



SEATY THUNDERBOLT

TECHNICAL DOCUMENTATION

2026 MATE ROV

Members

Management

Sit Yan Tung	CEO
Wong Tsz Hong	COO
Kong Pak Hei	CFO
Lo Tsz Chung	CTO
Lui Cheuk Lam	CMO
Mak Nok Hin	Safety Officer

Supervisors

Prof. Cheung Chak Chung Ray
Prof. Kang Wen Bin Kelvin
Prof. Ho Chin Pang Clint

Mentor

Guo Run Zhou
Wei Zhi Rui
Xu Jia Hao

Electrical Engineers

Carlos Berlin Arifin	Li Yu Sum
Kwok Shing Tung	Mok Kit Long
Lee Ka Fai	Tse Ka Ho

Mechanical Engineers

Cheung Pui Lam	Joe Anthony Kar Tong
Gracia Catalina Susilo	Maximillian Nicholas Hendrawan
Helena Gabrielle Susilo	Tsang Hing Lai
Jin Zi Chen	

Software Engineers

Emmanuelle Sebastian Sanjaya	Pun Ming Ho
Joseph Anggono Kurniawan	Zachariah Muya Kapya
Latisha Besariani Hendra	

Table of Contents

Table of Contents	p. 2	Buoyancy and Ballast	p. 15
Abstract	p. 2	Payload and Tools	p. 15
Teamwork	p. 3	Build vs. Buy, New vs. Used	p. 19
Design Rationale	p. 4	System Integration Diagram (SID)	p. 20
Innovation	p. 6	Safety	p. 21
Problem Solving	p. 6	Testing & Troubleshooting	p. 22
Systems Approach	p. 7	Accounting	p. 23
Vehicle Structure	p. 8	Acknowledgement	p. 24
Vehicle Systems	p. 8	Reference	p. 24
Electrical System	p. 10	Appendix	
Software Control System	p. 13	A. System Interconnection Diagram- Buoyancy Engine and Ground Receiver	p. 25
Mission Planner	p. 14	B. Safety Operation & Construction Checklist	p. 25
Propulsion	p. 14		

Abstract

SEATY presents Thunderbolt, a next-generation ROV engineered for the MATE 2026 Explorer Challenge. Thunderbolt is designed to address critical marine ecosystem decline through precision grip technology, optimized power electronics, and an adaptable structural framework.

The vehicle features a dual DC-DC converter architecture that isolates thruster power from sensitive electronics, eliminating reboot issues. A custom current detection module enables real-time gripper load monitoring. The modular slot card system centralizes control via CAN bus communication. Eight thrusters provide six degrees of freedom with enhanced stability.

The software stack uses ROS2 and Docker, offering manual, stabilization, and depth-holding control modes. A web-based GUI allows any browser-equipped device to serve as a control station. Six IP cameras provide 360-degree coverage for mission tasks.

Thunderbolt represents a fusion of robotics innovation and environmental stewardship, specifically engineered to support ocean conservation and climate resilience. Through this platform, SEATY demonstrates its commitment to developing sustainable solutions for the future of our oceans.



Fig. 1: Team Photo of SEATY 2026

Teamwork

Company Profile

SEATY is the student-led robotics team of CityUHKUR, founded in 2005 and dedicated to the development of innovative underwater vehicles. SEATY operates with a streamlined and effective organizational structure comprising four departments: Mechanical, Electronics, Software, and Public Relations (PR). Team members are assigned to these departments based on their technical expertise and strengths, ensuring efficient utilization of skills. Each department is led by an experienced engineer overseeing task allocation, while the overall project is directed by a project manager responsible for resource management, budget compliance, and cost control. Strategic guidance for the team and the company is provided by the CEO, ensuring alignment with overarching goals and objectives. This structure fosters seamless collaboration and optimal project execution.

Team Communication

To maintain cohesion and alignment with project objectives, SEATY implements a structured meeting schedule. Biweekly team meetings provide a platform for cross-departmental collaboration, where progress and performance are reviewed, and collective solutions to challenges are developed. Additionally, weekly department meetings focus on specific departmental goals, ensuring that each team is aligned with the broader organizational strategy. These regular gatherings foster an environment of open communication and collaborative problem-solving, ultimately enhancing overall productivity and synergy across the organization.

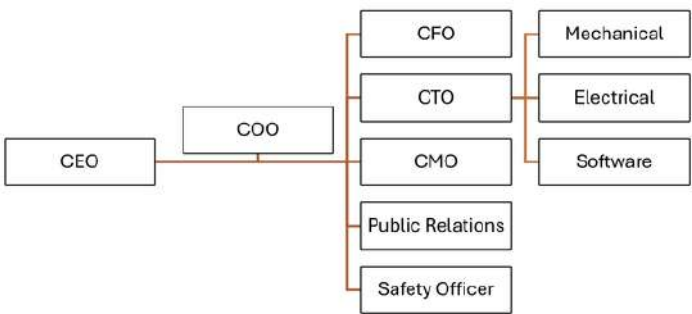


Fig. 2: Introduction of Team Structure

Management Platform

SEATY utilizes a diverse suite of tools to streamline operations. Cloud platforms like Google Drive and Discord enable file storage and communication, while OpenProject supports task tracking and workflow automation. Self-hosted services including Wikijs, NAS, GitLab, and CVAT provide secure infrastructure for resource sharing, code management, and computer vision annotation. This setup ensures remote accessibility, automates daily backups and CI/CD pipelines, and maintains office access logs.

HackMD and Wikijs serve as centralized repositories for meeting notes and technical documentation. The team has invested in documenting past projects, particularly legacy machines, to preserve institutional knowledge and address challenges in deciphering historical design decisions and standard operating procedures. Following a security review, SEATY implemented regular password updates, stricter firewall rules, automated file backups, and advanced access control protocols to protect critical data and mitigate cybersecurity threats. This integrated approach to project management ensures that SEATY operates efficiently from initial concept through final competition.

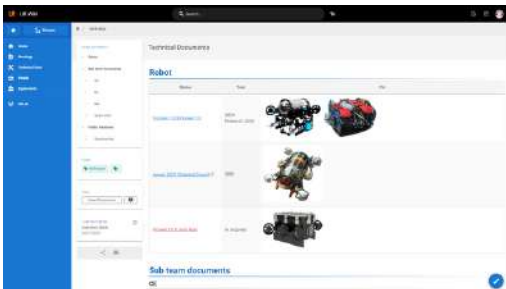


Fig. 3: Interface of URWiki

Project Schedule

At the beginning of each academic year, the CEO and department leads work together to create a detailed schedule that includes key milestones such as new member training, design and prototyping, testing and refinement, and report deadlines. This proactive approach ensures clear timelines and expectation for all tasks. This consistent review process enables timely adjustments and effective course corrections to keep the project on track.

Design Rationale

Design Overview

Building on past experiences, our team improved *Thunderbolt's* design. Key updates include a new gripper and a compact, advanced electronic system, addressing performance issues and **enhancing flexibility, mobility, and stability**.

Dimensions (LxWxH): 65 cm x 65 cm x 36 cm

Weight: 18.7 kg

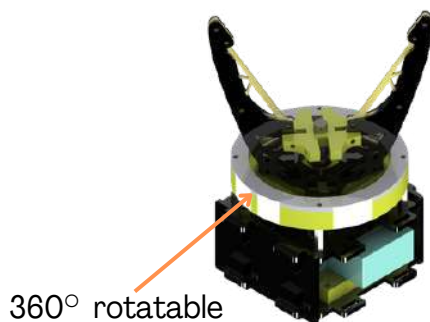
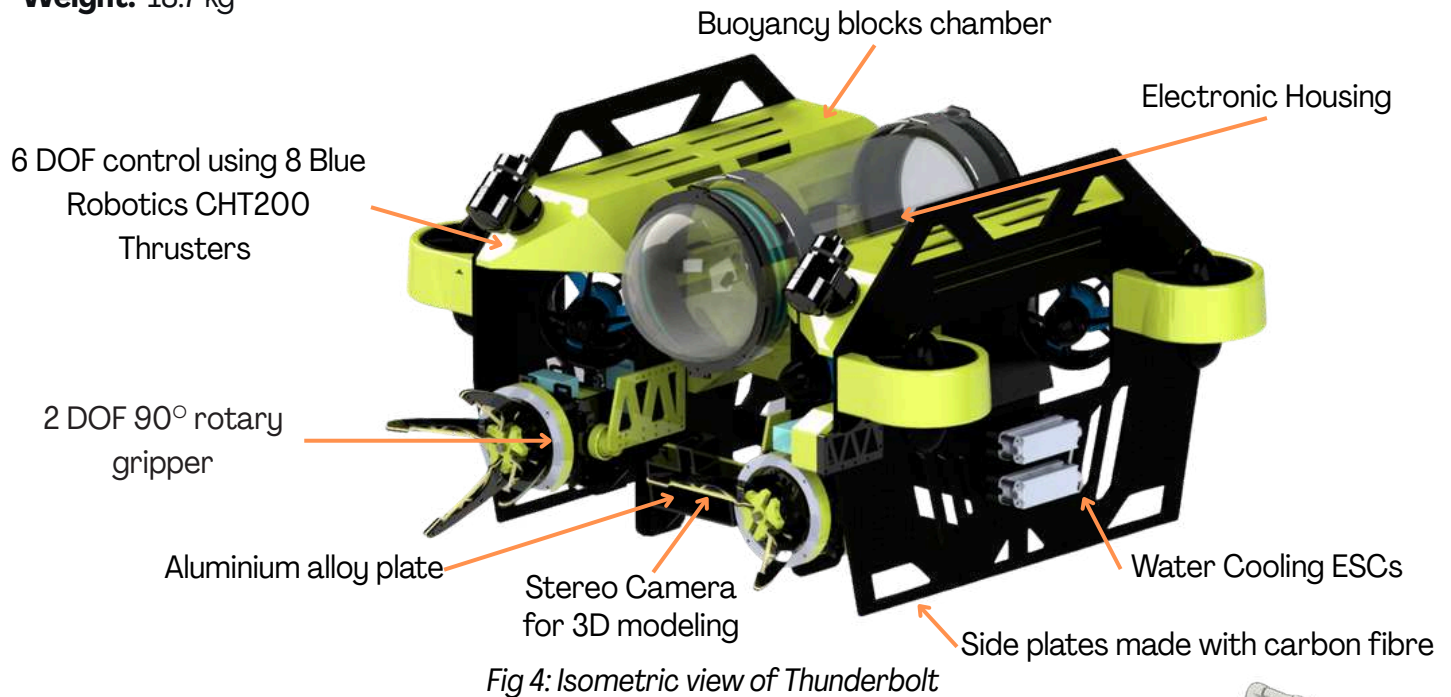


