TECHNICAL DOCUMENTATION

INKAY 2025

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THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Abstract

EPOXSEA has engineered resilient remotely operated vehicles (ROVs) to address underwater challenges for 14 years. This time, our 26-member interdisciplinary team introduces INKAY, representing major innovations to combat the Great Lakes' most pressing threats: invasive species, habitat degradation, and climate change impacts.

Inspired by interlocking building blocks, the vehicle's quick-mounting architecture enables mission-specific tools to be integrated and swapped, allowing more efficient and compact functionality. Meanwhile, implementation of high-thrust vectoring propulsion ensures maneuverability even under harsh conditions and stable camera system delivers real-time clarity in turbid waters.

Development followed a rigorous, iterative prototyping process. From testing 3D-printed components to pool tests and interdepartmental meetings, our ROV is optimized for performance and reliability. Each design decision is based on our company's philosophy, where mechanical efficiency, electrical precision, and ecological responsibility converge.

At MATE ROV 2025, our ROV represents more than advanced engineering — it embodies our commitment to conserving the environment. This vehicle proves that adaptive, mission-driven design can address environmental challenges one piece at a time. As we continue our legacy in underwater robotics, INKAY stands as a testament to what can be done to preserve Earth's marine life.

Figure 1. EPOXSEA team members and supervisor

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Design Rationale

Design Overview

In the 2025 MATE ROV competition [1], EPOXSEA's newest ROV, INKAY, embodies the most efficient, reliable, and creative mechanical designs to execute complex competition task. While drawing from the lessons learned from previous ROVs - WAHOO (2024) [2] and MANTA (2019) [3] - the EPOXSEA team also committed to resolving previous issues. As a result, compared to its predecessors, INKAY has made drastic improvements in modularity, portability and eco-friendliness.

Such advancements are achieved through multiple design choices in structural layout, material selection, thruster placements, and many sub-systems integrated into the ROV.

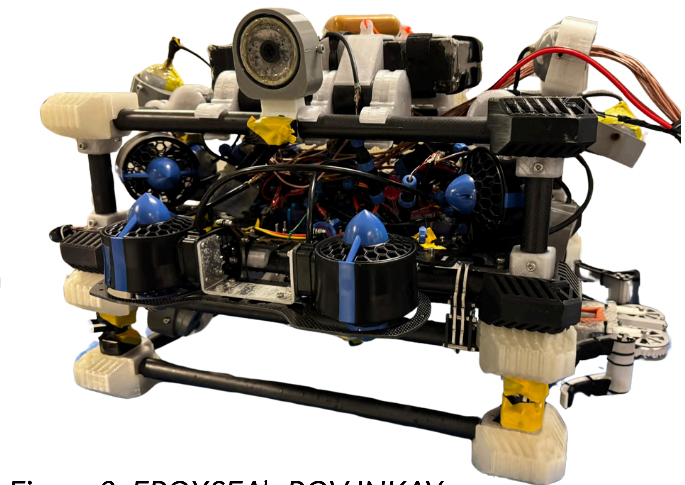


Figure 2. EPOXSEA's ROV INKAY

Modularity

INKAY's modular design allows rapid reconfiguration of manipulators and sensors. Standardized mounting points enable seamless integration of mission-specific components without extensive modifications. Furthermore, the double-decker structure allows INKAY's maneuver frame and manipulator frame to be individually serviced, greatly reducing the complexity of installing and uninstalling manipulators and hardware. Such design choices also allude to the benefit of portability.

Portability

Previous ROVs have proven the difficulty in overseas transportation. INKAY tackles the issue with its unparalleled modularity: by disengaging the quick-release clamps, INKAY becomes two rectangular components that easily fit into safety crates. The thrusters extruding from the sides can also fold into the upper deck, further protecting the fragile components.

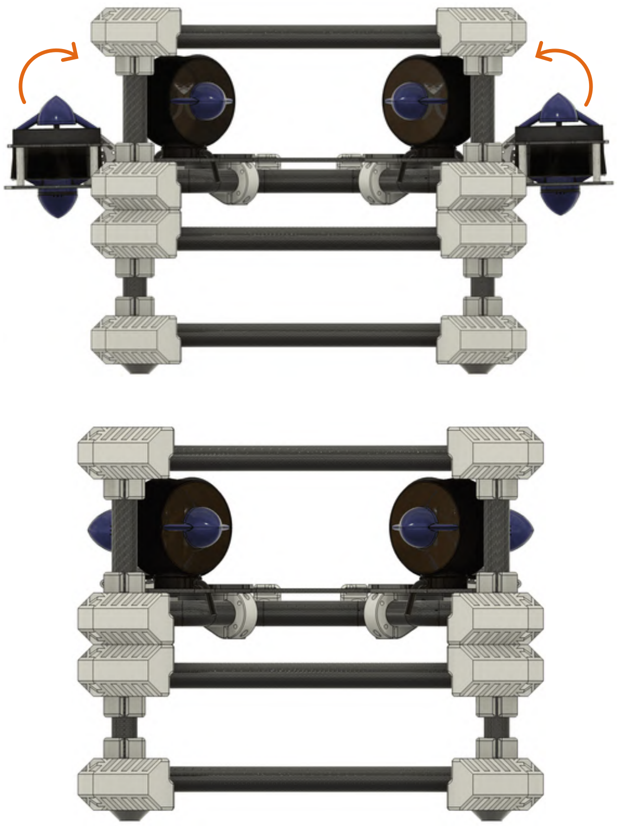


Figure 3. Retractable side thrusters

Eco-friendliness

EPOXSEA values sustainability throughout our design. To minimize environmental impacts, INKAY utilizes biologically inert or recyclable materials. This significantly reduced waste production and enhanced the safety of the working environment.

Design and Manufacturing Process

EPOXSEA's mechanical engineers follow a structured and collaborative design process to optimize both designing and manufacturing, ensuring a systematic approach from start to finish. At the beginning of every design cycle, the entire team reviews previous designs to preserve successful elements and refine weaknesses.

For instance, in previous years, the ROV's thrusters were positioned at all corners of the frame. This arrangement increased the likelihood of thruster damage and resulted in frequent maintenance. To address this, the thrusters were relocated to the upper deck of the frame this year, and newly developed Thermoplastic Polyurethane (TPU) bumpers were installed at corners for impact absorption. Stainless steel mesh guards were also added to shield the exposed parts of the thrusters to further enhance overall durability.

Once the design features and details are set in stone, the team moves on to the development, testing, and production phases. To streamline collaboration, mechanical department transitioned from SolidWorks to Autodesk Fusion 360, cloud-based 3D CAD design platform [4][5]. This facilitates work division in large design projects, enabling multiple engineers to work on different aspects simultaneously. Shared files also retain consistency with synchronized metrics and precise dimensions. The collaborative nature of this online workspace allows real-time feedback, enabling early flaw detection and improvements, increasing knowledge exchange and engagement between team members.

After the initial design is completed in January 2025, the team holds meetings to discuss strategies concerning cost, size and weight. Once revisions are finalized, the components are produced, and the final product is manufactured.

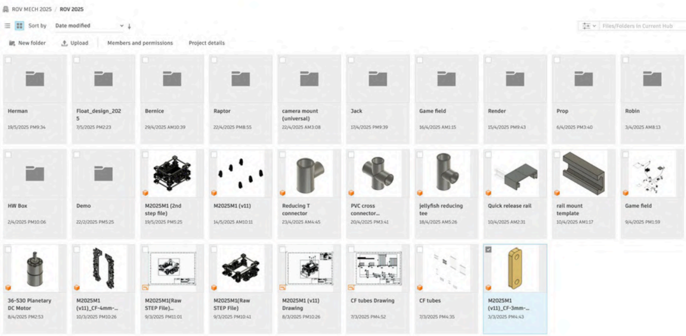


Figure 4. 3D CAD Design Platform

Decision and Trade-offs Process

During the design process, decision making is involved in several stages. In order to find the optimal choice, we utilized a collaborative platform, Lark, as a medium to organize documents and preserve our existing knowledge base. This platform sorts and analyzes data neatly to aid our decision making process. For instance, when evaluating claw prototypes, we create a table that compares different factors of motors including advantages and disadvantages, as well as unique aspects. This way, we can easily pinpoint the most suitable motor for controlling the manipulator.

	Servo Motor	Stepper Motor	DC Motor
Cost*	3	5	1
Precision*	4	5	3
Coding Difficulty*	5 (PID required for closed-loop control)		2
Durability*	2	3	4
Torque*	4	4	3
Additional Notes	Suffer from a performance downgrade underwater		Cost efficient, water proofing treatment easy to conduct

**from 1 to 5, lowest to highest*

Figure 5. Decision matrix for motor selection in Lark

Vehicle Structure

INKAY's frame is divided into two sections: the maneuver frame and the manipulator frame. The frames are connected by six quick-release clamps which are made of aluminum and carbon fiber plating and are easily mass-produced via CNC. Meanwhile, the dimensions of the ROV (60 cm × 40 cm × 40 cm) are reduced by 30% compared to last year's ROV, which improves the mobility and maneuverability. The new frame design also relieves the pain of swapping the whole frame due to a single leak or crack. INKAY's modularity minimizes the number of pieces to be replaced during fixes - a "LEGO-like" take on design.

