



Oceaners *Shanghai, China*

Technical Documentation 2026



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Figure 1: Nemo ROV

Oceaners is a student-led company from Shanghai, China, developing the Nemo ROV and the Tulkun float for the 2026 MATE ROV Ranger Competition.

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Figure 2: Oceaners team members

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1. Abstract

Oceaners is a student-led marine engineering company based in Shanghai, China, founded in August 2025 to participate in the 2026 MATE ROV Ranger Competition. The team consists of 13 members specializing in software engineering, electrical systems, mechanical engineering, systems integration, and operations management. Organized under a structured engineering and operations framework, Oceaners adopted a milestone-driven development process featuring subsystem ownership, cross-department coordination, and iterative design validation throughout the project life cycle.

For the 2026 season, Oceaners developed two primary underwater systems: Nemo, a tethered eight-thruster observation-class ROV, and Tulkun, an independent ESP32-based profiling float. Nemo was built around a modular aluminum structure with custom 3D-printed components, vectored propulsion for full 6-DOF maneuverability, and a near-neutral buoyancy configuration optimized for stability and operational flexibility. Its control architecture combined a four-depth-sensor and IMU-based closed-loop stabilization system, STM32 embedded PID control, Raspberry Pi onboard communication and video streaming, and a multi-station surface control network supporting piloting, monitoring, and mission coordination. Tulkun was designed for autonomous vertical profiling, stable depth regulation, environmental data acquisition, and post-recovery wireless data transmission and visualization.

To support the development of both platforms, Oceaners implemented a phased engineering workflow including subsystem prototyping, dry-bench verification, pool testing, systems integration, and mission rehearsal validation. Key testing activities included thrust calibration, waterproofing verification, sensor fusion validation, depth-control tuning, communication reliability testing, and full mission simulations. Through iterative engineering refinement and interdisciplinary collaboration, the team demonstrated effective systems integration, practical engineering trade-off analysis, and cost-conscious innovation while developing a reliable, maintainable, and competition-ready underwater robotics platform aligned with Ranger-class mission requirements.

2. Teamwork

2.1 Company Structure

Oceaners operates under a dual-management structure consisting of a Chief Technical Officer (CTO) and a Chief Operations Officer (COO), supervised by CEO Jiang Zimu. This structure was designed to improve technical development efficiency, operational management, and system-level coordination throughout the project life cycle.

Under the leadership of CTO An Rongde, the technical division was organized into four engineering groups: Software, Electrical, Mechanical, and Systems Integration. The Software team developed the control logic, topside interface, network communication, and onboard software systems. The Electrical team was responsible for power distribution, embedded electronics, sensor integration, and float electronics development. The Mechanical team focused on structural design, waterproofing, buoyancy layout, and mission tool fabrication. The Systems Integration group coordinated subsystem testing, vehicle balancing, mission integration, and full-system validation.

The operations division, led by COO and Safety Officer Luo Yuhao, managed documentation, budgeting and finance, media outreach, safety management, and overall team coordination. This organizational

structure enabled Oceaners to maintain clear subsystem ownership while supporting efficient interdisciplinary collaboration during the design, testing, and competition preparation phases.

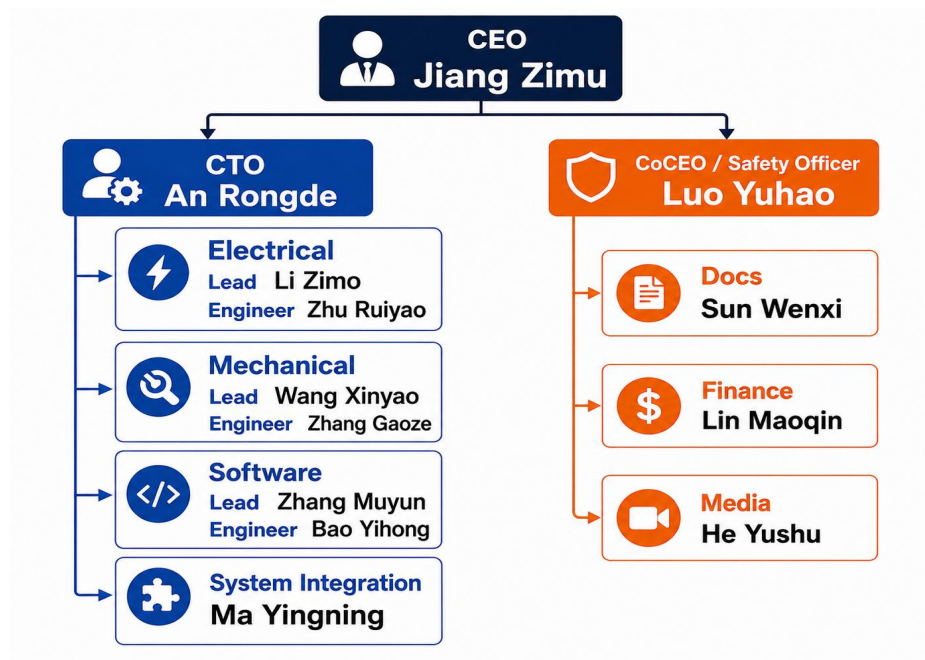


Figure 3: Company Structure

2.2 Project Management and Schedule

The Oceaners project launched on August 15, 2025, and consisted of two phases.

Phase 1 (170 days) focused on building a low-cost prototype, mastering ROV structure, thruster operation, and joystick control, and testing the main control board, with over 1,000 student-hours invested.

Phase 2 ran from February 2 to May 20, 2026. A milestone-driven approach was adopted to manage the tight timeline, with four sequential phases and clear deliverables. Oceaners coordinated parallel development of mechanical, electronic, software, float, documentation, and testing subsystems, investing over 1,200 student-hours. Milestone reviews synchronized progress and mitigated risks, while daily departmental communication ensured efficient issue resolution.

2.2.1 Project Timeline and Milestones

A structured milestone schedule coordinated parallel development across all subsystems, including Mechanical, Electronics, Software, Float Systems, Documentation, and Testing, enabling concurrent progress while maintaining system-level alignment.

Table 1 : Oceaners Project Milestone Schedule (Aug 2025 – May 2026)

Phase	Period	Key Deliverables
Phase 1.1: 1st Gen Low-cost Prototype Iteration	Aug 15,2025 – Nov 10,2025	Iterate 1st Gen low-cost prototype; mastered ROV basic operation; initial main control board tested.
Phase 1.2: 2nd Gen Low-cost Prototype Iteration	Nov 11,2025– Feb 1, 2026	Iterate 2nd Gen low-cost prototype; debugged main control board; verified prototype functionality; $\geq 1,000$ student-hours invested; prepared for Phase 2.
Phase 2.1: Architecture & Procurement	Feb 2,2026 – Feb 28,2026	System architecture finalized; Bill of Materials submitted; all components ordered

Phase	Period	Key Deliverables
Phase 2.2: Fabrication & Integration	Mar 1,2026 – Mar 25,2026	Frame assembled; Electronics wired and bench-tested; Tether validated; Float hardware was completed
Phase 2.3: Software & Pool Testing	Mar 26,2026 – Apr 10,2026	Thruster calibration completed; PID tuning finished; 3 pool test sessions conducted; Float vertical profile validated
Phase 2.4: Iteration & Competition Preparation	Apr 11,2026 – May 20,2026	Final waterproofing verification completed; documentation submitted; full rehearsal completed

2.2.2 Risk Management

Table 2 : Risk Register Summary

Risk Category	Description	Impact	Mitigation
Technical	Waterproofing failure	High	Early enclosure testing
Technical	Thruster instability	High	Calibration & PID tuning
Schedule	Integration delay	Medium	P0 task prioritization
Procurement	Component lead time	Medium	Early ordering

A lightweight risk management process was implemented. A centralized risk register categorized risks into technical, schedule, and procurement domains, with assigned owners and mitigation actions. High-impact risks, including waterproofing integrity, thruster reliability, control stability, and delayed procurement of key components, were addressed through early validation and prioritized scheduling. Risk status was reviewed during milestone meetings.

