

2026 Technical Documentation

**Blue Fins (New Team in Pioneer Class)
at Shanghai Jiao Tong University
Shanghai, China**



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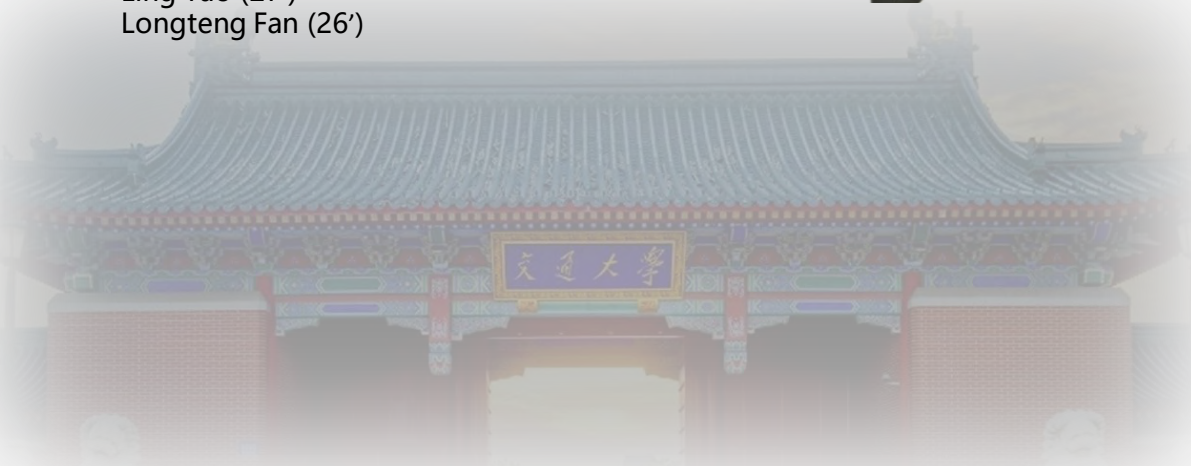
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Abstract

Blue Fins is a **first-year undergraduate team** from Shanghai Jiao Tong University that designs, builds, and tests underwater robotic systems for the 2026 MATE ROV Competition. We present **FinsROV**, a compact observation-class ROV, together with a complementary profiling float developed for the 2026 MATE Request for Proposals tasks, including seabed mapping, habitat monitoring, offshore energy support, and depth-hold operation.

FinsROV integrates an eight-thruster layout, a compact 4-DOF manipulator, binocular vision, and a two-layer onboard architecture combining a Jetson Orin NX with a DJI RoboMaster A-board running the FineMote control framework. The tether provides surface power and communication for the ROV, while the independent float is dedicated to the mission's depth-hold task. Development followed an iterative process of subsystem prototyping, integration, and pool testing, allowing the team to refine both hardware and software in parallel.

This report summarizes the organization, design rationale, subsystem implementation, safety practices, and accounting behind Blue Fins' first competition platform. Together, FinsROV and its supporting systems represent our effort to translate the 2026 MATE mission themes into a complete, competition-ready underwater robotic solution.



Fig. 1. **Blue Fins** Team Photo

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Teamwork

Company Overview

Blue Fins is a **newly established** and highly motivated team from Shanghai Jiao Tong University (SJTU), composed of 2 mentors and 19 undergraduate students. We are dedicated to developing intelligent, reliable, and sustainable underwater robotic systems for real-world marine applications, with a focus on underwater inspection, environmental monitoring, and scientific exploration. As a young team, we are united by a shared passion for marine technology and a strong commitment to innovation and sustainability.

Our team brings together students from diverse disciplines, including control, mechanics, communications, and marine science, enabling us to approach underwater robotics from both engineering and oceanographic perspectives. Through this competition^[1], we strive to strengthen interdisciplinary collaboration, enhance hands-on engineering skills, and foster innovation in ocean technology.

Company Organization

Blue Fins operates under a student-led organizational structure supported by two faculty mentors. The mentors provide funding and workspace, while also offering guidance on management, technical planning, and problem-solving throughout the competition season.

Within the team, students are responsible for the overall operation and development of **Blue Fins**, including recruitment, internal coordination, project management, system design, fabrication, testing, and deployment. To ensure efficient collaboration, the team is organized with clear leadership and division of responsibilities. Core management roles oversee ma-

jor decision-making, technical planning, budgeting, and team operations, while subsystem leads coordinate development in specific project areas and guide other members in implementation and documentation. This structure allows the team to maintain both effective management and smooth technical integration.

Position	Responsibilities
CEO	Defines overall team goals, coordinates major decisions, and manages external relations.
CTO	Leads technical planning and coordinates system integration.
CFO	Oversees budgeting and expenses.
COO	Oversees team operations, scheduling, and organizational coordination.
Technical Lead	Supervises subsystem development and mentors members within their areas.
Member	Contributes to design, build, testing, and documentation under lead guidance.

Table 1. **Blue Fins** Positions and Responsibilities

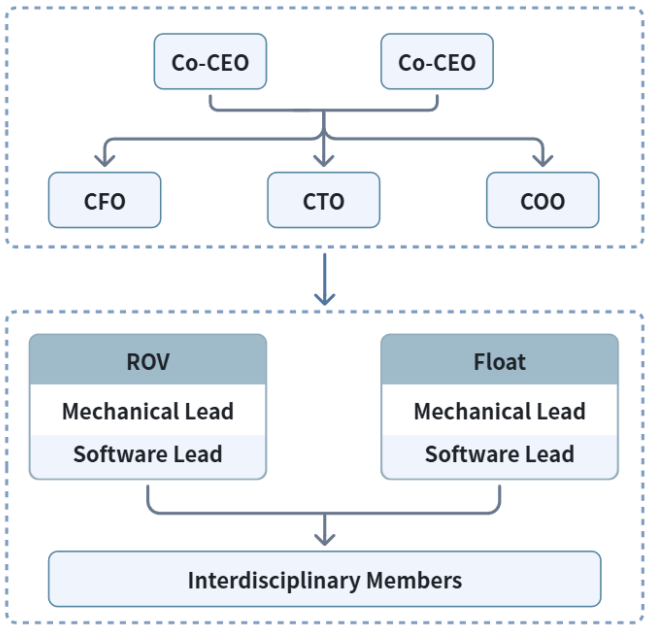


Fig. 2. **Blue Fins** Organizitional Structure

In addition, our organization reflects the dual-project nature of this year’s work, with dedicated leadership for both the ROV and float systems, supported by interdisciplinary members working across mechanical and software

tasks. This arrangement promotes communication across subsystems and helps us balance specialization with teamwork. Detailed position responsibilities and the overall organizational structure are shown in Table 1 and Fig. 2.

Project Schedule

As a newly established team, **Blue Fins** began this season without prior project foundation, including team formation, project planning, and the development of both the ROV and float systems. **Fig. 3** presents the timeline of all major tasks from December to April, with mechanical and software work progressing in parallel.

1. Team Recruitment and Project Planning

In December, we focused on building the team and establishing the project framework from the ground up. This phase included recruitment, role assignment, and the initial definition of the system roadmap.

2. Mechanical and Software Development

From January to February, both platforms entered their main development stage. During this period, hardware fabrication and software development were carried out in parallel to accelerate progress and establish the first complete subsystem prototypes.

3. System Integration and Prototype Assembly

From late February to March, the project shifted from separate development to integration. We assembled prototypes, connected electrical and software subsystems, and used early integration results to identify and resolve interface issues.

4. Testing, Validation, and Refinement

From March to April, we focused on testing, validation, and final refinement. Repeated trials allowed us to improve reliability and prepare both systems for stable competition performance.

		December	January	February	March	April
Team Recruitment and Project Planning	Team Recruitment and Organization	Team Recruitment and Organization				
	Project Planning	Project Planning				
ROV Mechanical Development	ROV Frame Design and Fabrication		ROV Frame Design and Fabrication			
	Manipulator Design and Fabrication		Manipulator Design and Fabrication			
	Electrical System Integration			Electrical System Integration		
	Prototype Assembly and Iteration				Prototype Assembly and Iteration	
	Testing and Validation					Testing and Validation
ROV Software Development	Firmware Development		Firmware Development			
	Computer Vision Development		Computer Vision Development			
	Software Testing and Integration				Software Testing and Integration	
Float Development	Float Mechanical Design and Fabrication		Float Mechanical Design and Fabrication			
	Float Control Software Development			Float Control Software Development		
	Float Testing and Validation				Float Testing and Validation	

Fig. 3. Project Schedule

Overall, the schedule reflects a step-by-step process of building a new team and two competition systems from scratch. It also shows how parallel development and continuous iteration supported steady progress throughout the season.

Resources & Protocols

To support efficient project execution and effective collaboration across the team, we have established a clear set of communication, project management, and development protocols. These resources help us coordinate daily work, track progress, manage technical materials, and maintain smooth collaboration among members from different subteams.

A weekly team meeting is held every Friday evening, during which members report progress, discuss technical problems, share new ideas, and plan upcoming tasks. After each meeting, key decisions, progress updates, and future plans are documented in Lark to maintain continuity and ensure that all subteams remain aligned throughout the competition season.

For daily collaboration, We primarily use **WeChat, Lark, GitHub, and Autodesk Fusion 360** as its main working platforms. WeChat is used for rapid communication and urgent notifications, Lark serves as the central platform for project management and documentation, GitHub supports code storage and version control, and Autodesk Fusion 360 is used for collaborative mechanical design. Together, these tools provide the foundation for efficient coordination, clear information sharing, and parallel development across the team.

By combining regular communication, centralized documentation, and shared development tools, **Blue Fins** is able to maintain an organized workflow throughout the competition

season. These protocols not only improve day-to-day coordination, but also help ensure continuity, accountability, and steady progress across all aspects of the project.

Design Rationale

Systems Approach

Blue Fins adopts a highly **collaborative and parallel systems approach** throughout the development of both the ROV and float platforms. While the team is managed through a layered structure with clear responsibilities, as shown in Table 1 and Fig. 2, communication remains open and frequent across all members. This combination of structured management and active cross-team interaction is one of the strengths of our young team, allowing ideas, feedback, and technical adjustments to move quickly between subteams.

System-level decisions are primarily discussed during **weekly team meetings**, where members share progress, raise technical challenges, and coordinate next steps. These meetings help align mechanical and software development, ensure consistency across subsystems, and support joint decision-making on key design issues. Beyond formal meetings, team members maintain continuous **day-to-day communication** through WeChat, which enables rapid discussion and timely responses to emerging problems. Lark is used for project planning, progress tracking, technical documentation, and meeting records, while GitHub manages all software and firmware repositories through a shared team organization. For mechanical development, Fusion 360 supports collaborative CAD design and file management. Together, these tools create an efficient workflow for communication, documentation, version control, and design coordination.