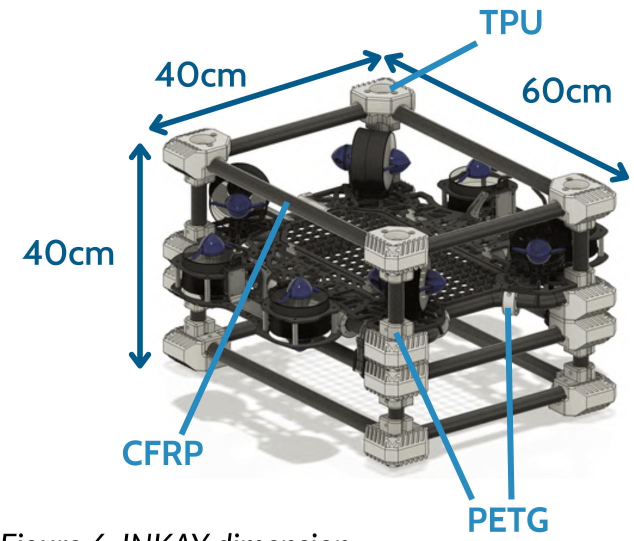


Figure 6. INKAY dimension

Carbon Fiber-reinforced Polymer (CFRP)	• superior strength-to-weight ratio • corrosion resistance
Thermoplastic Polyurethane (TPU)	• for thruster mounts and bumpers • absorb impacts during underwater operations
Polyethylene Terephthalate Glycol (PETG)	• for custom mounts and brackets • balance between strength and manufacturability

Compared to past ROVs' enclosed structure, the open-frame architecture improves accessibility to internal hardware and mechanical components, improving efficiency in maintenance. Furthermore, TPU bumpers at frame corners absorb impact forces, ensuring safe and efficient operation in challenging underwater environments.

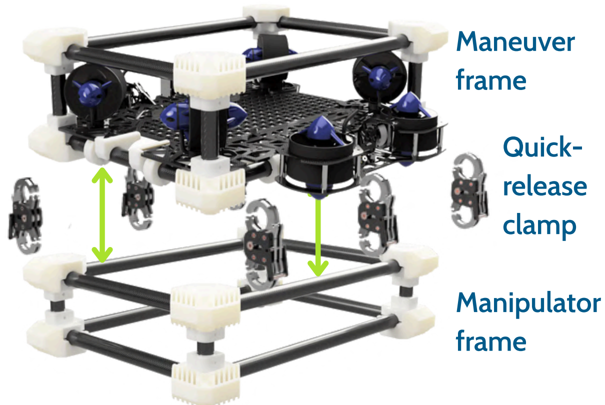


Figure 7. INKAY frame structure

Hydrodynamics

This low-profile frame design, paired with streamlined thruster shrouds, benefits INKAY's hydrodynamic performance. Topology optimization minimizes surface area and reduces drag while retaining structural strength.

Buoyancy

Smooth underwater operation also requires a neutral buoyancy ROV which is achieved via a R-3318 polyurethane foam block. Such material has high impact resistance and can be easily machined. Meanwhile, it has great corrosion resistance while being biologically inert [6], adhering to EPOXSEA's philosophy for environmental friendliness. It is attached to the top of the INKAY by 3D printed quick-release connectors. This strategic placement protects the hardware components beneath the buoyancy block while providing a restoring torque using its buoyancy, further enhancing INKAY's stability underwater.

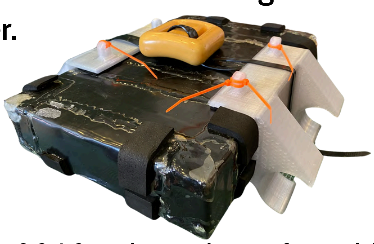
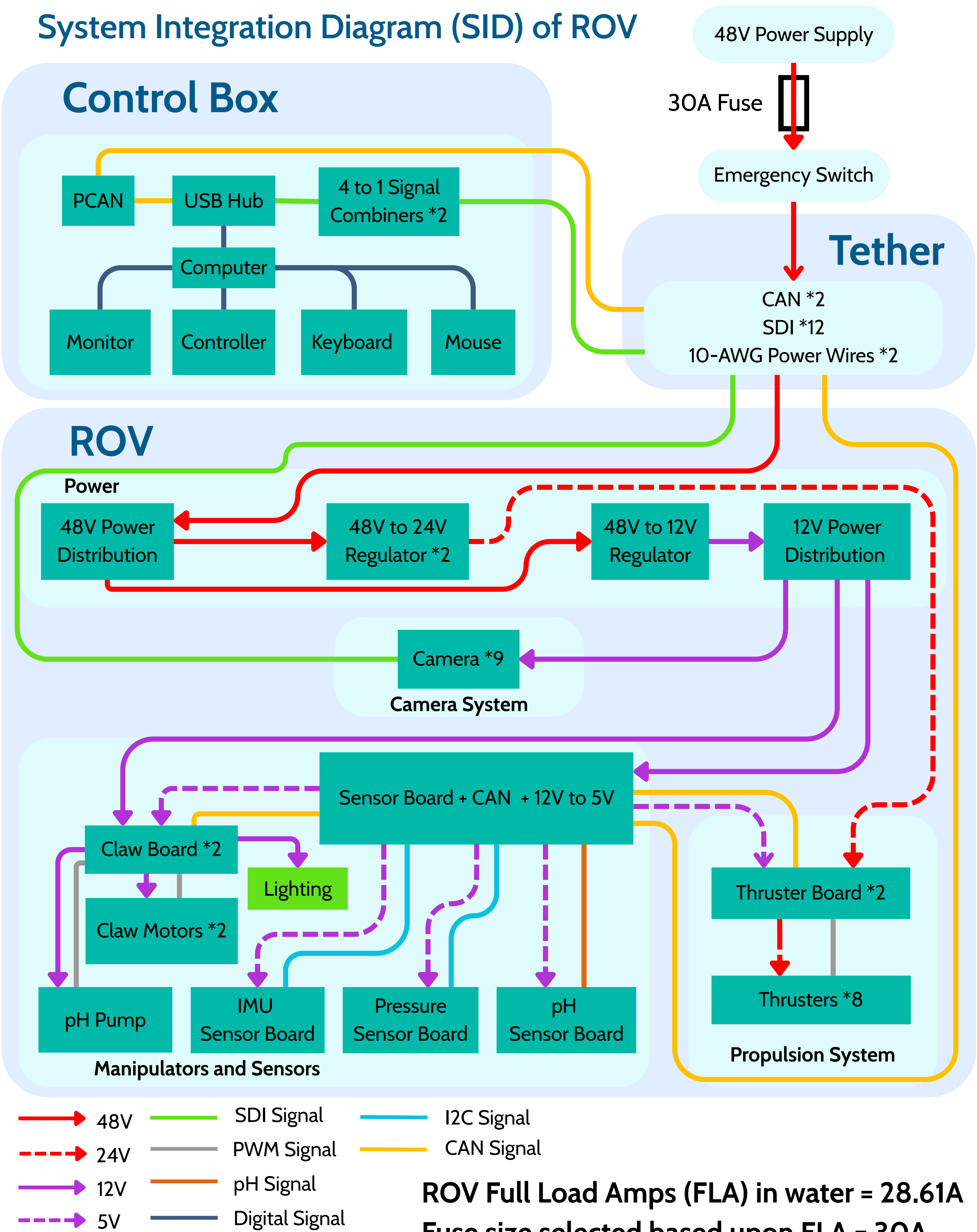


Figure 8. R-3318 polyurethane foam block

System Integration Diagram (SID) of ROV



ROV Full Load Amps (FLA) in water = 28.61A

Fuse size selected based upon FLA = 30A

Figure 9. ROV SID

Controller Area Network

The Controller Area Network (CAN) protocol serves as a vital communication interface connecting the offshore control box with the ROV. It facilitates the transmission of signals for the operation of thrusters and manipulators, as well as data from the sensor board. With a high baud rate of up to 1.25 Mbps, the CAN protocol supports rapid and efficient real-time data exchange. Moreover, its robust error detection [7] and correction mechanisms ensure reliable communication, even in the demanding conditions of underwater environments. This reliability is essential for the successful operation and control of the ROV, enhancing its performance in various underwater tasks.

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 bits if not mentioned explicitly

Figure 10. CAN protocol

CAN Connection

The CAN has been incorporated into the sensor board to conserve space on the ROV. Its primary function is to manage all CAN signals transmitted from the tether, ensuring effective communication within the system. The CAN connects to both the claw board and the motor driver board, enabling precise control over the movement of the manipulators and thrusters under the direction of the offshore control unit. Furthermore, it plays a crucial role in transmitting signals back to the control box, thereby optimizing the ROV's performance and operational efficiency.

Power Distribution

The 48V power distribution board is essential for the efficient allocation of power throughout the system. It connects to both a 48V to 12V regulator and two 48V to 24V regulators. The 12V output is utilized for the camera's SDI signal and lighting, which is then converted to 5V to power the manipulator and sensor board. The 24V output is dedicated to driving the eight thrusters. Meanwhile, the new implementation of 48V to 12V regulator minimizes noise levels, thereby optimizing the overall system performance and reliability.

