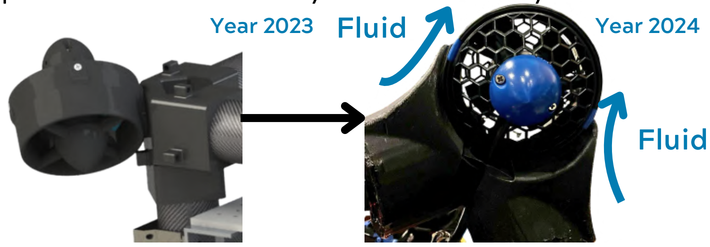
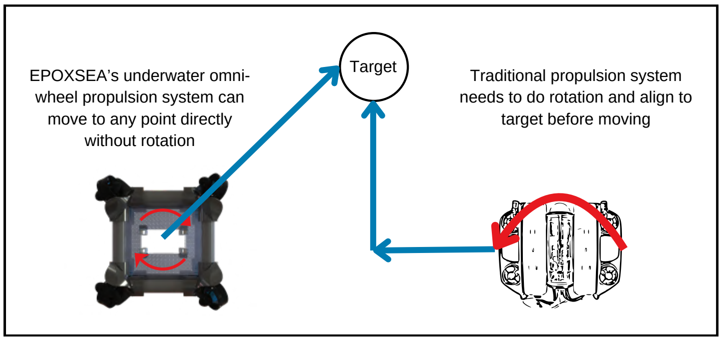


Figure 17 Evolution of thruster mount designs

Propulsion

EPOXSEA has engineered an in-house underwater omni-wheel propulsion system, facilitating omnidirectional movement (Figure 18) for WAHOO. All eight thrusters are strategically oriented at a 45-degree angle, enabling them to do tomnidirectional movement in any desired direction at a consistent speed with maximum speed of 2.32 m/s (Figure 19), over traditional ROV propulsion systems that require rotation before changing direction.



EPOXSEA's underwater omni-wheel propulsion system can move to any point directly without rotation

Traditional propulsion system needs to do rotation and align to target before moving

Figure 18 Comparsion of traditional ROV propulsion system to underwater omni-wheel propulsion system

The previous year's linear response curve control the ROV's propulsion without taking into account any preceding motion. This year, EPOXSEA has implemented an innovative dynamic response curve, enabling more balance and precise thruster control for enhanced stability and horizontal maneuverability using the feedback matrix from the past movements (Figure 20).

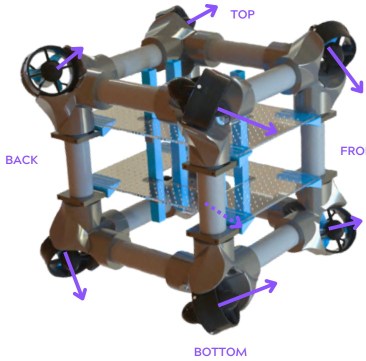


Figure 19 Direction of thrust for WAHOO to move forward

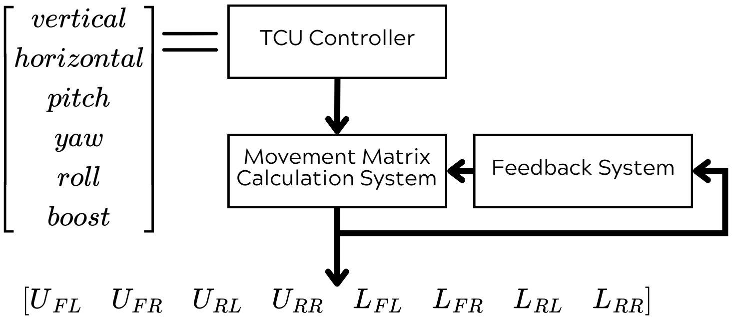


Figure 20 EPOXSEA Propulsion System

In Micro, the thrusters generate thrust and the water folow will be pushed in opposite side (Figure 21). Each thruster produces 6.3 kg of thrust at 20V and 20.3A with position directed 45 degrees off the z axis. The thrust is directed 45 degrees off the z axis, to get vertical force: 6.3kg × sin(45°) = 4.45 kg. Combining all eight propellers present on the ROV, we achieve the below amount of vertical lift: 4.45kg × 8 = 35.64 kg.

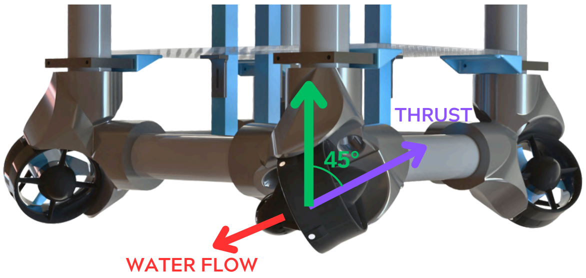


Figure 21 Direction of water flow and thrust

Despite a reduction in size compared to the previous year, WAHOO employs a more compact thruster system to execute intricate movements while preserving high aquatic stability with faster movement and enhanced flexibility.

Tether

The tether of WAHOO is 20m long from TCU to WAHOO, engineered to facilitate the transmission of essential data, signals, physical connectivity, and power between the control box and the ROV.

The tether comprises ten Serial Digital Interface (SDI) cables (Figure 22.2), one Controller Area Network (CAN) cable, one strain relief cable and two 10-AWG cables. SDI cables, capable of supporting 12 gigabits per second, are chosen for camera applications due to their low latency, WAHOO uses a one-to-one SDI cable to camera configuration to achieve minimal latency and reduced noise susceptibility, thereby optimizing WAHOO's performance for both manual and automated tasks.

The 10-American Wire Gauge (AWG) cables, known for their low-resistance, flexibility, and power stability under substantial current loads, are utilized for power supply. AWG cable has only 0.4 Ohm resistance, when WAHOO operates at a current of 25.2 A, induces a voltage drop of 10 V across the tether (25.2 A * 0.4 Ohm).

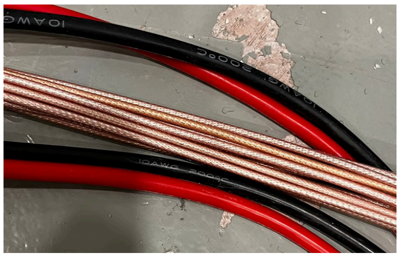


Figure 22.1 SDI cables and power lines

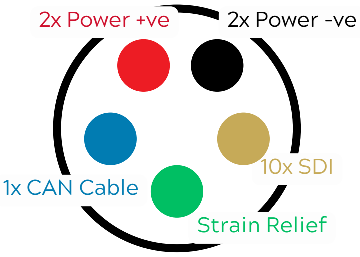


Figure 22.2 Tether Diagram

Ensuring the safety of the tether is of paramount importance to EPOXSEA. Our hardware engineers have employed a multitude of testing methodologies to ascertain its safety. For example, the SDI and 10-AWG cables are securely fastened together using zip ties (Figure 23.1) and encased in an expandable Polyester (PET) braided sleeve. This protective measure safeguards the cables and ensures their safe interaction with marine environments and wildlife.

The tether incorporates a strain relief cable, the ROV can be lifted by its tether without inflicting damage to the internal cables. This strain relief cable is bifurcated, with one end secured to the control box and the other affixed to the upper layout board of WAHOO.


Figure 23.1 cables secured by zip tie

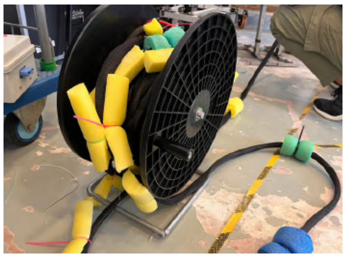


Figure 23.2 Tether transport reel

Tether Management Protocol

Safety is the first priority of EPOXSEA, including tether management. Prior to each deployment, conduct a comprehensive inspection of the tether for indications of wear or damage, including but not limited to fraying, kinking, or compromised electrical connections. Prior to operation, the tether will be securely stored in a transport reel (Figure 23.2) and conveyed to the swimming pool. Subsequently, personnel will unwind the tether, positioning one end towards the ROV and the other towards the control box. The strain relief cable will be secured first, followed by the connection of the tether's AWG cables and SDI cables to their respective ports on the control box and safety box. During operations, meticulously manage the length of the tether, ensuring adequate slack to alleviate tension on the ROV, while circumventing excessive slack that could result in entanglement or snagging hazards. Upon completion of the operation, personnel will deactivate the power supply. Subsequently, the tether connected to the ROV will be disconnected, followed by the disconnection of the tether on the control box side. Finally, both ends of the strain relief cables will be disconnected. The tether will then be coiled and securely placed into the designated reel. When not in use, store the tether in a clean, dry, and temperature-controlled environment to shield it from the elements and extend its service life. Employ suitable coiling techniques and evade sharp bends or kinks.

Camera


Figure 24.1 RH-SDI1600DK


Figure 24.2 CMOS290 sensor camera

In the current year, EPOXSEA employs an array of 8 cameras, comprising two distinct models: the reused RH-SDI1600DK (Figure 24.1) and the new CMOS290 sensor camera (Figure 24.2). Total of 6 RH-SDI1600DK and 2 CMOS290 sensor camera. The RH-SDI1600DK, a high-resolution 1080p red light camera, boasts several advantages. It supports high-speed SDI transfer over distances exceeding 150 m and is characterized by its low power consumption, which remains below or equal to 5W.