Fig. 5 : General Gripper for all task



Fig. 6: Task 2.3 LobsterPot



Fig 7: Task 2.4 Recover Buoy Anchor



Fig. 8: Front view of Thunderbolt

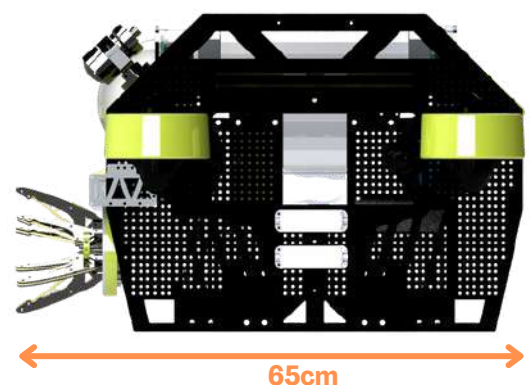


Fig. 9: Side view of Thunderbolt



Design Rationale

Planning and Design Process

Brainstorming was a foundational step, involving sketching, 3D printing, and physical examination of components to eliminate flaws before manufacturing. SEATY assembled a simulated acrylic prototype to aid buoyancy estimation, wiring design, and unit testing. We used SolidWorks to create FDM-printed prototypes and run fluid dynamics simulations, making adjustments based on simulation results to enhance reliability [1]. Throughout the project, SEATY established a decision-making process encouraging cross-departmental collaboration, balancing usability, material availability, cost-efficiency, and performance to ensure all components met rigorous standards.

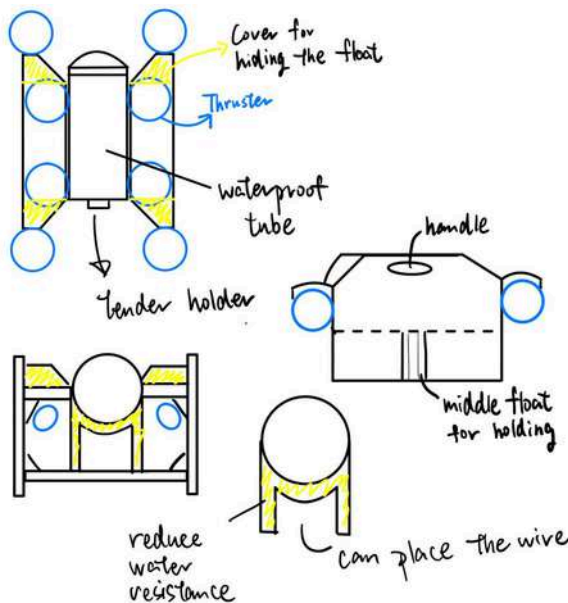


Fig. 10: Hand sketch of Thunderbolt at Brainstorming Stage



Fig. 11: Prototype of Thunderbolt at Brainstorming Stage

Material Selection Trade-Offs

SEATY constructed the ROV frame with carbon fibre for its superior strength-to-weight ratio [2], while an aluminium plate supported the electronic housing due to its high load-bearing capacity [3]. A 3D-printed base provided a lightweight platform for the housing tube, and we incorporated reusable components from last year to ensure durability.

Carbon fibre side plates replaced last year's full 6061 aluminium alloy plates, reducing weight and cost while maintaining strength via a custom 6061 aluminium bottom plate. We integrated threaded holes on the plates to eliminate the need for screw nuts and reduce assembly time. Furthermore, handle grips on the top allow easy transport, and large frame openings enhance movement by allowing better water flow.

Thruster Configuration Trade-Off

The team identified that placing vertical thrusters close to the vehicle's centre resulted in poor power efficiency. For 2026, we positioned all four vertical thrusters at the corners of the ROV to enhance stabilization, maneuverability, and control [4]. Although this adjustment results in a slightly larger footprint, the gains in stability justify the trade-off.



Fig. 12: 2024 Thruster Configuration

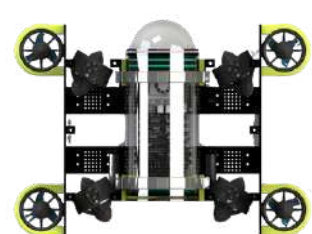


Fig. 13: 2026 Thruster Configuration

Thruster selection

We have decided to replace the original T200 thruster with the more efficient CHT200-CH. For instance, at 1850 μ s PWM, the CHT200-CH requires a current input of only 13 A, compared to 27.5 A for the T200 .

Gripper and Manipulator Upgrades

The new design integrates a 2-DOF gripper with an elevator and rotatable component, facilitating easier catching and positioning of props compared to last year's 1-DOF version [5].



This represents a deliberate trade-off: SEATY accepted increased mechanical complexity and weight in exchange for significantly improved maneuverability and task completion.

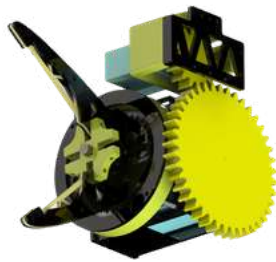


Fig. 14: Render photo of Gripper

Cable Management & Maintainability

Clear wire and cable management provides a larger usable area for components and reduces damage risks during maintenance. By streamlining the installation and removal of the electronic tube, the team enhanced the maintenance experience, allowing for quick servicing between competition runs.

Innovation

The newly developed slot card serves as a centralized control center, employing a 168 MHz ARM Cortex-M4 STM32F407VET6 processor to manage complex thruster and servo PWM signals [6]. By integrating digital isolators to protect signal isolation, the design effectively reduces electromagnetic interference (EMI) inherent in high-current motor environments. The system architecture prioritizes safety and transparency, featuring a physical emergency stop switch and an OLED interface for real-time telemetry and control status. For developers, integrated troubleshooting ports ensure seamless fault diagnosis and integrate different modules into a single high-performance slot card.



Fig. 15: Thruster and Servo Slot card

In our latest ROV iteration, SEATY significantly overhauled the power and sensing architecture to ensure mission-critical reliability. We integrated a dedicated current sensor into the

manipulator for real-time load monitoring and transitioned to a dual-converter configuration to provide isolated power rails for thrusters and servo [7]. Additionally, we upgraded the vision system to a high-definition IP camera, drastically reducing signal noise for the pilot. Physically, we redesigned the manipulator to be more compact and robust; despite its smaller footprint, its upgrade to 2-DOF offers superior maneuverability. Finally, next-generation ESCs ensure smoother thruster response and higher efficiency, resulting in a more responsive underwater platform.



Fig. 16: IP Camera and IP Camera Board

Problem Solving

Brainstorming and Ideation Process

SEATY employed a structured, subteam-driven approach to problem-solving. At the start of each design iteration, subteams (Mechanical, Electrical, Software, and Operations) held meetings to state problems in clear, measurable terms and broke them down through functional decomposition into power, propulsion, and control subsystems. To solve the power instability issue, the team generated four solution paths: upgrading to a higher voltage DC-DC converter, adding back electromotive force module, separating power into two isolated rails, or reducing thruster PWM slew rates.

Rational Process and Trade Study

After brainstorming, SEATY used a data-driven process to evaluate design alternatives. A primary example is our decision to transition from a single DC-DC converter to a dual DC-DC converter architecture. This shift followed our observation of system instability under high-load conditions, where a shared unisolated power bus caused critical failures in the control electronics.



During pool testing, we observed that the Jetson Orin Nano rebooted unpredictably whenever thruster power exceeded 40%, and the servos exhibited significant jitter. Root cause analysis traced these issues to the inrush current draw from the thrusters, which caused the bus voltage to droop and triggered a system reset. To resolve this, we conducted a trade study comparing the original single-converter design against the proposed dual-converter architecture, as shown in Table 1.

Based on this study, we selected the dual-converter system. We dedicated a 24V rail exclusively to the thrusters and a 12V rail to all other components, including the Jetson Orin Nano, servos, cameras, and sensors. While this change added approximately 25g of mass, it eliminated all power-induced reboots. Subsequent validation testing confirmed that the Jetson Orin Nano operated continuously across the entire thruster power range without a single reset.

Systems Approach

The team demonstrated a balanced systems approach by designing mechanical, electrical, and software components as an integrated whole to maximize total vehicle performance for the MATE 2026 mission tasks.