Motor Driver Boards

We employ two motor driver boards. Each board provides PWM outputs to four thrusters, resulting in a total of eight thrusters. Furthermore, the addition of a CAN port, in conjunction with the ST-Link interface, greatly enhances connectivity between the thrusters and the control box. This configuration fosters robust communication and control, thereby significantly optimizing the operational efficiency of the entire system.

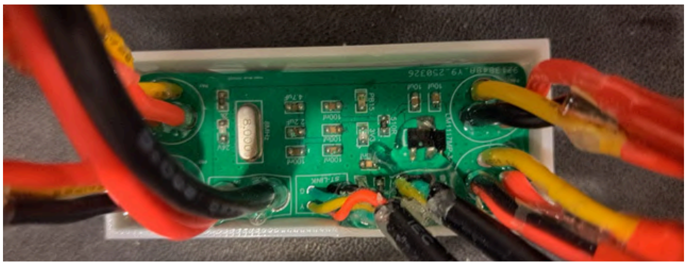


Figure 11. Motor driver board

Claw Board

The claw board is meticulously crafted to generate three PWM signals at 5V, each associated with a specific motor component. It features three H-bridge circuits, one dedicated to each motor section, ensuring optimal performance and precise control. Additionally, a port for a bulb utilizes the AO3400 MOSFET, providing adequate lighting for capturing high-quality camera images. A three-pin port is also allocated for pump operations, enhancing the board's overall functionality. Similar to motor driver boards, the design incorporates a CAN interface and an ST-Link input, allowing for seamless connectivity and efficient signal transmission to the offshore control system. The addition of the DRV8251 driver further augments the claw board's capabilities, enhancing its performance and operational efficiency.

Sensors Board

The system comprises three primary sensor components: Inertial Measurement Unit (IMU), pressure sensor, and pH sensor. The IMU (MPU9250) is responsible for measuring angular velocity and orientation, providing critical data essential for navigation and reposition of the ROV. The pressure sensor (MS5837) accurately gauges ambient pressure and depth, which facilitates precise underwater positioning and enhances the vehicle's operational capabilities. Both the IMU and the pressure sensor employ the Inter-Integrated Circuit (I2C) protocol for seamless communication with the offshore control box, ensuring efficient data transfer and system integration. The pH sensor (PH sensor E-201-C), is integrated into the system to perform the task of measuring the pH of the water. This is crucial for monitoring water quality and ensuring that the ROV operates within the desired environmental parameters. To sum up, these sensor components work in concert to provide comprehensive data that supports the ROV's functionality and mission objectives.

Thrusters

The P75 model has been selected for retention this year due to its commendable performance last year, showcasing both high efficiency and stability. In comparison to the previous year, INKAY has made significant advancements by integrating thrusters equipped with compact Electronic Speed Controllers (ESCs). In WAHOO, each thruster necessitated a connection to a larger ESC. However, INKAY allows the thrusters to connect directly to a small integrated ESC situated beneath each unit. This modification streamlines the design by eliminating external connections, resulting in substantial reductions in both spatial occupancy and power consumption. Ultimately, this enhancement elevates operational performance and overall effectiveness.

Year	Model	Dimension of ESC (cm)	Power required
2024	P75 + Magellan 5-14S80A ESCs	4 x 10 x 2	48V
2025	P75-170ESC	3 x 5 x 1	24V

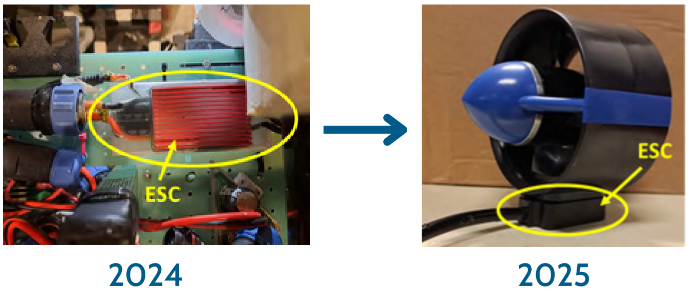


Figure 12. ESC application evolution

Propulsion

INKAY's propulsion system addresses the inefficiencies observed in WAHOO's eight-thruster setup. The updated design includes eight P75 thrusters, each capable of delivering 5.1 kg of thrust, arranged in a BlueROV2 "Heavy" configuration [8]: four vectored horizontal thrusters for precise maneuvering and four vertical thrusters for altitude and roll-pitch control. This setup provides six degrees of freedom (6-DOF) while simplifying thrust vectoring and enhancing user-friendliness. Although this configuration prioritizes operational simplicity and reliability, it presents a balanced trade-off in speed compared to WAHOO's fully vectored thrusters.

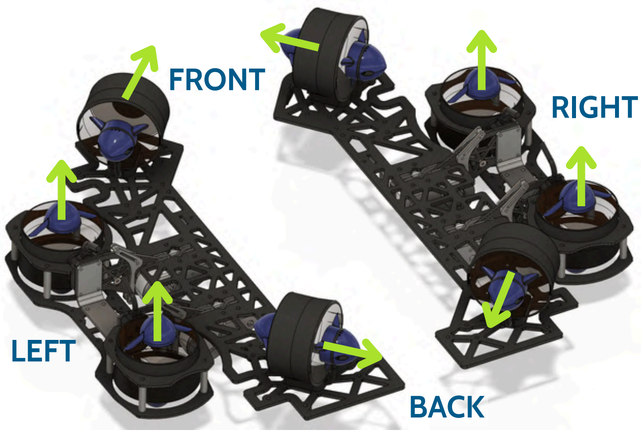


Figure 13. Configuration of thrusters

As the heart of INKAY, the thruster system needs to be reliable and easily serviced. To protect the thrusters from debris, protective PETG shrouds and stainless steel mesh guards are used. In the past, swapping out a thruster took an hour, while servicing an INKAY thruster requires a mere 2 minutes.

Tether

The tether is an integral component of the ROV, establishing a secure connection to the surface. It not only acts as a power supply for the ROV but also serves as a conduit for data exchange and signal transmission, both of which are crucial for real-time operational capabilities.

The tether consists of four primary components: two Controller Area Network (CAN) cables, twelve Serial Digital Interface (SDI) cables, two 10 American Wire Gauge (AWG) cables, and a strain relief mechanism. Utilized for power supply at 48V, the 10 AWG cables are known for their flexibility, a low resistance of 0.003 ohms per metre [9], and their ability to sustain power stability under significant current loads. In addition to the power supply, the SDI cables play a crucial role in the system by transmitting real-time image signals from the camera at a rate of 12 gigabits per second, effectively utilizing their robust capabilities for long-distance transmission. Meanwhile, the CAN cables are dedicated to relaying control commands that govern the ROV's movement and facilitate data exchange with the offshore control unit, thereby ensuring effective real-time communication. Furthermore, to enhance system reliability, one CAN cable and three SDI cables have been served as backups to ensure continuous operation and stability of the tether system in the event of a failure.

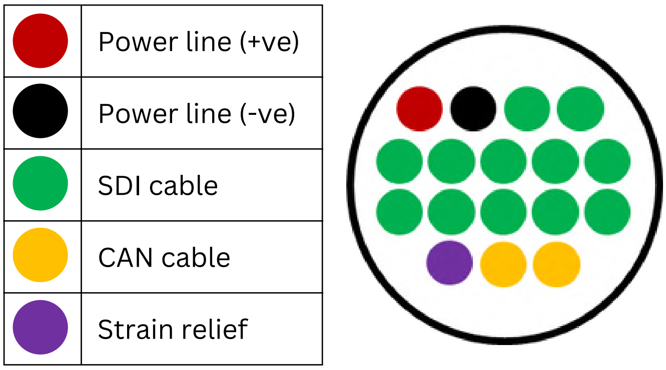


Figure 14. Tether diagram

To address safety considerations, the strain relief mechanism is incorporated into the tether, with one end securely connected to the control box and the other end affixed to the ROV. This configuration ensures a robust connection. All cables, except for the strain relief, are secured with zip ties every 15 cm to mitigate the risk of damage and maintain stable signal transmission. Furthermore, all cables are encased in an expandable Polyester (PET) braided sleeve, providing additional protection against potential damage during underwater operations.

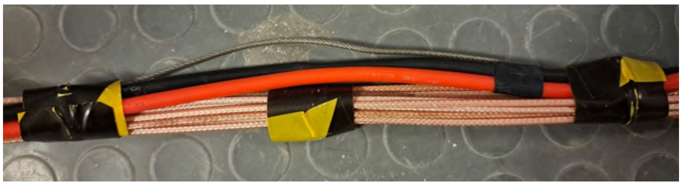


Figure 15. SDI cables, AWG cables, and strain relief

Tether Management Protocol

We have implemented a range of precautions to ensure the tether's effective performance. A systematic tether management protocol has been established to enhance both safety and operational efficiency.

Before each deployment, it is crucial to conduct a detailed assessment of the tether for any signs of wear or damage, including fraying, kinking, or compromised electrical connections. During operations, the strain relief mechanism is first secured at both ends — on the ROV and the control box — before connecting any additional cables. This guarantees a secure physical connection and alleviates tension on the other cables. Upon concluding the operation, a reverse procedure is carefully executed to maintain the tether's condition.

on the ROV — on the control box

Figure 16. Strain relief mechanism

While the ROV is submerged, crew members vigilantly monitor and adjust the tether's length, ensuring adequate slack to mitigate tension while preventing excessive slack that could result in entanglement or snagging hazards. When not in use, the tether is securely stored in the bottom layer of the cart, providing a dry, clean, and temperature-controlled environment to protect it from external factors and enhance its durability. Furthermore, appropriate coiling techniques are utilized, and sharp bends or kinks are meticulously avoided to further ensure the tether's functionality.