This year we purchase the CMOS290 sensor camera as it offers an enhanced shutter speed, albeit at a cost five times greater than the RH-SDI1600DK. In a strategic move to manage our budget effectively, we have equipped only two units of the CMOS290 sensor camera, specifically for tasks necessitating high-quality imaging, such as photogrammetry.

The camera configuration empowers WAHOO with comprehensive manipulators control in all degrees of freedom during mission execution. This design, diverging from the conventional front-oriented layout, significantly enhances flexibility.

Camera Connection System

The camera system transmits signals via an SDI cable, with each camera utilizing a single SDI cable. The system experiences a latency of 100 milliseconds to allow WAHOO system maintains smooth operation during mission execution.

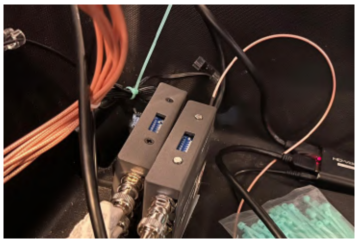


Figure 25.1 4x1 SDI signal combiners

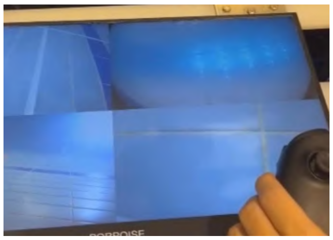


Figure 25.2 Camera feed of WAHOO underwater

Subsequently, the signals are amalgamated within the control box using two 4x1 SDI signal combiners (Figure 25.1), enabling the operator to simultaneously monitor the feeds from four cameras on a single display. (Figure 25.2)

Software Innovation

EPOXSEA's preceding generation of the ROV utilized the Robot Operating System (ROS) as its control mechanism. To enhance reliability and performance, WAHOO was integrated with the latest self-developed ROV system. The ROV control system underwent an upgrade from ROS to ROS2, as it employs the Data Distribution Service (DDS), a design paradigm aimed at enhancing efficiency and reliability, minimizing latency, and promoting scalability. [5]

This year, our software engineers have established a ROV simulation environment utilizing the Gazebo simulator [9] (Figure 26). This development enables the team to test algorithms and ROS2 implementations without requiring access to a physical ROV. The ROV system facilitates the direct transfer of code used in the simulator for application in ROV production.

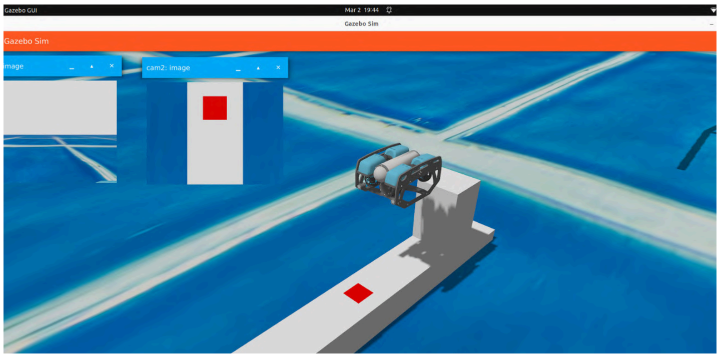
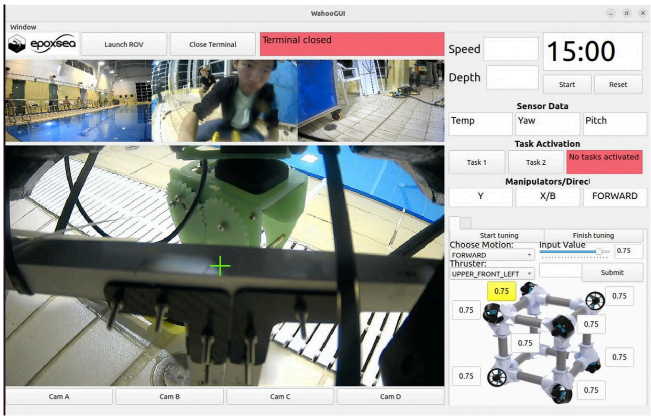


Figure 26 Mission simulation in Gazebo simulator

Topside Software

The ROV System operates on an Intel NUC 11 Mini PC. This year, EPOXSEA has enhanced the Graphical User Interface (GUI) (Figure 27) to facilitate more stable operation by the driver. The GUI, developed using the Python library, PyQT5, [6] now supports a novel feature, the dynamic movement adjustment system. This feature empowers the operator to modify the control matrix during mission execution, thereby enabling the use of an optimally tuned matrix corresponding to varying water levels for smooth movement. This capability was not available in previous years; once the ROV was deployed, the control matrix could not be altered without resetting the system.



Terminal closed
15:00
No tasks activated
Choose Motion: FORWARD
Thruster: UPPER_FRONT_LEFT
Input Value 0.75

Figure 27 WAHOO Graphical User Interface

The GUI presents a lot of crucial data, encompassing sensor readings, timer status, camera feed, mission automation controls, and thruster force indicators. This comprehensive display enables the operator to gain a complete understanding of WAHOO's operational status.

Control Architecture

The ROV System is an amalgamation of various systems and software, including ROS2, PyQT5, and PhotoCatch, designed to control WAHOO. Given the complexity of managing these systems with a conventional program architecture, the ROV System has continued to employ the Event-Driven Architecture (EDA) this year.

The EDA listens for event triggers and executes subsequent programs in a multi-threaded manner. When the ROV System is idle, it prioritizes the retrieval and processing of sensor data, as well as the computation of the movement matrix, to ensure stable and flexible performance.

Furthermore, the ROV System employs a centralized computation solution. All data and calculations are processed within the control box computer, which transmits only the essential control signals via the tethered CAN cable. Consequently, WAHOO merely needs to parse the CAN signals to manage the thrusters, servo motor, and sensors, thereby reducing its operational load.

The WAHOO control architecture is efficiently constructed utilizing ROS2. The ROV is manipulated by the pilot via a Microsoft Xbox joystick. The control signals, post calculation of the movement matrix, are transmitted through the GUI node to the thrusters topic. The thruster subscriber subsequently receives the thruster data and updates the thruster PWM signals. Sensor and camera data are published to their respective topics, upon which the GUI node receives and updates the interface. Reference Appendix E for Software Flowchart

Bottomside Software

All signals are processed and transmitted via the CAN cable to the CAN Board within WAHOO for MCU control. The backend of WAHOO operates using the ROS2 system. For instance, the ROV System establishes nodes for each thruster, camera, and manipulator. The primary categories of nodes include the Motor Driver Node, Sensor Node, Manipulator Node, and SDI Camera Node. The Motor Driver Node subscribes to the Xbox controller joystick and throttle, and publishes to the drive vector on the CAN Board to facilitate communication with ESCs by generating PWM signals for thruster control. The Manipulator Node subscribes to the GUI and, upon button activation, publishes the signal to control the manipulator. Sensor and Camera data are published to the Sensor Node and SDI Camera Node, respectively, enabling the control box to access WAHOO's sensor and camera data.

This methodology is advantageous for our extensive software development team, as individual engineers can independently modify or establish distinct nodes without impacting other nodes and systems. This decentralized project management structure enhances the productivity of our software engineers.

Payload and Tools

Camera Placement

Given that WAHOO is a cuboid-shaped ROV, it is crucial to equip it with comprehensive camera coverage on all sides to enhance the pilot's visual field. Regarding the camera placement (Figure 28), WAHOO strategically positions a camera on each side of the bottom, including the right, front, back, and left sides. These cameras are angled 30 degrees downward to enable monitoring of the manipulators while maintaining a forward view. This configuration allows WAHOO to observe four different aspects. In conjunction with the bottom camera, WAHOO achieves a comprehensive view of the bottom environment, eliminating any blind spots. The top camera primarily serves to monitor the tether status, as suggested by our driver, to prevent the tether from interfering with WAHOO. The top front and top left cameras are primarily utilized for photogrammetry. The rationale for employing dual cameras is to establish a contingency strategy for image capture, should one camera fail to document certain perspectives.