2.2.3 Tools, Task Tracking, and Communication

Feishu was used as the primary project management platform, integrating task boards, real-time communication, and progress tracking. All tasks were assigned an owner, deadline, and priority level (**P0** / **P1** / **P2**). High-priority tasks were executed first to reduce integration risk. Missed deadlines were escalated to the Project Manager and reviewed during weekly sync meetings. Dedicated department-level communication channels supported focused and efficient collaboration across the company.

2.3 Lessons Learned

The 2026 season provided Oceaners with valuable technical and organizational lessons that will directly shape future development.

Lesson 1 — Communication Must Scale with Team Size.

With 13 members across four departments, early-season coordination was challenged by fragmented communication, unclear task ownership, and delayed identification of cross-team dependencies. The adoption of structured Feishu department channels and a shared task board significantly reduced duplicated work and improved schedule visibility. The key takeaway is that **a clear communication architecture is essential for effective coordination in larger teams.**

Lesson 2 — Cross-Subsystem Integration Should Begin Early.

The Float subsystem and the ROV software were initially developed in parallel with limited interface alignment. During integration testing in early April, incompatibilities between sensor data formats and the surface control software led to unplanned rework. In future seasons, shared interface definitions will be established earlier, and regular cross-subsystem integration tests will be conducted to identify issues sooner.

3. Design Rationale

Oceaners adopted an in-house, iterative design approach to balance performance, cost, maneuverability, and continuous improvement. Tools such as 3D printing and electronic prototyping were used for rapid subsystem development and validation. On the software side, **C++** was used for embedded programming on the **STM32** and **ESP32** platforms to support real-time control and hardware reliability, while **Python** was used to develop the integrated topside control interface and support data processing tasks.

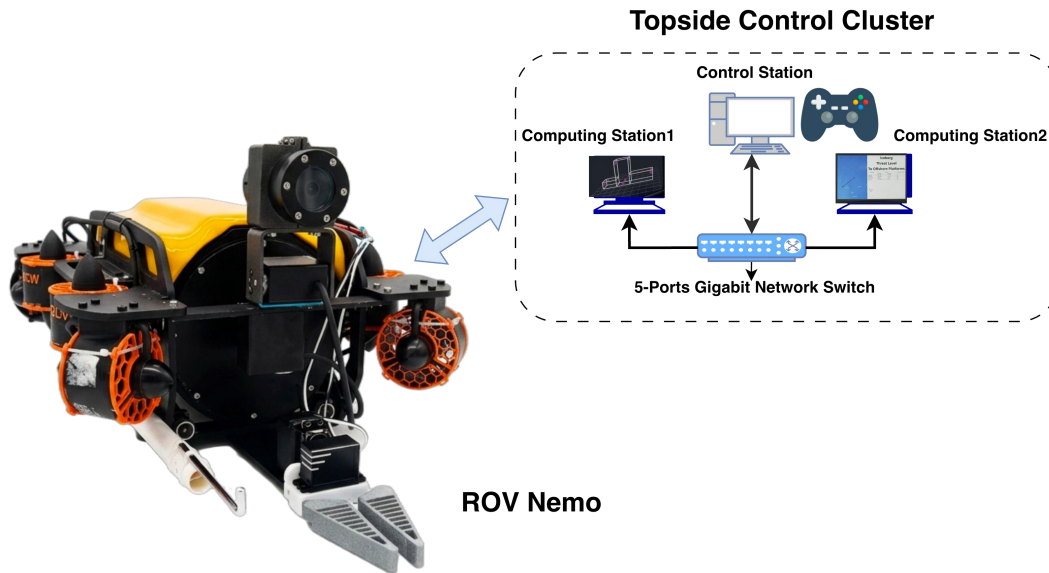


Figure 4: Topside Control Cluster

3.1 Engineering Design Rationale

3.1.1 Overall System Design Rationale

The overall Nemo system emphasized **human-machine collaboration** and **distributed operation**. Its architecture integrated onboard sensing, embedded control, real-time video transmission, and topside multi-operator support through a modular hardware and software framework. This enabled stable underwater operation while allowing piloting, observation, and mission-related processing to proceed in parallel. The overall design focused on four priorities: **operational stability, maneuverability, maintainability, and multi-operator coordination**. These priorities guided the design and integration of the propulsion layout, structural system, control architecture, tether system, and topside processing workflow. **Tulkun**, the autonomous profiling float, is described separately in **Section 3.7**.

3.1.2 From Mission to Design Objectives

The design objectives of the Nemo ROV were directly derived from the mission requirements of the MATE ROV competition. Oceaners first analyzed the practical constraints of each task and translated them into specific engineering requirements.

Table 3 : Mission–Requirement–Design Mapping

Mission Task / Constraint	Engineering Requirement	Design options
Fly a transect / maintain position in a current while recording video	Stable depth holding and attitude control	Custom STM32-based PID control

Underwater navigation and task execution (Task 1–3)	High maneuverability with multi-directional control	8-thruster vectored layout (4 horizontal + 4 vertical)
Continuous visual feedback required during operation	Low-latency and stable video transmission	Optimized video pipeline with tethered transmission
Structural reliability under multi-directional thrust	High strength and durability	CNC-machined frame
Frequent system adjustment during development	Rapid maintenance and iteration capability	Modular system architecture

The design of Nemo was guided by four primary engineering objectives:

- **Operational stability** ensured reliable depth holding and attitude stabilization under external disturbances, enabling consistent performance during transect, hovering, and station-keeping tasks.
- **Maneuverability** enabled motion and attitude control across all six degrees of freedom through a vectored propulsion system, supporting precise positioning and flexible movement in complex underwater environments.
- **Maintainability** supported rapid iteration and efficient troubleshooting through a modular architecture with accessible, replaceable, and inspectable components.
- **Multi-operator coordination** supported efficient mission execution through a distributed topside system in which control, video display, and data-processing tasks could be separated across multiple computers, reducing pilot workload and improving operational efficiency.

3.1.3 Design Methodology — Iterative Development

Nemo was developed through an iterative engineering process involving evaluation, failure analysis, redesign, and repeated validation. Rather than assuming the initial design approach would be sufficient, Oceaners used testing results to refine major subsystems until the final configuration reached an acceptable balance between performance, reliability, and complexity. Several representative design revisions illustrate this methodology:

- **Control system:** An initial **Pixhawk-based** solution failed to achieve stable depth holding because of unstable response and limited tunability under the current system configuration. It was replaced with a custom **STM32-based PID control system**, which significantly improved depth stability and overall control performance.
- **Structural design:** An initial **3D-printed frame** fractured under operational loading, indicating insufficient structural strength. The design was revised to a **CNC-machined frame** to improve mechanical reliability.
- **Video system:** The initial transmission pipeline exhibited high latency of approximately **300 ms**, which degraded operator control. After optimization, latency was reduced to approximately **50 ms**, significantly improving real-time responsiveness.
- **Processing architecture:** Early implementation concentrated all functions on a single computer, which caused lag and unstable performance. The system was later revised to a **distributed Ethernet-based local network architecture**, separating control and video-related processing tasks across multiple computers and improving responsiveness and system stability.

Through this iterative process of testing, identifying failure modes, and redesigning subsystems, the final Nemo configuration was established as a balanced engineering solution rather than a purely theoretical one.

Table 4: Iterative Design Evolution of Nemo ROV

Generation	Key Design Features	Issues Identified	Design Improvements
Gen 1	1. PVC pipe frame;	1. Poor fixation and low	1. Transition to modular

	2. Pixhawk control; 3. initial video pipeline; 4. single-computer processing	assembly precision; 2. unstable depth control; 3. high video latency; system lag	structure; 2. custom control system; 3. video pipeline optimization
Gen 2	1. 3D-printed modular frame; 2. STM32 PID control; 3. optimized video pipeline (~50 ms); 4. single-computer processing	1. Structural fracture under load; 2. performance limited by single-computer processing	1. Adoption of CNC-machined frame; 2. preparation for distributed architecture
Gen 3	1. CNC-machined frame; 2. STM32 PID control; 3. optimized video pipeline; 4. distributed multi-computer system	-	Final system integration and architecture refinement

3.1.4 Trade-offs Analysis

To ensure that the design of **Nemo** was both practical and mission-effective, Oceaners evaluated multiple alternatives for each major subsystem through trade-off analysis. These comparisons considered factors such as **cost vs. performance**, **complexity vs. reliability**, **manufacturability vs. structural strength**, and **mission capability vs. maintenance burden**. Final design decisions were therefore based not on a single parameter, but on the balance of overall system requirements. These analyses were validated through our own prototyping and pool testing.