Cameras

INKAY's nine-camera system provides comprehensive coverage, granting the pilot 360 degrees of visibility. Five cameras positioned on the right, front, back, left, and bottom sides of the maneuver frame serve as primary control cameras. Each RHSDI1600DK camera provides high-resolution 1080p imagery and transmits signals via their own individual SDI cables. Each manipulator also has its own camera, while additional ones are mounted around the frame to eliminate blind spots and streamline underwater operation.

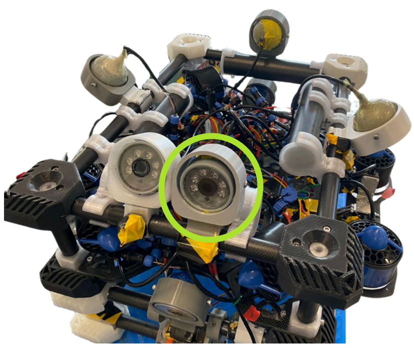


Figure 17. Front primary control camera

Software Innovation

This year's system upgrade introduces a robust camera perspective-switching architecture that ensures seamless viewpoint transitions while maintaining thruster control alignment, significantly improving operational versatility. The ROV's control system features a dedicated controller button that allows operators to dynamically switch between front camera feeds while automatically adjusting the robot's movement perspective to match the selected view. When pressed, the button cycles through available camera streams (e.g, forward, backward) on the "main camera" frame on the GUI, simultaneously adapting the ROV's movement reference frames. In case the designated front camera fails during a mission, the operator can instantly reassign the rear or side camera feed to serve as the new "front" view, ensuring the driver can still operate the ROV without much hindrance during the competition run, besides it also eliminates the need for time-consuming U-turns or manual repositioning, ensuring uninterrupted mission continuity even in high-stakes scenarios.

Software Architecture

INKAY's software architecture continues to employ a dual-layered Event Driven Architecture (EDA) to enhance modularity, maintainability, and real-time responsiveness. The control system is implemented with ROS2 on a Mac Mini M4, which coordinates decentralized processes while maintaining real-time performance. High-level commands generated in ROS2 are encrypted and transmitted via a CAN bus to the lower-layer CAN transceiver onboard INKAY. Heavy computations run on the Mac Mini, while mission-critical hardware control remains with the ROV's embedded systems for optimal performance. This design choice optimizes both performance and modularity, enabling independent yet coordinated operation of sensor polling, thruster control, and other critical functions.

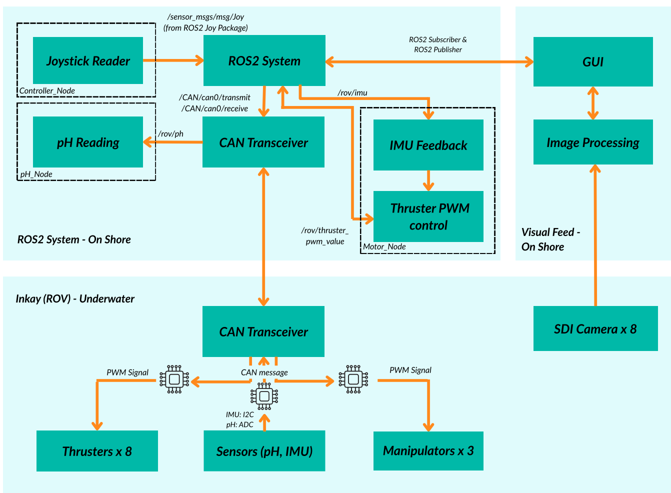


Figure 18. Dual-layered architecture

Top Layer - ROS2

Utilizing ROS2's Data Distribution Service (DDS), the system decomposes the ROV's functionality into discrete, interoperable nodes that communicate via standardized topics. DDS is a design paradigm aimed at enhancing efficiency and reliability, minimizing latency, and promoting scalability. Hence, with DDS, each component — such as joystick input, motor control, and sensor processing — operates as an independent node, enabling modifications or replacements without system — wide refactoring. Figure 19 summarizes each node's responsibilities in INKAY's system.

Node	Details
Controller	Processes joystick inputs and give motor node commands to move thrusters
Motor	Receives IMU Feedback and controller node instructions to dynamically adjust the thrusters' speed to compensate for the ROV's offset
pH	Receives pH data then publishes processed data onto GUI

Figure 19. Table of Nodes and their details

Bottom Layer - CAN Distribution System

INKAY's control system architecture employs a robust CAN bus communication protocol to facilitate reliable, high-speed signal transmission between all onboard components. The CAN Distribution Board acts as the central nervous system of the ROV serving as the primary interface for MCU coordination and message routing. This implementation follows the same distributed architecture principles as the previously described ROS2 system, where each subsystem operates independently yet collaboratively within the network ecosystem.

Each STM32 board in INKAY's design is purpose-built to execute a specialized set of functions, with their operations governed by a sophisticated message filtering system based on CAN IDs. This filtering mechanism ensures that only relevant messages are processed and network bandwidth is optimized by eliminating unnecessary data transmission. This ensures system responsiveness is maintained even under heavy communication loads.

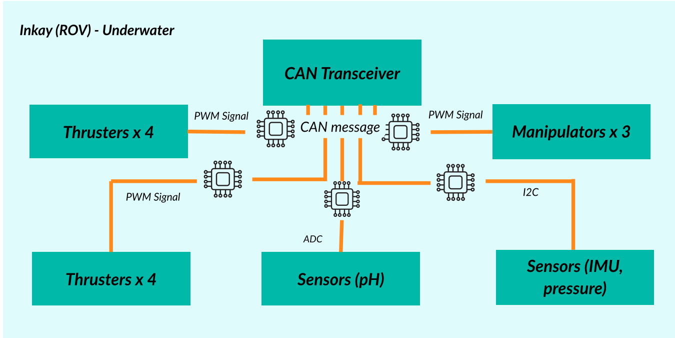


Figure 20. CAN Distribution to STM32 Boards on INKAY

Graphical User Interface (GUI)

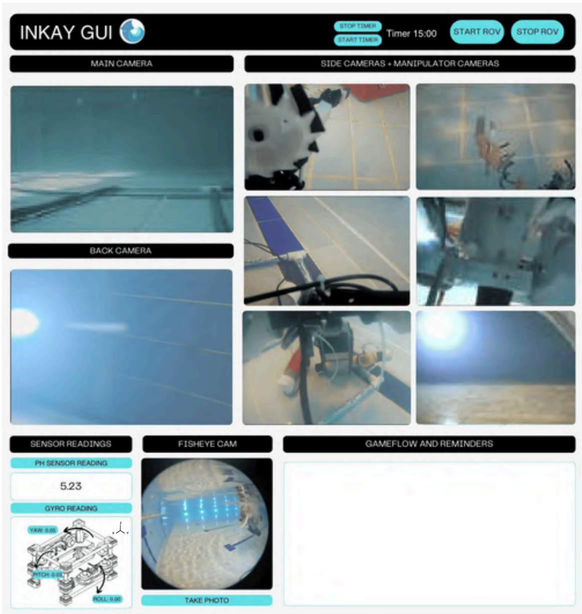


Figure 21. INKAY ROV Control GUI

The GUI was developed using PyQt5, chosen for its proven stability, robustness, and cross-platform compatibility. It interfaces with the ROV through ROS2, maintaining the same decoupled design philosophy as the core system. By subscribing to real-time data streams - including telemetry (depth, orientation), sensor readings (pH), control feedback, and camera feeds - the interface achieves complete isolation from the ROV's operational logic. With this architecture, adding new sensor displays simply requires subscribing to their respective topics without modifying existing nodes.

In addition, alluding to one of INKAY's top priority being safety, safety protocols are embedded throughout the GUI, including a box for safety reminders and a prominently displayed emergency stop message "STOP ROV" on the panel. Designed with user experience in mind, the interface combines a clear layout with intuitive controls, making it accessible to both experienced operators and new users alike.

Sensor Data Processing

To accurately determine our ROV's orientation, a sensor fusion system is implemented using the MPU9250, combining its IMU, and magnetometer data as part of INKAY's EDA. Unlike the previous MPU6050, this upgrade reduces gyroscope drift, enhancing yaw precision.

The system processes raw sensor data by first applying a low-pass filter to smooth out noise, then uses a complementary Kalman filter to blend the gyroscope's short-term angular rate integration (tracking orientation changes) with long-term corrections from the accelerometer (computing roll and pitch via gravity) and magnetometer (determining yaw from magnetic north). For calibration, gyroscope offsets are derived by averaging multiple stationary readings to remove bias, while hard iron offset correction adjusts the magnetometer for magnetic distortions. The resulting Euler angles (roll, pitch, yaw) are calculated in real-time and published to ROS2 topics, enabling precise PID-based control of the ROV's movements. The IMU processing node publishes the data, allowing other nodes (e.g., motor control) to react in real-time without direct sensor access. This encapsulation ensures that IMU calibration or filter adjustments never risk breaking motor logic.