From the beginning of the season, **Blue Fins** has developed the ROV and float projects **in parallel**, while also advancing mechanical and software work simultaneously. The ROV mechanical team carried out frame and manipulator design and fabrication, while the software team worked in parallel on firmware and computer vision development. During the same period, the float group simultaneously advanced its mechanical design and control software. This parallel approach improved efficiency and allowed early coordination between related subsystems.

As development progressed into late February and March, the focus shifted from subsystem development to integration. Electrical system integration, prototype assembly, and iterative refinement were carried out alongside software testing and integration, ensuring that hardware and software matured together rather than sequentially. In March and April, both the ROV and float systems entered testing and validation, where feedback from integration and trial operation was used to refine performance and improve reliability.

Overall, our systems approach emphasizes parallel development, continuous communication, and early integration. By maintaining close coordination across the ROV and float projects, as well as across mechanical and software teams, **Blue Fins** is able to reduce design inconsistency, respond quickly to technical challenges, and steadily move toward a cohesive and competition-ready system.

Vehicle Structure

The structural design of *FinsROV* was **independently developed** by our team, with reference to the general open-frame concept used in earlier IWIN-FINS Lab platforms^[2]. To meet the mission requirements^[1], we designed a **compact, lightweight, and highly**

expandable architecture that provides sufficient internal volume and flexible mounting interfaces for mission payloads, including the vision system and a self-developed **multi-degree-of-freedom force-controlled robotic arm**. To maintain strong maneuverability, *FinsROV* adopts an eight-thruster configuration to achieve full omnidirectional motion underwater.

The vehicle structure integrates an aluminum-alloy frame, a 2-DOF camera gimbal, an acrylic waterproof housing for the electronic and control modules, PVC foam buoyancy blocks, and the manipulator system. **The following subsections describe these major structural components and the corresponding design considerations in detail.**

Frame & Camera Gimbal

The frame and camera gimbal are both fabricated from **5052 aluminum alloy** and together form the main aluminum structural subsystem of *FinsROV*. These components directly affect overall vehicle weight, maneuverability, manufacturability, and subsystem integration. In our design, the frame must provide sufficient stiffness for the eight-thruster configuration while supporting the pressure housing, buoyancy blocks, camera gimbal, and manipulator system, while the gimbal must remain lightweight enough for agile camera positioning. To satisfy these requirements, the structural design prioritizes low density, adequate strength, corrosion resistance, and compatibility with efficient in-house fabrication. After comparing several candidate materials, we selected 5052 aluminum alloy as the primary material for both components. Relative to stainless steel, it greatly reduces structural mass while still providing sufficient strength and stiffness for the current vehicle scale. Compared with higher-strength but less formable materials, 5052 also offers a better

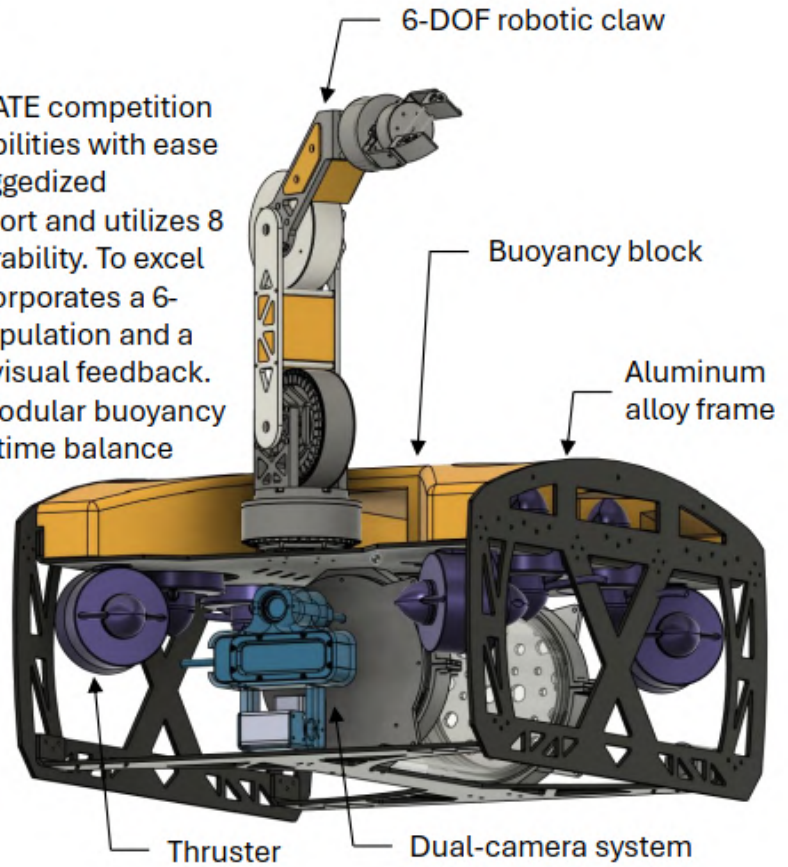
FinsROV

Note: all dimensions in this page are in millimeters

Design Overview

FinsROV is engineered specifically for MATE competition tasks, balancing high-performance capabilities with ease of deployment. The vehicle features a ruggedized aluminum alloy frame for structural support and utilizes 8 thrusters to achieve full 6-DOF maneuverability. To excel in complex underwater operations, it incorporates a 6-DOF robotic claw for high-precision manipulation and a dual-camera system for comprehensive visual feedback. Furthermore, integrated sensors and a modular buoyancy system ensure optimal stability and real-time balance control.

An autonomous profiling float is also engineered for precise depth-hold and data collection tasks. It features a pump-driven buoyancy engine within a durable acrylic housing. Managed by an ESP32 controller, the system utilizes advanced PD control to ensure hovering stability and reliable WiFi data transmission upon surfacing.



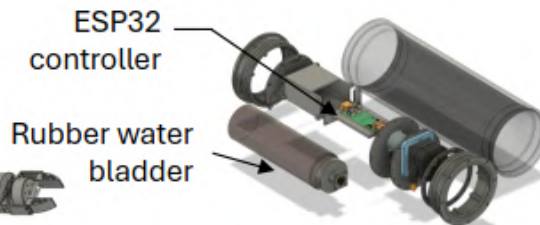
6-DOF robotic claw



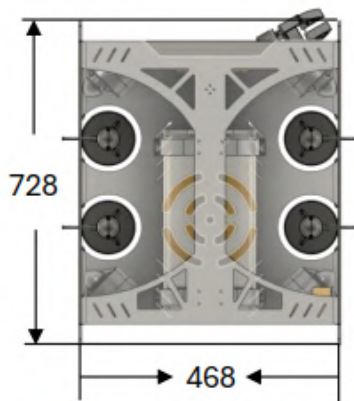
dual-camera



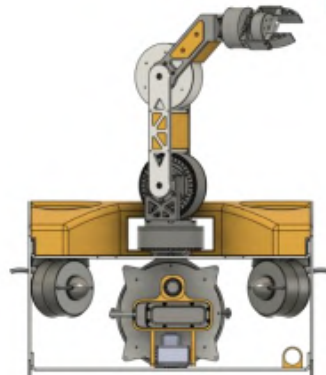
Overview of the float designed for Task 4



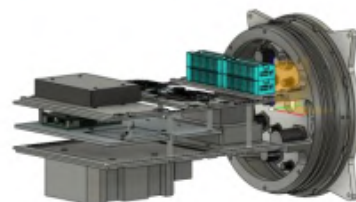
Interior structure of float



The bottom of FinsROV



The front of FinsROV



Interior structure of FinsROV

Material	Density (g/cm ³)	Yield Strength (MPa)	Corrosion Resistance	Manufacturability	Relative Cost
5052 aluminum alloy	≈ 2.68	≈ 190	High	Excellent	Low
304 stainless steel	≈ 7.93	≈ 215	High	Medium	Medium
Titanium alloy	≈ 4.43	≈ 800	Excellent	Low	High

Table 2. Comparison of Candidate Frame Materials for FinsROV ^[3]

balance among corrosion resistance, bendability, and manufacturing cost, making it particularly suitable for the sheet-metal structure adopted in *FinsROV*.

As summarized in Table 2, 5052 aluminum alloy does not provide the highest absolute strength, but it offers **the most balanced** combination of low weight, corrosion resistance, and manufacturability for our application. In particular, its low density is highly beneficial for reducing total vehicle mass, while its good formability makes it well suited to bent plates, brackets, and mounting members produced through sheet-metal processes. This supports rapid structural iteration during prototyping and simplifies replacement if individual parts are damaged during testing.

The frame is manufactured primarily through sheet-metal cutting and bending, which keeps the fabrication workflow simple, cost-effective, and time-efficient while maintaining good dimensional accuracy for assembly. Its geometry is designed to provide reliable mounting points for the pressure housing, buoyancy blocks, thrusters, manipulator, and auxiliary components while preserving an open architecture for maintenance and future expansion. To improve durability in underwater environments, the aluminum surfaces are anodized to mitigate corrosion and enhance surface stability.

The camera gimbal follows the same 5052 aluminum-alloy and sheet-metal process route, which helps maintain consistency

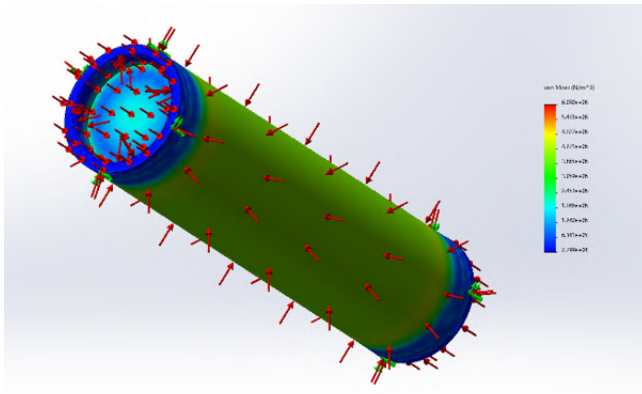
in fabrication and spare-part management. Together with two servo motors, it forms a 2-DOF mechanism that provides horizontal (yaw) and vertical (pitch) rotation for the forward vision system, allowing the pilot to adjust the viewing direction according to task demands. Using the same lightweight material solution for both the frame and the gimbal reduces structural mass while maintaining a unified and practical design philosophy across the aluminum structural subsystem.

Pressure Housing

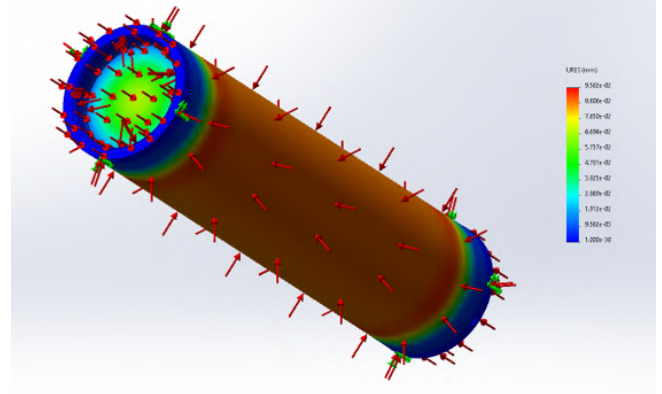
To protect the onboard electronics, *FinsROV* uses a dedicated waterproof pressure housing designed with **sufficient sealing and structural margin for underwater operation**. The waterproofing scheme combines a pressure-resistant acrylic tube, matched aluminum flanges, O-ring sealing interfaces, sealed through-hull connectors, and epoxy reinforcement at critical sealing locations. This arrangement keeps the electronic and control modules dry while still allowing reliable cable routing, convenient assembly, and regular maintenance.