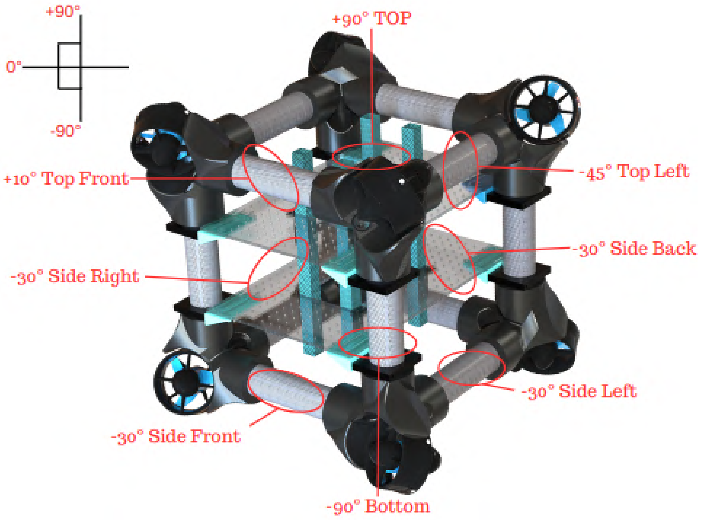


Figure 28 WAHOO cameras placement

2-axis Claw

The 2-axis claw (Figure 29), an innovative design, comprises an arm and an end-effector, each measuring 15 cm in length and 10 cm in width. Consequently, the total length of the 2-axis claw is 30 cm, maintaining a consistent width of 10 cm. The 2-axis claw is outfitted with three servo motors: one dedicated to controlling the elbow's position and the others responsible for managing the wrist's rotation and the claw's activation. Operating at 12V, these motors deliver a torque of 1.5 Nm. The wrist of the 2-axis claw possesses a 360-degree rotational

capability, enabling WAHOO to rotate the stop valve a full 360 degrees clockwise, thereby activating the irrigation system. Additionally, the elbow of the 2-axis claw has a range of motion from 0 degrees (facing upwards) to 180 degrees (facing downwards). This flexibility facilitates precise control over the claw's movements, ensuring accurate control to finish the whole task 1, "Trigger" the release of the multi-function node's recovery float; Pull a pin to release the failed recovery float; Return the failed recovery float to the surface and Connect a recovery line to the bale on the multi-function node for manual recovery. It can also finish task 2.1, Deploy SMART cable through three waypoints; Place the SMART repeater in the designated area; Return the end of the cable to surface, side of the pool; Connect the AUV docking station to the SMART cable repeater. And task 3.1, 3.2, Deploy the probiotic sprinkler on coral head; Activate the irrigation system
Transplant branching coral; Transplant brain coral.

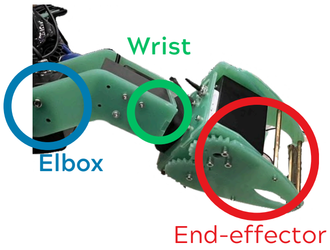


Figure 29.1 2-axis claw

Figure 29.2 2-axis claw CAD

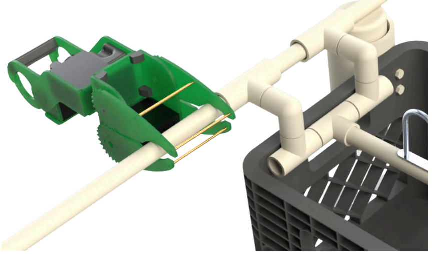


Figure 29.3 illustration of mission execution

Linear gripper

The linear gripper (Figure 30), constructed with a single servo motor, operates at 12V and delivers a torque of 1.5 Nm. This design is utilized for tasks necessitating a more robust and stable gripping force. The end-effector is equipped with a screw and a protective cover to prevent damage to the gripped item and enhance friction, thereby ensuring stability and preventing the item from slipping. The team of mechanical engineers has innovated a dual-sided sliding mechanism. This mechanism not only has the capability to grip objects through inward sliding from both sides, but it can also expand on both ends to accommodate items of a box-like shape.

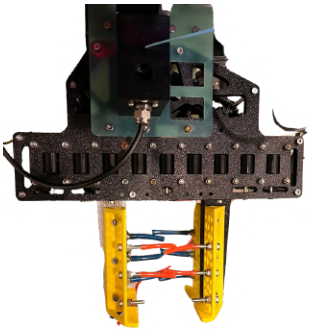


Figure 30.1 Linear gripper view from above

Figure 30.2 Linear gripper CAD drawing

This is designed for 3.1, 3.2, 3.4 and 4, Place a probiotic irrigation system in the designated location; Transplant branching coral; Transplant brain coral; Recover an acoustic receiver; Determine the location of a potential spawning site; Characterize the habitat at potential spawning site; Deploy the float into a designated area.

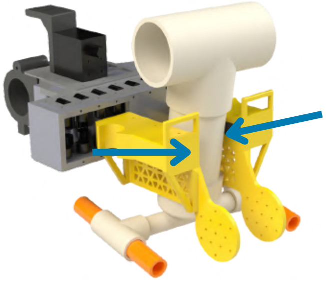


Figure 31.1 illustration of gripping

Figure 31.2 illustration of carrying

Sensors

WAHOO is equipped with temperature and pressure sensors. The temperature sensor, a DS18B20 model, has a detection range from -55°C to +125°C with a precision of ±0.5°C. This sensor is utilized in Task 2.1 to measure temperature, thereby verifying the readings from the SMART cable sensors. The pressure sensor is employed in Task 3.2, which involves the transplantation of brain coral. It acquires water pressure data, which is subsequently utilized to compute the water depth and the autonomous positioning of WAHOO.

Water Depth Algorithm

According to the principles of physics, The hydrostatic pressure formula (Figure 32) there exists a direct proportionality between water depth (h) and pressure (P).

$$P = h\rho g$$

Figure 32 The hydrostatic pressure formula

The challenge in estimating water depth lies in the variability of fluid density across different bodies of water.

To address this issue and calculate the water depth, our software engineers employ a comparative testing algorithm. Initially, WAHOO records the water pressure at the surface (w1).

Subsequently, it descends directly to the pool bottom. Given that the pool's depth is known , WAHOO continuously logs changes in water pressure during the descent. Upon reaching the bottom, it records the water pressure (w2) for an extended period to ensure data stability.

The water depth algorithm extrapolates the approximate direct proportionality between water pressure and water depth using a machine learning algorithm, Stochastic Gradient Descent. This approach allows us to estimate the water depth accurately and efficiently.

$$y = w_1 + w_2 x$$

Figure 33 The objective function of Stochastic Gradient Descent

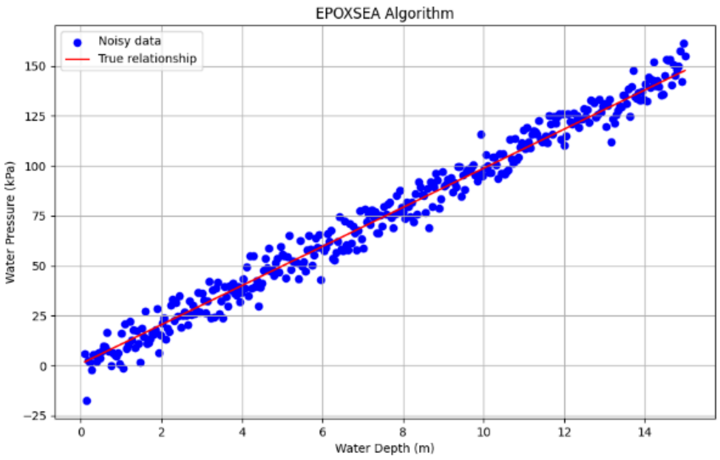


Figure 34 Testing graph of Stochastic Gradient Descent during pool test

This can be interpreted as a stochastic approximation of the gradient descent optimization process. It substitutes the true gradient, computed from the complete dataset, with an estimated gradient, derived from a the water pressure data subset. Based on the obtained results, we can formulate a linear equation that enables the estimation of water depth solely from water pressure measurements. This approach provides a streamlined method for depth calculation, reducing the need for additional data inputs.

Sensors Calibration

For temperature calibration, EPOXSEA engineers opted to simulate a near-actual temperature using a stirred ice-bath, which provides commendable accuracy for the 0 °C reference point. The engineers monitored the temperature variation over time and computed the deviation between the retrieved data and the actual temperature. An additional temperature sensor was employed to fine-tune the offset, ensuring the highest possible accuracy.

In the calibration process of the pressure sensor, our engineering team employs a depth offset calculation methodology. This involves immersing the pressure sensor in water of a known depth. Subsequently, data is gathered and utilized to compute the actual water depth. The discrepancy between the known and calculated depths is identified as the offset of the pressure sensor. This offset is instrumental in the calibration process.

Photogrammetry

WAHOO employs the CMOS290 sensor camera for photogrammetry, specifically for task 3.3. It successfully completes the automated task utilizing the Object Capture API [7], consistent with the previous year's approach. However, this year, we upgraded to the CMOS290 sensor camera camera, which yields superior quality results and produces aesthetically pleasing 3D models (Figure 35). We also refined the ROV control program to ensure more stable horizontal shifts, as photogrammetry necessitates stable image inputs. Post video recording, we utilize ffmpeg to convert the video into images and automatically compute the dimensions (width, length, and height) of the coral reef area.

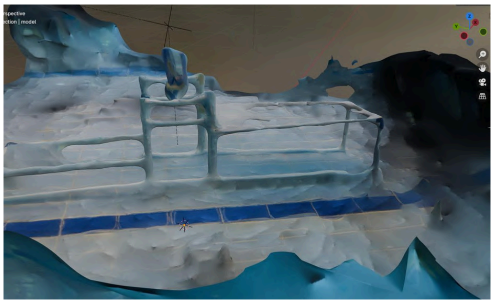


Figure 35 3D model produced from photogrammetry

Motor Wheel

The Motor Wheel (Figure 36.1) is a DC motor that drives the 3D-printed wheel. It is designed and fixed at the correct position to turn the valve and hence, activate the sprinkler system. It can complete the Task 3.1, Activate the irrigation system (Figure 36.2).