Image Processing

A major software challenge in this year's competition task involves developing a 360-degree photosphere mapping solution for shipwreck documentation. INKAY's software engineers have explored multiple technical approaches to achieve this goal, as outlined below.

Initial Development: Manual Stitching of Two Fisheye Perspective Image

The underwater imaging system uses two 190° fisheye cameras mounted on the ROV to create 360° photospheres. Operating as an independent ROS2 node, it processes raw feeds by correcting lens distortion, aligning overlapping regions, and applying exposure normalization and blending for seamless transitions. Optimized for embedded hardware, the system outputs photospheres for visualization. However, while effective on land with a phone and fisheye lens, underwater implementation with waterproof cameras suffers from lower resolution and water inflow issues, prompting the need for an alternative.

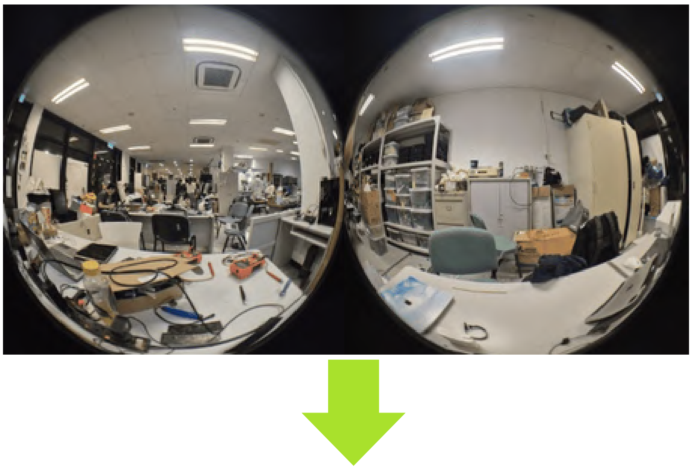


Figure 22. 360-degree photosphere generated

Alternative Solution: PTGui

PTGui, a professional stitching software, creates photospheres from overlapping images. Users capture a grid of photos, which PTGui merges into an equirectangular projection, correcting distortion and optimizing exposure. While this leverages the ROV's existing cameras (avoiding fisheye lenses), it requires over 100 images per photosphere and significant processing power, making it resource-intensive hence inefficient.

Final Alternative: Insta360

The simplest solution is an Insta360 camera, which instantly generates high-quality photospheres. However, it lacks waterproofing (requiring a case) and needs external power, requiring extra power cables to eliminate the internal battery. Despite these drawbacks, its superior output quality and speed made it the chosen method over the other two.

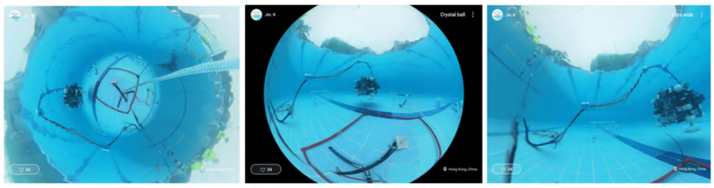


Figure 23. Interactive photospheres

	Manual Stitching	PTGui	Insta360
Time (Avg Across 20 trials)	1 min 28 sec	26 seconds	5 seconds
User-friendliness*	1	4	3
Quality and replicability*	2	4	5
Cost (in USD)	Free	Free (Trial), $205 for license.	$299
Additional Notes	Budget option. Quality and stability depend on too many variables.	Watermarked (Trial). Requires lots of photos for high quality.	Not attached to ROV, allowing for unobstructed image capture

**Scores: 1 (worst) to 5 (best)*

Figure 24. Decision matrix for image processing

Payload and Tools

Raptor 2-Axis Manipulator

The Raptor 2-Axis Manipulator is a 30 cm modular system comprising a 22 cm arm and a 3 cm-wide glass fiber-reinforced 6-jaw gripper, matching the critical reach of 2023's design while reducing width by 20% and total weight by 40% (285.5g vs. 485g). Raptor is powered by a 12-volt DC motor linked to a worm gear system. The unidirectional nature of worm gear transmission brings high torque and eliminates back-driving while evenly distributing stress on the spur gears, enhancing reliability in demanding scenarios [10]. Its curved claws, combined with friction-tape padding, provide a secure grip on cylindrical and irregularly shaped objects. Raptor's asymmetrical layout allows its claws to pass through each other, enabling self-locking and a tight grip on thin objects.

EPOXSEA's ROV previously breaks many 3D-printed claws during collisions underwater. To avoid this, glass fiber plate (GFP) parts are inserted in between the PETG parts of Raptor's claws, which are further secured using aluminum screws running through the claws. This hybrid material design can withstand 45N lateral loads, tripling the durability of WAHOO's PETG and TPU design.

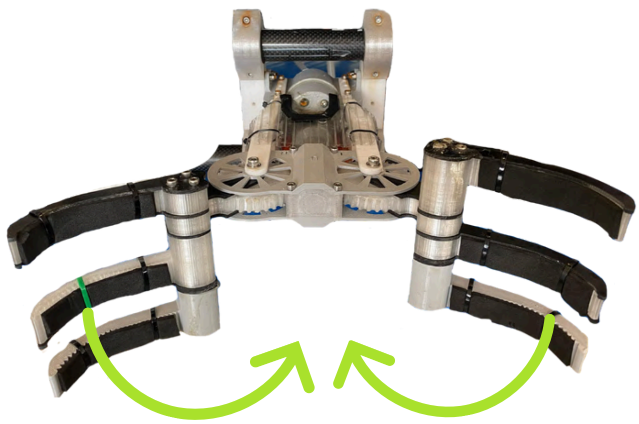


Figure 25. Raptor

Slide Rail Mount

To quickly iterate through manipulators, the EPOXSEA team developed the slide rail mount, which is installed underneath the maneuver frame. Its ergonomic design allows the manipulator platform to be easily removed via pinching the two buttons, allowing the pieces to slide apart. To install, the manipulator platform is pushed into the rails, which locks its target via an elastic mechanism. The design represents a pivotal success in moving on from EPOXSEA's previous over-reliance on screw-based installation, further embracing our philosophy of modularity and serviceability.

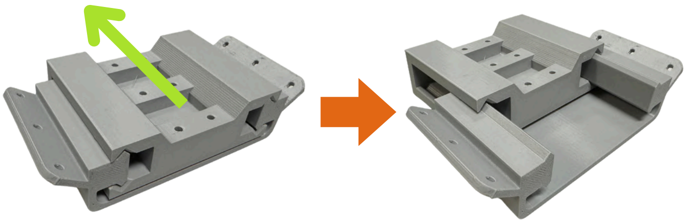


Figure 26. Slide rail mount

Sampler and pH Sensor

This mission-specific system enables precise fluid extraction and electrochemical analysis to fulfill the competition's environmental monitoring requirements. The integrated solution combines a motorized sampling with real-time water quality assessment capabilities. At the system's core, it lies a dual-chamber architecture featuring a 12V brushless DC pump (200 ml/min flow rate), with a sampling tip that penetrates the competition-specified plastic film barriers. Lastly, the fluid pathway employs silicon tubing and connectors to prevent ionic contamination, routing samples through an analysis chamber housing a HI1131B glass electrode pH probe. This electrode is a refillable probe as its filling solution does not contain any silver, preventing clogging caused by silver precipitates [11].

During the making of WAHOO, the EPOXSEA team learnt in the hard way of the fragile nature of sensors. To avoid such heavy monetary loss, INKAY harbors the sensor within the manipulator frame, using the frame itself as a shield.

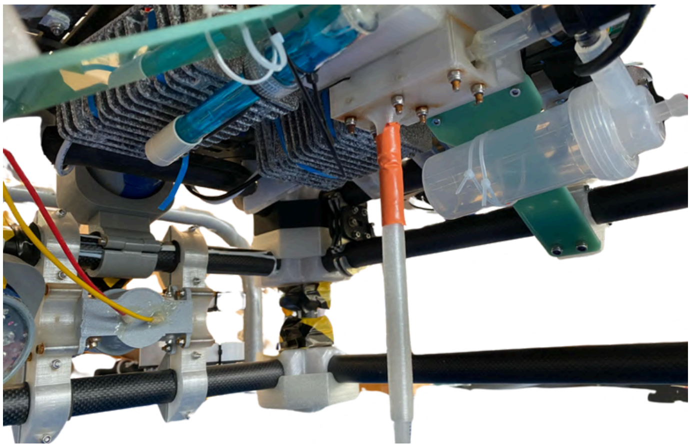


Figure 27. Sampler & pH sensor

Insta360 X3

The Insta360 X3, housed within a custom-modified waterproof case, is deployed as an independent sensor to capture comprehensive situational data. This configuration enables the collection of high-resolution 360-degree photospheres while INKAY conducts other mission operations. The power is supplied via a 10-meter, low-resistance USB Type-C cable routed through the enclosure. The modified epoxy-sealed case ensured a complete protection against water ingress. For retrieval, a strain relief is secured to the camera's tripod mount, allowing the device to be safely withdrawn as needed. Once deployed and positioned by INKAY, all image capture processes are autonomously executed through preprogrammed software. The use of this independent sensor exemplifies INKAY's modular design philosophy, reducing dependence on the primary operational vehicle and enhancing overall system flexibility.