1. Acrylic Pressure Hull

The housing body uses a cylindrical SUBLAB acrylic pressure hull^[4] with an inner diameter of 151 mm, an outer diameter of 165 mm, and a length of 300 mm. It provides sufficient internal volume for the circuit and control components while maintaining a compact footprint inside the vehicle frame. The transparent acrylic body also allows quick external inspection



a) Equivalent stress distribution, with a maximum von Mises stress of 6.09×10^6 N/m².



b) Displacement distribution, with a maximum displacement of 9.56×10^{-2} mm.

Fig. 4. FEA results of the pressure hull at 30 meters water depth, showing the stress and displacement response of the structure.

of the internal electrical status, which helps with troubleshooting and early fault detection during testing and competition preparation. According to manufacturer data, the hull is rated to a depth of 80 m, which is well above the required operating depth. In addition, a 30 m pressure simulation reported a maximum von Mises stress of 6.09×10^6 N/m², far below the approximate acrylic strength limit of 1.1×10^8 N/m². This indicates that the selected hull provides sufficient structural margin for the intended application.

2. Flanges, Seals, and Connectors

Matched aluminum flanges are used at the two ends of the acrylic tube to support the hull body, provide O-ring compression, and offer mounting locations for penetrators and other sealing features. The O-ring interfaces form the primary end-cap seal, while epoxy is applied at selected sealing locations to further improve water resistance and long-term reliability. Cable penetrations use HUBOSWER IP68 underwater connectors mounted on the end closures, allowing each pass-through to be sealed independently while preserving the integrity of the cylindrical hull. This approach

simplifies cable management and reduces the risk associated with direct cable exits through the tube wall.

Component	Parameter	Selected Value
Pressure hull	Material	Transparent acrylic
	Inner diameter	151 mm
	Outer diameter	165 mm
	Length	300 mm
	Rated depth	80 m
	Weight	1092 g
Flange	Material	Aluminum alloy
	Outer diameter	165 mm
	Weight	276 g

Table 3. Selected Pressure Housing and Flange Parameters^[5]

The key parameters of the pressure housing and flange assembly are summarized in Table 3. Overall, this design provides a practical balance among structural safety, sealing reliability, visual inspectability, and ease of integration within the open-frame vehicle architecture.

Buoyancy Blocks

The buoyancy blocks are a key part of the static-balance design of *FinsROV*, providing the uplift needed to offset the weight of the frame, pressure housing, thrusters, and other onboard components. In addition to supplying sufficient buoyancy, this subsystem must remain dimensionally stable underwater, resist water absorption, and allow convenient trimming during integration so that the final center of buoyancy and vehicle attitude can be adjusted efficiently.

To satisfy these requirements, we selected PVC foam as the buoyancy material. PVC foam combines low density, low water absorption, good pressure resistance, and easy machinability, allowing the blocks to be shaped to match the open-frame layout while keeping the vehicle compact. With a density of about 0.1 g/cm^3 and pressure tolerance suitable for approximately 50 m water depth, the buoyancy blocks provide reliable flotation margin and also function as modular trimming elements for fine adjustment of vehicle balance.

Manipulator

The manipulator consists of joint motors, structural links, and an end-effector^[6]. Material selection for each part balances load capacity, corrosion resistance, manufacturability, and lightweight performance.

1. Joint Motor

The outer rotor and stator coil are adapted from a standard frameless torque motor. The outer rotor consists of permanent magnets and anodized aluminum alloy, while the stator coil uses a silicon-steel stator and copper enameled wire.

The stator is protected by electrophoretic anti-corrosion treatment, and the coil is encap-

sulated with epoxy resin. Other components are self-designed: the front cover, stator shaft, and motor base are made of anodized 60-series aluminum alloy; the stator bearings are stainless steel; the FOC drive board is epoxy-potted; and the radial magnet is mounted on an ABS 3D-printed base.

2. Joint Links

The links use a combination of ABS, anodized 70-series aluminum alloy, and carbon fiber plate according to the structural demands of each joint. Joint 1 carries the highest load and involves relatively difficult machining, so aluminum alloy is selected to ensure sufficient strength. Joint 2 emphasizes both strength

and lightweight performance, and therefore uses carbon fiber with an embedded ABS buoyancy block. Joint 3 adopts a single-link structure with high deflection resistance requirements, so it uses aluminum alloy together with an ABS buoyancy block to reduce underwater weight. To solve the water leakage risk caused by poor interlayer bonding in Fused Deposition Modeling (FDM), the buoyancy blocks are post-treated with acetone to dissolve surface layers and re-solidify, eliminating leakage hidden dangers.

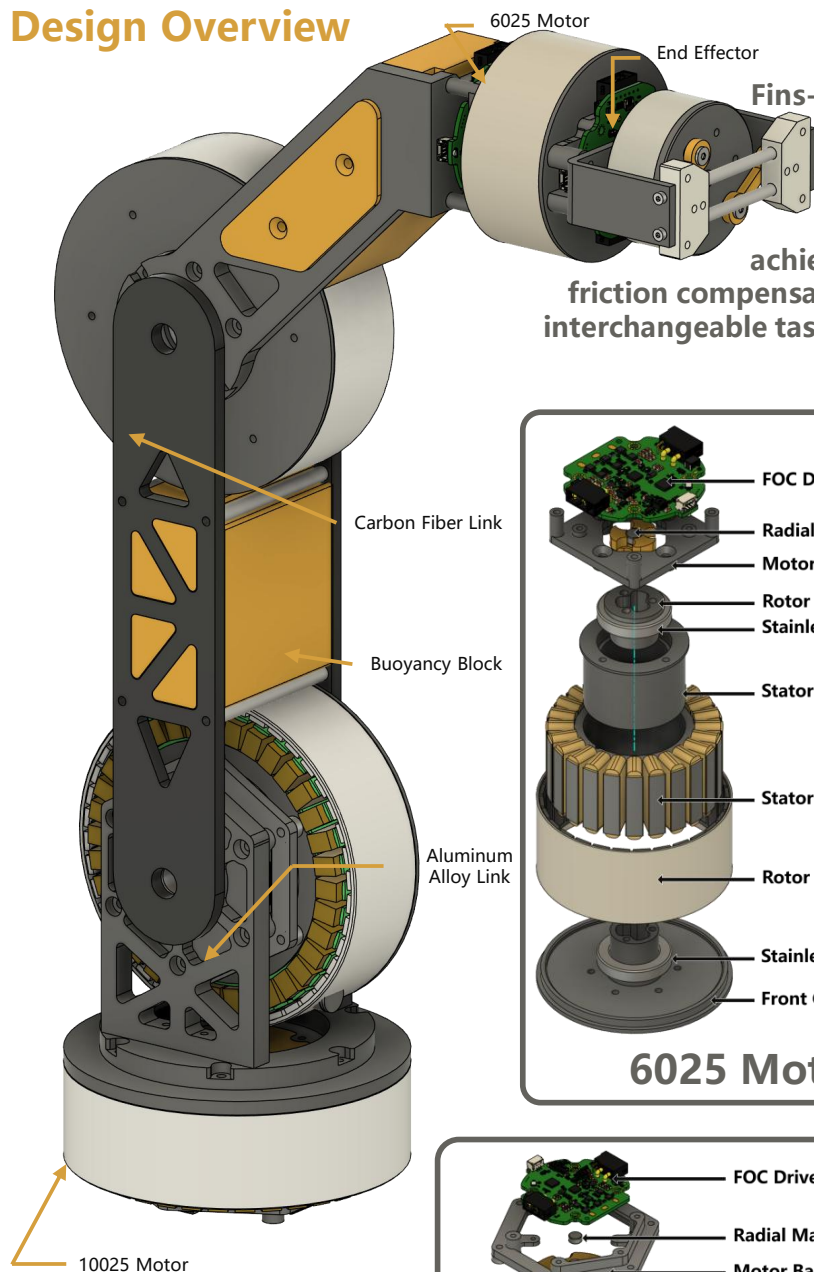
3. End-Effector

The end-effector uses a stainless steel smooth shaft as the guide rail, a self-lubricating POM slider, an ABS link, and stainless steel bearings. This combination provides a practical balance between precision, wear resistance, corrosion resistance, and manufacturing cost for the grasping mechanism.

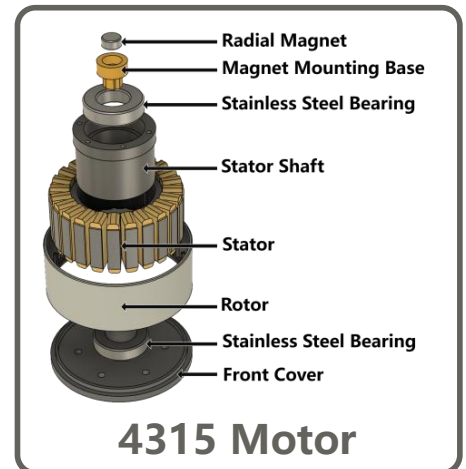
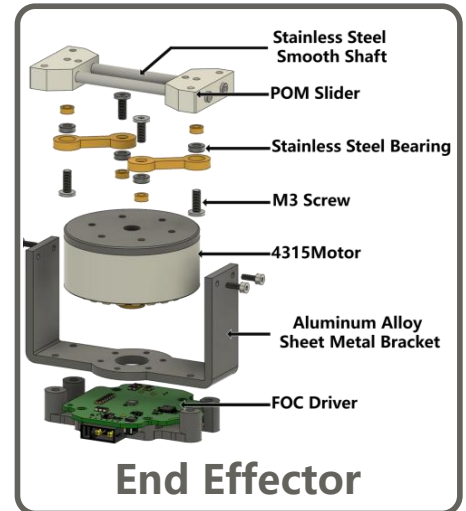
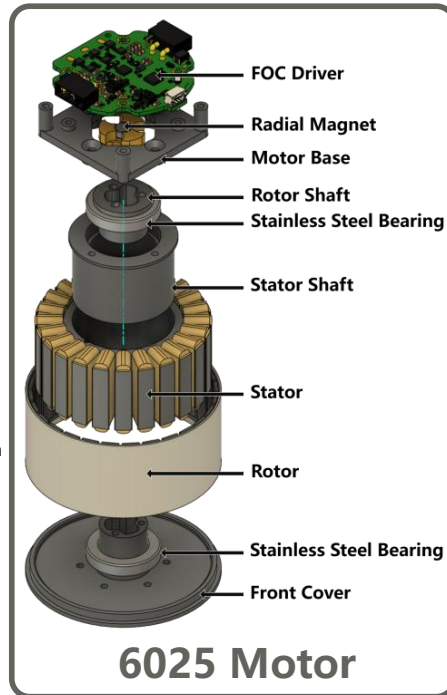
Overall, the manipulator design balances machinability, cost, and structural strength by using aluminum alloy for complex or high-load components, ABS for lightweight and low-cost buoyancy-related parts, carbon fiber where mass reduction is especially important, and

MANIPULATOR

Design Overview



Fins-ROV employs a 4-joint motor + end effector manipulator design. Unlike conventional underwater manipulators with harmonic reducers and double-layer dynamic seals, it uses custom direct-drive joint motors to achieve precise underwater force control without friction compensation. The end effector's POM sliders support interchangeable task-specific grippers, ensuring high versatility.