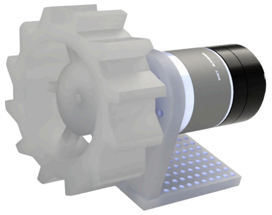


Figure 36.1 The Motor Wheel

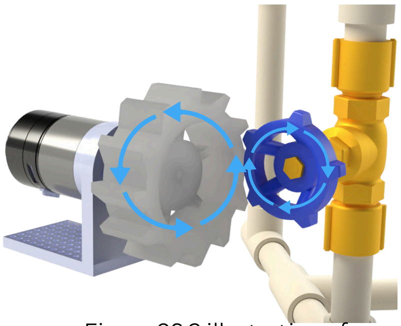


Figure 36.2 illustration of mission execution

Float

This year, EPOXSEA implemented significant modifications to the float design, addressing several shortcomings of the previous model, which was not a vertical profiling float and had rapid power depletion. The design is enhanced to incorporate vertical profiling capabilities and increased the total number of AA batteries from 12 to 16. The L298N Motor Driver continues to be utilized. The float engineer transitioned from the Arduino Nano to the Arduino Mega, which offers greater convenience due to its direct wire plug-in capability, eliminating the need for a breadboard.

The float (Figure 37) can fulfill Task 4 mission, it is composed of two modules: the buoyancy and the transmission module. The buoyancy module utilizes a motor to regulate the pump, thereby controlling buoyancy. The output power is governed by the Pulse Width Modulation (PWM) signal generated by the Arduino Board. When the actuator ascends, water is drawn into the syringe due to the negative pressure differential, and conversely, it is expelled when the actuator descends. Approximately 85 ml of water is required to sink the float. The transmission module comprises the EWRF 7082TM RCA Transmitter, DS1302 Real-Time Clock and MS5837 Pressure Sensor.

Float System Interconnection Diagram

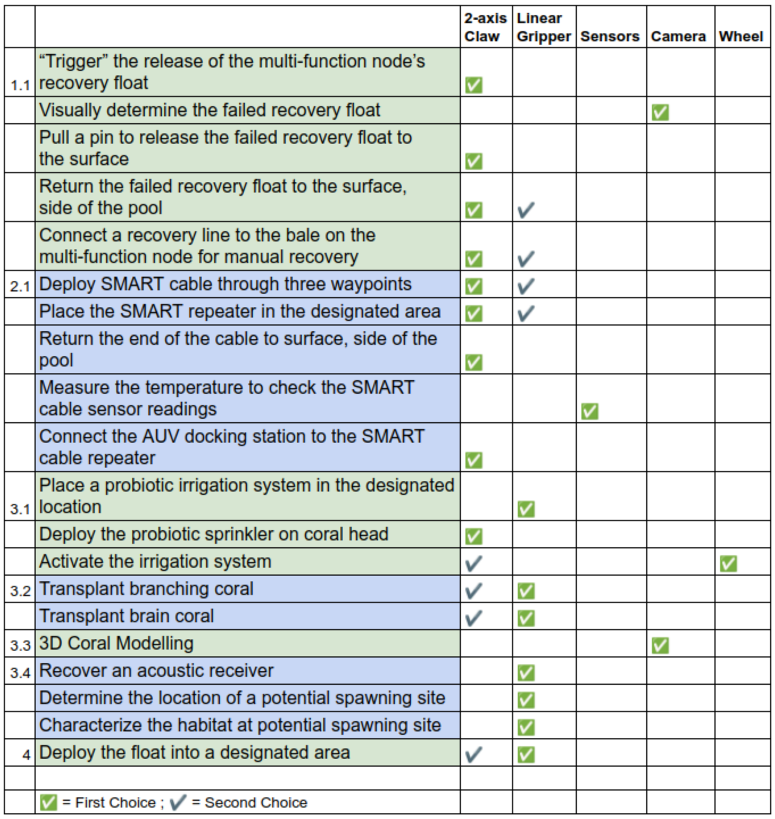
The float SID is attached to the Appendices page (Appendix C).

Figure 37 Float

Mission Systems Approach

EPOXSEA adheres to a balanced systems approach in the design of payloads and tools. We strive to create safe, reliable, and seamlessly integrated systems, in line with our design principles, by proactively identifying and addressing integration challenges. Our engineering team diligently works on the integration of vehicles, manipulators and sensors, enabling us to utilize a minimal set of three active manipulators to accomplish a broad range of mission tasks. This approach not only significantly reduces costs but also simplifies control for operators due to the reduced number of manipulators.

Our innovative design strategy mitigates the risk of mission failure due to a single point of failure during mission execution. Our engineers employ a general manipulator approach, which allows for task versatility and serves as a contingency plan in the event of a manipulator failure during mission execution. This approach underscores our commitment to reliability and operational efficiency. The mechanical engineers use the manipulator capability table (Figure 38) to do evaluation of the generality of manipulators.



		2-axis Claw	Linear Gripper	Sensors	Camera	Wheel
1.1	“Trigger” the release of the multi-function node’s recovery float	☑				
	Visually determine the failed recovery float				☑	
	Pull a pin to release the failed recovery float to the surface	☑				
	Return the failed recovery float to the surface, side of the pool	☑	✓			
	Connect a recovery line to the bale on the multi-function node for manual recovery	☑	✓			
2.1	Deploy SMART cable through three waypoints	☑	✓			
	Place the SMART repeater in the designated area	☑	✓			
	Return the end of the cable to surface, side of the pool	☑				
	Measure the temperature to check the SMART cable sensor readings			☑		
	Connect the AUV docking station to the SMART cable repeater	☑				
3.1	Place a probiotic irrigation system in the designated location		☑			
	Deploy the probiotic sprinkler on coral head	☑				
	Activate the irrigation system	✓				☑
3.2	Transplant branching coral	✓	☑			
	Transplant brain coral	✓	☑			
3.3	3D Coral Modelling				☑	
3.4	Recover an acoustic receiver		☑			
	Determine the location of a potential spawning site		☑			
	Characterize the habitat at potential spawning site		☑			
4	Deploy the float into a designated area	✓	☑			
	☑ = First Choice ; ✓ = Second Choice					

Figure 38 Manipulator capability table

The sensor exhibits excellent integration with the ROV system. For instance, we utilize data from the IMU gyroscope to calibrate the movement matrix during operations. Additionally, we employ the pressure sensor to estimate the ROV’s water depth, facilitating the execution of automated tasks. This integration enhances the system’s operational efficiency and accuracy.

Safety

Philosophy

At Epoxsea, we place paramount importance on the safety and well-being of our employees, without any exceptions. We are of the firm belief that accident prevention is achievable through adherence to appropriate regulations and risk assessment. This responsibility is both individual and collective, necessitating all employees to comply with and document their adherence to the safety guidelines set forth by EPOXSEA and MATE. This fundamental value is enforced through a comprehensive set of rigorous regulations, designed to safeguard our employees while optimizing productivity throughout the operational season.

Figure 39 Epoxsea employee in safety training

Training

Newly inducted employees are required to complete a winter training course to gain proficiency in the use of laboratory equipment, with a particular emphasis on power tools and soldering stations. Through hands-on demonstrations and mentorship from senior members and the safety officer, the objective is to instill a comprehensive understanding of safety procedures, hazard awareness, and to foster the ability to use equipment independently and confidently. Whenever new equipment is introduced into the laboratory, a dedicated training session is conducted to ensure employees are updated with safe usage practices. EXPOXSEA enforces a stringent policy regarding the use of high-powered tools such as the band saw and the CNC machine. A peer monitoring policy is in place, and any employee found using these tools without prior training will be prohibited from using any tool and will be required to retake the training course from the beginning.

Lab Protocols (Personnel)

Following the recruitment period spanning October to early December, both newly inducted and seasoned members participate in the laboratory's restructuring process.

It is imperative to maintain the fire escape route unobstructed and readily accessible.

To ensure safety and efficiency, cluttering at workstations should be avoided, thereby reducing the risk of fire hazards and tripping incidents.

It is crucial that all personnel are well-acquainted with the locations of safety equipment and hazardous material storage.

Prior to obtaining unrestricted access to the laboratory, employees are required to familiarize themselves with the workshop safety regulations.

When dealing with toxic gases, such as those involved in soldering, 3D-printing, spray painting, and epoxy resin handling, adequate ventilation is essential.

Lab Protocols (Equipment)

Personal Protective Equipment (PPE) is readily accessible at all times. Tasks such as drilling and hammering necessitate the use of safety glasses and hearing protectors. Furthermore, gloves and masks are consistently available for use when handling potentially toxic or skin-irritating substances, including epoxy and carbon fibre.

Figure 40 Epoxsea laboratory personal protective equipments, construction materials and tools

Lab Protocols (Operational)

First aid kits and fire extinguishers are strategically positioned for immediate access in the event of accidents.

The designated safety officer is responsible for the periodic update of the job safety analysis and safety handbook throughout the operational season.

In the event of equipment malfunction, tool damage, or potential hazards, operations must be immediately suspended and the issue promptly reported to the relevant supervisor or safety officer.

Employees bear the responsibility of performing pre-operational inspections of tools and equipment to detect any defects or issues that could potentially pose a risk during operation.