The power system architecture exemplifies this thinking by using a dual DC-DC converter to separate the 24V thruster rail from the 12V logic rail, directly addressing the observed

instability where the Jetson Orin Nano rebooted at 40% thruster power. While the 12V rail powers all logic components, cameras, and sensors, an additional converter steps down to 8.4V for the servos, representing a deliberate systems-level trade-off between simplicity and reliability.

The communication architecture further integrates vehicle functions through a centralized CAN bus that handles both command signals and feedback data from the 3-in-1 current detection modules. By using this single protocol for bidirectional communication, we enabled closed-loop control of the gripper system: the current sensor detects increased draw during closure and carries that value back via the CAN bus to the pilot to prevent mechanical damage.

Modularity and Thermal Management

The modular slot card architecture, inspired by modern PC motherboards, has been refined since 2018. A dedicated power slot card converts 12V to 5V for all microcontroller boards, while the thruster, servo, and current sensor slot cards can be developed and tested in parallel using the test vehicle platform before final ROV integration.

Thermal management was treated as a cross-subsystem concern. We moved the Electronic Speed Controllers (ESCs) outside the pressure tube for water cooling and upgraded them from plastic to aluminum cases to increase heat

Evaluation Criterion	Single DC-DC Converter	Dual DC-DC Converter (Selected)	Justification
Power stability	Poor – Jetson Nano reboots when thrusters exceed 40% power	Excellent – 24V thruster rail isolated from 12V logic rail	Stable 12V power required for reliable Jetson operation and precise servo control
Weight and volume	Better – single converter only	Good – two converters add approximately 25g	Acceptable trade-off given performance improvement
Cost	Lower – approximately \$15	Higher – approximately \$28	Within budget; reliability justifies incremental cost
Fault tolerance	Low – single converter failure disables entire vehicle	High – thruster failure does not affect logic; vehicle can still surface	Improves mission completion rate

Table 1: Power Decision Matrix

dissipation. Each ESC is potted with epoxy inside its aluminum enclosure, balancing electrical insulation, thermal performance, and reliability.

Sensor Integration & Tether System

Sensor integration followed a deliberate interface strategy: the IMU, temperature, and pressure sensors connect via I2C for low-latency state data, in which the data received by the sensor will be synchronized with the GUI and the IMU detects variations between each data point and outputs feedback for stabilization in the Offshore Engineering Basin Tank while current detection modules use CAN bus for reliable feedback in noisy environments. For vision, the stereo camera uses USB for high bandwidth, while the IP camera utilizes Ethernet for longer cable runs.

The tether and ground station were designed as integrated system endpoints. Our 15-meter tether balances competing requirements: 12-AWG wires minimize voltage drop, Cat-6 supports high-speed data, TPE foam provides neutral buoyancy, Kevlar adds tensile strength, and aluminum foil shields against interference. On the surface, a modified Pelican case houses the laptop, router, controller, and monitor, creating a single networked control station that connects seamlessly with the vehicle. This systems-level approach ensured that every design decision was evaluated by its impact on the complete ROV.



Fig. 17: PowerBox



Fig. 18: Tether

Vehicle Structure

SEATY evaluated the trade-offs between cost, dimensions, and mass for the ROV's structural design. While a larger vehicle entails higher initial manufacturing costs and reduced maneuverability, it offers a versatile platform capable of accommodating diverse mission tasks over multiple years. By maintaining the core frame and designing modular attachments, the ROV remains adaptable for future requirements without needing a complete redesign.

Compared to smaller ROVs, our ROV is more prone to collisions, so we chose to design thruster protection to safeguard the propulsion system. At the same time, the higher weight reduces the ROV's susceptibility to unintended movement caused by external forces [11]. We also found that maintaining the existing design incurs lower costs than designing a new shell, allowing us to allocate the budget to optimizing other components such as the ESC and manipulator claw.



Fig. 19: Thunderbolt's front view

Vehicle Systems

SEATY consists of a frame, pressure-resistant chamber, mechanical claw, and buoyancy blocks. Building on the previous year's design, carbon fiber and aluminum are used as the main materials for the frame.

Frame

Carbon fiber plates and aluminum alloy are used for the frame. Carbon fiber allows for pre-made screw holes, making it easy to add accessories without extra nuts. Meanwhile, the base plate is made of 6061 aluminum alloy to



place heavier components at the bottom for stability. We also provide base plates of different lengths to adjust for various mission tasks.

Buoyancy System

Buoyancy blocks are used as the buoyancy system, allowing dynamic on-site rebalancing. Modular buoyancy units can be placed into the top space of the frame, enabling weight changes without tools.



Fig. 20: Buoyancy system of Thunderbolt

Mechanical claw

The claw has relatively higher strength requirements, utilizing a gear mechanism driven by a servo. The components are made of ABS, aluminum alloy, and carbon fiber plates, with carbon fiber used for the housing and critical nodes to prevent part wear [2]. The gear rack is made using metal 3D printing for superior wear and heat resistance .The gripping surfaces interfacing with props are made from TPU, a compliant material that enhances effective grip force while preventing damage to coral during Task 1.1. For the gears, we ultimately chose ABS over aluminum to address frequent wear issues, as other metal alternatives were cost-prohibitive. Referring to the properties in Table 2, ABS was selected for its superior cost-effectiveness and ease of modification.

Pressure-Resistant Chamber

SEATY's pressure-resistant chamber is composed of a a transparent acrylic cylinder with lathed, chamfered endplates to ensure a reliable O-ring seal. The backplate incorporates 19 potted through-hole expansion ports using slow-set adhesive to safeguard internal components. This layout optimizes physical space while streamlining cable routing and maintenance access.

Acrylic was selected based on Table 2 criteria; its optical transparency allows instant visual diagnostics, and wall conduction satisfies internal thermal dissipation needs. To validate this choice, hydrostatic pressure at our maximum target depth ($h = 4.0\text{ m}$) is evaluated with $P = \rho \times g \times h = 39.24\text{ kPa}$. Comparing our cylinder's compressive limit to this load yields an exceptional factor of safety, mathematically proving structural integrity while saving 55.9% in dry mass over aluminum.



Fig. 21: Electronic housing



Fig. 22: Overview of Electronics Components

Quick mount

our quick mount allow for rapid installation of a claw that is used to Retrieve the lobster pod for task 2.3 and Carabiners for recovering Task 2.4 Buoy Anchor

Composition	Expense	Rust Resistance	Compressive Limit [Mpa]	Specific Mass [kg/m^3]	Heat Conductivity [W/m·K]
Acrylic	Low	High	120	1185	0.2
ABS	Low	Medium	80	1050	0.25
6061 Aluminum Alloy	Medium	Medium	276	2700	167
Carbon Fiber	High	Excellent	600	1600	10

Table 2: Material Used In Thunderbolt



Electrical System

Design Evolution

New components and daughter boards have been introduced this year to operate the innovative gripper system, allowing for adjusted gripping force using current-sensing techniques.

The CAN protocol has been introduced to centralize all communication between slot cards, offering greater flexibility through software-defined message IDs that enable dynamic node addition. Minor modifications such as updating components with newer technologies and redesigning the single-board computer voltage regulator have been implemented to improve overall electrical stability, reduce volume, and lower the cost of the ROV.

System Architecture

The electronic system comprises four major components: the voltage conversion stage, motherboard, slot-based card system, and single-board computer. 48V DC from the tether passes through two independent DC-DC converters, stepping down to 24V exclusively for thrusters and 12V for all other components to supply the motherboard.

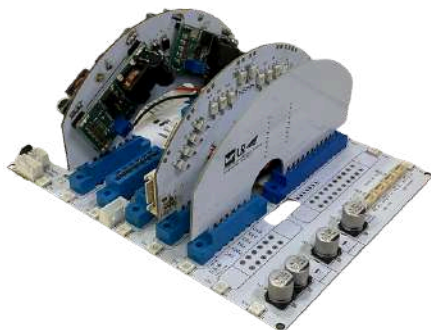


Fig. 23: Slot card system

The slot card system, inspired by modern PC motherboard architecture, allows different daughter boards to utilize a centralized signal bus on the same basic motherboard architecture used since 2018, though this year it was shortened for compactness. A dedicated power slot card converts 12V down to 5V for the slot card microcontrollers, while the pilot issues commands to the single-board computer via power line communication through the tether. The computer communicates with the

daughter boards through the CAN bus [9] to control all manipulators and retrieve sensor values from the current detection modules, enabling bidirectional communication.

Power System

For 2026, the ROV employs a dual-rail topology using two DCDC Converter to step 48V down to 24V exclusively for thrusters, and an isolated GDE25S12B buck converter to handle the 12V logic bus (SBC, sensors, cameras). An ancillary converter steps the 12V rail down to 8.4V for servos. This architecture physically decouples inductive motor dynamics from sensitive processing logic. Oscilloscope bench testing verified that isolating the rails suppresses peak transient voltage ripple to under $\pm 120\text{mV}$ completely eliminating the legacy power sags that triggered critical SBC brownouts when thruster output exceeded 40% [8].



Fig. 24: 48 to 24
DC-DC Converter



Fig. 25: GDE25S12B

Motherboard

To enhance subsystem management, *Thunderbolt* features a backplane divided into the Main Board, Rear I/O, and Power Board, along with an SBC with autopilot. The backplane utilizes defensively designed plugs and daughter board slots to prevent connection errors while a high-efficiency heat dissipation design prevents overheating. This new version reduces PCB length to free space in the housing for upgrades like a more powerful SBC or a ZED camera without sacrificing functionality. With five daughter board slots, the modular design allows independent sub-systems to share power and signal buses, ensuring reliability and easy upgrades.