Joint Torques

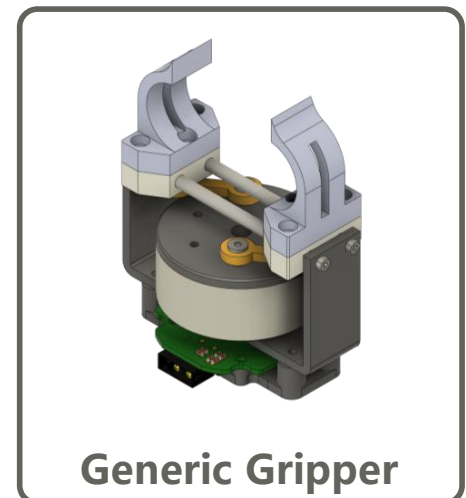
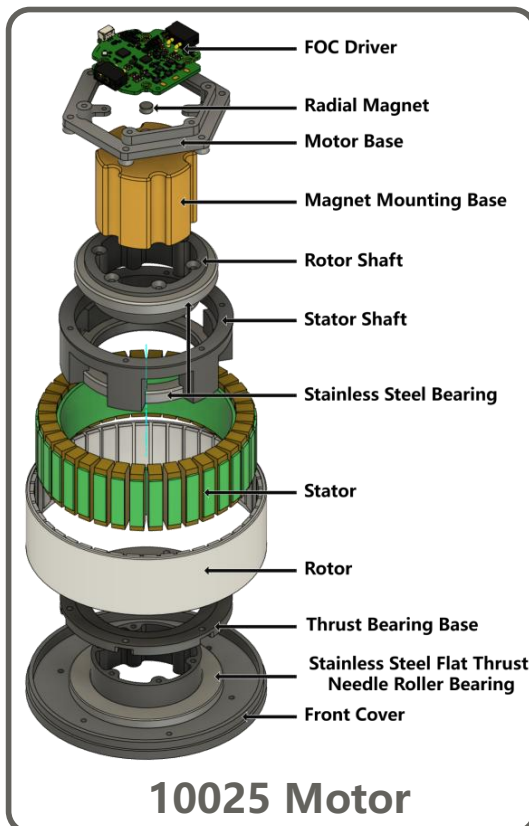
Joint 1: 6 N•m

Joint 2: 6 N•m

Joint 3: 6 N•m

Joint 4: 1.5 N•m

End Effector: 0.6 N•m



off-the-shelf stainless steel parts for precision and wear-critical elements.

Control and Electrical Systems

Power Electronics

FinsROV adopts a hierarchical power architecture centered on a **48 V DC input**. Because the thrusters, manipulator, and several onboard subsystems operate at lower voltages, the main supply is first stepped down to 24 V through a DC–DC converter and then distributed by a dedicated power distribution board. In addition, the DJI RoboMaster A board used as the low-level controller provides regulated 12 V and 5 V auxiliary outputs, forming **three onboard power rails: 24 V, 12 V, and 5 V**.

The 24 V rail powers the thrusters, MCU, NVIDIA Jetson Orin NX, and manipulator. The 12 V rail is used for the pressure sensor and camera lighting, while the 5 V rail supplies the camera gimbal servos. This arrangement simplifies electrical integration, matches the voltage requirements of each subsystem, and improves the overall reliability of the onboard power system.

MCU

The low-level controller is a **DJI RoboMaster A board**^[7] based on an STM32F4 microcontroller. It serves as the real-time control core of the vehicle and provides sufficient PWM channels, UART interfaces, and auxiliary power outputs for the integrated system. Within the overall control architecture, this board is responsible for deterministic sensing and actuation tasks that must remain stable under underwater operating conditions.

The MCU reads the pressure sensor and IMU through UART interfaces, executes PID-based control algorithms, and outputs PWM com-

mands to the eight thrusters, servos, and lighting system. It also maintains serial communication with the onboard computer, receiving high-level motion commands and converting them into reliable low-level actuator control. This partition enables stable attitude regulation and robust task execution while keeping mission-level computation separated from the time-critical control loop.

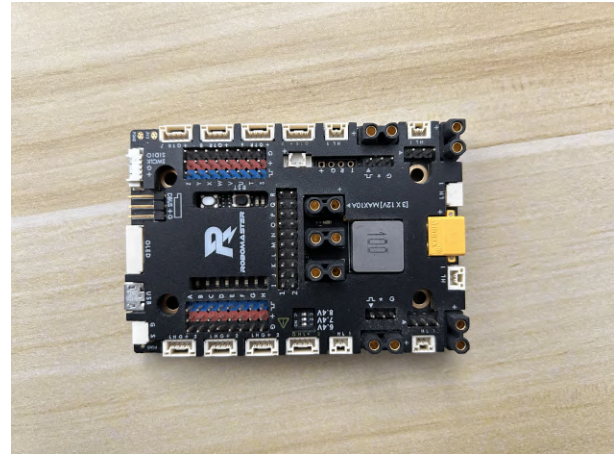


Fig. 5. Physical view of the DJI RoboMaster A board.

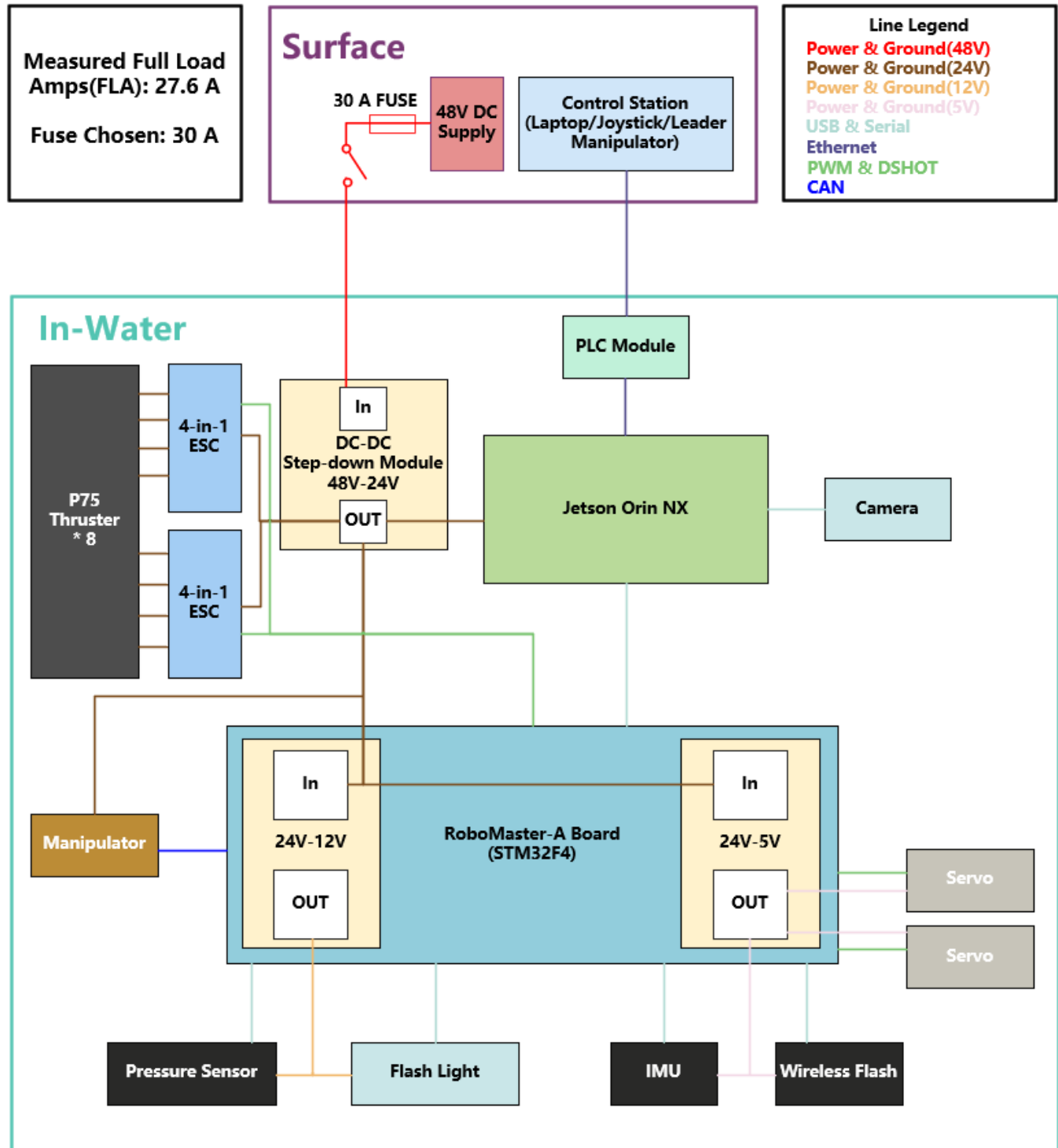
Onboard Computer

The onboard computer is an **NVIDIA Jetson Orin NX**^[8], selected for its embedded computing performance, software flexibility, and suitability for vision-intensive workloads. It runs Linux and acts as the middleware layer between the low-level controller and the surface operator system. On the vehicle side, it communicates with the MCU through a serial interface to exchange commands, status information, and sensor-related data.

Communication with the topside laptop is implemented through a PLC (power-line communication) module. Through this link, the Jetson forwards real-time video streams, relays telemetry, and receives operator commands from the surface. In this way, the onboard computer provides the computational bridge

System Integration Diagrams (SIDs) of FinsROV

Electrical SID



between perception, communication, and supervisory control while leaving time-critical motion control to the MCU.



Fig. 6. Physical view of the Jetson Orin NX.

Ground Station

The ground station forms the surface-side operator layer of the complete control system. It connects to the Jetson Orin NX through the **power-line carrier link** and interacts with the vehicle exclusively through that network path. The operator accesses the onboard web interface and live video stream through a standard browser, while outbound commands from the joystick and custom controller are transmitted over the same link and then forwarded by the Jetson to the A-board via serial communication.

Functionally, the ground station integrates operator input, live video monitoring, and task-level computation. Placing these workloads on the surface improves usability for the pilot and copilot, reduces the computational burden on the vehicle, and preserves a clear separation between mission-level decision support and onboard real-time control. This organization is consistent with the overall design goals of modularity, maintainability, and control reliability.