Table 5 : Propulsion System Configuration

Option	Advantages	Limitations	Selected Trade-off Rationale
8-thruster vectored	Full 6-DOF control, <5 cm drift, <0.2 s latency	+35 % power consumption, higher cost	Chosen for mission-critical precision in coral mapping; differential thrust algorithms offset extra energy cost.
4- or 6-thruster linear	Lower cost & power consumption	No independent pitch/roll control	Rejected: insufficient maneuverability for confined-space tasks.

Table 6 : Frame Material and Fabrication Method

Option	Advantages	Limitations	Selected Trade-off Rationale
CNC-machined aluminum	40 % higher stiffness, ± 0.1 mm accuracy	Higher fabrication cost & lead time	Chosen for control precision and repeatability; prototype tests proved PVC flex caused unacceptable deformation.
Traditional PVC pipe	Low cost, fast assembly	Measurable flex under load	Rejected: degraded positional accuracy during manipulation.

Table 7: Distributed System Architecture

Option	Advantages	Limitations	Selected Trade-off Rationale
Distributed (ROV + Float + Surface)	Parallel development, fault tolerance, scalability	Higher interface complexity	Chosen for mission flexibility and in-house cost control; enables simultaneous testing of subsystems.
Monolithic self-contained ROV	Simpler integration	Limited scalability, single-point failure	Rejected: reduced fault tolerance and slower iteration.

3.2 Innovation

Oceaners incorporated several innovations in system architecture and implementation to improve functionality, flexibility, and cost efficiency across both **Nemo** and **Tulkun**. These innovations were developed in response to specific operational and integration challenges encountered during the season.

3.2.1 Custom Electronic Design — ESP32 Control Board and Motor Driver Board

For **Tulkun**, Oceaners designed the ESP32 control board and motor driver board fully in-house. The boards were fabricated through LCSC and assembled manually with electronic components. This approach reduced cost compared with purchasing a fully integrated commercial solution and allowed the electronics to be tailored to the float's specific control and sensing requirements.

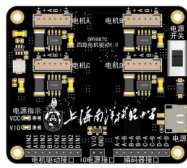


Figure 6: Motor Driver Board

The board interfaces were designed with clearly defined input and output connections, supporting convenient integration, debugging, and future replacement. This custom design also improves maintainability and provides a foundation for future refinement and productization of the float system.

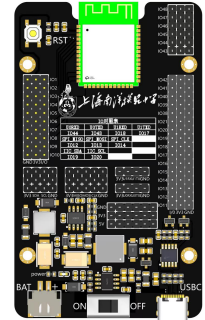


Figure 5: ESP32 Control Board

3.2.2 Distributed Network Architecture — Gigabit LAN and Multicast Collaboration

A key innovation of the **Nemo** system was its distributed topside network architecture based on a high-bandwidth Gigabit LAN. Instead of a traditional single-console workflow, underwater video streams were distributed via multicast, allowing multiple terminals to access the same data simultaneously.

This enabled parallel human-in-the-loop operation, where the pilot focused on navigation while other stations handle modeling, analysis, and observation independently.

Compared to centralized systems, this approach reduced bottlenecks, improved scalability, and significantly increased mission efficiency.

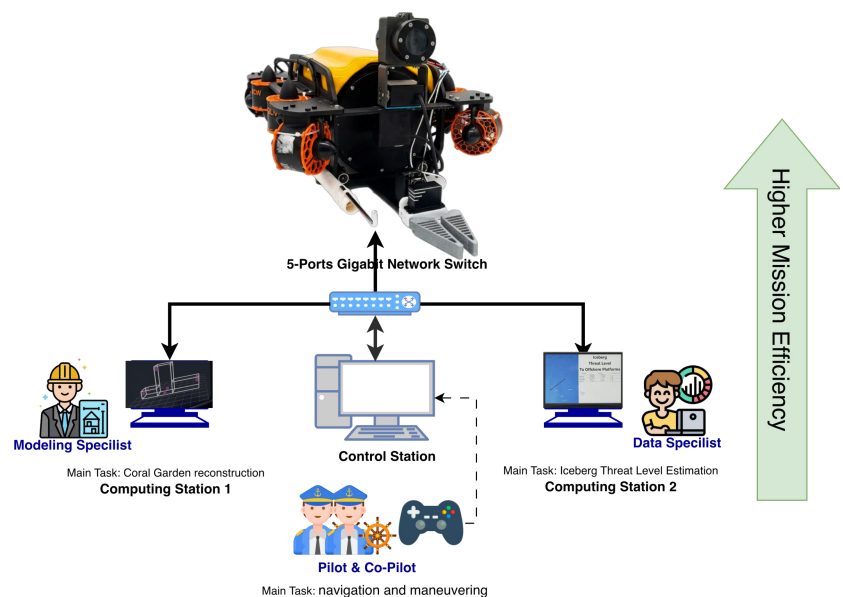


Figure 7: Distributed Control Architecture and Task Division of ROV System

3.2.3 Integrated Control Console — Multi-View Visualization and Collaborative Operation

To support the distributed system architecture, Oceaners developed an integrated control console for topside operation. The console provided a unified interface for mission control, including multi-camera video display, real-time vehicle attitude visualization, and configurable control layouts for different operating needs.

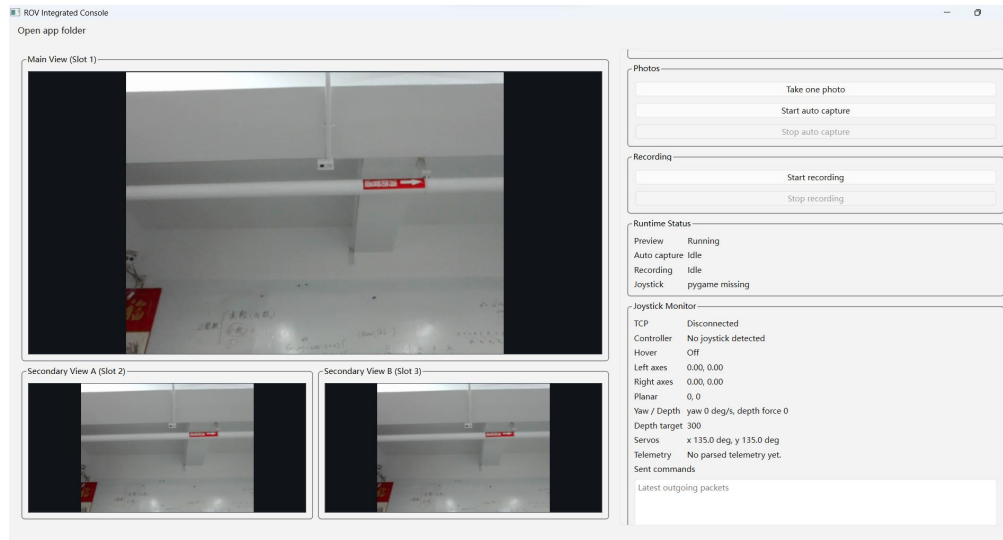


Figure 8: Video Streaming Software Interface

The interface allowed the pilot and co-pilot to work through a shared joystick-based control setup while maintaining access to critical system feedback. Compared with a conventional single-view control interface, this design improved situational awareness and supported more efficient collaborative operation during complex mission tasks.

3.3 Mechanical System

The mechanical system of **Nemo** was designed to provide structural stability, modular integration, and reliable underwater operation. Its mechanical design combined a rigid frame, an eight-thruster propulsion layout, and a carefully tuned buoyancy system to support precise maneuvering and mission execution.

3.3.1 Structural Design

The structural design of **Nemo** was centered around three key objectives: **stability, maintainability, and modularity**. The overall layout was

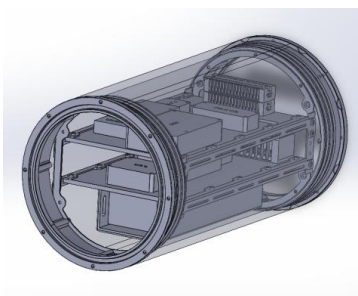


Figure 10: 3D Assembly View of the Watertight Enclosure

developed through 3D modeling to optimize component placement and spatial arrangement and the primary frame was manufactured from **CNC-machined aluminum alloy**.