Instructions are effectively relayed between the drive team and those responsible for tether management, ROV deployment, and retrieval of objects in water or in contact with the vehicle. Commands such as "Kill" and "Launch" are issued by the driver to the operations team, and actions are executed following confirmation from team members.

These communication protocols have demonstrated their efficacy in ensuring the ROV is not in operation during maintenance activities by crew members, and in facilitating immediate shutdown during emergencies.

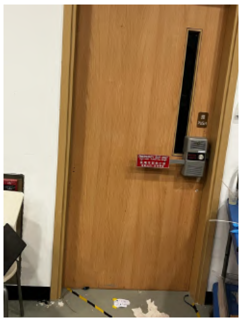


Figure 41 Laboratory fire escape


Figure 42 Laboratory first aid box

Vehicle Safety Features

Our personnel are dedicated to consistently adhering to, if not surpassing, all safety protocols stipulated by MATE annually. The thruster is equipped with shields and warning labels are displayed on the thruster for safety. Mechanical engineers meticulously ensure that the ROV frame is devoid of sharp edges, thereby protecting both crew members and marine life. Hardware engineers utilize 3D-printed enclosures to house electronic components, which are subsequently filled with epoxy resin to prevent underwater short circuits. Software engineers diligently ensure code stability to maintain reliability and prevent the ROV from losing control during mission tasks. Through the concerted efforts of all divisions, we guarantee the safety and stability of our ROV. Despite these precautions, unforeseen incidents may still occur. To ensure constant safety, a 'kill-box' (Figure 43), outfitted with an inline fuse and an emergency stop button, is on standby to instantaneously sever the power supply in emergency scenarios.


Figure 43 WAHOO 'kill-box'


Figure 44 WAHOO 48V power supply

Operational And Safety Checklists

Safety procedures, as outlined in WAHOO's Operational and Safety Checklists (Appendix D), are rigorously adhered to prior to, during, and subsequent to the deployment of the ROV. Employees diligently adhere to operational protocols to safeguard both wildlife and crew members.

Critical Analysis

Testing Methodology

EPOXSEA's testing involves four stages: Simulation Test, Dry Test, Mini Pool Test, and Pool Test.

This year, we have endeavored to incorporate the Gazebo simulator into our ROV Simulation process. Software Engineers evaluate their programs during the "Simulation Test", such as OpenCV and the ROS2 control system. This process aligns with the EPOXSEA software pipeline, facilitating efficient troubleshooting. Mechanical Engineers supply 3D models to the software engineers in constructing accurate simulation environments to rigorously test the buoyancy and manipulator of ROV.

The "Dry Test" is primarily conducted to power on the ROV and evaluate the hardware components within the controlled environment of the EPOXSEA laboratory. This process is crucial to ensure the safety and proper connectivity of the hardware components.

The "Mini Pool Test" involves deploying the ROV into a mini pool located within the EPOXSEA lab. This test is designed to assess the waterproofing of the hardware and the buoyancy of the ROV. The duration of this test is approximately two hours per day.

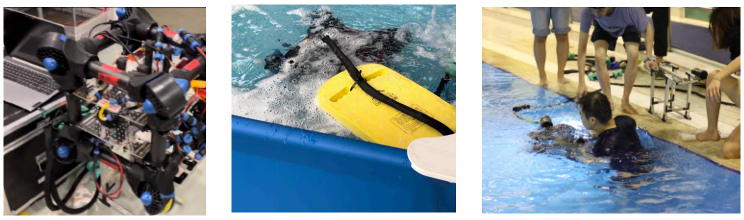


Figure 45 ROV in dry test, mini pool test and onsite test

Upon completion of the initial three procedures, the ROV undergoes "Onsite Test" in a swimming pool. This environment is carefully prepared with props to simulate mission-specific conditions. Each testing session spans approximately three hours and is conducted twice weekly.

This rigorous testing schedule ensures the ROV's readiness for real-world deployment and its ability to perform under various conditions.

Troubleshooting Strategy

In the current year, EPOXSEA has adopted the Gazebo Simulator to facilitate software testing. Also the employees has established an open sharing platform, referred to as the Knowledge Base (KB), which serves as a forum for receiving feedback and offering suggestions on each other's designs. Each department implements its unique troubleshooting methodology, employing a pipeline to identify, address, and enhance WAHOO. For the software department, this process comprises four stages: "Ideation", "Work Division", "Research", and "Continuous Advancement". Despite the brevity of the development cycle, the continuous iteration enables agile software development, ensuring a rapid response to changes. Furthermore, the "Continuous Advancement" stage involves the collaborative efforts of additional employees.

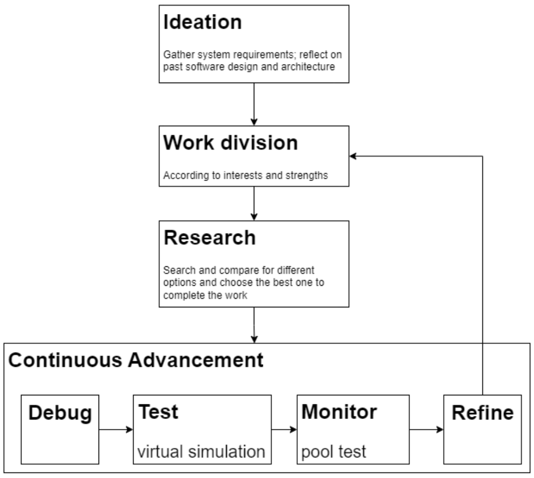


Figure 46 Software pipeline flowchart

For the mechanical department, the workflow pipeline is composed of six stages: "Work Division", "Sketch & Development", "CAD & Simulation", "Prototype", "Iteration", and "Onsite Test".

During the "Work Division" stage, each employee presents a preliminary idea for the manipulator design, and the most suitable member is selected to execute it. The "Sketch & Development" stage involves creating a detailed design plan and posting it onto the KB for peer review and feedback.

In the "CAD & Simulation" stage, the design is constructed in Solidworks, and the 3D model is tested using a software simulator. For the "Iteration" stage to ensure its functionality before advancing to the "Onsite Test".

After the "Onsite Test", the mechanical engineers will refine it and improve it.

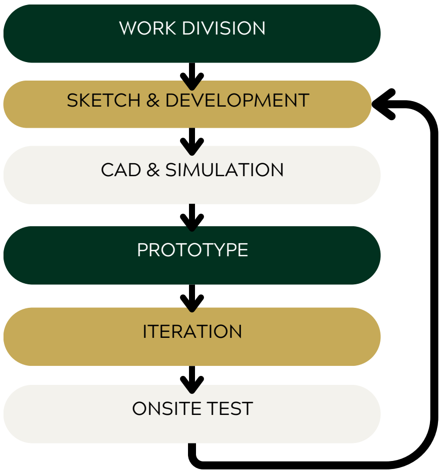


Figure 47 Mechanical department pipeline flowchart

For the hardware department, Root Cause Analysis (RCA) is a systematic approach employed to discern the fundamental causes of faults or problems. RCA can be broken down into four stages:

- Accurately identify and articulate the problem.
- Construct a timeline from the normal state to the occurrence of the problem.
- Differentiate between the root cause and other contributing factors, for instance, using event correlation.
- Develop a causal graph linking the root cause and the problem.

Noteworthy Troubleshooting Experience

A significant troubleshooting incident involved our engineers encountering difficulties with the pressure sensor configuration of the ROV. They discovered that the sensor was inaccurately retrieving pressure data underwater, despite functioning correctly above water. Initially, the hardware engineers suspected a flaw in the waterproofing. After three days of rigorous troubleshooting, a software engineer identified the root cause as an overflow issue within the program. This experience underscored for EPOXSEA employees the importance of cross-departmental communication during troubleshooting processes.

Prototyping

In the current year, EPOXSEA has adopted the Gazebo Simulator to facilitate software testing. To prototype, software engineers will do research of different method to code for finishing the task. Software engineers will execute the implementation on a simulator, conducting unit tests to evaluate performance and stability. Upon selection of the optimal method, the engineers will apply the code to the actual ROV, WAHOO.

This approach facilitates rapid prototyping without the need for physical interaction with the ROV.

In the mechanical department, team members construct 3D models using Solidworks, subsequently testing these in a simulator. They utilize KB as a collaborative platform for exchanging feedback and proposing enhancements to each other's designs. The team also organizes bi-weekly virtual meetings in preparation for the pool test. After the approval from most of the engineers, the engineers proceed to 3D print the design. The goal is to progressively optimize the design, ensuring its resilience and the effectiveness of the manipulator designs during the pool test.

Within the hardware department, diagnostic processes are commenced in a regulated environment like a laboratory. Digital multimeters are employed during electronic evaluations to verify the correct connectivity of the circuit boards. Prior to conducting underwater assessments, circuit boards are treated with waterproof materials to guarantee peak performance in aquatic conditions.

Team Work

Company Profile

EPOXSEA is a company with 29 students from The Hong Kong University of Science and Technology (HKUST), committed to the design, construction, and marketing of ROVs. These ROVs are aimed at preserving Earth's resources and addressing pressing environmental issues, including climate change and the impact of human activities on the environment.

EPOXSEA prioritizes continuous learning and promotes cross-training among its members. Senior engineers are entrusted with the responsibility of training junior engineers. The company also encourages interdepartmental training, enabling each employee to acquire a broad range of skill sets for effective collaboration.