Fig. 7. Ground station schematic.

Tether Construction

The tether of **Blue Fins** is designed to satisfy two primary engineering requirements: **safe power transmission** and **stable long-distance communication** between the surface and the vehicle. The selected 50-meter tether, specified as model **rstlkable 73800**, combines a subsea-suitable outer jacket with an internal cable arrangement optimized for underwater deployment, repeated handling, and reliable electrical performance.

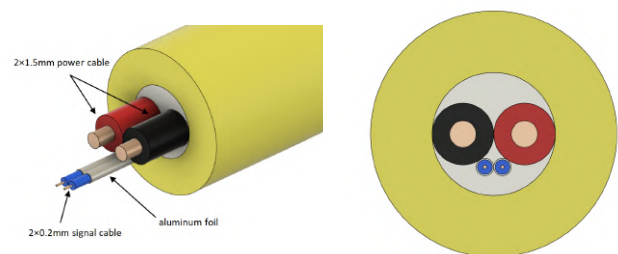


Fig. 8. Tether cross-section diagram.

1. Tether Jacket

The tether jacket is made of imported seawater-resistant foamed polyurethane (PUR). This material provides a near-zero-buoyancy characteristic, helping the tether maintain neutral behavior underwater and reducing disturbance to vehicle maneuvering.

It also offers strong saltwater corrosion resistance and high flexibility, allowing the tether to withstand repeated deployment and recovery cycles in subsea operating conditions.

2. Power Cables

Two internal power conductors are used to transmit vehicle power, with stranded ultra-fine annealed oxygen-free copper wires compliant with VDE0295 CLASS 6. This conductor structure provides high flexibility and fatigue resistance, which is important for repeated bending during launch, recovery, and routine operation. To balance electrical performance and cost, bare copper conductors are adopted in the final configuration.

Tether Management Protocol

- 1) A dedicated team member must be assigned to manage the tether during all ROV operations.
- 2) The tether should be neatly arranged on the deck in an organized layout to prevent tangling, kinking, or twisting.
- 3) Before deployment, the tether must be correctly connected to the surface station, including power and signal connections.
- 4) The tether handler should release only enough cable length to allow the ROV to reach its working depth without excessive slack.
- 5) The pilot must avoid performing continuous 360° rotations and close movements near obstacles to reduce entanglement risks.
- 6) Team members must never step on or crush the tether, as this may damage internal power and signal wires.
- 7) After operations are finished, the tether must be safely disconnected from the surface station and properly coiled for storage.

3. Signal Cables

Two signal conductors configured as a twisted pair serve as the transmission medium between the surface-side and onboard power-line carrier modules. The twisted-pair structure improves noise immunity during long-distance communication, while the added aluminum-foil shield suppresses electromagnetic interference from nearby power lines and onboard electrical equipment. A non-woven wrapping layer is further included to improve abrasion resistance and protect the signal pair mechanically.

This combination of twisted-pair transmission, shielding, and structural wrapping ensures stable and low-noise signal communication throughout tether operation, reducing the risk of interference from the subsea environment and from adjacent power conductors.

Software Systems

Our software stack is organized around three tightly coordinated layers: the **ground station**, the **Jetson NX companion computer**, and the **A-board FineMote control stack**. This partition follows the actual operational flow of the vehicle during competition. The ground station handles human-in-the-loop operation, task execution, and video consumption. The Jetson NX acts as the onboard middleware, managing camera acquisition, video streaming, telemetry relay, and command forwarding. The A-board focuses exclusively on deterministic real-time motion control, actuator coordination, and hardware abstraction.

1. System Data Flow

Control commands originate at the ground station joystick and custom controller, travel over the power-line carrier link to the NX, and are forwarded by the protocol node to the A-board over serial. The A-board translates these commands into actuator outputs and closes the motion control loop using onboard

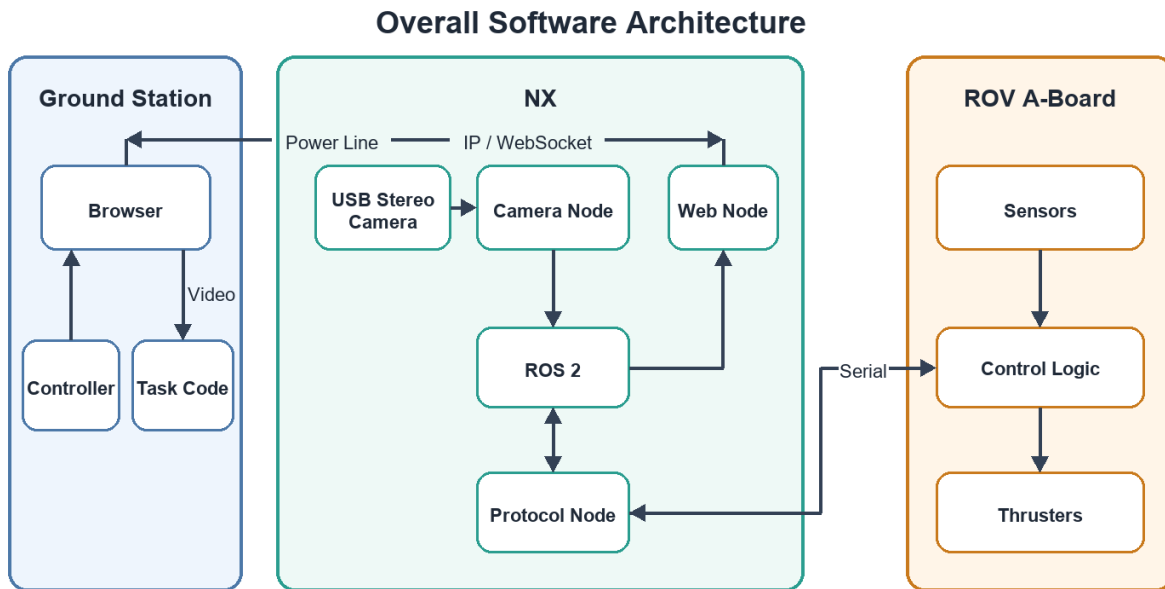


Fig. 9. Overall software architecture of the **Blue Fins** ROV system

sensor feedback. In the reverse direction, the A-board sends debug and sensor data over serial to the NX protocol node, which publishes them as ROS topics. The web node picks up these telemetry topics and pushes them to the operator browser over WebSocket alongside the live video stream. The same video stream is consumed by surface-side task code modules for vision inference and 3D reconstruction.

2. Ground Station

At the surface side, the software system contains three major functionalities:

- **Task code**, including mission-oriented algorithms such as the Task 1.2 scaled 3D reconstruction pipeline and the Task 2.1 invasive species detection module. Both modules consume the live video stream received from the NX as their primary data source.
- **Human control input**, which converts pilot and copilot commands into structured control messages and transmits them to the NX over the power-line carrier link.

- **Camera streams**, which receive the browser-delivered video stream published by the NX and present it to the operator and task code modules through a unified web interface.

3. Jetson NX Companion Computer

Inside the ROV, the **Jetson NX** runs a ROS 2 environment that contains several major software nodes:

- **Camera node**, which reads frames from a stereo USB camera and publishes them as ROS topics.
- **Protocol node**, which maintains the serial connection to the A-board, publishes incoming debug and sensor information as ROS topics, subscribes to the control-command topic, and forwards those commands to the A-board over the same serial link.
- **Web node**, which subscribes to image and telemetry topics, encodes the video stream using GStreamer, and delivers the operator webpage, video stream, and telemetry to the ground station over IP and

WebSocket.

- **Node.js backend**, which runs alongside the ROS 2 nodes and serves the web interface.

Ground station and NX communicate exclusively through the **power-line carrier link**. The surface operator accesses the NX by IP address and port number, retrieving the operator webpage and video stream through the same network path. Outbound control commands from the joystick and custom controller are similarly routed over this link to the NX, which forwards them to the A-board via serial.

4. A-board FineMote Control Stack

The **A-board FineMote control stack** receives motion commands from the NX through the serial link and executes the core real-time control logic, driving the propulsion and sensing hardware directly.

This layered partition was selected to satisfy four engineering goals: **modularity**, **maintainability**, **real-time responsiveness**, and **expandability**. Separating the computationally heavy surface tasks from the NX middleware and the deterministic A-board controller means that algorithm changes on the surface do not affect vehicle stability, and NX-side updates do not require reflashing the low-level controller.

Task Code

The task code layer contains competition-oriented software modules that run on the ground station and consume the video stream received from the NX. In the current system, two major applications are integrated into this layer:

- **Task 1.2:** scaled 3D digital reconstruction and measurement of the coral garden ridge.
- **Task 2.1:** automated detection and count-

ing of invasive green crabs.

Both modules use the WebRTC video stream from the NX as their primary visual input. Running them on surface-side hardware gives them access to stronger compute resources, easier debugging workflows, and greater algorithmic flexibility than an embedded-only deployment.

Scaled 3D Digital Model

Task 1.2 requires the development of a scaled 3D digital model of the coral garden ridge using autonomous photogrammetry, together with a measurement workflow for dimensional estimation. To support this task, we deploy the underwater 3D reconstruction pipeline on the ground station, where compute resources are more available and easier to maintain than on embedded hardware.

1. Data Acquisition and Video Ingestion

The workflow begins by piloting the ROV around the coral garden and recording a video clip of about 1.5 minutes. The visual input comes from the NX streaming service described in *Camera Streams*. When reconstruction is needed, a Python receiver on the ground station subscribes to the same WebRTC stream through WebSocket signaling and uses a GStreamer pipeline to depayload RTP packets and decode the H.264 feed into image frames.

To avoid bottlenecks, video reception uses a **multithreaded design**: networking and decoding run in the background, while the main thread remains available for visualization and downstream processing. This keeps the display responsive and provides a reusable visual input channel for reconstruction.

2. Image Selection and Feature Matching

After video acquisition, representative frames

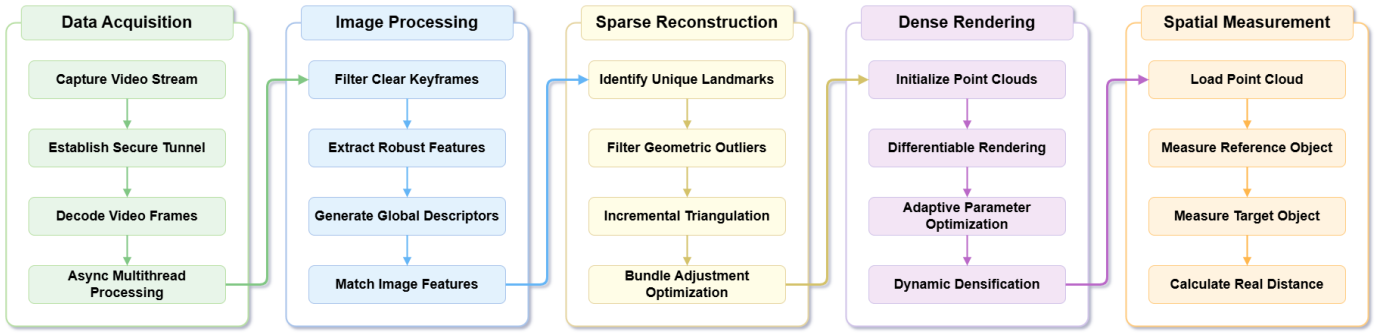


Fig. 10. Task 1.2 technical pipeline

are selected for reconstruction. Image sharpness is first evaluated with a **Laplacian-based definition score** so that only clear frames are retained. To preserve overlap while avoiding redundancy, the interval between selected frames is controlled between 0.5 and 2 seconds.