Figure 9: External Structural Frame of the Nemo ROV

Compared with a traditional PVC-based frame, the aluminum structure provided higher rigidity and better dimensional consistency. This reduced deformation under multi-thruster operation and helped maintain consistent thruster alignment, which improved control precision and repeatability. CNC machining also ensured more symmetrical thruster installation and a more predictable structural response

during operation.

At the center of the vehicle was a **transparent acrylic cylindrical electronics enclosure**, which housed the onboard electronics while allowing rapid visual inspection without disassembly. This design made it easier to identify and address issues such as water ingress, loose wiring, or abnormal indicator status during testing and troubleshooting.

The overall mechanical layout adopted a **central enclosure + external functional modules** architecture. Thrusters, cameras, and other functional components were mounted on the external frame, which separated sensitive electronics from mechanical loads and simplified maintenance, replacement, and future upgrades.

3.3.2 Propulsion System

Nemo used an **eight-thruster configuration**, consisting of four horizontal thrusters and four vertical thrusters. This layout was selected to provide high maneuverability and stable multi-axis control for mission tasks requiring precise positioning and attitude adjustment.

The four horizontal thrusters were arranged in a **vectored configuration**, enabling forward and backward motion, lateral translation, and yaw control through different thrust combinations. The four vertical thrusters controlled ascent and descent and also contributed to attitude stabilization through differential thrust. Together, this configuration enabled control of **pitch, yaw, and roll**, providing the vehicle with full **6-DOF maneuvering capability**.

Compared with simpler propulsion layouts, the eight-thruster design offers better controllability in tasks such as coral garden mapping, transect navigation, and precision alignment near mission targets. Although this configuration increases system complexity, the improvement in maneuverability and stability is considered necessary for mission requirements.

To improve safety and reliability, each thruster was equipped with a **3D-printed PLA protective guard**. These guards formed a physical barrier around the propellers, reducing the risk of foreign-object entanglement and helping protect operators from accidental contact with rotating components during handling and deployment.



Figure 11: 8-Thruster Vector Propulsion System Layout of ROV



Figure 12: Rear propeller



Figure 13: Front propeller guards

3.3.3 Buoyancy and Ballast

Nemo's buoyancy came from a central acrylic enclosure and top-mounted buoyancy foam. The enclosure provided displacement and electronics protection, while the foam allowed fine buoyancy adjustment.

Based on Archimedes' principle, the displaced volume was approximately 6.4 L, corresponding to about 6.4 kg of buoyant force. After full system integration, the ROV exhibited negative buoyancy, requiring iterative optimization of foam volume and placement to a slight positive buoyancy effect.



Figure 14: Buoyancy Foam

The structure followed the principle of placing the center of buoyancy above the center of gravity, with buoyant materials positioned higher and heavier components lower. This created passive stability and maintained upright orientation. The slight positive buoyancy also allowed the ROV to ascend slowly in case of power loss, enhancing safety.

3.4 Electrical System

The electrical system of **Nemo** was designed to provide reliable power distribution, robust communication, and clear separation of functions between onboard and topside hardware. **As shown in the System Integration Diagram (SID) in Appendix A**, the complete electrical architecture was divided into three main sections: the **topside system**, the **tether**, and the **ROV onboard system**. This arrangement supported stable operation, easier troubleshooting, and modular subsystem integration.

3.4.1 Onboard Electrical System

The onboard electronic system of this ROV adopted a hierarchical control architecture, based on a Raspberry Pi and an STM32 microcontroller.

In the system structure, the STM32 served as the low-level controller, communicating with the Raspberry Pi via a USB serial port to exchange control commands and data. Depth sensors and the IMU were both connected to the STM32, which uniformly performed data acquisition and processing. After obtaining sensor data, the STM32 implemented closed-loop control over the propulsion system based on the PID algorithm. By coordinating the outputs of the 8 thrusters, it achieved attitude control and motion regulation of the ROV.

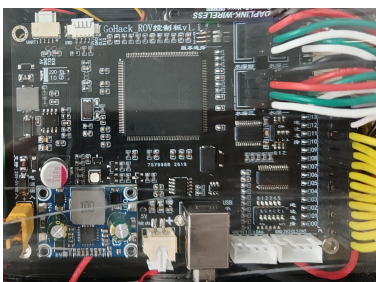


Figure 15: STM32

As the upper-level computing unit, the Raspberry Pi was mainly responsible for data processing and communication functions. On one hand, the Raspberry Pi connected to a camera and acquires real-time video data; on the other hand, it established a communication link with the ground workstation via the TCP/IP protocol and transmitted the video stream to the ground for the operator.



Figure 16: Raspberry Pi

In the control flow, the ground workstation sent operation commands to the Raspberry Pi, which forwarded the commands and sent them to the STM32 through serial communication for parsing and execution. The STM32 controlled the thrusters in real time according to the received control commands.

3.4.2 Ground Station

The ground station served as the control and data processing center for the ROV. It was responsible for receiving data transmitted by the onboard system and sending control commands to the ROV, enabling real-time operation and mission processing of the underwater vehicle. The ROV connected to an Ethernet switch via a network cable, which linked to multiple ground computing devices to form a local area network system. This setup allowed multiple devices to simultaneously access data transmitted by the ROV, supporting parallel processing of multiple tasks.



Figure 17: Laptop Computer with Game Controller

In this system architecture, three ground computing devices were configured. One device acted as the main operating unit, running the control program and accepting operation commands input through a gamepad. Control signals were sent to the ROV over the network to achieve real-time control of the thrusters and actuators. The other two devices were assigned to image processing and data processing tasks respectively: one performed analysis and processing on the real-time video stream, while the other conducts data computation and coral garden modeling.

By separating control and data processing functions, the system reduced the computational load on a single device, improved overall operational efficiency and response speed, and enhanced system scalability. Different task modules could run independently and be optimized according to specific requirements.

3.4.3 Tether System

The ROV employs a dual-cable system that separated power and communication, consisting of one Ethernet cable and one power cable. The Ethernet cable connected the onboard Raspberry Pi to the ground station for bidirectional data and control transmission, while the power cable supplied external power to onboard systems.



Figure 18: Tether

Both cables were designed to be nearly neutrally buoyant and were bundled within a braided sleeve to reduce drag, prevent entanglement, and improve durability.

The power cable used an Anderson connector, with a fuse installed within 15 cm of the input to protect against overcurrent or short circuits. The tether was secured to the frame using carabiners to form a strain relief, preventing mechanical loads from being transferred to electrical interfaces and improving system reliability.

3.5 Control System

Nemo adopted a **software-based hierarchical control system** integrating a **topside control station**, an **onboard computer (Raspberry Pi)**, and an **onboard controller (STM32)**. This

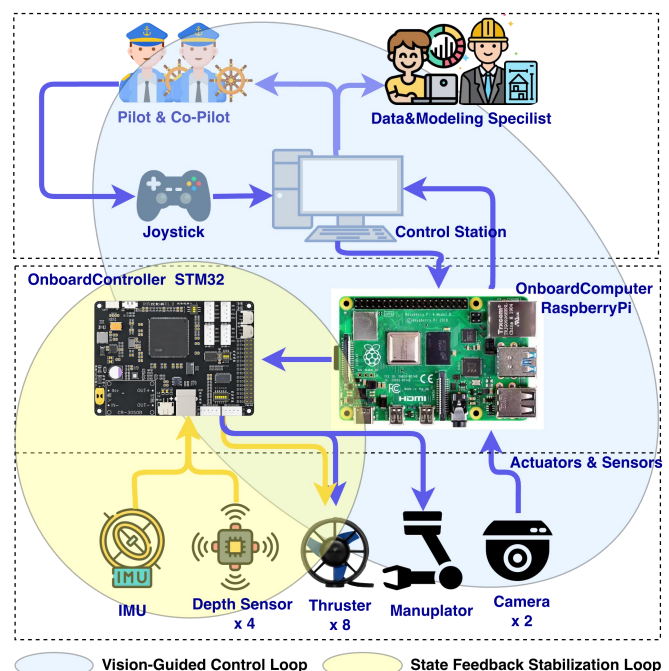


Figure 19: Control System Architecture of Nemo

architecture separated operator interaction, communication and data handling, and real-time control execution, improving modularity, maintainability, and overall system responsiveness.