Diversity and safety is also the core values of EPOXSEA. The team comprises individuals from diverse backgrounds, including Hong Kong, China, Indonesia, Taiwan, Kazakhstan, and Australia.

Company Organization And Assignments

This year, EPOXSEA has implemented a significant update to its organizational structure. A new department, Business Department has been established, responsible for all non-technical operations, including documents, reports, presentations, recruitments, and promotional activities. The aim is to alleviate the workload of the technical team members, thereby enabling them to focus entirely on the construction of the ROV.

EPOXSEA's organizational structure (Figure43) now comprises four pivotal departments: Software, Hardware, Mechanical, and Business. The CEO maintains a close working relationship with the department leaders, ensuring the maintenance of project schedules, task completion, and department collaboration. Each department leader is then responsible for determining and assigning the goals of their department and the work assignments of individual employees. This approach ensures a streamlined workflow and promotes efficiency within the organization.

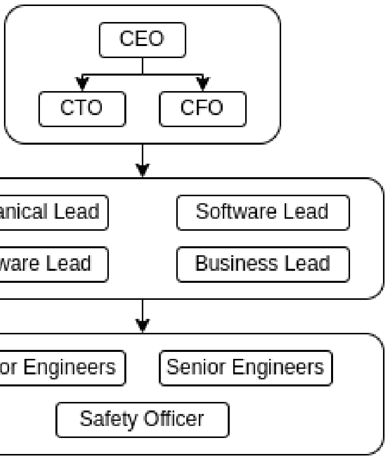
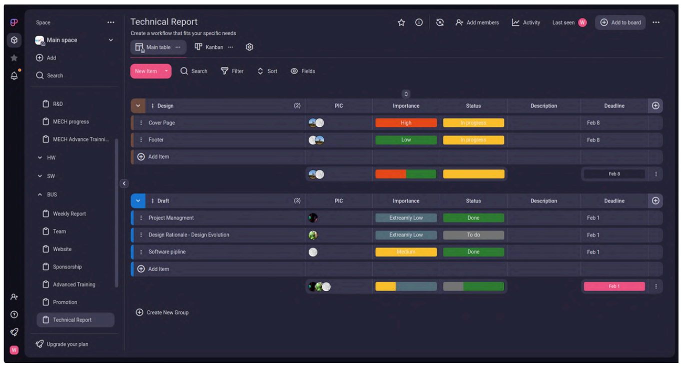


Figure 48 Epoxsea organizational structure

Project Management

EPOXSEA utilizes 'Plaky' [8] as a project scheduling tool (Figure49), accessible to all team members. This facilitates progress tracking and promotes cross-departmental collaboration. The CEO provides overarching direction and schedules for the hardware, software, mechanical, and business departments. Department leaders further refine these directives by setting detailed tasks for their team members. It is incumbent upon members to adhere to the task schedule and provide frequent status updates. Tasks are prioritized on a scale ranging from 'Extremely Low' to 'Urgent'.

Furthermore, members are required to update their progress according to five statuses: ‘To do’, ‘In Progress’, ‘Stuck’, ‘Need help’, and ‘Done’.



Technical Report

Create a workflow that fits your specific needs

Design (2)	PIC	Importance	Status	Description	Deadline
Cover Page		High	In progress		Feb 8
Footer		Low	In progress		Feb 8
					Feb 8

Draft (3)	PIC	Importance	Status	Description	Deadline
Project Managment		Extreamly Low	Done		Feb 1
Design Rationale - Design Evolution		Extreamly Low	To do		Feb 1
Software pipline		Medium	Done		Feb 1
					Feb 1

Figure 49 Epoxsea use of KB to track task schedule

Weekly Progress Report

A weekly meeting is held on Thursday to discuss progress and scheduling. Prior to this, a report by departments summarizing the past week’s progress, challenges, and future plans is prepared before the meeting. The first hour is a general session with departmental updates presentation and a Q&A session led by the CEO and Technical Coordinator. This is followed by a three hours department-specific meetings to discuss task distribution, next week planning and improvements based on feedback.


Figure 50 CEO during weekly meeting


Figure 51 in-department meeting

Project Schedule

New junior engineers are selected through an extensive training program that runs from September to November, during which existing junior engineers oversee the training while concurrently conducting research and managment planning. In December, these junior engineers are promoted to senior positions, paving the way for the induction of new junior engineers. To facilitate the integration of new junior engineers, EPOXSEA organizes welcoming parties and team-building events. These initiatives foster camaraderie, stimulate team spirit, and encourage new engineers to contribute innovative ideas to the company.


Figure 52 Epoxsea team-building events

Upon their induction in December, the new junior engineers will undergo comprehensive technical and safety training to ensure a secure working environment within the laboratory. From January to March, the period will be dedicated to the prototyping, innovation, and research of the ROV. Department leaders will engage in strategic long-term planning while imparting advanced training to junior members. Commencing in March, EPOXSEA will conduct bi-weekly swimming pool tests every Monday and Thursday. Concurrently, the business department will initiate documentation processes. In summary, the construction of the ROV adheres to a three-stage process.

Stage One: ROV System Design

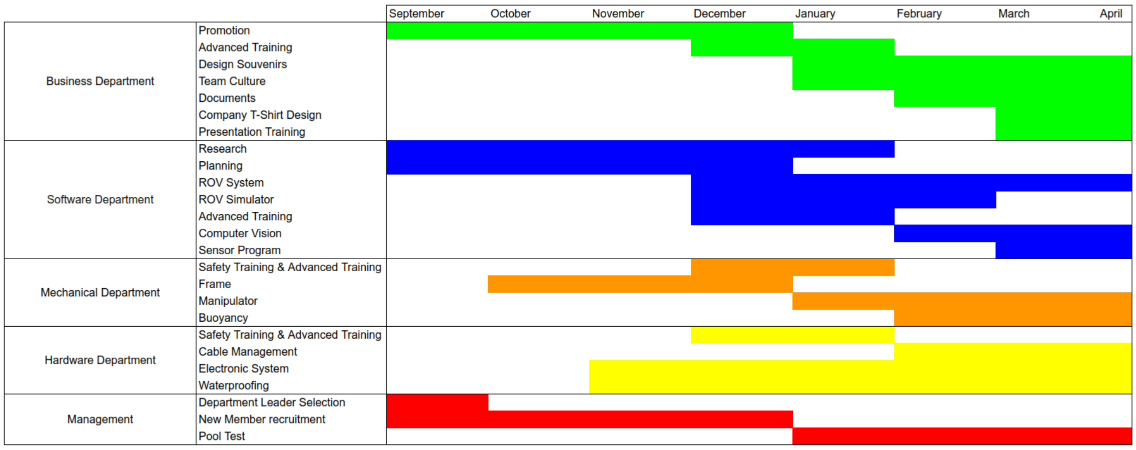
- Incorporate insights from previous generation ROV designs
- Formulate a comprehensive long-term strategy
- Facilitate the training and selection of proficient engineers
- Engage and foster learning among newly recruited engineers

Stage two - ROV System Building

- Building Frame and Electroinc system
- Dividing tasks responsibilities to respective employees
- designing and developing manipulators according to tasks
- in-department analysis and feedbacks for prototypes
- on-shore testing of ROV

Stage three - ROV System Testing

- pool tests
- documentation
- refining manipulators



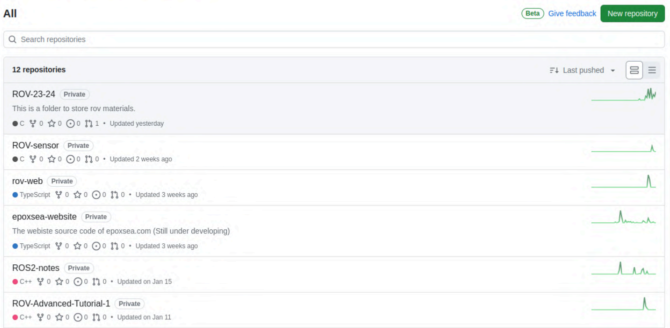
		September	October	November	December	January	February	March	April
Business Department	Promotion	🟩	🟩	🟩	🟩				
	Advanced Training				🟩	🟩			
	Design Souvenirs					🟩	🟩	🟩	🟩
	Team Culture					🟩	🟩	🟩	🟩
	Documents						🟩	🟩	🟩
	Company T-Shirt Design							🟩	🟩
	Presentation Training							🟩	🟩
Software Department	Research	🟦	🟦	🟦	🟦	🟦			
	Planning	🟦	🟦	🟦	🟦				
	ROV System				🟦	🟦	🟦	🟦	🟦
	ROV Simulator				🟦	🟦	🟦		
	Advanced Training				🟦	🟦			
	Computer Vision						🟦	🟦	🟦
	Sensor Program							🟦	🟦
Mechanical Department	Safety Training & Advanced Training				🟧	🟧			
	Frame		🟧	🟧	🟧				
	Manipulator					🟧	🟧	🟧	🟧
	Buoyancy						🟧	🟧	🟧
Hardware Department	Safety Training & Advanced Training				🟨	🟨			
	Cable Management						🟨	🟨	🟨
	Electronic System			🟨	🟨	🟨	🟨	🟨	🟨
	Waterproofing			🟨	🟨	🟨	🟨	🟨	🟨
Management	Department Leader Selection	🟥							
	New Member recruitment	🟥	🟥	🟥	🟥				
	Pool Test					🟥	🟥	🟥	🟥

Figure 53 Epoxsea monthly progress planning

Code Management

This year, EPOXSEA has opted for GitHub as its Version Control System (VCS), transitioning from GitLab. The decision was influenced by GitHub's user-friendly interface and freemium. Our previous experience with GitLab revealed challenges in setup and stability, prompting the migration of all projects to GitHub. GitHub facilitates collaborative code management and maintenance for EPOXSEA engineers. It supports software branching and merging, a critical feature when multiple contributors are working on interdependent files. Engineers can raise issues and request code reviews, fostering a supportive environment for bug resolution.