The selected images are then processed through **HLOC**, which serves as the top-level orchestration framework for feature extraction and matching. SuperPoint is used for local feature extraction, MegaLoc provides global descriptors for image retrieval, and LightGlue performs robust matching on candidate image pairs. This stage establishes the geometric constraints needed for sparse structure recovery.

3. Sparse Reconstruction and Novel View Synthesis

We use **COLMAP** to estimate camera poses, recover sparse 3D structure, and calibrate the camera intrinsics. Through incremental reconstruction and bundle adjustment, COLMAP produces a sparse but geometrically reliable representation of the scene.

This sparse result is then refined using **3D Gaussian Splatting (3DGS)**, which represents the scene with a large collection of optimized 3D Gaussians. Starting from the sparse point cloud, the model is trained by comparing rendered views with the captured underwater

imagery and iteratively optimizing geometry, opacity, orientation, and appearance. The resulting representation supports high-quality visualization from multiple viewpoints.

4. Scaling and Measurement

Because the reconstructed model is initially defined only in virtual coordinates, a scaling step is required before physical measurements can be reported. We import the generated point cloud into CloudCompare, measure the target pipe length in virtual coordinates, and compute the real-world scale factor using a reference object of known size. In the current workflow, a red plastic card with a physical length of 10 cm is used as the calibration reference:

$$r_{\text{pipe}} = r_{\text{card}} \frac{V_{\text{pipe}}}{V_{\text{card}}}.$$

This method keeps the measurement error below 3% in our practical tests, satisfying the competition requirement while remaining simple enough for repeated field use.

Detection and Counting of Invasive Species

The primary objective of this module is to automate the identification and counting of European green crabs in an underwater environment. The module runs on the ground station, receiving the live video stream from the NX and processing it in real time to

support operator decision-making during task execution.

1. Objective and Deployment Strategy

To balance accuracy, latency, and deployment complexity, our team selected the **YOLOv11n** object detection model. The software pipeline follows a hybrid strategy of Python-based offline training and C++ deployment for runtime inference on the ground station. This arrangement combines Python's flexible training ecosystem with compiled C++ inference to reduce runtime overhead and preserve smooth visual feedback.

2. High-Performance Inference Pipeline

To maximize runtime efficiency, trained weights are exported from PyTorch into ONNX format, with TensorRT conversion available for NVIDIA hardware. This removes the need to keep the full training framework in the deployment environment and reduces the runtime software footprint.

At inference time, OpenCV C++ is used for image preprocessing, postprocessing, and result rendering. This choice keeps per-frame latency low and minimizes the risk of frame drops in the live video stream. In internal testing, single-frame inference remains below 10 ms, which is sufficient for real-time operator assistance.

3. Data Engineering and Robustness

Underwater visual perception suffers from domain shift due to color cast, scattering, blur, and lighting instability. To improve robustness, we implemented a **three-stage data strategy**.

First, custom OpenCV scripts simulate underwater optical degradation by introducing randomized blue/cyan color filtering and brightness variations. Second, Roboflow-based augmentation introduces Mosaic, Shear, and Perspective transforms to reproduce viewpoint

distortion and camera-angle variation. Third, the workflow is prepared to incorporate real underwater frames extracted from experimental videos, further improving robustness under live competition conditions.

4. Rule Compliance and Output Logic

The competition requires that native crabs must not be boxed, so the software was designed to prioritize class discrimination in addition to simple object counting. The model is trained on multiple crab classes, but only the European green crab detections are passed to the final counting and display stage. Native species may still be recognized internally to reduce false positives, yet they are suppressed in the operator-facing output.

The runtime interface overlays a stable count indicator on the live video stream, giving the operator immediate feedback without adding extra cognitive burden. The module therefore serves as both a vision system and a practical decision-support tool during time-constrained task execution.

Human Control Input

The Human Control Input module adopts a **dual-controller architecture**. The **joystick** is responsible for vehicle motion, including forward/backward translation, lateral strafing, vertical ascent/descent, and yaw rotation, while a **custom controller** is dedicated to manipulator operation. In this arrangement, the operator can control the vehicle and the arm in parallel without mixing the two command streams. All control inputs are processed at the surface station and then transmitted to the ROV.

For vehicle control, the joystick input is organized through a predefined input-mapping scheme, in which virtual actions are bound to specific buttons. At runtime, button events are

converted into a normalized vehicle-motion command containing surge, sway, heave, and yaw components. The thruster control module then translates this command into individual motor outputs through thrust allocation and sends the resulting commands to the thrusters using the DSHOT protocol rather than conventional PWM signaling. The scheme also supports multi-button combinations; for example, pressing forward and right at the same time produces a diagonal-motion command, while dedicated yaw inputs generate rotational commands about the vehicle's vertical axis.

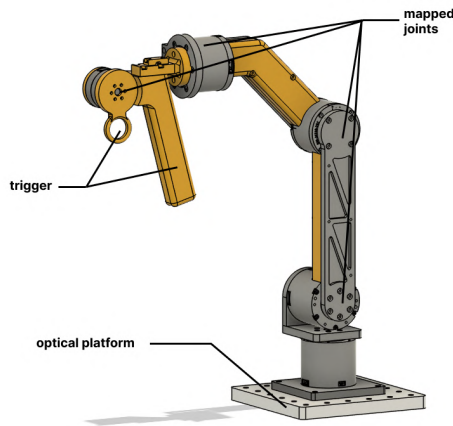


Fig. 11. Custom controller for manipulator teleoperation

For manipulator control, the custom controller provides intuitive end-effector teleoperation. Its 3D positional input is mapped to the manipulator end effector, while a distal trigger controls gripper opening and closing. The surface station converts these inputs into joint-angle commands through inverse kinematics and forwards them to the NX for execution.

To reduce operator effort, the NX-side ROS 2 control loop implements **real-time gravity compensation** and **bidirectional force feedback** for the custom controller.

A URDF model defines each link's mass, center of mass, and joint axis. Based on real-time joint angles, a ROS 2 node computes gravitational torque at each joint using Lagrangian dynamics and adds the result as a feedforward compensation term to the motor torque command. This allows the manipulator to maintain its pose without continuous operator effort and updates continuously during motion. All computations run in real time on the NX at **1 kHz**.

Bidirectional force feedback is realized by detecting current variations and transmitting signals to the custom controller, giving the operator haptic awareness of contact and workspace limits. This mechanism is used in two situations. First, gripper motor current is monitored to detect grasping events; when the gripper closes on an object, the resulting current rise triggers vibration or reverse torque in the controller, confirming a successful grasp. Second, joint-motor current feedback is used to indicate workspace boundaries. When the manipulator approaches a pool wall or reaches a motion limit, the controller generates progressively stronger resistance until full lock, simulating a physical constraint and guiding safer operation.

Camera Streams

The camera stream subsystem delivers live underwater video from the ROV to the ground station over the power-line carrier link. The onboard pipeline is described in *Jetson Orin NX / ROS 2 Middleware*; this section covers ground station access and how the stream is consumed.

1. Ground Station Access

The streaming and telemetry services are hosted entirely on the Jetson Orin NX. The surface computer needs only network access to the NX IP address and port through the

power-line carrier link. Opening that address in a browser triggers the WebRTC signaling handshake and immediately presents the unified operator interface: pilot video, vehicle state, and software diagnostics on a single screen. No additional software installation is required on the ground station.

2. Integration with Task Code

Both the Task 1.2 reconstruction pipeline and the Task 2.1 detection module run on the ground station and use the video stream from the NX as their primary visual input. Each runs a separate Python process that connects to the WebRTC stream via WebSocket signaling and uses a GStreamer pipeline to depayload RTP packets and decode the H.264 feed into image frames, reusing the same consistent source as the operator display without any changes to the onboard capture pipeline.

Onboard Software

The onboard software architecture is distributed across two computing layers: the **Jetson Orin NX** onboard computer and the **DJI RoboMaster A-board** MCU. The Jetson NX provides the vehicle's onboard computing and middleware layer, running ROS 2 services for camera acquisition, video streaming, telemetry relay, and command forwarding. The A-board serves as the low-level real-time controller and runs the FineMote control stack^[9], which interfaces directly with propulsion and sensing hardware. The two processors communicate over a serial link, keeping operator-facing media and network services on the NX decoupled from the vehicle's safety-critical motion-control loop.

Jetson Orin NX / ROS 2 Middleware

The Jetson Orin NX is the onboard computer responsible for communication-facing and computation-intensive services aboard

the ROV. It serves as the ROS 2 middleware layer between the ground station and the A-board MCU.

Within this layer, cooperating ROS 2 nodes handle camera acquisition, serial communication with the A-board, video encoding and WebRTC streaming, telemetry relay, and web-interface delivery. Together, these services maintain a unified data path for operator control, live video, and onboard status exchange.

This partition keeps media handling, networking, and future perception-related functions on the Jetson Orin NX, while the A-board retains deterministic real-time control. As a result, high-level software can be expanded on the Jetson side with limited impact on the vehicle's safety-critical control loop.

RoboMaster-A Board / FineMote Control Stack

The **FineMote** embedded architecture^[9], developed by **IWIN-FINS Lab**, is deployed on the DJI RoboMaster A-board as the low-level control framework of *FinsROV*. FineMote organizes the embedded software into three coordinated layers: **Component** for control modules and scheduling logic, **Devices** for sensors and actuators, and **Buses** for communication and data exchange. Through this structure, sensing, actuation, communication, and closed-loop control are integrated under a deterministic execution order rather than being implemented as isolated driver code.

In *FinsROV*, this architecture is used to host the A-board control stack for propulsion, sensing, and real-time motion regulation. The clear separation among control modules, hardware abstraction, and bus communication reduces coupling between algorithms and peripherals, making the embedded system easier to maintain and extend while improving the stability

and reliability of safety-critical low-level control.