The system was structured around two primary control loops:

- **Vision-Guided Control Loop** enabled mission-oriented operation through visual perception, where camera data supported navigation, manipulation, and target recognition.
- **State-Feedback Stabilization Loop** maintained vehicle stability using real-time feedback from the IMU and depth sensors, forming a closed-loop PID-based stabilization system.

These two loops were mapped directly to mission requirements, allowing the vehicle to combine task execution capability with stable underwater operation.

3.5.1 Requirement Derivation from Mission Tasks

Control system requirements were derived from mission tasks and translated into subsystem-level specifications:

Table 8: Mission Task–Driven Requirement Derivation Process

Mission Requirement	Control Requirement	System Implementation
Precise navigation in confined underwater space	Real-time manual control with low latency	TCP socket communication from control station to STM32 via Raspberry Pi
Stable depth and orientation control	Closed-loop feedback control	PID control using IMU + 4 depth sensors
Object manipulation (e.g., grasping)	Fine actuator control	Independent manipulator control loop via STM32
Visual inspection and target identification	Real-time video feedback	RTP/UDP H.264 video streaming pipeline
Operator situational awareness	Integrated telemetry feedback	Bidirectional data transmission (command + state)

All major requirements were verified through pool testing, including: depth-hold accuracy tests, response latency measurement, manipulator operation validation and video transmission stability tests.

3.5.2 Software Functional Modules and Performance Optimization

The control software of **Nemo** was composed of three coordinated modules: the **Topside Control Station Software**, the **Onboard Computer Software**, and the **Embedded Control Software**. Each module had clearly defined responsibilities and incorporated design choices intended to improve system responsiveness, stability, and operator efficiency.

1. Topside Control Station Software

The topside control station software served as the human–machine interface. It was responsible for joystick input processing, command generation, and real-time video visualization, allowing operators to control the ROV intuitively while maintaining situational awareness. Control and monitoring functions were integrated into a unified interface to support efficient mission execution.

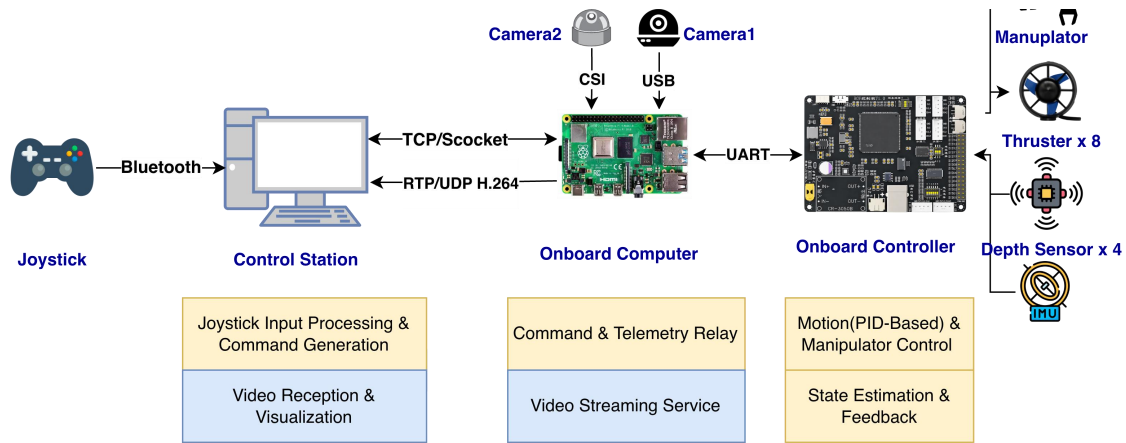


Figure 20: ROV Control System Software

The major features and optimizations of this module are summarized in **Table 9**.

Table 9: Control Station Software Design Improvements

Feature	Initial Design	Improvement
Joystick-to-Command Pipeline	Multi-layer mapping, generic protocol	Direct mapping to custom TCP socket protocol → reduced latency, higher transmission efficiency
Multi-Stream Video Interface	Single video, basic display	Multi-camera switching + real-time display → improved situational awareness and task flexibility
Operator Support Tools	No auxiliary tools	Video recording + screenshot → supported operators collaboration and post-mission analysis

2. Onboard Computer Software (Raspberry Pi)

The onboard computer acted as a middleware layer responsible for command relay, telemetry transmission, and video streaming. It bridged high-level operator control and low-level controller execution while handling communication and computational tasks that were not time-critical enough to be assigned to the STM32. This division improves system modularity and communication efficiency.

The major features and optimizations of this module were summarized in **Table 10**.

Table 10: Onboard Computer Software Performance Improvements

Feature	Initial Design	Improvement
Video Pipeline	FFmpeg (~200 ms latency)	GStreamer (~50 ms latency)
Multi Camera Support	Single camera	Improved awareness and multi-role collaboration, increasing mission efficiency.

3. Embedded Control Software (STM32)

The embedded control software executed real-time control algorithms, processed sensor data, and drove the actuators. The PID control algorithm running on the STM32 was used primarily to maintain **depth and attitude stability**. It regulated depth using pressure-sensor feedback and adjusted roll, pitch, and yaw using IMU and depth-related feedback. In the current configuration, the four inner thrusters mainly supported depth, roll, and pitch control, while the four outer thrusters were responsible for planar motion and yaw

correction.

This resulted in improved attitude stability, reduced disturbance impact, approximately a 50% increase in pilot efficiency, and higher mission completion reliability.

3.5.3 Software Development and Testing Methodology

The software development process followed a structured and incremental approach to ensure reliable system integration. A Git-based workflow was used for version control, enabling effective collaboration and consistency. Development was modular, with independent components connected through standardized interfaces and integrated step by step from basic control to a complete operational system.

Testing was conducted at multiple levels, including unit testing for individual modules, integration testing for subsystem interaction, and field testing under real conditions. Task-based evaluations focused on stability, positioning, manipulation, and depth control. Key software features such as human-in-the-loop control, multi-camera visualization, and depth feedback were implemented to improve operator performance and mission efficiency.

3.6 Payload and Tools

The payload and tool systems of **Nemo** were designed to support mission-specific observation and manipulation tasks while preserving vehicle stability, maintainability, and operational flexibility. The current payload configuration included the **camera system** and the **gripper**, both of which were developed to improve task precision and reduce the risk of damage to delicate targets.

3.6.1 Camera System

To enable efficient underwater observation and precise task execution, **Nemo** was equipped with a high-definition camera mounted on a **two-degree-of-freedom (2-DOF) gimbal system**. The gimbal provided independent **pitch** and **yaw** control, allowing the operator to dynamically adjust the viewing direction without repositioning the vehicle. This enabled efficient switching between forward navigation and downward manipulation perspectives, improving operational flexibility during mission tasks.

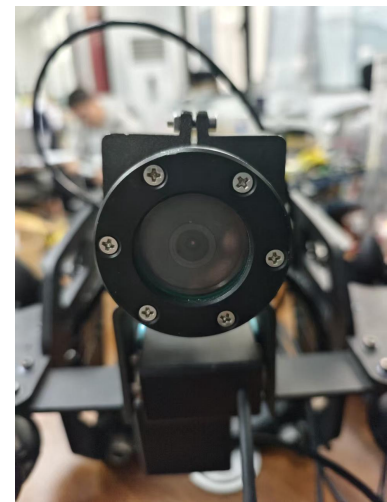


Figure 21: Nemo ROV Camera

The video stream was transmitted through the Ethernet communication link to the **topside system**, where it could be accessed by multiple topside workstations. This supported piloting, real-time image observation, and mission-related processing in parallel. By separating visual processing tasks from direct vehicle control, the system improved responsiveness and reduced the computational load on any single device.



Figure 22: ROV Gripper

In addition, a downward-facing camera was installed on the underside of the ROV for crab image recognition and bottom-view observation, helping operators more clearly identify target positions and surrounding conditions during seabed-related mission tasks.

3.6.2 Gripper

To equip **Nemo** with precise and safe manipulation capability, the ROV was fitted with a **3D-printed mechanical gripper** featuring a modular structure. This design supported rapid iteration, convenient maintenance, and easy replacement of damaged or upgraded components.