Fig. 26 : Rendered *Thunderbolt's* backplane



Electronic Speed Controller Cooling

All electronic speed controllers (ESCs) are placed outside the main pressure tube to utilize water cooling directly from the surrounding environment. Each ESC is waterproofed by potting it with epoxy inside an aluminum enclosure. In previous design years, plastic cases were used for the ESCs, but the team changed to aluminum cases for the 2026 vehicle to increase heat dissipation [10] and improve cooling performance during extended mission operations.



Fig. 27: Water Cooling ESC

Sensor Integration

All environmental sensors, including the IMU, temperature sensor, and pressure sensor, connect directly to the Jetson single-board computer via the I2C bus, ensuring low-latency access to critical vehicle state data. For current monitoring, the team designed a custom 3-in-1 current detection module that measures power draw across three servos simultaneously. This module utilizes the INA226 current sensor, which communicates via the I2C bus to provide high-precision real-time voltage and data, while a 0.02Ω shunt resistor enables accurate real-time current monitoring. The module is mounted outside the main electronic housing and reports values back through I2C to the Jetson inside the housing. The main stereo camera connects to the Jetson via USB, providing high-bandwidth video data for computer vision and pilot situational awareness. The gimbal control signal also connects to the Jetson via USB, while gimbal power is drawn directly from the 12V DC-DC converter to avoid overloading the single-board computer's power supply.

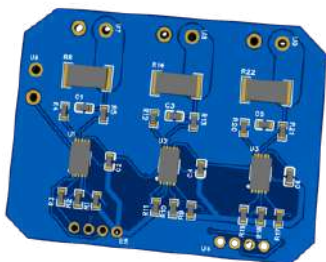


Fig. 28: Current Sensor board

Slot Card System

The ROV utilizes multiple specialized slot cards, each designed for a specific function and communicating via the CAN bus.

The thruster and servo slot card translates Jetson CAN bus commands into precision PWM signals. It integrates an I2C OLED to display real-time PWM values for diagnostics, along with an ESP32 and M24C02 EEPROM to support over-the-air (OTA) firmware updates. Debug ports enable oscilloscope waveform analysis, while a digital isolator protects the STM32 microcontroller from high-current motor noise. An RGB LED provides instant status feedback: blinking green confirms active CAN communication, and solid red indicates a control program stall.

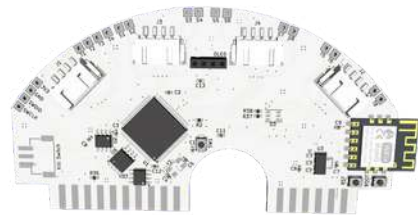


Fig. 29: Thruster and Servo Slot card

The sensor slot card receives telemetry from the externally-mounted 3-in-1 current detection modules and converts these signals into CAN bus messages for the Jetson. This allows the pilot to monitor gripper servo loads in real-time. When high current is detected, which indicates tight gripping, the pilot stops the closing command, preventing mechanical damage. The card includes two I2C channels for future sensor expansion.

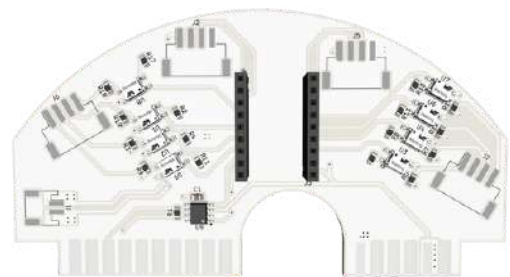


Fig. 30: Sensor Slot Card

The power slot card converts the 12V input from the motherboard down to 5V, with four voltage channels available for future needs. It supplies regulated power to all slot card microcontrollers, ensuring clean logic-level power independent of main bus fluctuations.

Tether Design

The ROV is connected via a 15-meter tether that includes two 12-AWG cables for high-power delivery and one Cat-6 Ethernet cable for high-speed signal transfer. The 12-AWG gauge was chosen to minimize voltage drop over the tether length, ensuring efficient power delivery from the surface to the vehicle. The Cat-6 cable enables rapid data communication supporting both video streaming and real-time control commands.

To achieve neutral buoyancy and reduce the disruptive pull of tether weight, the tether is surrounded by thermoplastic elastomer (TPE) foam sponges. Additionally, integrated Kevlar structural members provide tensile strength to withstand pulling and snagging during missions, while aluminum foil shielding protects the signal conductors from electromagnetic interference, ensuring reliable performance in underwater environments.

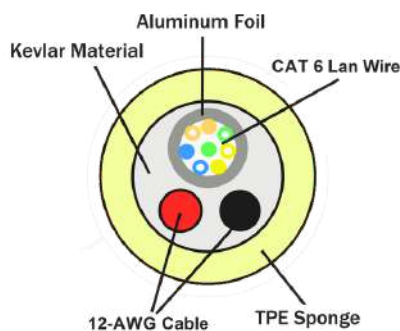


Fig. 31: Cross section of the tether



Fig. 32: Tether Connection Plug

Ground Station Design

The control station utilizes a modified Pelican case to house all surface components, allowing crew members to mobilize the entire control station alongside the vehicle quickly. A standard game controller is connected to a laptop, which

serves as the primary pilot interface. The laptop connects to a router, and the Jetson single-board computer's Ethernet cable from the tether plugs into the same router, establishing a local network between the laptop and the ROV. This allows the pilot to send commands and receive telemetry data through a direct Ethernet connection. A large external monitor is connected to the laptop to provide expanded vision for the pilot and mission support crew, improving situational awareness during complex tasks.



Fig. 33: Ground station of Thunderbolt

Tether Management Protocol

Pre-Deployment: Designate a tether tender. Inspect the full tether length for cuts, kinks, or damage. Clean and inspect connectors. Uncoil the tether in a figure-eight pattern on the deck. **Connect to the surface station:** strain relief first, then power, then Ethernet. Verify strain relief is secure on both ends.

During Operations: Deploy only enough tether to reach working depth. Select a deployment site up-current with direct line of sight when possible. The pilot avoids 360° rotations and close maneuvers around obstacles. Never step on or crush the tether. Do not bend the tether tighter than the minimum bend radius. Keep the tether clear of thrusters and pinch points.

Post-Operation: Disconnect Ethernet first, then power, then strain relief. Rinse with fresh water if used in salt water; allow to dry. Coil using figure-eight or over-under technique. Secure connector caps and store in a clean, dry location.



Software Control System

The team undertook a complete redesign for 2026, developing the control system in-house to reduce reliance on commercial components like Pixhawk while ensuring the vehicle remains stable even if a thruster fails. The backend utilizes ROS2 and Docker to containerize components into nodes, enabling accurate system replication and enhancing robustness through a decentralized discovery process without a master node.

The IMU provides real-time attitude data, fused with pressure sensor depth readings for accurate state estimation to support three operating modes. In manual mode, the pilot has direct proportional control over all thrusters, while in stabilization mode, the ROV automatically maintains position and heading using a cascaded PID controller that manages attitude angle, angular speed, depth, and vertical speed. Additionally, in depth-holding mode, the vehicle keeps its operational depth above the seafloor for high-stability tasks.

The graphical user interface, developed in ReactJS, interfaces with ROS2 WebSockets to offer cross-platform accessibility, making it available on any device with a browser unlike the previous RQt desktop GUI. This allows pilots to view sensor values, mission timelines, camera feeds, and buoyancy controls on tablets or laptops, with a UI that supports joystick and keyboard inputs and includes a dedicated mode selector switch.

By mapping node communication paths through system architecture diagrams and data flow charts, the team achieved modularity through Docker, platform independence via a web-based GUI, fault tolerance through ROS2, and reduced pilot workload through stabilization mode. However, limitations include increased development time compared to using Pixhawk and the necessity for accurate IMU calibration.

Software Development Process

The team employed a Git feature-branch workflow, where each module was developed in a separate branch, reviewed, and merged only after passing automated tests. Using Docker

Compose, independent nodes were integrated via defined ROS2 topics and services, with integration testing performed weekly on the test vehicle.

Testing followed a three-level approach: unit tests using pytest, integration tests verifying node communication, and in-water testing validating end-to-end performance including thruster latency, IMU accuracy, and stabilization hold stability.

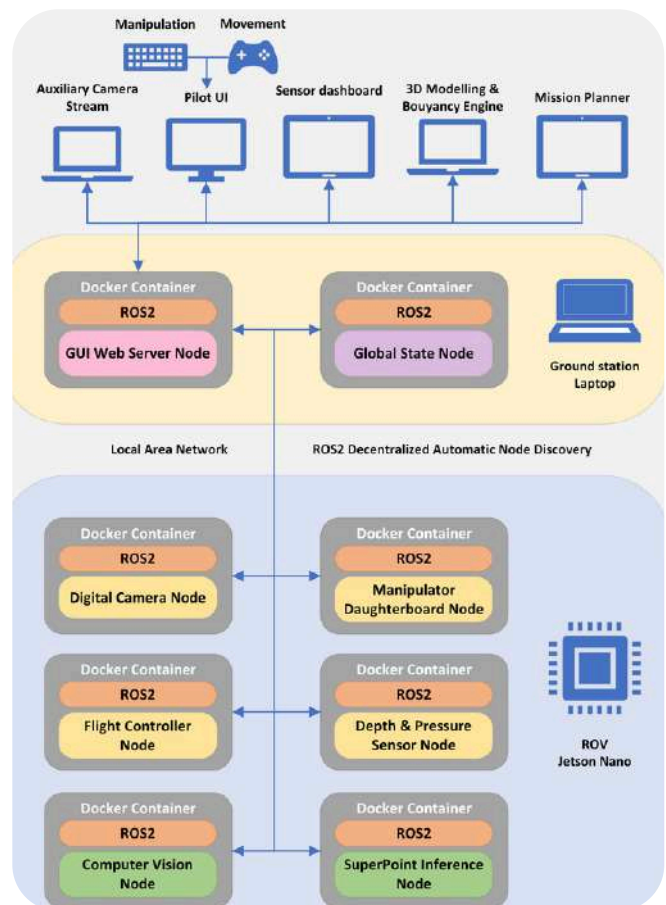


Fig. 34: Control System

Features for System and Operator Performance

The simulator, developed in Unity with CAD and Blender support, creates high-quality underwater scenes with water physics, resistance, buoyancy noise, and waves, serving as a training ground for pilots and algorithms.