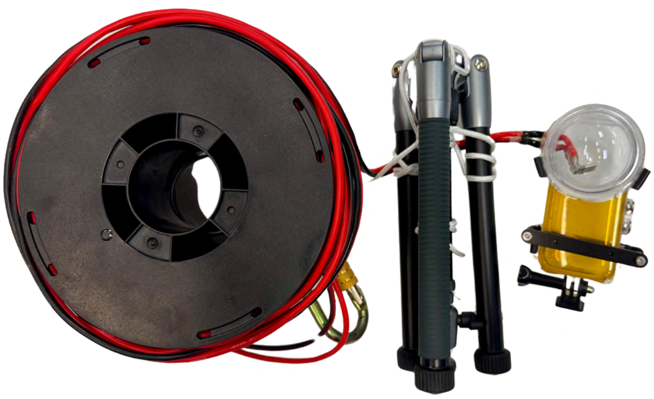


Figure 28. Insta360 X3

Non-ROV Device (Float)

The movement of the float is powered by the buoyancy engine. The engine mechanism is driven by a DC motor and a water-sealing piston. By changing the piston's position, the volume of the closed compartment of the float decreases. In terms of buoyancy force (i.e., FB = (gravitational constant) × (density of water) × (volume of container), the buoyancy force of the float will decrease, and the gravitational force acting on the float will cause it to sink into the water until the buoyancy force and gravitational force are equal — and vice versa.

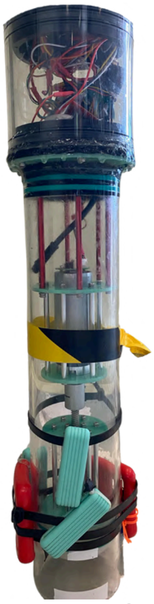


Figure 29. Float

The float SID is attached in Appendix D.

Battery Safety

The battery pack's output is intended to be 12V and 2A, with 8 NiMH batteries connected in series. When there is a short circuit, it is protected by a 32V 3A blade fuse. The battery pack's output and the highest voltage of the components is 12V. Additionally, the float device's full load current requirements are about 1.8A, which is less than the battery pack's maximum current of 2A. As a result, in a normal situation, the battery pack can manage the float device's entire load current and voltage requirements, and the blade fuse ensures operating safety.

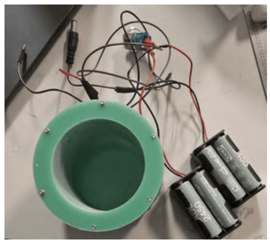


Figure 30. Battery pack

Figure 31. 32V 3A blade fuse

Mission Systems Approach

	Task	Raptor Claw	Camera	Sampler and pH sensor	Independent sensor (360 camera)
1.1	Visually identify the type of shipwreck		✓		
	Measure the length of the shipwreck		✓		
	Removing the container's cover	✓			
	Determine the cargo type by identifying the color-coded cargo inside the container		✓		
	Replace the cargo container's cover after identifying the cargo	✓			
	Create a 360° photosphere image of the shipwreck area		✓ (alternative)		✓
1.2	Replace damaged thermistor	✓			
	Install pCO2 sensor	✓			
1.3	Collect a water sample from a designated container.			✓	
	Measure pH in situ			✓	
2.1	Connect a floating solar panel array to the grid	✓			
	Replace a sacrificial anode on the base of an offshore wind farm	✓			
	Apply an underwater epoxy patch to a corroded area on the wind farm base.	✓			
2.2	Collect Medusa stage jellyfish	✓			
	Collect Polyp stage jellyfish	✓			
	Collect fish species aggregated beneath the solar panel array.	✓			
	Place a hydrophone in a designated area and release it by pulling a pin.	✓			
3.1	Deploy the float into a designated area	✓			

Figure 32. Manipulator capability table

At EPOXSEA, we adhere to a balanced system approach in designing payloads and tools. We integrate our sensors, manipulators, and thrusters to achieve seamless synergy. For example, our responsive thrusters are connected to the IMU. The IMU provides dynamic feedback to the thrusters, allowing the thrusters to adjust to stabilize the ROV.

And as to mitigate delays in mission progress owing to a single point of failure during execution, our team of engineers design manipulators with the idea of "doing more, with less", using only 3 manipulators, with each manipulator designed to handle multiple tasks. This approach not only reduces cost, size and weight, it also reduces handling complexity for the pilot.

Safety

At EPOXSEA, we prioritize our members' well-being with safety as our core value. We have a culture of shared responsibility and proactive risk assessment to ensure all activities are up to the strict safety standards.

Personnel Safety

All engineers must review and acknowledge the lab safety guidelines before entering the lab. These guidelines outline the proper use of equipment, required protective gear, and emergency procedures, reinforcing awareness of associated risks and responsibilities. Ventilation systems and fume extractors remove harmful substances during soldering electronic components, operating 3D printers, and handling epoxy glue.

Operational Safety

Fire extinguishers and first aid boxes are located in both the electronics and assembly zones, allowing for instant responses in emergencies. We keep the workspace clean and make sure emergency exits and fire escape routes are always clear, which helps prevent accidents and allows quick and safe evacuation if needed. Annual fire drill training is also mandatory for all members to enhance their emergency preparedness.

Figure 33. Laboratory fire escape

Figure 34. Laboratory first aid box

Equipment Safety

Personal Protective Equipment (PPE) is required when handling hazardous materials such as carbon fiber and epoxy. We provide PPE to all members and ensure its availability for safety protection. Additionally, monthly tool and equipment inspections ensure prompt repair or replacement of rusted, dull or damaged items. Team members must report any unsafe tools to a supervisor or safety officer immediately to prevent accidents. For newly recruited members, they must receive tool-use training from senior engineers to reinforce safety precautions for equipment handling. These safety measures foster a secure lab environment, upholding the culture of safety in workspace.

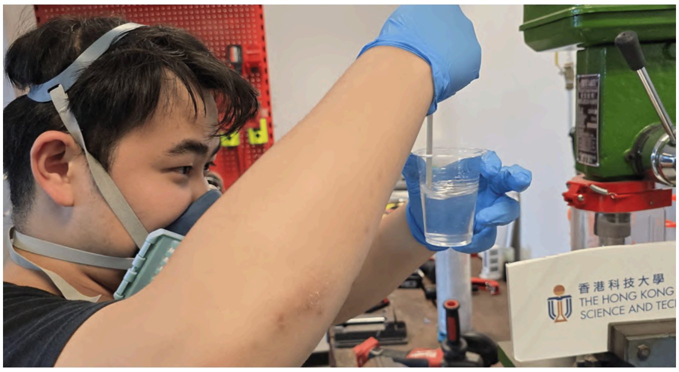


Figure 35. EPOXSEA CEO working

Vehicle Safety

For safe ROV operation, we include an emergency "kill-box" featuring a stop button and inline fuse, connected via an SBS50 Anderson powerpole connector, to instantly cut power in emergencies. Hardware engineers also use epoxy-filled, 3D-printed shells to protect electrical components from water-induced short circuits.

Figure 36. INKAY "kill-box"

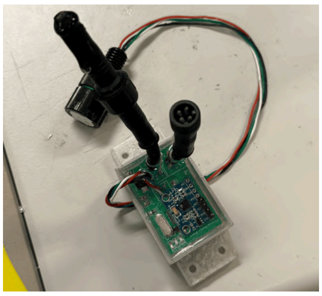


Figure 37. Epoxy-filled shells

Our control box features a clean and organized internal layout with no exposed wiring, ensuring safety and quality workmanship. We operate the ROV using a Mac Mini paired with a controller for intuitive and responsive control.

The round-edges of the ROV ensure smoother operation and reduce mission downtime. Furthermore, rounded and blunt edges prevent accidental scrapes, which protect the surroundings and diver. By minimizing physical interference, being edge-free enhance operational safety and environmental stewardship during underwater exploration.

Figure 38. Round-edges of the ROV

The driver gives the operations team commands like "Kill" to cut the power and "Launch" to start the ROV. After a confirmation from team members, operations proceed. This protocol prevents ROV operation while crew members are performing maintenance and enables prompt shutdown during emergencies. The clear communication structure reduces human error and ensures smooth running mission execution.

Operational and Safety Checklists

INKAY's operational and safety checklists (Appendix E) ensure strict adherence to safety measures before, during, and after operations. Employees follow the operational guidelines to protect wildlife and crew members.

Critical Analysis

Testing Methodology

To assess the ROV's performance, our team has developed a four-stage testing protocol.

1. Simulation

At the first simulation stage, we utilize the Gazebo simulator to debug algorithms and enable drivers to practice operating the ROV in a realistic virtual environment. By simulating various operational scenarios, we quickly identify and rectify coding errors, expediting development. Additionally, drivers gain experience maneuvering the ROV, enhancing familiarity with ROV's capabilities and limitations. This hands-on practice builds confidence and ensures robust algorithms for real-world operations.

2. Dry Tests

Following the Gazebo simulation, we carry out "Dry Tests" in a laboratory to evaluate the ROV's thruster and manipulator functions. This phase evaluates mechanical viability and verifies hardware safety by assessing movements onshore. Early issue identification allows prompt debugging and minimizes risks for subsequent tests.

3. Mini Pool Tests

In the third stage, we conduct "Mini Pool Tests" in a lab pool for a neutral buoyancy assessment. This test analyses how well the ROV maintains its position in water without expending energy. By observing equilibrium depth, we fine-tune buoyancy, ensuring stable performance for more extensive testing. It also verifies the integrity of the waterproof component, enhancing safety and effectiveness before the "Pool Test".