A key feature of the gripper was the use of **flexible material in the finger sections**, which provided adaptive grasping capability. This allowed the gripper to conform more effectively to irregular surfaces during operation and distributed contact forces more evenly. As a result, the design reduced the risk of damage when handling delicate targets such as coral or other fragile mission objects. Serrated contact surfaces were added to the gripper fingers to increase friction and reduce slipping during grasping, improving overall gripping stability.

In addition, the ROV was equipped with an auxiliary hook as a secondary manipulation tool to assist with mission tasks. In the event of accidental gripper damage or limited gripper functionality, the hook could still provide basic operational capability, improving overall mission reliability and system redundancy.

3.6.3 Retrieval tool

A carabiner (Figure 23) used for securing the buoy anchor was 3D printed using PETG material. Compared with more rigid materials, PETG provides improved flexibility and toughness, reducing resistance during the securing process and allowing Nemo to complete the operation more smoothly.

The retrieval rope was designed in red to improve underwater visibility, making it easier for operators to identify its position during operation. This also reduced the risk of the rope becoming entangled with the ROV after task completion due to limited underwater visibility, improving operational safety and mission reliability.

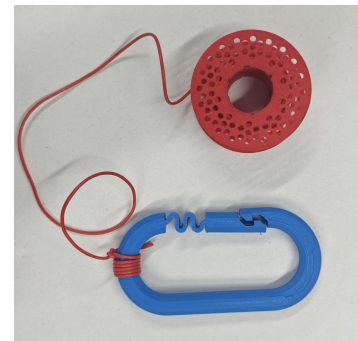


Figure 23: Retrieval tool

3.7 The "Tulkun" Float

Tulkun (Figure 24) is an autonomous vertical profiling float developed by Oceaners for the 2026 MATE float mission. Its primary task is to collect underwater pressure data beneath the ice while performing two vertical profiling measurements between depths of 2.5 m and 0.4 m. After the mission is completed, operators can connect to Tulkun's web interface through the topside workstation for real-time data display and analysis.

3.7.1 Mechanical Design

Tulkun uses an acrylic cylindrical enclosure as its main pressure housing. Both ends are sealed using metal flanges and O-rings to prevent water ingress into the electronics compartment. To improve operational safety, the endcaps also function as pressure-release components and can detach when internal pressure becomes excessively high.



Figure 24: Tulkun Float

Before deployment, Tulkun is configured to have slight positive buoyancy. The buoyancy adjustment system consists of a peristaltic pump and a 500 ml water bladder. When the peristaltic pump transfers water into the bladder, the overall weight of Tulkun increases, reducing buoyancy and causing the float to descend. When water is pumped out of the bladder, the overall weight decreases, allowing the float to rise. This system enables Tulkun to dynamically adjust buoyancy and perform vertical profiling tasks.

To simplify deployment and recovery in the ice pool environment, a U-shaped handle was installed on the top of the float. In addition, a circular support structure was added to the bottom of Tulkun to elevate the intake and outlet ports when resting on the pool floor, preventing blockage that could interfere with water transfer operations.

3.7.2 Electrical and Control Design

Tulkun uses an ESP32 microcontroller as the main control unit for receiving and processing depth sensor data. The ESP32 is connected to a motor driver board to control the peristaltic pump. Combined with a PID control algorithm, the system dynamically adjusts the float position according to the target depth to perform vertical profiling measurements.

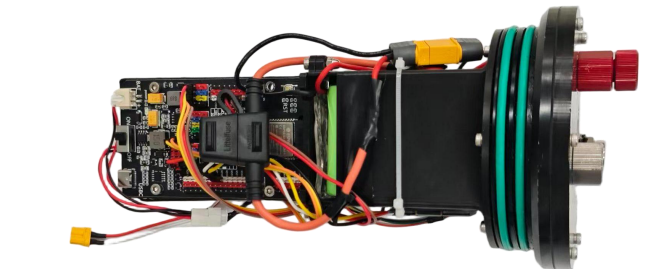


Figure 25: Tulkun internal electronic components

After completing the profiling task, the ESP32 transmits collected data to the topside workstation through its built-in WiFi module. Operators can connect to Tulkun's web interface via WiFi to view automatically generated data graphs and measurement results in real time.

The electronic system of Tulkun is powered by ten 2300 mAh NiMH batteries connected in series to provide a 12V power supply, meeting the operational requirements of the peristaltic pump and control electronics. To improve electrical safety, a 2A fuse was installed on the battery pack output line. When the system current exceeds the rated limit, the fuse automatically disconnects power to protect the onboard electronics and electrical system.

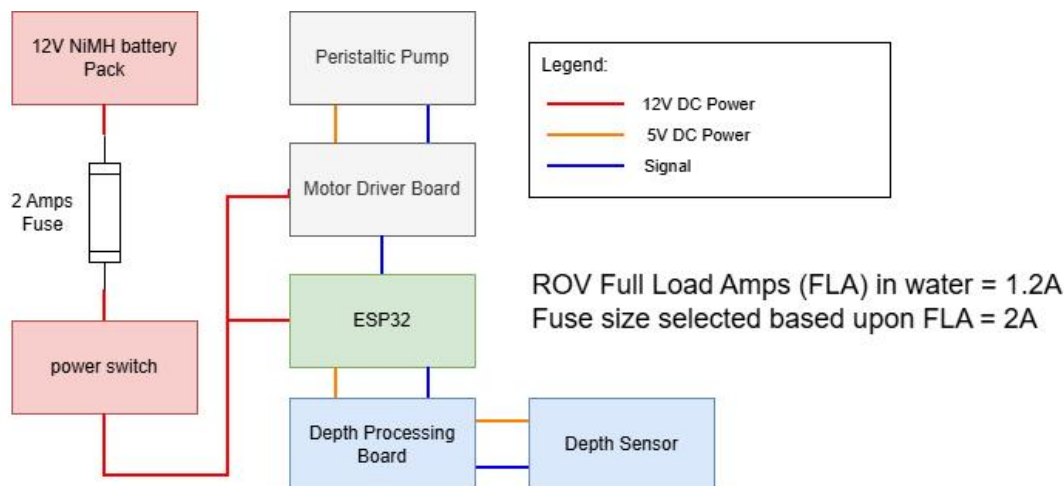


Figure 26: Tulkun Electronics Systems Integration Diagram (SID)

4. Safety

4.1 Safety Philosophy

Safety was integrated throughout the design, fabrication, testing, and operation of both **Nemo** and **Tulkun**.

Oceaners followed a preventive safety philosophy: potential risks were identified early and reduced through design choices, protective hardware, and standardized procedures, rather than being addressed only after failures occur. This approach helped protect **personnel, equipment, and the operating environment** during all stages of the project.

4.2 Safety in Design

System safety was achieved through **mechanical protection, electrical protection, and sealing verification**.

For **mechanical safety**, all exposed structural edges were rounded to reduce the risk of scratches or cuts during assembly, transport, and deployment. All thrusters were fitted with **IP20-compliant protective guards** to prevent accidental human contact with rotating components.

For **electrical safety**, Nemo used appropriate fuse protection near the power input to reduce the risk of electrical damage caused by overcurrent or short circuit. Tulkun employed a self-designed ESP32-based control board with a modular layout, color-coded functional interfaces, and reverse-polarity protection to reduce wiring errors and protect the circuit during assembly and operation.

For **sealing safety**, airtightness testing was conducted before deployment to verify enclosure integrity and reduce the risk of water ingress, which could cause electrical failure or loss of system control.

4.3 Operational Safety

Operational safety was maintained through standardized procedures during construction, pre-deployment inspection, and in-water operation.

During the **construction phase**, all components were assembled according to electrical and structural requirements, and interface labeling was used to reduce human error. During **pre-deployment**, Oceaners verified electrical connections, structural stability, strain relief, and sealing condition before launch. During **operation**, the team monitored system response, tether condition, and equipment status to reduce the risk of overheating, water ingress, entanglement, or unexpected mechanical failure.

To meet the experimental requirements of Wave Tank, Flume Tank, and Ice Tank, we are equipped with non-slip toe-protective shoes, safety gloves, life jackets, Warm layers and ice-traction footwear. In addition, we have established detailed standard operating procedures for safety.