The web-based GUI allows any browser-equipped device to act as a control station. Real-time sensor displays show vehicle attitude,



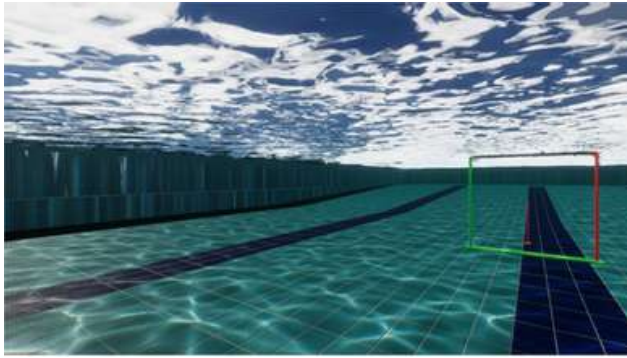


Fig. 35: Underwater simulation graphic

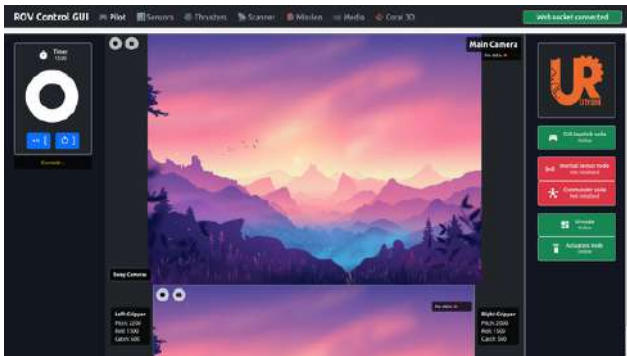


Fig. 36: Control Station GUI

depth, temperature, and gripper current draw. The mission timeline helps pilots prioritize tasks, and the mode selector provides clear visual indication of the active mode.

The stabilization mode uses a PID controller tuned for the vehicle's mass and thruster configuration. In pool testing, the ROV maintained position within a 5 cm radius under calm conditions and within 15 cm under moderate water flow. The fault tolerance feature detects thruster failures by monitoring current draw and expected thrust output. When a failure is detected, the control system dynamically reassigns thrust commands to remaining operational thrusters, validated by deliberately disabling one thruster during pool testing.

Mission Planner

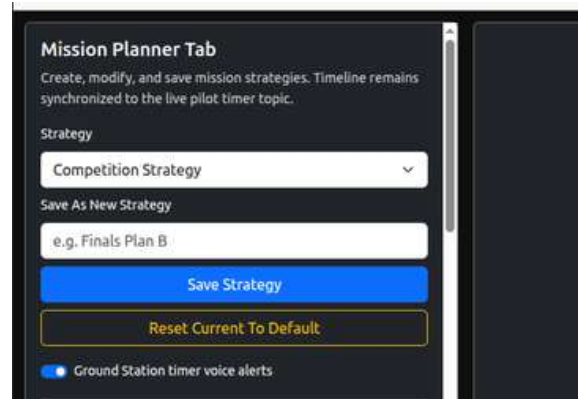


Fig. 37: Mission planner tab

The Mission planner tab helps pilots manage mission time by presenting task content as an intuitive timeline synchronized with the live pilot timer. This year, we enhanced the tab/page so teams can create, modify, and save mission strategies directly from a tablet or laptop, making quick pre-run and between-run adjustments much easier. The timeline remains linked to real-time timer updates, and we added optional voice countdown alerts on the Ground Station PC speakers to improve situational awareness during operation. This keeps the pilot workflow focused while still allowing strategy updates and timing cues in real time.

Propulsion

The propulsion system comprises eight CHT200 thrusters arranged in a vector configuration to achieve six degrees of freedom. Four CHT200 motors control sway, surge, and yaw, while the remaining four control roll, pitch, and heave. With the autopilot system, the vehicle maintains complete control over its pose.

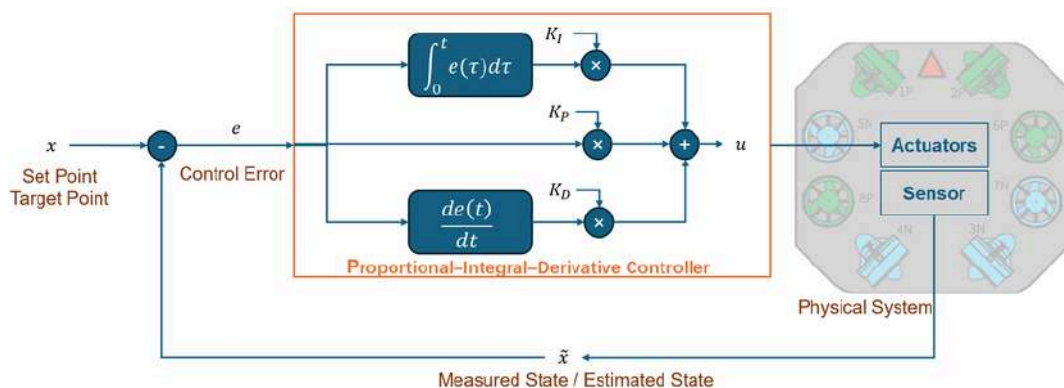


Fig. 38: Propulsion System

The propulsion system has been significantly enhanced this year to improve efficiency, performance, and adaptability. All eight thrusters are strategically positioned at the corners of the ROV, optimizing force distribution and reducing power consumption when balancing heavy objects.

This configuration enhances stability and maneuverability, particularly for tasks requiring precise control while carrying props at the front of the vehicle.



Fig. 39: CHT200 Thruster

The sway, surge, and yaw thrusters are positioned at a 60-degree angle toward the surge direction to enhance forward thrust. The four thrusters collectively generate a total thrust of 23.2 kg in the surge direction, approximately 5.8 kg per thruster. Surge movement was prioritized because it demands more thrust for long-distance travel, while sway movement is designed for more precise, lower-force tasks. This represents a deliberate trade-off: angling the thrusters reduces maximum thrust available for pure sway movement, but the gain in forward thrust for transit between task zones was deemed more valuable for overall mission performance. Power consumption was balanced against mission requirements by selecting CHT200 thrusters, which offer a proven balance of thrust output, current draw, and cost.

Axis	Forward	Reverse
Force X(N)	33.938	-29.187
Torque X(Nm)	8.487	-7.299
Force Y(N)	19.617	-16.871
Torque Y(Nm)	6.742	-5.798
Force Z(N)	39.2	-33.712
Torque Z(Nm)	7.849	-6.75

Table 3: Force in different axis

Buoyancy and Ballast

The ROV is engineered for static equilibrium, with a primary focus on neutral buoyancy to minimize vertical thruster load and extend mission duration. Buoyancy is generated through the displacement of the main electronics housing and a high-density foam insert located under the upper fairing. By concentrating buoyancy at the top of the chassis and placing heavy components, such as cameras, electronics, and sensors at the bottom, the vehicle achieves passive stability and naturally returns to an upright position.

To further enhance this stability, we integrated a modular weight system along the bottom of the frame. Mounting stainless steel weights at the lowest possible point maximizes the separation between the Center of Gravity (CG) and Center of Buoyancy (CB), providing a stable platform for precise imaging and manipulation. Additionally, the weight interface features adjustable mounts for rapid reconfiguration based on varying payloads. To ensure the ROV remains level at rest, we refined the foam distribution under the top cover to achieve precise longitudinal and lateral balance.

Payload and Tools

Camera

The ROV utilizes six cameras for the 2026 mission tasks. A front-facing stereo camera enables real-time 3D modeling of the coral garden ridge, providing critical depth perception for autonomous distance measurement. For primary navigation, a camera mounted on a 3-DOF gimbal at the bow ensures a stabilized, wide-angle view for the pilot, while a four-camera bottom-facing array delivers 360-degree coverage to eliminate blind spots during lifting and seafloor operations.

The imaging system uses a customized SoC IP solution optimized for high compression, low bandwidth, and strong anti-interference. To minimize signal degradation and eliminate long internal cable runs, each IP camera connects to a dedicated, epoxy-potted external network switch. This external unit, along with the Jetson



Orin Nano, links to a primary internal switch that routes all network traffic to the ground station via the tether's Ethernet cable.

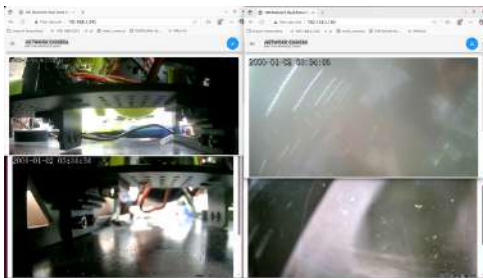


Fig. 40: IP camera screen



Fig. 41: Main camera screen

Crab Detection

For the crab identification task, we developed a two-stage vision pipeline using only three reference images. To overcome data scarcity, we applied underwater-specific augmentations such as color shifts, turbidity, illumination glare, bubbles, and motion blur to expand the training set for a binary K-Nearest Neighbors (KNN) classifier. This classifier learns to distinguish species based on handcrafted color and texture features.