The software department leader oversees the entire source control and versioning process, ensuring a seamless management of code changes. Regular updates regarding code modifications on GitHub are communicated via WhatsApp by the software department leader.



ROV-23-24 Private
This is a folder to store rov materials.
C 0 0 0 1 • Updated yesterday

ROV-sensor Private
C 0 0 0 0 • Updated 2 weeks ago

rov-web Private
TypeScript 0 0 0 0 • Updated 3 weeks ago

epoxsea-website Private
The webiste source code of epoxsea.com (Still under developing)
TypeScript 0 0 0 0 • Updated 3 weeks ago

ROS2-notes Private
C++ 0 0 0 0 • Updated on Jan 15

ROV-Advanced-Tutorial-1 Private
C++ 0 0 0 0 • Updated on Jan 11

Figure 54 Software department use of GitHub

Collaborative Workspace

This year, to streamline file management, our software engineers have established a Knowledge Base (KB). This unified platform allows team members to access and upload files and documents efficiently. The decision was influenced by our experience with Google Drive.

Last year, which we found to be less than optimal for document management due to its user interface and storage limitations. Consequently, we developed a KB to effectively manage our documents and files.

Accounting

At the onset of each season, EPOXSEA projects a considerably reduced budget compared to the previous year. Expenses related to employee transportation and competition meals are separately estimated, as these are individually covered by the employees. EPOXSEA's funding and revenue are derived from competitions and sponsorships. The budget plan was planned by CEO, CFO and department leaders, it is baed on last year estimation and this year ROV improvment planning. All budgetary expenditures are meticulously recorded and uploaded to the Knowledge Base (KB), with physical receipts retained by the CFO. In an effort to foster collective fiscal responsibility, EPOXSEA ensures these expenses are accessible to all employees, enabling them to collaboratively adhere to the budget plan. The Budget, Project, and Costing data sheets are appended in the Appendix A abd B.

Conclusion

Challenges

In the current year, EPOXSEA has encountered numerous obstacles. the most important design decisions EPOXSEA made is to overhauled the entire project architecture and introduced the innovative ROV System. The transition of all historical documents and codes from GitLab to GitHub presented a significant challenge, as did the establishment of a Gazebo simulator and the new file management platform, KB. This has imposed a considerable burden on the software engineers, causing a slight delay in the project schedule and resulting in a brief WAHOO downtime. Consequently, we have had to conduct several training sessions to familiarize all employees with these systems.

Furthermore, the newly established Business Department has also faced its share of challenges. As a nascent department without prior experience, the department leader has had to employ a trial-and-error approach to establish effective management practices.

Lessons Learned And Skills Gained

In terms of technical perspective, despite the slight delay in the project schedule due to the overhaul of the project architecture, Knowledge Base (KB) and the development of the ROV system, our employees have found these changes to be highly beneficial, significantly enhancing their productivity. We have received positive feedback from our staff, who are eager to continue using and maintaining this system for future ROV development. The new system has also facilitated the testing of WAHOO prior to pool testing, resulting in substantial savings in terms of budget and time. Furthermore, the system has improved interdepartmental communication compared to the previous year, as all documents are now publicly accessible to all employees in KB.

In terms of team management, the establishment of the new Business Department has led to the implementation of numerous policies, such as weekly progress reports and team-building events. These initiatives have significantly enhanced the communication, presentation, and documentation skills of our employees. We have also recognized the importance of keeping junior engineers informed about ongoing developments. Compared to the previous year, junior engineers have shown increased involvement this year, contributing numerous innovative ideas.

In conclusion, from a technical perspective, it is crucial to maintain a continuous development platform. From a management standpoint, it is essential to ensure that all documents are accessible to all employees and to keep them informed about the latest project progress.

Future Improvements

Looking ahead, we plan to continue the development of the next-generation ROV in the coming year, leveraging our current ROV system. EPOXSEA intends to implement a linear stability matrix system next year, based on our current research. This system will enable the ROV to maneuver not merely through matrix calculations, but also through computations involving gyroscope and IMU sensors, thereby enhancing the speed and stability of the ROV.

Additionally, EPOXSEA is set to refine the workflow of the simulator test branch. This will provide a more user-friendly procedure for our mechanical and hardware engineers when utilizing the simulator for testing purposes.

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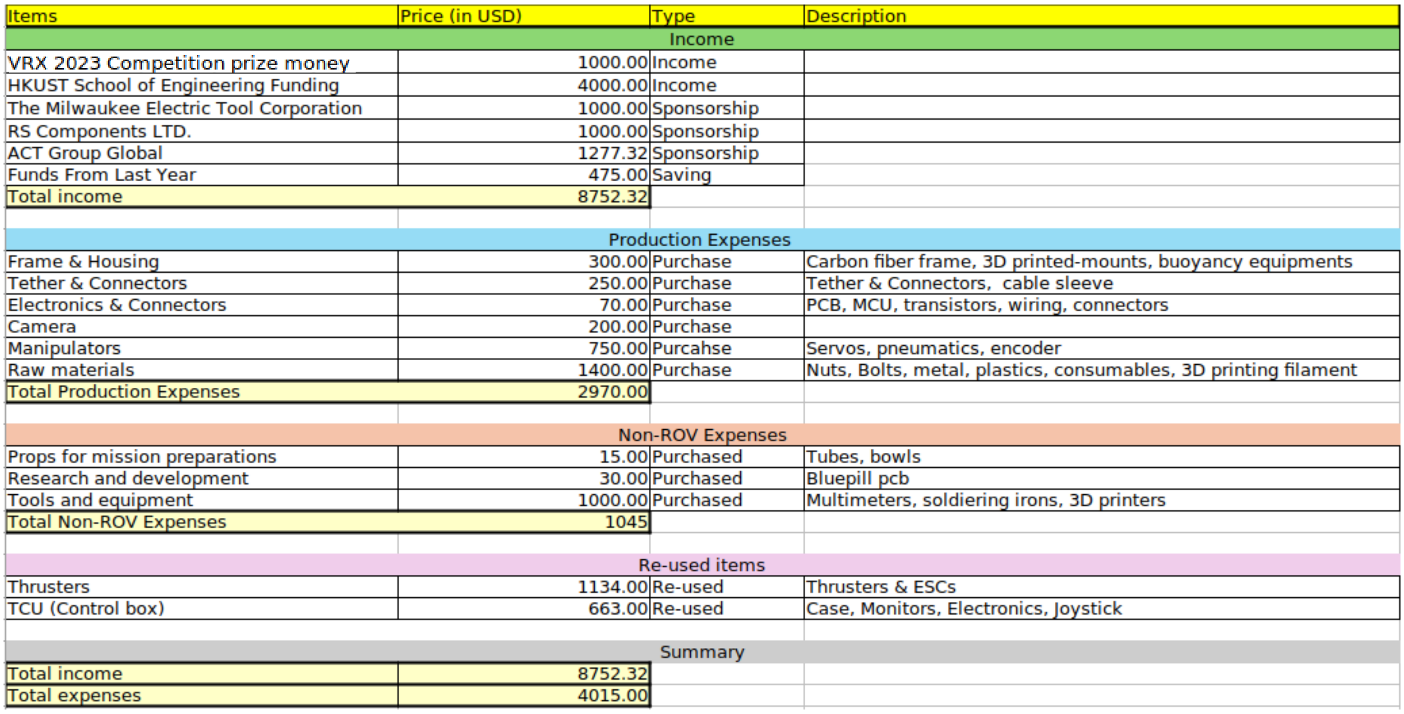
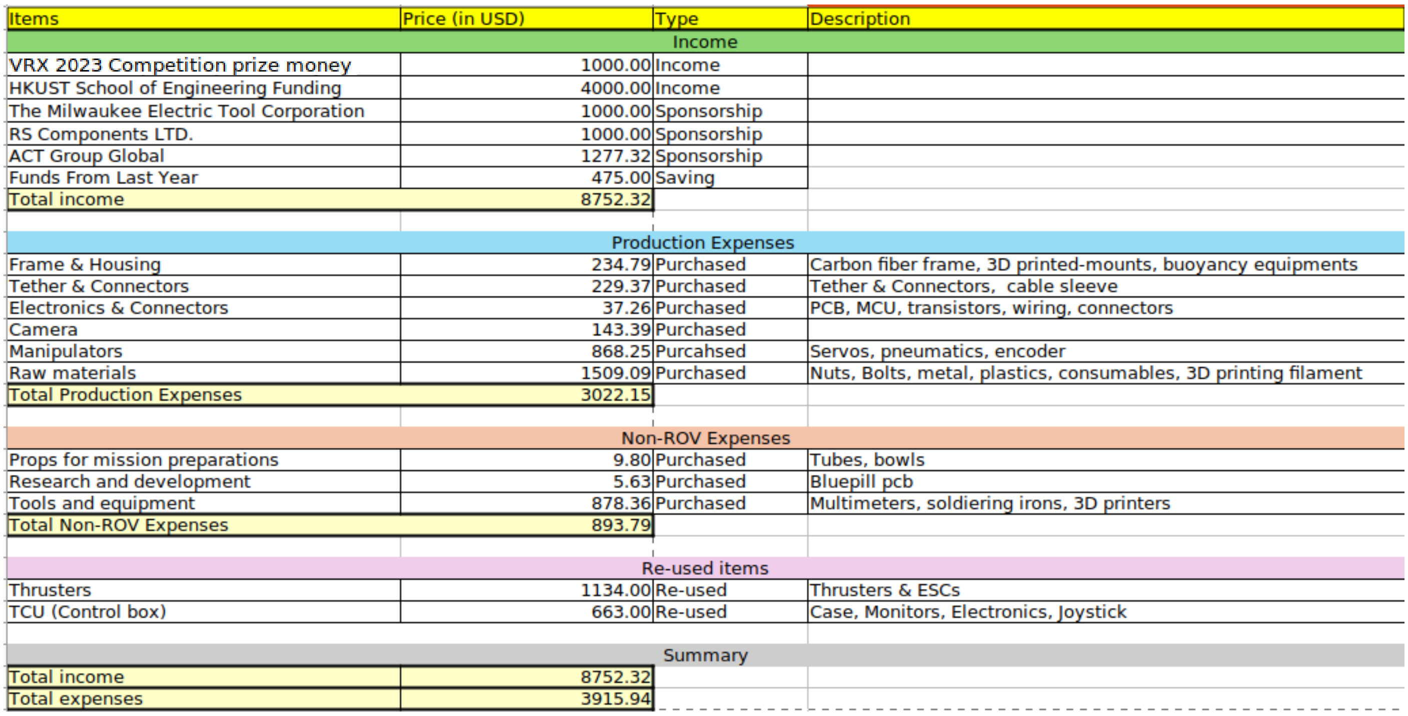
Appendices