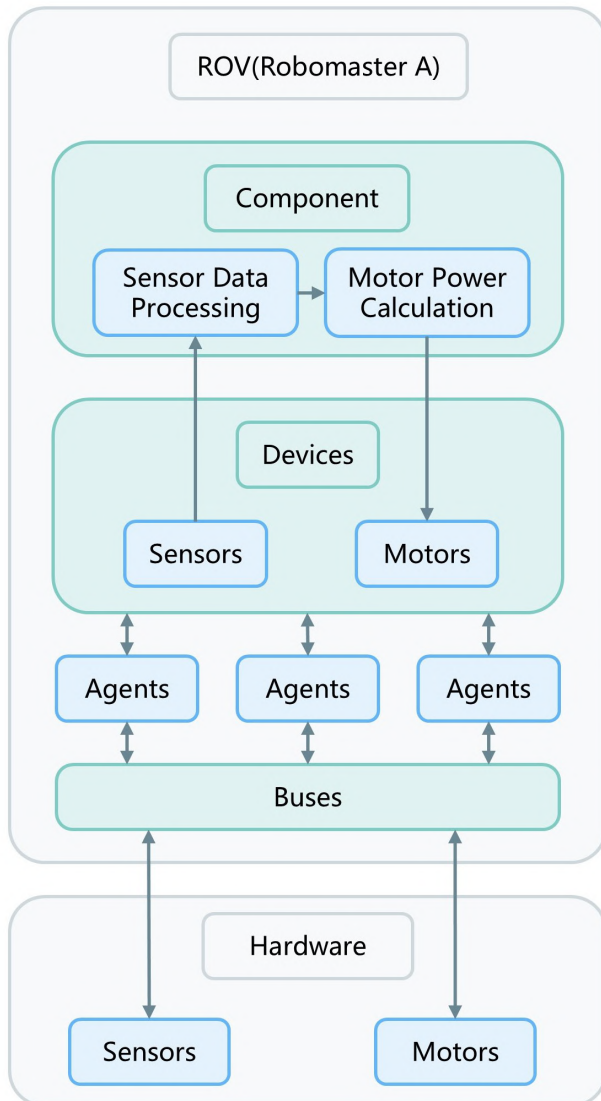


Fig. 12. FineMote embedded control framework on the A-board.

In the **Component** layer, the core motion-control algorithms are implemented to regulate vehicle attitude and depth. To handle underwater non-linear damping and vehicle inertia, the controller combines a cascade PID structure with feed-forward compensation: the outer attitude loop converts Euler-angle errors into target angular rates, the inner rate loop uses IMU feedback to compute corrective torque, and the feed-forward term improves response speed while reducing lag and over-

shoot. Depth is regulated independently by a dedicated PID controller that computes the vertical thrust needed to maintain or change the current depth. This control structure improves attitude stability and depth-holding performance during maneuvering, while also providing faster command tracking under underwater disturbances. Together, these characteristics help the ROV maintain smoother and more predictable motion during teleoperation and task execution.

Propulsion

The ROV uses **eight MOT-P75-170 thrusters** in a fully vectored configuration, including four horizontal thrusters and four vertical thrusters. Designed for marine operation, each unit uses seawater-compatible bearings and a robust housing, and delivers 5.8 kg (≈ 56.9 N) of thrust at 24 V. The availability of both CW and CCW propellers helps cancel reaction torque in paired configurations, while the detachable tail and propeller simplify maintenance.

This 8-thruster layout provides redundant 6-DOF maneuverability. The four horizontal thrusters are mounted symmetrically at the chassis corners to generate planar forces for surge, sway, and yaw, while the four vertical thrusters provide heave, roll, and pitch control. Their spatial distribution was optimized relative to the vehicle center of mass to reduce hydrodynamic interference and improve attitude stability.

To map desired vehicle motion to physical actuation, the system constructs an 8x6 thruster-allocation pseudoinverse matrix based on the installation coordinates and thrust-vector directions derived from the CAD model. The 6x1 target wrench generated by the motion controller is multiplied by this allocation matrix to compute the independent thrust commands for all eight motors. This formulation decou-

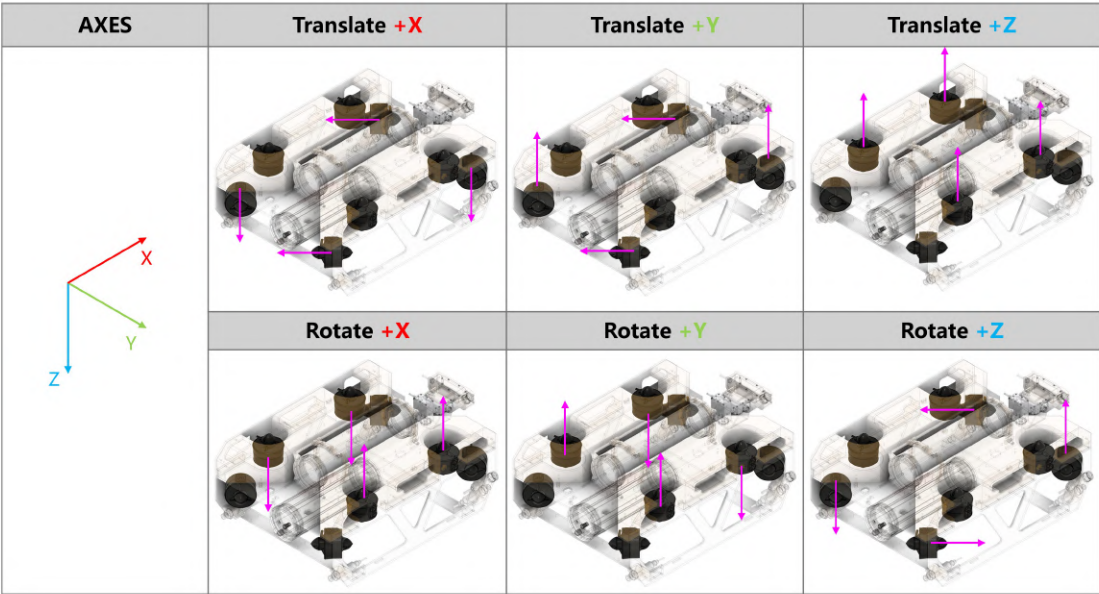


Fig. 13. Thruster force directions for each translational and rotational axis of the ROV.

ples vehicle motion from individual thruster output, giving the ROV strong control authority and disturbance-rejection capability.

Buoyancy and Ballast

FinsROV is engineered for neutral buoyancy and hydrostatic stability in an upright position. Neutral buoyancy ensures the ROV’s weight equals the buoyant force underwater, eliminating any tendency to sink or float. Hydrostatic stability is achieved by placing the center of mass directly below the center of buoyancy, so any attitude deviation induces a restoring moment restoring the vehicle to equilibrium.

To meet these goals, a detailed CAD model of *FinsROV* was constructed with accurate mass, density, and volume for all components, from which the total mass, enclosed volume, and the exact positions of the center of mass and center of buoyancy were derived. Using these theoretical results, the team estimated the quantity and installation locations of polyurethane foam buoyancy blocks and bal-

last weights required to meet target buoyancy and stability performance.

Guided by the theoretical baseline, the team conducted iterative water testing by submerging the assembled ROV and adjusting buoyancy blocks and ballast to fine-tune the system. Through repeated validation and optimization, **Blue Fins** achieved stable horizontal suspension in water, maintaining upright stability with no vertical drift, fully satisfying the stringent underwater mission requirements.

Payload and Tools

Camera

The ROV is equipped with a **SUBLAB underwater binocular vision camera** mounted on a forward-facing gimbal. The camera is chosen for its ability to provide accurate depth information through synchronized dual-channel video output, its adjustable focal length for adapting to different underwater scenarios, a 70-degree field of view without distortion, and

its minimal processing load during video compression, which ensures smooth and reliable live feeds.

The gimbal-mounted design allows the camera to be dynamically repositioned, giving the pilot flexible viewing angles to better adapt to changing operational needs. In addition, a lightweight SUBLAB underwater fill-light is integrated to provide the pilot with a broad, clearly illuminated field of view. With a 90-degree beam angle and 1500 lumens output, it ensures extensive coverage and minimal shadowing, facilitating navigation and fine-detail visibility. The light is fully dimmable via PWM, allowing brightness adjustment for diverse operational tasks. Emitting a 6000K cool white light, it improves underwater penetration and mitigates red wavelength attenuation, thereby enhancing image clarity for vision-based applications.

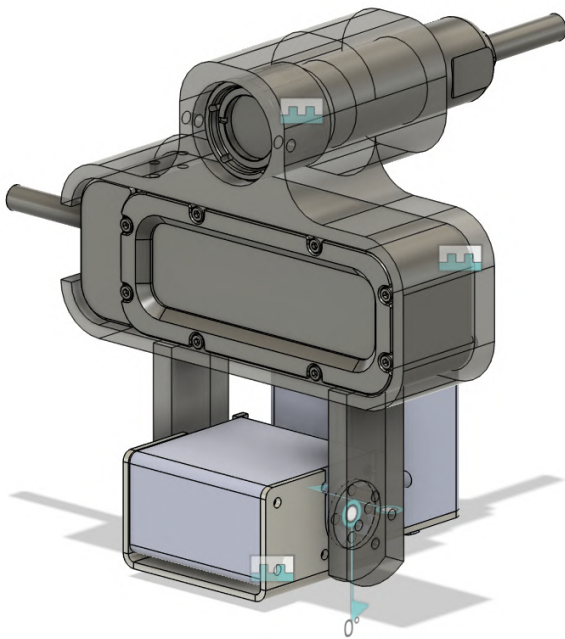


Fig. 14. ROV binocular vision camera

9-axis IMU sampled at 400 Hz, centrally located on the ROV's abdomen. The IMU incorporates a gyroscope for angular velocity measurement and an accelerometer for gravitational reference. The complementary data streams are fused via an Extended Kalman Filter (EKF), generating drift-free attitude estimates for accurate real-time orientation. This IMU is selected for its unique isolated island design at the sensor's base which significantly enhances vibration resistance, allowing the ROV to maintain a stable attitude even under persistent disturbances such as vortex shedding.

For depth perception, the vehicle is equipped with one PCM380 pressure sensor. This sensor measures ambient water pressure and converts it into depth information for underwater depth regulation. It supports RS485-MODBUS communication and a 9–24 VDC supply, which makes it convenient to integrate with the onboard control system. Its 316L stainless-steel construction and rated accuracy of up to 0.1%FS also provide a practical balance of corrosion resistance, reliability, and measurement precision.