5. Validation, Testing, and Critical Analysis

Validation and testing were conducted throughout the development of both Nemo and Tulkun to verify structural integrity, communication reliability, control performance, and mission readiness. Rather than treating testing as a final step, Oceaners adopted a phased and iterative methodology, combining dry-bench validation, pool testing, and full-system mission rehearsal to continuously refine the design.

5.1 Testing and Iterative Development

Testing served as a core driver of design evolution.

For the structural system, the team initially adopted a 3D-printed frame for rapid prototyping. However,

operational testing revealed insufficient strength under load, leading to deformation and fracture. The design was subsequently revised to a CNC-machined metal frame, significantly improving durability and reliability.

For the video transmission system, early tests using an FFmpeg-based pipeline resulted in approximately 300 ms latency, which limited real-time operability. The system was redesigned using GStreamer, reducing latency to approximately 50 ms and significantly improving responsiveness during piloting and mission execution.

For Tulkun, validation focused on leak resistance, vertical profiling behavior, depth-holding accuracy, and post-recovery data transmission. The float was validated through vacuum leak testing and repeated pool trials, confirming reliable autonomous profiling and successful data transmission after recovery.

These examples demonstrated how iterative testing enabled data-driven design decisions and continuous system improvement.

5.2 Testing Methodology and Procedures

Oceaners developed a structured testing protocol to ensure system reliability and reduce integration risk. Testing progressed from subsystem validation to full-system operation, including dry-bench testing, pool trials, and mission rehearsal.

Watertightness was verified using an air-pressure method followed by underwater validation. The enclosure was pressurized to 15 psi and held for 25 minutes, with stable pressure indicating effective sealing.

Video system testing focused on communication stability and latency performance, including long-duration streaming and validation of recording and data storage functions.

Control validation included thrust calibration, PID tuning, depth-hold verification, and repeated mission rehearsal until stable performance targets were achieved.

All testing results, observations, and corrective actions were documented, ensuring traceability and supporting iterative refinement.

5.3 Troubleshooting and Design Evaluation

A structured troubleshooting approach was used based on subsystem isolation, root-cause analysis, and iterative re-testing. Issues were identified through interface checks, parameter inspection, and controlled validation.

Representative problems included sensor data mismatches, PID overshoot, and tether drag, which were resolved through interface standardization, parameter tuning, and operational optimization.

Overall, testing and prototyping enabled Oceaners to make informed engineering decisions based on observed performance, improving the robustness and practicality of the final system.

6. Build vs. Buy (New vs. Reused)

Oceaners evaluated whether key subsystems should be **built in-house** or **purchased** based on mission suitability, reliability, maintainability, and cost. Components requiring strong customization, such as the **Tulkun control board**, **motor driver board**, and **gripper**, were developed in-house to better match mission requirements and support rapid iteration. Mature commercial components, including the **sealed**

enclosure, thrusters, and standard connectors, were purchased to reduce technical risk and improve reliability.

For the 2026 season, most major subsystems of **Nemo** and **Tulkun** were **newly developed or newly procured**. Existing design experience was retained where useful, but all final component choices were re-evaluated against this year's mission requirements before adoption. Overall, Oceaners followed a balanced strategy: **build where customization created clear mission value, and buy where commercial products provided better reliability and lower risk**.

7. Budget and Accounting

7.1 Budget Planning

At the beginning of the project, Oceaners established a preliminary budget based on the anticipated requirements of the 2026 MATE ROV Ranger Competition. In accordance with MATE guidance, the budget was prepared by **major categories** rather than by every individual part, allowing the team to estimate overall feasibility while retaining flexibility during design iteration. Major budget categories included **ROV structure, electrical and control systems, float development, payload tools, documentation, and travel**. All values were tracked in **USD**.

As development progressed, the budget was reviewed and adjusted according to test results, subsystem priorities, and actual procurement needs. This approach helped the team direct resources toward mission-critical items while avoiding unnecessary spending. A final comparison between the planned budget and actual project cost was completed after system integration, confirming that funds were allocated in a manner consistent with the technical priorities of **Nemo** and **Tulkun**.

A detailed budget table is included in **Appendix C**.

7.2 Funding Sources and Cost Accounting

Oceaners' project was funded through a combination of private funding and **in-kind contributions**. Direct project expenses, including purchased components and materials, were primarily covered by team members' families. Oceaners also received non-cash support from the **GoHack Innovation Club**, which provided access to training facilities, 3D printing equipment, and tools, and from the **IWIN-FINS Laboratory at Shanghai Jiao Tong University**, which provided testing facilities and technical support. These supporting organizations are also acknowledged in the acknowledgments section.

For accounting purposes, all items were recorded using a consistent classification system: **purchased, re-used, parts donated**, or **cash donated**. For all donated or re-used items and services, Oceaners assigned a **fair market value** and recorded the source of the contribution. This ensured that the total project value reflected both direct spending and non-cash support. All costs, including travel estimates, were recorded in **USD** to align with competition requirements.

This accounting method improved traceability, distinguished clearly between funding sources and expense types, and demonstrated effective use of available resources. The detailed costing records in **Appendix D** show how funds and donated resources were distributed across the major system categories for **Nemo**, **Tulkun**, and travel.

8. Conclusion

Within the development cycle, Oceaners successfully developed two integrated systems for the 2026 MATE ROV Ranger Competition: **Nemo**, a tethered ROV designed for precise underwater operation, and **Tulkun**, an autonomous profiling float designed for Task 4. Through structured project management, iterative design, subsystem-level testing, and full-system validation, Oceaners produced a reliable and maintainable underwater robotics platform that met Ranger-class mission requirements. The final system demonstrated effective integration of mechanical, electrical, control, and mission-support subsystems, while reflecting Oceaners' emphasis on practical engineering, cost-effective innovation, and continuous improvement.

9. Acknowledgments

Oceaners would like to express our sincere gratitude to the individuals and organizations whose support made this project possible.

First and foremost, we thank the parents of all team members for their continuous encouragement, financial support, and assistance with commuting throughout the 2026 season.

We also sincerely thank **our mentors and advisors** for their guidance, encouragement, and technical support throughout the design, fabrication, testing, and refinement of **Nemo** and **Tulkun**.

We would like to extend our special thanks to **Jinpu Zhang**, our **enterprise mentor**, for his professional guidance, engineering advice, and industry perspective throughout the development of the project.

In addition, we gratefully acknowledge the following organizations:

GoHack Innovation Club — for providing access to training facilities, 3D printing equipment, and various tools.

IWIN-FINS Laboratory at Shanghai Jiao Tong University — for providing an excellent testing environment and professional technical support.