During operation, a zero-shot OWL-ViT detector localizes potential crab regions in the camera feed. The system then passes each detected crop to the trained KNN classifier to categorize the specimen as either invasive (European Green Crab) or native (Rock/Jonah Crab). This modular design allows us to update either component independently while ensuring reliable performance with minimal training data.



Fig. 42: Original Crab photo

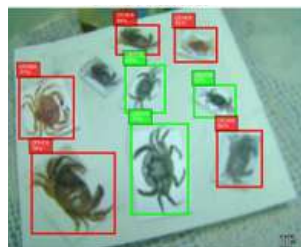


Fig. 43: Detected photo

Coral Garden

For the Seabed 2030 task, the company developed a spatial reconstruction pipeline utilizing a calibrated stereo camera system. This approach replaces manual measurement with algorithmic reconstruction to fulfill autonomous 3D modeling requirements. The pipeline employs a block-matching approach that prioritizes high-gradient regions, such as PVC pipe edges and the eight 10 cm x 10 cm colored targets. This creates a structural "skeleton" of the ridge while maintaining high computational efficiency and feature reliability in underwater environments.

The final 3D result is achieved through geometric transformation involving rectification and disparity calculation. Left and right stereo frames are aligned using pre-computed rotation and translation matrices to generate an accurate point cloud. To meet scaling requirements, the software includes a calibration interface that applies a linear scaling factor based on a "True Length" provided by the judge. This enables precise estimation of the coral garden's height, providing an accurate digital twin for the station judges

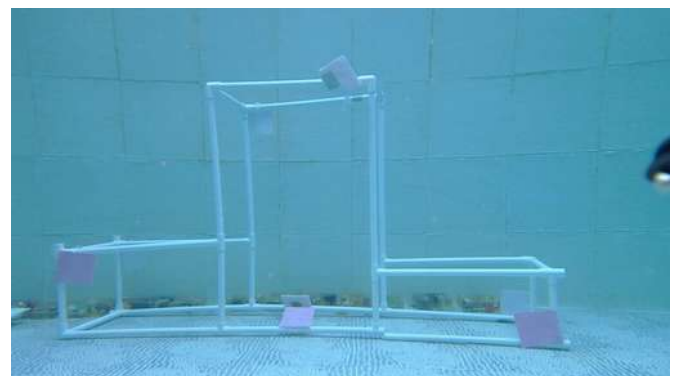


Fig. 44: Coral Garden

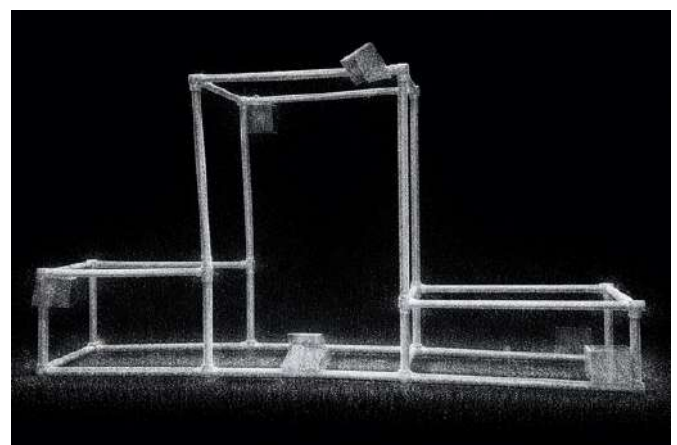


Fig. 45: 3D result of Coral Garden



General-purpose Gripper

The ROV features two interchangeable gripper configurations, consisting of a two-claw version and a four-claw version. We designed the two-claw gripper for large objects such as coral species bases, as it opens wide enough to grasp oversized props securely. The four-claw gripper offers superior stability for handling a broader range of mission props.

To enhance flexibility, we equipped each gripper with a rotary mechanism utilizing bearings, servo motors, and gears. A servo with a ball screw drives the jaws to allow for precise linear movement. Each jaw incorporates two carbon fibre plates with a 3D-printed TPU middle layer. The carbon fibre provides necessary strength while the TPU offers the flexibility and adaptability required to handle various shapes during deployment, installation, or retrieval tasks. Additionally, a current sensor integrated into each gripper servo provides real-time motor load feedback. This system triggers a safety cutoff if it detects excessive resistance to prevent mechanical damage [12].



Fig. 46: 4 claws gripper

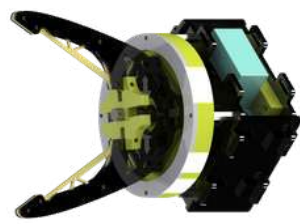


Fig. 47: 2 claws gripper

Rotary Sector Gear

The rotary sector gear system provides an additional degree of freedom for both grippers, allowing 360-degree rotation. This rotation is used for tasks such as rotating the inner plastic sheeting of the Holyrood subsea observatory camera. The system incorporates a pinion mechanism managed by a combination of a spur gear and a sector gear, with the gripper directly connected to the sector gear for precise control [13]. Bearings on both sides of the assembly enhance rotational smoothness. The sector gear includes an extra cylinder, and the sidewall features a quarter-section hole to

limit the rotary angle and prevent over-rotation. A 45-degree gear mechanism enables vertical movement, allowing the gripper to position sensors for easier connection to the Holyrood subsea observatory.

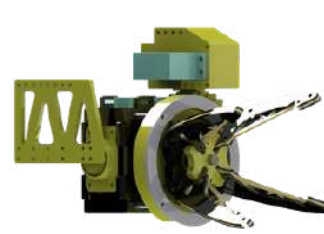


Fig. 48: Rotary sector gear



Fig. 49: Heavy-Duty Hook

Heavy-Duty Hook

The heavy-duty hook features a specialized carabiner-style geometry with a spring-loaded gate, specifically engineered for rapid underwater attachment. The pilot can secure heavy props by simply moving the ROV downward to engage the prop's lifting eye. We use this tool specifically for recovering the lobster pot.

String Roll Mechanism

The string roll mechanism features a custom-machined spool designed for active wire management. It ensures lines are deployed and retracted in organized layers, effectively eliminating the risk of internal entanglement. This mechanism is used to attach a recovery line to the buoy anchor.

Underwater Lighting

Since this year's MATE competition features a 5-meter-deep pool, the Underwater Lighting with 12V is used to solve the concern about insufficient lighting and have added this waterproof LED light to ensure clear underwater visibility.



Fig. 50: String roll



Fig. 51: Underwater Lighting



pressure and temperature sensor node to provide real-time environmental telemetry; the pressure data is translated into millimeter-accurate depth readings for precise vertical station-keeping, while the temperature readings fulfill the mission's environmental monitoring mandates.

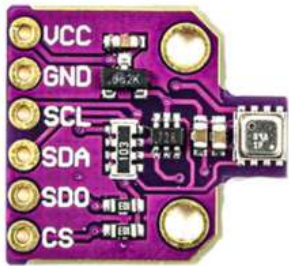


Fig. 52: BME680



Fig. 53: JY901

The 9-axis IMU provides critical real-time attitude sensing (pitch, roll, and yaw), ensuring the ROV remains a stable platform for delicate manipulation and accurate data logging. For Task 1.3 (Fly a transect over the coral garden), the IMU is essential for maintaining a level flight path and providing precise spatial orientation for high-fidelity 3D modeling. This inertial feedback allows the system to compensate for underwater currents, ensuring consistent survey integrity throughout the competition

Buoyancy engine

The buoyancy engine features a unique mechanism that integrates a DC motor and planetary gears connected to a ball screw. This ball screw mechanism enables vertical movement through rotational motion. The syringes manipulated by the ball screw regulate water volume, thereby altering the engine's weight for controlled vertical motion. The engine itself consists of a tube with an inner diameter of 100 mm, an outer diameter of 110 mm, and a height of 600 mm. The majority of electronic components are housed in the upper section, while the lower section accommodates the pressure sensor and 4 x 60 mL syringes.

The operation of the buoyancy engine begins upon receiving a signal from the ground station. The motor gradually pulls the syringe by rotating

the ball screw, causing water to be driven into the syringes and increasing the overall weight of the engine. A pressure sensor send feedback water depth data to MCU and output corresponding PWM through the Algorithm of PID. Once the engine over the target depth, the mechanism reverses, pushing the syringe to withdraw water and reduce weight, allowing the engine to ascend.

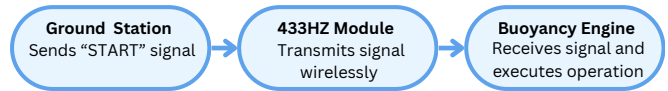


Fig. 54: Communication illustration between the buoyancy engine and ground station



Fig. 55: Rendered buoyancy engine



Fig. 56: Real-life buoyancy engine

For electronic control, a printed circuit board (PCB) is designed to manage the DC motor and collect data from the pressure sensor. Communication between the ground station and the buoyancy engine is facilitated by a 433 MHz communication module. Additionally, an ultrasonic device and LDR detects the distance between the syringe piston and motor cover to prevent damage caused by the motor. A voltage display meter is included to check whether sufficient power is available for operation.