Figure 39. Mini Pool Test

4. Pool Tests

We conduct "Pool Tests" twice a week for three hours in an indoor pool. This setup mimics real-world conditions, assessing the ROV's efficiency in navigation, object manipulation, and data collection. These sessions challenge the ROV with operational scenarios, enabling adjustments and driver training to enhance proficiency in maneuvering the ROV.

Figure 40. Pool Test

By consistently evaluating the ROV's capabilities in all the testing stages, we ensure that it is well-prepared for real-world applications and environmental protection missions.

Troubleshooting Strategies

When problems arise, a systematic root cause analysis is promptly initiated to effectively diagnose and resolve the issue. The process begins with the identification of the specific problem at hand. By employing the "divide and conquer" strategy, the issue is deconstructed into smaller, more manageable components, each subjected to a thorough examination of its functionality to identify any malfunctioning elements. These two methods work in tandem to efficiently address the various potential issues of the ROV.

Following this extensive evaluation, a methodical trial-and-error approach is employed, which involves the reassembly of components and conducting retests to identify viable resolutions. This process effectively eliminates components that are functioning correctly from consideration as potential causes, thereby narrowing down the search for the issue.

Once a final solution is identified, the root cause is documented comprehensively to prevent future recurrence of the issue. This documentation serves not only as a valuable resource for future iterations of the prototype across various departments, it also ensures that similar challenges can be avoided in subsequent projects.

Noteworthy Troubleshooting Experience

During our pool test, both the front and back claws of the ROV were found to have functionality issues. The mechanical department swiftly initiated an investigation, ensuring that the motor connections to the claws were secure and operational. Initially, the hardware department suspected that the problem could be related to a broken connection within the CAN wiring, which might disrupt the communication necessary for the claws to function correctly. As debugging progressed, the software department conducted a thorough analysis of the code governing the claw operations. It is discovered that the same button on the controller was inadvertently programmed to control both claws at once, resulting in conflicting commands that led to the observed malfunctions.

This situation illustrates the importance of interdepartmental communication and collaboration, enabling the mechanical, hardware, and software department to identify the root cause and restore the overall functionality.

Prototyping

To address the diverse procedures and tasks across various departments effectively, distinct prototyping methodologies are utilized.

In the mechanical department, the workflow consists of six distinct stages. The first stage, “Work Division,” requires each team member to propose their ideas for manipulator design, with the most innovative concept chosen for further development. This is followed by the “Sketch and Development” stage, where a detailed design plan is formulated and shared on an open platform for peer review and evaluation. The “CAD and Simulation” stage ensues, during which a 3D model prototype is constructed using Fusion 360 and subjected to rigorous software simulations. The “Prototype” and “Iteration” stage facilitates necessary modifications to enhance functionality, progressing to the “Onsite Test” stage, which includes dry tests and pool tests, followed by additional refinements and improvements.

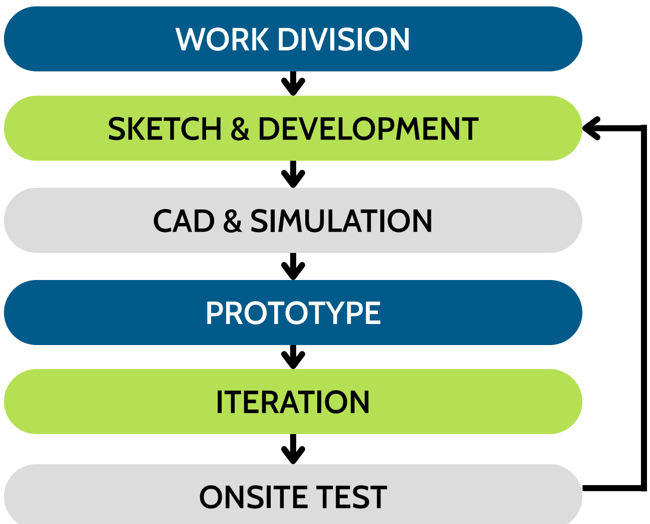


Figure 41. Mechanical department pipeline flowchart

In the hardware department, the initial stage involves work division, where team members are assigned to create different printed circuit board (PCB) designs tailored for specific functions within the ROV. Each PCB design undergoes meticulous review by the software department to ensure its operational effectiveness. Upon completion, the PCB's connectivity is assessed with a digital multimeter to verify correct connections. It is then subjected to the dry test to confirm effectiveness, followed by waterproof testing after protective materials are applied. Continuous iterations are made, accompanied by ongoing communication with other departments to explore additional functionalities or address signaling issues, thereby maximizing operational efficiency.

Figure 42. Waterproof test

In the software department, the process begins with the ideation of algorithms for the code. Following this, work is divided among team members to allocate coding responsibilities for various components of the ROV. The research and development stage involves investigating various coding methods to achieve mission objectives, culminating in the creation of a coding prototype. The iteration stage employs the Gazebo Simulator to facilitate testing and debugging the overall algorithm. The final testing phase evaluates the ROV in both the dry test and the pool test, with further iterations aimed at enhancing overall performance.

Teamwork

Company Profile

EPOXSEA, a dynamic team of 26 members from eight nationalities, is affiliated with the Hong Kong University of Science and Technology (HKUST). We are dedicated in advancing ROV technology to support marine conservation and address climate change. Our mission is to develop an advanced, eco-friendly ROV equipped with high-resolution sensors, capable of monitoring marine ecosystems and supporting ocean protection initiatives. Leveraging interdisciplinary expertise in engineering and data analytics, EPOXSEA drives innovation to enhance biodiversity preservation and reduce environmental impact.

Figure 43. EPOXSEA group photo

Company Organization

With our mission of marine conservation, we aim for persistent progress and continuous improvement, emphasizing both sustainability and safety. Our employees are the foundation of success, and seamless collaboration is achieved through a clear hierarchical structure across four departments: Mechanical, Hardware, Software, and Business. Department leaders mentor junior members, ensuring effective delegation and professional growth. The Chief Executive Officer (CEO) governs the entire team, providing strategic oversight and hosting regular cross-departmental meetings to foster unity and operational efficiency. The Chief Financial Officer (CFO) oversees financial strategy and budgeting, while the Chief Technical Officer (CTO) ensures adherence to MATE ROV Competition 2025 standards. Prioritizing employee well-being, the Safety Officer collaborates across departments to enforce rigorous safety protocols. This integrated framework drives efficiency, safety, and progress toward our goal.

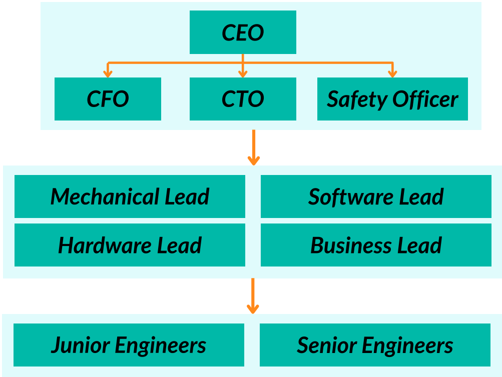


Figure 44. EPOXSEA organizational structure

Project Schedule

Aligned with our cohesive organizational structure, our project schedule is divided into four distinct phases:

1. Recruitment and Training

From September to November 2024, we focus on recruiting passionate and proactive new members to ensure team sustainability. The selected new members will undergo safety training led by senior members. This foster technical proficiency and independence while instilling a sense of commitment to our mission and safety standards.

2. ROV and System Designing

After the training period, each department leverages their expertise to advance ROV development. The Mechanical department creates computer-aided design (CAD) files for the ROV structure and task-specific manipulators. The Hardware department designs PCBs, and the Software department begins coding the initial ROV system, laying the foundation for mission-specific refinements.

3. Manufacturing and Prototyping

With the mechanism design, the Mechanical department manufactures the ROV frame and manipulator prototypes, enabling the Hardware department to integrate PCBs and wiring. Concurrently, the Software department programs mission-specific codes, preparing the ROV for testing.

4. Testing and Refining

Ensuring consistent ROV performance, pool tests are conducted twice a week, on every Monday and Thursday. Refinements are made to optimize ROV's sophisticated systems. Meanwhile, the Business department compiles documents, finalizing reports as the ROV framework is validated, ensuring alignment with MATE ROV Competition 2025 requirements.

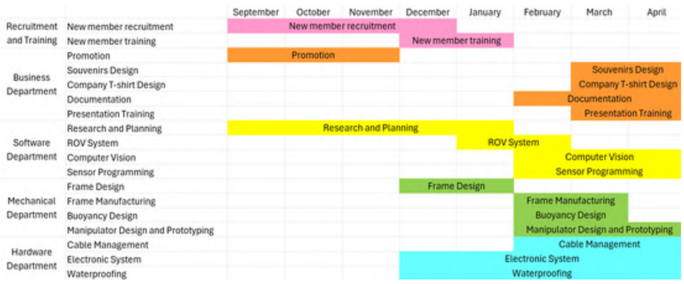


Figure 45. Gantt chart showing project schedule

Resources, Procedures, and Protocols

To ensure timely project execution and foster interdepartmental collaboration, EPOXSEA conducts weekly meetings on Mondays. Each department leader shares their respective progress updates and raises challenges faced, enhancing transparency and teamwork.