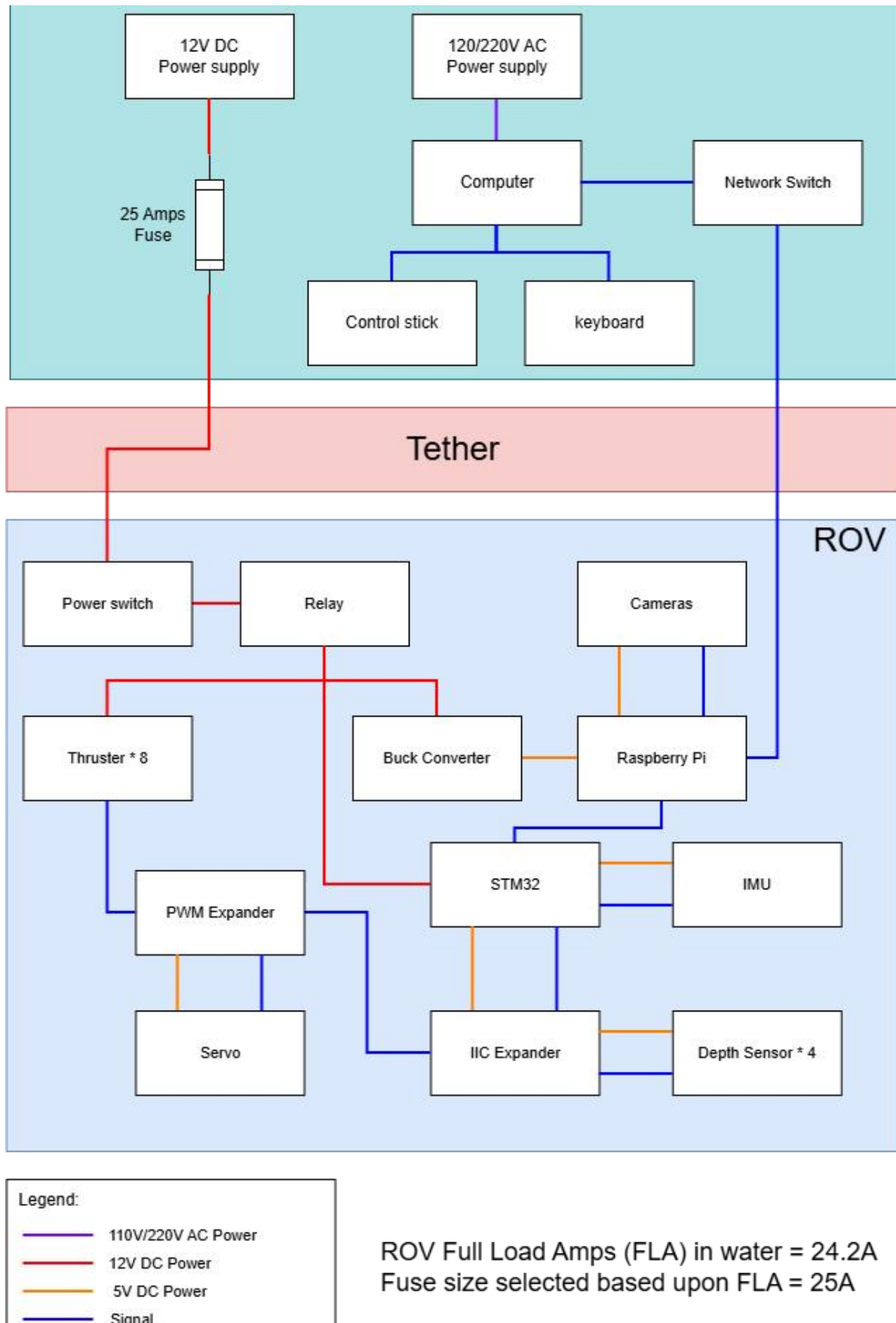
Finally, we appreciate the opportunity provided by the **MATE ROV Competition**, which has given our team a valuable platform to apply engineering knowledge, strengthen practical skills, and gain hands-on experience in underwater robotics.

10. References

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11. Appendices

Appendix A: Nemo ROV Electrical System Integration Diagram(SID)



Appendix B: Safety Check List

ROV Construction

Assembly

- ☐ Workplace is clean and dry
- ☐ Team members are wearing proper PPE (e.g., safety glasses, closed-toe shoes)
- ☐ At least two team members are present during assembly
- ☐ All components are securely mounted
- ☐ Frame structure is stable with no loose parts
- ☐ All edges are rounded with no sharp corners

Electrical & Power

- ☐ All wiring is correct and firmly connected
- ☐ No exposed conductors or damaged insulation
- ☐ Connectors are clearly identified and color-coded
- ☐ Power polarity is correct with no reverse connection
- ☐ Fuse is installed within 30 cm of the power source

Pre-Deployment

Sealing & Structure

- ☐ Endcaps are properly oriented and fully seated
- ☐ O-rings provide a complete seal
- ☐ Enclosure passed airtightness/vacuum test with no leakage
- ☐ No structural cracks, deformation, or loose components

Electrical System

- ☐ All electrical connections are stable
- ☐ Voltage and polarity are verified

Propulsion & Tether

- ☐ Thruster guards are installed and intact
- ☐ Thrusters rotate in the correct direction
- ☐ Tether is securely connected with no damage
- ☐ Tether strain is properly managed

Sensors & Vision

- ☐ Cameras and sensors are functioning properly

ROV Operation

Pre-Power Checks

- ☐ Fuse is properly installed
- ☐ All thruster guards are securely attached
- ☐ No obstruction around thrusters
- ☐ No exposed wiring
- ☐ Power source is secured
- ☐ Tether is secured to both ROV and control station

In-Water Operation

- ☐ Thrusters operate safely with no obstruction
- ☐ Safe distance maintained from moving parts
- ☐ Control system responds correctly
- ☐ No tether entanglement or excessive tension
- ☐ No signs of water ingress
- ☐ No abnormal temperature rise

Emergency Response

- ☐ System can be powered off immediately in case of abnormal conditions
- ☐ Monitor for abnormal bubbles indicating potential leakage

Recovery

- ☐ Ensure the ROV is fully stopped before retrieval
- ☐ Retrieve the ROV safely and notify the operator



Appendix C: Detailed Budget Breakdown Table

Incomes				
Source				Amount(\$)
Team Contributions				35200
Expenses				
Category	Type	Description	Projected Cost(\$)	Budgeted Value(\$)
Purchase	Hardware	ROV Frame	500	500
Purchase	Hardware	Thruster	300	300
Purchase	Hardware	Camera	300	300
Purchase	Hardware	others	100	100
Purchase	Electronics	Detachable tether plug	200	200
Purchase	Electronics	Tether	400	400
Purchase	Electronics	STM32/ESP32/Raspberry Pi 4B	300	300
Purchase	Electronics	others	180	180
Purchase	Sensors	Sensor	300	300
Purchase	General	Computer	400	400
Purchase	General	Tools	100	100
Donation	General	Training Venue Fee	200	0
Purchase	General	Team Uniforms	100	100
Purchase	General	Poster	20	20
Donation	General	ROV Pool Venue Fee	400	0
Purchase	General	Personal Protective Equipment	1400	1400
Purchase	Travel	Local Transportation	30000	30000
			35200	34600

Appendix D: Actual Cost Accounting Records

Date	Type	Category	Expense	Sources/Notes	Amount(\$)
2026/2/2	Purchase	Hardware	ROV Frame	CNC Machined ROV Frame	330
2026/2/2	Purchase	Hardware	Watertight Enclosure	ROV & Float Watertight Hulls	190
2026/2/2	Purchase	Hardware	Thruster	-	300
2026/2/2	Purchase	Electronics	Detachable Tether Plug	Detachable Cable Connector	175
2026/2/2	Purchase	Electronics	Tether	Ethernet & Power Cable	440
2026/2/2	Purchase	Electronics	STM32	-	55
2026/2/2	Purchase	General	Computer	-	400
2026/2/2	Purchase	General	Controller	Team-owned Controller	10
2026/2/2	Purchase	General	Tools	Team-owned Tools	30
2026/2/8	Purchase	Hardware	Camera	-	310
2026/2/8	Purchase	Hardware	Peristaltic Pump	-	13
2026/2/8	Purchase	Hardware	Power Switch	-	18
2026/2/8	Purchase	Hardware	Terminal Blocks	For ROV Internal Wiring	15
2026/2/8	Purchase	Electronics	Raspberry Pi 4B	-	120
2026/2/8	Purchase	Electronics	ESP32	-	12
2026/2/20	Purchase	Hardware	Power Supply	Float Power Supply	10
2026/2/20	Purchase	Hardware	Ballast	Float Ballast Weight	25
2026/2/20	Purchase	Electronics	Motor Driver Board	For Peristaltic Pump Control	10
2026/2/20	Purchase	Electronics	Relay	-	30
2026/2/20	Purchase	Electronics	Ethernet Switch	-	21
2026/2/20	Purchase	Sensors	Depth Sensor	4 for ROV, 1 for Float	210
2026/2/20	Purchase	Sensors	H30 IMU	-	37
2026/2/20	Purchase	Sensors	Servo	-	176
2026/2/20	Purchase	General	Air Tightness Testing Tools	-	40
2026/2/20	Donation	General	Training Venue Fee	Donated by Partner Institution	200
2026/4/4	Purchase	General	Team Uniforms	-	100
2026/4/4	Purchase	General	Poster	-	10
2026/4/4	Donation	General	Swimming Pool Venue Fee	Donated by Venue Partner	400
2026/4/25	Purchase	Travel	Local Transportation Expenses	Regional Competition Expenses	100
2026/4/30	Purchase	General	Personal Protective Equipment		1400
2026/4/30	Purchase	Travel	Transportation Expenses	World Championship Expenses	30000
					34587