Build vs. Buy, New vs. Used

Build vs. Buy

For new capabilities required by the 2026 mission, the team made deliberate build versus buy decisions based on cost, performance, integration complexity, and technical expertise.

The 3-in-1 current detection module was built in-house because a single-board solution for monitoring three servos simultaneously was not available commercially. The dual DC-DC converter configuration was assembled from purchased telecom-grade converters, with the team focusing on isolating the 16V and 12V rails and adding the 12V to 8.4V stage for servos. The HD IP camera was purchased, as commercial units offer superior optical performance and waterproofing at lower cost than an in-house design. The compact 2-DOF manipulator was built entirely in-house because off-the-shelf options could not satisfy the specific geometric and force requirements of the MATE 2026 tasks. The next-generation ESCs were purchased but modified by replacing plastic cases with aluminum enclosures and potting with epoxy for waterproofing and water cooling. The new slot card was built in-house around an STM32F407VET6 microcontroller because no commercial product offered the required combination of thruster PWM, servo PWM, CAN bus, optocoupler isolation, physical kill switch, OLED display, and debug port on a single board.

New vs. Used

For the 2026 competition, the team systematically evaluated all existing ROV components to determine whether they could be reused or required replacement. Components were reused when they met current mission requirements and were not performance bottlenecks. Reusing proven components reduced development costs, shortened the build timeline, and increased reliability by retaining hardware already validated through extended pool testing.

The Jetson Orin Nano RGB was reused because its computing power remains sufficient for

vision processing, control, and camera streaming. The CHT200 thrusters provide adequate thrust for all mission tasks. The Logitech controller was retained due to high pilot familiarity. The outer frame supports the vehicle's structural loads without modification. The existing mechanical claw manipulator handles all required MATE tasks effectively. The 48V to 12V power converter continues to supply adequate power. The ground station was also reused, as it communicates with the ROV via the tether without any deficiencies.

Component	Decision	Justification
Jetson Orin Nano	Reused	Sufficient computing power
CHT200 Thruster	Purchased	Better performance & Power Efficiency
Logitech Controller	Reused	Pilot familiarity
Outer Frame	Reused	Adequate structural capacity
Mechanical Claw	Reused	Handles all required tasks
48V-12V Converter	Reused	Adequate power capacity
Ground Station	Reused	Fully functional
Current Sensor Module	Built	3-in-1 custom design not commercially available
Dual DC-DC	Purchased; integrated	Commercial converters; team integration
IP Camera	Purchased	Better performance and lower cost
2-DOF Manipulator	Built	Custom geometry for MATE tasks
ESCs	Purchased; modified	Commercial base; aluminum case; epoxy potting
Logitech Controller	Reused	Pilot familiarity
Slot Card	Built	No commercial product with all required features
Underwater Lighting	Reused	Illuminate 5m Depths

Table 4: Components Detail

System Integration Diagram (SID)

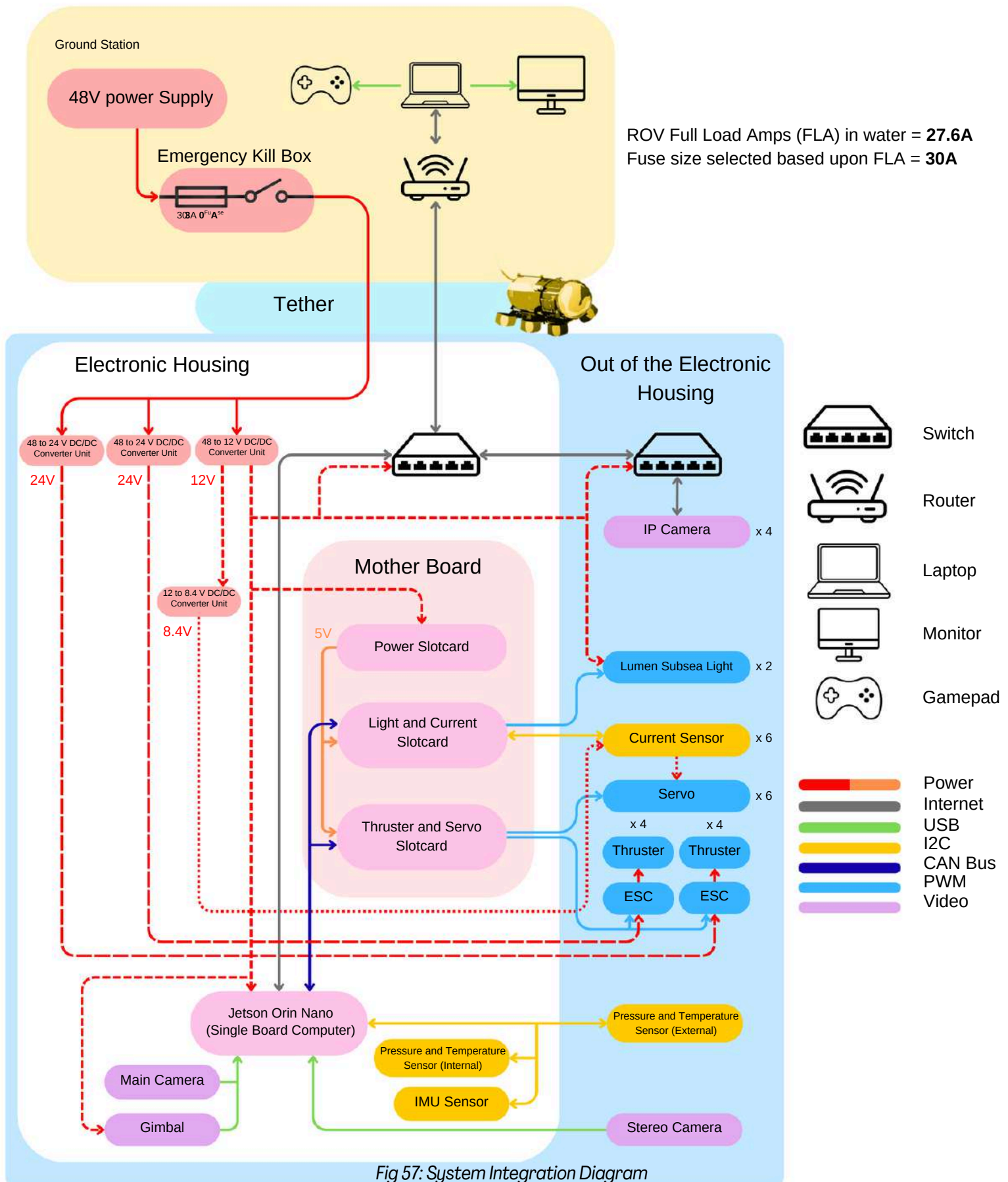


Fig 57: System Integration Diagram

Safety

SEATY safety philosophy is to control risks through design and discipline rather than last minute reactions. We give equal priority to personnel safety and equipment safety, especially when bringing on new employees with limited engineering experience. A designated safety lead manages all high risk activities, making sure everyone learns and follows our internal standards alongside local regulations. Safety is covered across the board, from lab work and ROV construction to operational testing in water, with clear and scenario specific procedures for each.

Personnel Safety

Before using the lab, all employees complete mandatory annual safety training led by senior engineers. The session covers lab rules, proper use of personal protective equipment (PPE), safe operation of machinery, and emergency procedures. As part of this training, employees learn that required PPE includes safety glasses, closed toe shoes, and tied back long hair. Peer evaluations are also conducted during training to reinforce a culture of safety awareness.

For using power tools such as drills, soldering irons, and grinders, employees must receive one on one training with an experienced lead. This includes a live demonstration of safe operation, followed by a written check on tool parts and procedures. Employees are not allowed to use power tools independently until they complete this training.



Fig. 58: Wear gloves when using epoxy

Equipment Safety

During Thunderbolt's development, a major design focus was preventing injury through vehicle safety features. SEATY makes hazards visibly clear to employees and eliminates dangerous features and surfaces. All moving parts and hazardous components are clearly labeled, and sharp edges or corners of the frame have been removed entirely to reduce injury risks. Thrusters and manipulators are fully shrouded to prevent injuries and protect ropes, cables, and biological samples from rotating parts. A kill box with fuse and kill switch enables immediate emergency shutdown during critical operations. The general purpose gripper uses TPU 3D printed components to protect delicate items and marine life. Finally, a management unit with overcurrent protection guards against short circuits, overvoltage, and transient voltage.



Fig 59: Peer training system for machine operation

Operational Safety

Before each deployment, the team performs a Jobsite Safety and Environment Analysis (JSEA) to identify potential hazards specific to the operation site and tasks. This includes checking that tools are properly restrained, clamps are secure on any items being manipulated, and the work area is clear of loose debris.

Safety Procedures

CityUHKUR's operators follow a detailed safety checklist before, during, and after each dive. The checklist covers start up procedures, in water checks, power supply verification, launch and retrieval steps, and loss of communication protocols. The full checklist is attached in Appendix C.



Testing & Troubleshooting

Vehicle Testing Methodology

Testing validates designs through practical application. The team built multiple prototypes and conducted independent component tests before full vehicle integration. SolidWorks simulations were complemented by pool tests to capture real-world performance. Key parameters evaluated included vehicle stability, power efficiency, and static and dynamic buoyancy.

Testing followed three progressive phases. First, bench testing verified individual components including slot cards, dual DC-DC converters, ESCs, and sensors. Second, subsystem integration testing with the test vehicle verified that combinations of components operated together correctly, such as the thruster slot card responding to CAN bus commands. Third, full system pool testing operated the complete ROV through simulated mission tasks.