Beyond these regular meetings, project management and Knowledge Base (KB) has transitioned from Plaky to Lark. This shift offers a more comprehensive task coordination platform with morerobust file storage system, streamlining workflow and improving overall productivity. Additionally, integration of specialised tools supports department-specific needs. For instance, Autodesk Fusion 360 is used for collaborative CAD file management within the mechanical department. The software department also leverages GitHub for efficient code management and change tracking.

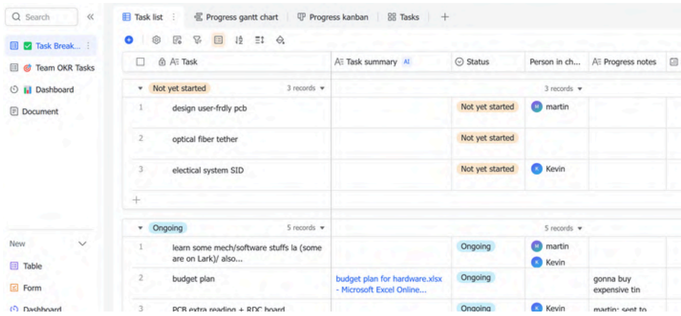


Figure 46. Progress tracker in Lark

Apart from team correspondence protocols, environmental sustainability is another core pillar of EPOXSEA's mission. By recycling 3D printing materials and upcycling used prototypes, we reduce our environmental footprint, aligning with our dedication to marine conservation. These integrated tools and practices promote effective collaboration, scalability, and sustainable progress.

Accounting

This year, we strategically used a combination of new and reused components for our ROV, to make a trade-off between performance and cost-efficiency. We purchased new thrusters and a control box to enhance functionality. Meanwhile, we retain older parts, such as the carbon fiber tubes and cameras, which remained in good condition. This approach allowed us to upgrade our ROV without incurring unnecessary expenses, though the total cost was slightly higher than last year due to the new equipment.

Our primary sources of funding include sponsorships and awards from previous competitions. Budget planning is a collaborative team effort, informed by analysis of last year's spending and this year's performance goals. All expenses are tracked in our team's KB, ensuring transparency and allowing all members to monitor financial activity. The travel expenses of 2500 USD will be paid by the team members, including flight tickets, living expenses, and daily expenses. For more details, the budget and costing data sheets are avaliable in the Appendix A and B.

Appendices

Appendix A: Proposed Budget

Items	Price (in USD)	Type	Description
Income			
HKUST School of Engineering Funding	4000.00	Income	
The Milwaukee Electric Tool Corporation	1000.00	Sponsor	
RS Components LTD.	1000.00	Sponsor	
Funds From Last Year	500.00	Saving	
Total Income	6,500.00		
Production Expenses			
Frame & Housing	250.00	Purchased	Carbon fiber frame, 3D printed-mounts, buoyancy equipments
Tether & Connectors	250.00	Purchased	Tether & Connectors, cable sleeve
Electronics & Connectors	50.00	Purchased	PCB, MCU, transistors, wiring, connectors
Thrusters	150.00	Purchased	Thrusters
Manipulators	900.00	Purchased	Servos, encoder
Raw materials	1,500.00	Purchased	Nuts, Bolts, metal, plastics, consumables, 3D printing filament, epoxy chemical
TCU (Control box)	650.00	Purchased	Case, Monitors, Electronics, Joystick
Total Production Expense	3,750.00		
Non-ROV Expenses			
Props for mission preparations	20.00	Purchased	Tubes, bowls
Research and development	10.00	Purchased	Bluepill pcb
Tools and equipment	1,000.00	Purchased	Multimeters, soldiering irons, 3D printers, pH meters
Total Non-ROV Expenses	1,030.00		
Re-used items			
Camera	200.00	Re-used	
Summary			
Total Income	6,500.00		
Total Expenses	4,780.00		

Appendix B: Cost Projection

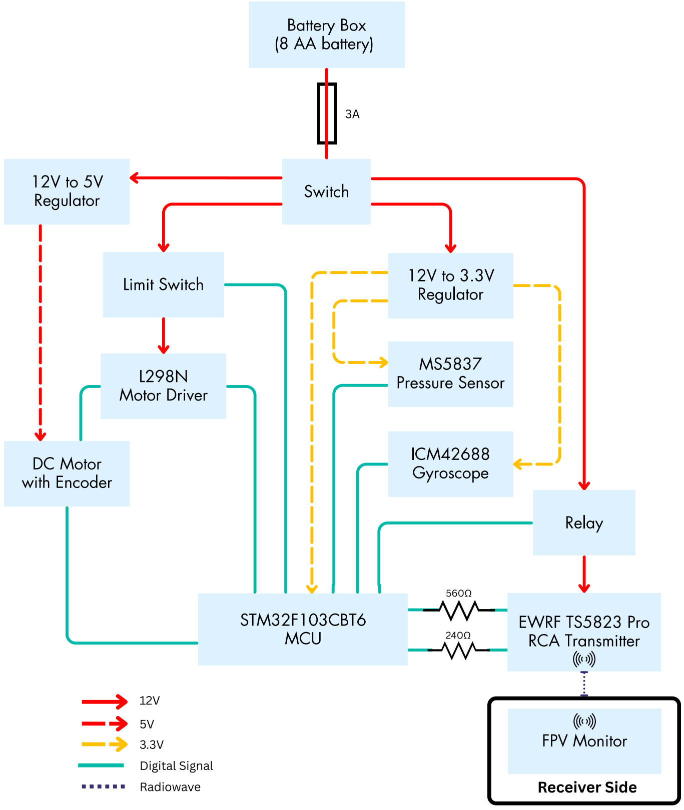
Items	Price (in USD)	Type	Description
income			
HKUST School of Engineering Funding	4,000.00	Income	
The Milwaukee Electric Tool Corporation	1,000.00	Sponsor	
RS Components LTD.	1,000.00	Sponsor	
Funds From Last Year	500.00	Saving	
Total income	6,500.00		
Production expenses			
Frame & Housing	246.28	Purchased	Carbon fiber frame, 3D printed-mounts, buoyancy equipments
Tether & Connectors	238.18	Purchased	Tether & Connectors, cable sleeve
Electronics & Connectors	43.37	Purchased	PCB, MCU, transistors, wiring, connectors
Thrusters	164.02	Purchased	Thrusters
Manipulators	833.27	Purchased	Servos, encoder
Raw materials	1,548.28	Purchased	Nuts, Bolts, metal, plastics, consumables, 3D printing filament, epoxy chemical
TCU (Control box)	630.39	Purchased	Case, Monitors, Electronics, Joystick
Total production expense	3,703.79		
Non-ROV Expenses			
Props for mission preparations	27.38	Purchased	Tubes, bowls
Research and development	13.52	Purchased	Bluepill pcb
Tools and equipment	942.37	Purchased	Multimeters, soldiering irons, 3D printers, pH meters
Total Non-ROV Expenses	983.27		
Re-used items			
Camera	200.00	Re-used	
Summary			
Total income	6,500.00		
Total expenses	4,687.06		

Appendix C. Build vs. Buy, New vs. Used

Component	Build vs Buy & New vs Reuse	Justification
Control Box & Computer (Mac Mini)	Buy + New (Computer), Reuse (Control box)	**Requirements met for Buy**: New computer offers higher computational performance, while our previous PC is more bulky and less powerful, Mac Mini with its compact size, offers higher portability and cost efficiency. **Benefits for Reuse**: Minimal modifications required for the control box, providing portability and ease of integration.
RH-SDI1600DK Camera	Buy + Reuse	**Requirements met for Buy**: Offers high-resolution capabilities, and is a replacement for the damaged unit. **Benefits for Reuse**: High compatibility with previous implementations and sufficient underwater functionality with waterproof connectors.
Carbon Fiber-Reinforced Polymer (CFRP)	Buy + Reuse	**Requirements met for Buy**: Customizable dimensions and efficient manufacturing processes. **Benefits for Reuse**: Well-maintained and is in optimal condition for continued use.
Underwater Thruster P75 with ESC	Buy + New	**Requirements met for Buy**: Reduced power consumption and enhanced stability in performance. **Requirements met for New**: Embedded ESC for simplified routing and a compact design that maximizes volume utilization.
12V DC Motor	Buy + New	**Requirements met for Buy**: Cost-effective and reliable performance. **Requirements met for New**: Replacing damaged servo motors to ensure maximum operational efficiency.
10m Tether	Built + New	**Requirements met for Built**: Commercially available tethers do not fit our requirement. **Requirements met for New**: To replace the previously damaged tether.

Appendix D: Float SID

System Interconnection Diagram (SID) of Non-ROV Device



The full load amps in water for non-ROV device is 1.99A and a 32V 3A blade fuse is used.

Appendix E: Safety Checklists

Safety Checklists for Construction and Operation

Construction

□ Ensure machinery and tools are 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
□ Use reusable or recycled materials for ROV components
□ Store batteries in designated fireproof containers

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
□ Verify no microplastics/debris are shed into the pool
□ Confirm post-operation cleanup plan

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 INKAY
  □ "Launch" when INKAY is ready to be operated underwater
  □ "Power on" before turning on INKAY
□ 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

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