Appendix A: Proposed Budget



Items	Price (in USD)	Type	Description
Income			
VRX 2023 Competition prize money	1000.00	Income	
HKUST School of Engineering Funding	4000.00	Income	
The Milwaukee Electric Tool Corporation	1000.00	Sponsorship	
RS Components LTD.	1000.00	Sponsorship	
ACT Group Global	1277.32	Sponsorship	
Funds From Last Year	475.00	Saving	
Total income	8752.32		
Production Expenses			
Frame & Housing	300.00	Purchase	Carbon fiber frame, 3D printed-mounts, buoyancy equipments
Tether & Connectors	250.00	Purchase	Tether & Connectors, cable sleeve
Electronics & Connectors	70.00	Purchase	PCB, MCU, transistors, wiring, connectors
Camera	200.00	Purchase	
Manipulators	750.00	Purcahse	Servos, pneumatics, encoder
Raw materials	1400.00	Purchase	Nuts, Bolts, metal, plastics, consumables, 3D printing filament
Total Production Expenses	2970.00		
Non-ROV Expenses			
Props for mission preparations	15.00	Purchased	Tubes, bowls
Research and development	30.00	Purchased	Bluepill pcb
Tools and equipment	1000.00	Purchased	Multimeters, soldiering irons, 3D printers
Total Non-ROV Expenses	1045		
Re-used items			
Thrusters	1134.00	Re-used	Thrusters & ESCs
TCU (Control box)	663.00	Re-used	Case, Monitors, Electronics, Joystick
Summary			
Total income	8752.32		
Total expenses	4015.00		

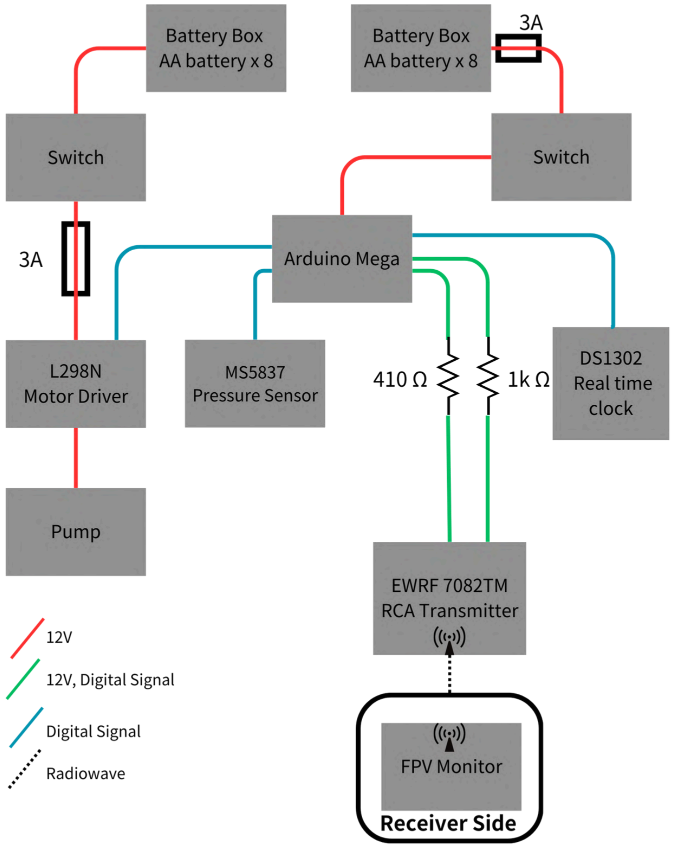
Appendix B: Cost Projection



Items	Price (in USD)	Type	Description
Income			
VRX 2023 Competition prize money	1000.00	Income	
HKUST School of Engineering Funding	4000.00	Income	
The Milwaukee Electric Tool Corporation	1000.00	Sponsorship	
RS Components LTD.	1000.00	Sponsorship	
ACT Group Global	1277.32	Sponsorship	
Funds From Last Year	475.00	Saving	
Total income	8752.32		
Production Expenses			
Frame & Housing	234.79	Purchased	Carbon fiber frame, 3D printed-mounts, buoyancy equipments
Tether & Connectors	229.37	Purchased	Tether & Connectors, cable sleeve
Electronics & Connectors	37.26	Purchased	PCB, MCU, transistors, wiring, connectors
Camera	143.39	Purchased	
Manipulators	868.25	Purcahsed	Servos, pneumatics, encoder
Raw materials	1509.09	Purchased	Nuts, Bolts, metal, plastics, consumables, 3D printing filament
Total Production Expenses	3022.15		
Non-ROV Expenses			
Props for mission preparations	9.80	Purchased	Tubes, bowls
Research and development	5.63	Purchased	Bluepill pcb
Tools and equipment	878.36	Purchased	Multimeters, soldiering irons, 3D printers
Total Non-ROV Expenses	893.79		
Re-used items			
Thrusters	1134.00	Re-used	Thrusters & ESCs
TCU (Control box)	663.00	Re-used	Case, Monitors, Electronics, Joystick
Summary			
Total income	8752.32		
Total expenses	3915.94		

Appendix C: Float SID

Float System Interconnection Diagram



Appendix D: Safety Checklists

Safety Checklists

Construction

☐ Ensure machinery and tools in good condition before use
☐ Wear suitable protective equipment
☐ Shut down electronic appliances that are not in use
☐ Perform soldering or other practices that involve toxic gas in a well-ventilated area
☐ Return all tools to designated areas after use

Operation

Pre-deployment

☐ All electronics connections are secured and correctly connected and non-exposed
☐ Screw caps on all cameras are secured
☐ Cables and tethers are properly tightened
☐ Manipulators are all properly mounted and secured onto ROV
☐ No damage in ROV frame
☐ Tether is laid out neatly without knots or tangles
☐ Surface station tether strain relief is connected, tether ethernet and power are connected
☐ Surface station is stable and on a level surface
☐ Deck area is clear of clutter and tripping hazards
☐ Thrusters free from obstruction
☐ All members wearing appropriate and safe attires

Power-up

☐ Control Box is receiving 48V nominal
☐ Verify camera connection to the Control Box is stable
☐ Perform thruster test, joystick movements correspond with thruster activity
☐ Test any electrical manipulators that require pilot control

Deployment

☐ Verify no excess bubbles are coming out
☐ Clear signal communication:
  ☐ "Kill" when power needs to be cut off
  ☐ "Contact" before touching WAHOO
  ☐ "Launch" when WAHOO is ready to be operated underwater
  ☐ "Power on" before turning on WAHOO
☐ Appropriate length of the tether is released into water to prevent pull on ROV or entanglement

Loss of Communication/ Camera feed

☐ Pilot calls out "Kill" and powers down ROV
☐ Crew members retrieve ROV via tether to shore
☐ Begin troubleshooting process until communication is restored
☐ Document the cause of failure and implemented repair method

Appendix E: SOFTWARE FLOWCHART