Fig 60: Testing Thunderbolt

Prototyping & Design Evaluation

The team used prototyping extensively to evaluate design options. Multiple gripper iterations were 3D-printed and tested for gripping force and structural integrity. A prototype power distribution board was breadboarded before PCB layout to verify the dual DC-DC architecture. The CAN protocol and pilot interface were bench-tested before vehicle deployment. Prototyping revealed the power instability issue that led to the dual DC-DC architecture.

Equipment Safety

Before integration into the main competition ROV, the team validated the performance of all slot cards in a separate test vehicle. This safe testing platform allowed them to evaluate power distribution, refine the dual DC to DC setup, and gather practical data for design decisions. A configuration was only approved for the final ROV after passing strict benchmarks, which included keeping thrusters running steadily, operating servos concurrently, maintaining uninterrupted Jetson processing, and ensuring reliable CAN bus communication.

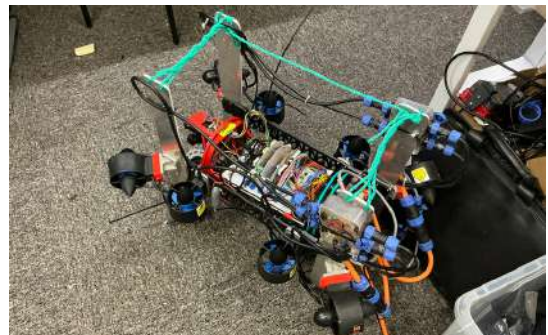


Fig 61: Testing ROV

Troubleshooting Strategies and Techniques

The team followed a four-step process: observation, hypothesis, test, and revision. When the Jetson Orin Nano rebooted at 40% thruster power, the team hypothesized that thruster inrush current caused voltage drop on the shared bus. Testing with a separate 12V battery for the Jetson confirmed the hypothesis. The team then selected the dual DC-DC architecture based on trade study results. The same process resolved CAN bus errors (missing termination resistors) and overheating ESCs (aluminum cases with epoxy waterproofing). Safety was maintained by never working on energized systems in wet environments and always having a second crew member during pool tests.



Fig 62: 3D model of Thruster Mount

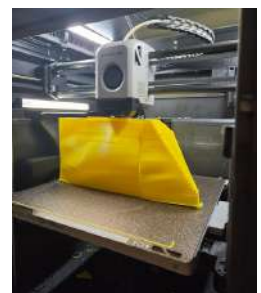


Fig 63: 3D Printing



Accounting

Total Cost For ROV:				
Item(s)	Remarks	Amount	Unit Price(US	Value(US)Type
Controller		1	50	50 Reused
CHT200 Thruster		8	230	1840 Purchased
Outer Frame	Carbon Fiber, Aluminium Plate	1	467.4	467.4 Reused
Jetson Orin Nano RGB		1	250	250 Reused
Control Station		1	700	700 Reused
Water-proof servo		8	30	240 Reused
Inner frame	3D Print	1	32.7	32.7 Reused
Manipulators Frame	Carbon Fiber, Aluminium Plate	2	62.7	125.4 Reused
Underwater Lighting		2	20	40 Reused
Customized PCB		1	358.3	358.3 Purchased
ESC	Aluminium 3D Print box, ESC	8	30	240 Purchased
Raw Material	Filament, Screw, Nuts	1	1358.2	1358.2 Purchased
IP Camera		4	20	80 Purchased
Buoyancy Engine		1	125.3	125.3 Purchased
Tether		1	141	141 Purchased
Total Purchased:				4142.8
Total Reused:				1905.5

Table 5: Total cost for ROV

Total Cost for Non-ROV Expense				
Pool-test		8	200	1600
Mate Registration Fee		1	1090	1090
Total:				2690

Table 6: Total Cost for Non-ROV Expense

Funding			
Department	Type	Quantity	Total (USD)
Income			
CityUHK Department of Biomedical Engineering	Sponsorship	1	1,400
CityUHK Department of Electrical Engineering	Sponsorship	1	3,600
CityUHK Department of Mechanical Engineering	Sponsorship	1	1,400
CityUHK Department of Computer Science	Sponsorship	1	1,400
CityUHK College of Architecture and Civil Engineering	Sponsorship	1	1,400
Total Income			9,200

Table 7: Funding

Overall cost: Total Purchased + Total Cost for Non-ROV = \$6832.80

At the beginning of the year, our team created a budget after reviewing previous years' spending and re-evaluating all cost categories. We mainly focused on reusing existing equipment and materials to minimize new purchases.

Our overall cost for the season was \$6832.8. This was achieved by reusing \$1905.50 worth of components and purchasing only \$4142.80 in new parts for the ROV. Non-ROV expenses totaled \$2,690, mainly for pool tests and the MATE registration fee.

We received \$9,200 in sponsorship from five CityUHK departments (Biomedical Engineering, Electrical Engineering, Mechanical Engineering, Computer Science, and Architecture & Civil Engineering). These efforts allowed us to complete the project efficiently while significantly reducing our budget compared to previous years.

Total Traveling Cost: 3514.54 per person

This year, we have to spend around USD 3514.54 for the travelling cost in St. John's in Canada. This table outlines the projected budget for an upcoming trip, totaling \$3,514.54 USD. The largest individual expense is the air ticket at \$1,976.97 USD, accounting for more than half of the entire budget. Accommodation costs for a multi-day stay at a hotel (from June 17th to 28th) make up the next major expenditure at \$937.57 USD.

	Price(USD)
Hotel(17-28 June)	937.57
Air-ticket	1976.97
In-town Transport	100
Catering	500
Total	3514.54

Table 8: Cost for Traveling from HK to St. John's



Acknowledgement

SEATY would like to express their appreciation to:

MATE centre - For organizing the MATE International ROV Competition 2026

CityUHK Apps Lab - For giving the team a lab space to work

CityUHK College of Computing - Their R&D funding to the team

CityUHK College of Engineering - Their R&D funding to the team

CityUHK Department of Electrical Engineering - Their R&D and travelling funding to the team

CityUHK Department of Computer Science - Their R&D and travelling funding to the team

CityUHK Department of Biomedical Engineering - Their R&D and travelling funding to the team

CityUHK School of Data Science - Their travelling funding to the team

CityUHK Department of Mechanical Engineering - Their R&D and travelling funding to the team

CityUHK Department of Architecture and Civil Engineering - Their R&D and travelling funding to the team

CityUHK Student Development Services - Their travelling funding to the team

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A. Gantt Chart of Thunderbolt Development



B. Safety Operation & Construction Checklist

OPERATION & CONSTRUCTION — SAFETY CHECKLIST			
START-UP PROCEDURE			
1	Safety goggles worn by every crew member	~1 min	☐
2	All crew members are not dangerously near the ROV	~1 min	☐
3	Main switches and circuit breaker on Surface Control Unit are off	~1 min	☐
4	Tether connected to/from ROV is secure and undamaged	~2 min	☐
5	Bolts are double-checked and secure in position	~1 min	☐
6	All jubilee clips are well tightened	~1 min	☐
7	All wires properly connected, no unwanted exposure	~2 min	☐
8	All components' waterproofing status is nominal	~1 min	☐
9	Thrusters not obstructed by wire or other obstacles	~1 min	☐
SUPPLYING POWER TO THE ROV			
1	All members are away from the water	~1 min	☐
2	Every member informed before power-on	~1 min	☐
3	All members are attentive and prepared	~1 min	☐
4	Power source switched on and connected to Surface Control Unit	~2 min	☐
5	Voltmeter reads 48V on the LCD	~1 min	☐
6	All crew on deck warned for thruster test	~1 min	☐
7	GUI started and codes are ready to run	~2 min	☐
8	Thruster test performed without abnormalities	~2 min	☐
9	No abnormalities (shoddy feed, etc.) found on display	~1 min	☐
10	Accessories tested	~1 min	☐
LAUNCH			
1	Hands removed from the ROV control panel	—	☐
2	"Prepare to launch" called out	—	☐
3	All deck members confirmed ready	~1 min	☐
4	"Launch" called out	—	☐
5	ROV completely submerged to water	~2 min	☐
6	Wait for release confirmation	~2 min	☐
IN WATER			
1	Tether man attentively placing the ROV in water	~1 min	☐
2	Checked for bubbles that could indicate leakage	~1 min	☐
3	All motors and servomotors confirmed functional	~1 min	☐
4	If burned smell detected — reel ROV back to surface immediately	—	☐
5	Everything OK — begin mission	~2 min	☐
ROV RETRIEVAL			
1	"Prepare for surfacing" called out	—	☐
2	Crew members ready for retrieval of ROV	~1 min	☐
3	ROV confirmed to be near the crew	~1 min	☐
4	Power killed after confirmation of retrieval	~1 min	☐
5	No power leak confirmed "safe to remove ROV" called out	~2 min	☐
6	"ROV secured on deck" called out after ROV is secured	~1 min	☐
LOSS OF COMMUNICATION / UNRESPONSIVE			
1	All connections checked for security	~1 min	☐
2	Communication system rebooted	~2 min	☐
3	If failed: pull out and re-plug all wires	~2 min	☐
4	Troubleshoot succeeded — mission continues as usual	—	☐
5	Troubleshoot failed — kill power	~1 min	☐
6	ROV retrieved via tether	~2 min	☐
CONSTRUCTION SAFETY			
1	Machinery and equipment confirmed in proper working order prior to use	~1 min	☐
2	Electronic devices not in active use are powered off	~1 min	☐
3	All tools returned to their designated locations after use	~1 min	☐
4	Appropriate protective gear is utilized	—	☐