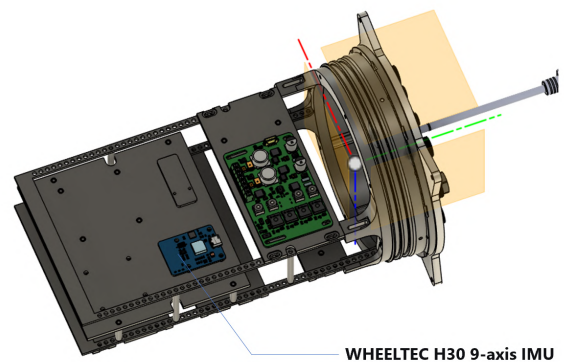


Fig. 15. WHEELTEC H30 9-axis IMU

Sensors

To achieve precise orientation and stabilization, the system integrates a **WHEELTEC H30**

Float Design

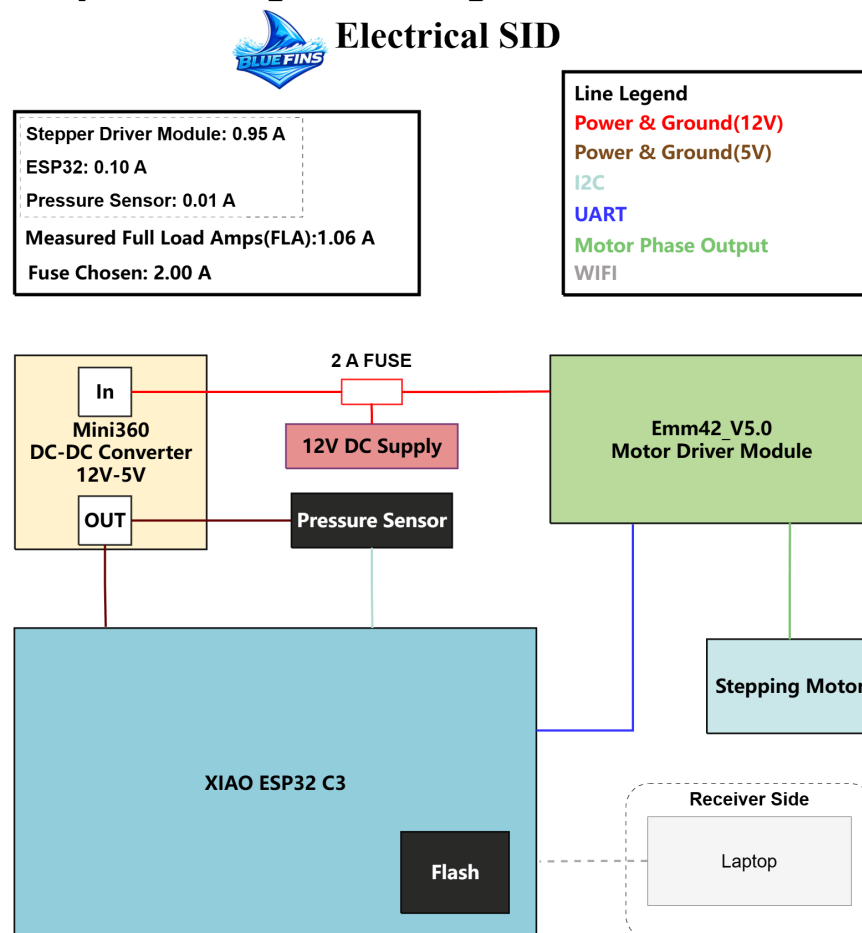
The float subsystem is designed as an auxiliary non-ROV device for buoyancy regulation and task support. Its electrical architecture is organized around a **12 V power path with a regulated 5 V control supply**, so that actuation, control, and interface electronics can be integrated in a compact and reliable manner. The system integration diagram summarizes the main power conversion path and the signal connections among the controller, stepper driver module, and buoyancy-related components.

At the functional level, the float combines closed-loop stepper motor actuation and lead screw-driven syringe displacement with buoyancy dynamics control to provide predictable and stable operation in water. This arrangement simplifies system integration while improving controllability, allowing the float to respond more consistently to commanded buoyancy changes and making it easier to deploy, tune, and maintain within the overall competition system.



Fig. 16. Physical view of the float device.

System Integration Diagrams (SIDs) of Float



4-DOF Manipulator

To meet the manipulation requirements of the 2026 MATE ROV Competition, *FinsROV* uses a self-developed 4-DOF manipulator with a general-interface end-effector. This configuration provides sufficient dexterity for grasping, tool positioning, and task interaction while avoiding the mass, drag, and control complexity of higher-DOF manipulators, making it well suited to a compact work-class ROV. The end-effector also supports rapid adaptation to different mission tools: customized tools are mounted to the POM slider with three M3 screws for simple and reliable replacement.

The overall layout of the manipulator, along with the design details of each joint motor and the end-effector, is shown on the MANIPULATOR DESIGN OVERVIEW page.

The actuator design further strengthens the advantages of this configuration. Compared with common underwater servos, the customized joint motors of *FinsROV* provide **precise torque control and position sensing**, and support **1000 Hz control** over CAN bus. Compared with harmonic-drive joints commonly used in underwater manipulators, they offer better back-drivability and real-time torque fluctuation sensing, while avoiding the friction compensation associated with reducer-based structures. This improves compliance, control transparency, and operational safety during contact-rich underwater manipulation.

Task-oriented Structure

To address the quick connection and release requirements of **Task 2.4**, a modular, carabiner-shaped connector has been designed for the end-effector interface. The assembly consists of three components: two rigid segments fabricated from PETG and a

flexible insert made of TPU, forming a unidirectional locking mechanism. A sloped feature at the interface allows the connector to be easily engaged under a light push force, while preventing unintentional disengagement under tension, ensuring secure yet reversible attachment. A cylindrical grip section, dimensionally matched to the ROV's mechanical jaw, is integrated into the assembly, enabling reliable manipulation by the manipulator during deployment and retrieval operations. The design balances ease of use, mechanical strength, and operational safety, making it suitable for repeated underwater task cycles.

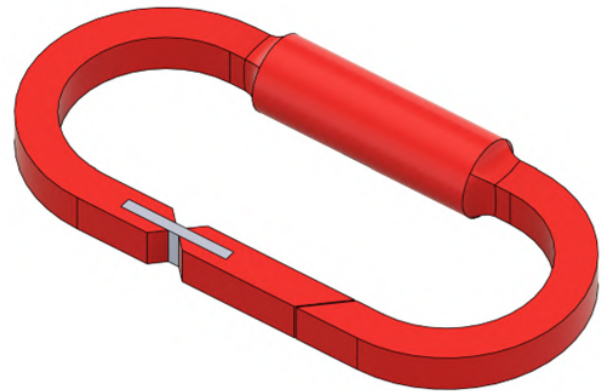


Fig. 17. Task-oriented Structure

Build vs. Buy, New vs. Used

Our Build vs. Buy decisions were guided by engineering value, reliability, and development efficiency. To maximize hands-on design experience, **Blue Fins** custom designed the ROV frame, pressure-housing integration, buoyancy layout, manipulator, tether structure, control architecture, and task-oriented software stack. Standard components with clear advantages in maturity and reliability, including the Jetson Orin NX, DJI RoboMaster A-board, binocular camera, IMU, pressure sensor, and thrusters,

were purchased and integrated into the system.

Because this is the team's **first competition platform**, no major subsystem was reused from a previous season. The ROV body, manipulator, tether, surface-control hardware, and software baseline are all newly developed for the 2026 vehicle.

Safety

Safety is treated as a core requirement throughout design, assembly, testing, and operation. Our safety approach combines personnel training, protective equipment, hardware safeguards, and standardized procedures to reduce risk to both team members and equipment.

Personnel Safety

All team members receive training in laboratory safety, tool use, PPE requirements, and emergency response before participating in fabrication or operations. Required PPE includes safety goggles, closed-toe shoes, protective gloves, and lab coats, while long hair must be secured during mechanical or electrical work.

New operators are supervised by experienced members before using unfamiliar tools or equipment, and the laboratory is equipped with first-aid kits, eyewash stations, and fire extinguishers. Regular drills and safety briefings are used to reinforce correct responses during abnormal or emergency situations.

Equipment Safety

Mechanical and electrical safety are addressed through both structural protection and maintenance control. Metal edges are deburred, exposed corners are smoothed or covered, and wiring is routed close to the frame

to reduce snagging, pulling, and accidental contact.

Propeller guards are installed to prevent contact with rotating parts and reduce entanglement risk. The pressure housing is sealed, internal electrical connections are protected from exposure, and all cables include strain relief to improve connector reliability. Emergency power-off provisions, fuses, and routine inspections of connectors, fasteners, and moving parts are used to maintain safe operating condition throughout deployment.

Operational Safety

We use a Job Safety and Environmental Analysis (JSEA) process to identify and control worksite hazards before operations begin. Before deployment, the work area is cleared, tools and equipment are secured, cables and power sources are kept dry, and personnel readiness is confirmed.

During operations, team members follow defined communication and operating procedures to maintain coordination and situational awareness. If an abnormal condition occurs, operations are stopped immediately and the area is secured or evacuated as required.

Safety Procedures

We maintain formal safety checklists for assembly, pre-operation inspection, deployment, recovery, and maintenance, together with response procedures for faults such as leaks and communication failures. These procedures are reviewed before use and serve as the standard reference for safe operation.

Work may proceed only after the relevant checklist has been completed and the system has passed inspection. The full checklist is provided in the appendix as an operational guide for personnel, equipment, and environ-

mental safety.

Critical Analysis

Blue Fins adopts an empirical development process to refine *FinsROV*. Rather than relying only on simulation, we used telemetry, prototype measurements, and repeated underwater trials to identify weaknesses and convert them into targeted improvements in waterproofing, electrical reliability, and motion control.

Waterproofing

The reliability of *FinsROV* begins with the integrity of its primary pressure vessel. The housing uses matched flanges, endcaps, and custom-fit gaskets, and the flange–endcap interface was optimized to maintain uniform gasket compression. Epoxy was applied to the sealing surfaces to improve conformity and reduce micro-leaks. Repeated hydrostatic tests at depths up to 5 m showed no water ingress, verifying that the sealing design provides sufficient waterproofing margin for the intended operating range.

Electrical Reliability & Signal Integrity

To ensure stable operation during high-intensity missions, the **Blue Fins** team conducted a comprehensive audit of the electrical distribution and communication backbone. Our testing focused on the survivability and data integrity of the internal electronics under both mechanical stress and high electrical loads.

- **Component-Level Validation:** We performed rigorous continuity and performance benchmarks on our **Power Line Communication (PLC) modules**, **Anderson connectors**, and **DC–AC power conversion units**.

These components are critical for power delivery and tether communication, and their stability was verified through multiple power-cycle stress tests.

- **Communication Reliability:** We specifically evaluated the **integrity and reliability of data transmission** across all interconnected modules. This involved monitoring signal consistency between the control system and peripheral devices to ensure that high-current draws from the thrusters did not compromise data packets.

This systematic verification of both physical connections and digital communication allowed us to build a robust electrical system. By confirming the reliability of our solder joints and the interference-free operation of our PLC modules, we achieved a high degree of fault tolerance, significantly reducing the risk of mid-mission failures.

ESC & Propulsion System Verification

Propulsion verification focused on practical calibration rather than complex thrust modeling. We identified the effective **command deadzone** of each thruster, verified **propeller placement** and **motor directions** through spin tests, and matched the physical thruster layout to the software allocation model. A linearized control mapping improved pilot responsiveness, while servo load tests confirmed that the manipulator could complete its required motion range without stalling or causing excessive disturbance on the main power rail. These checks produced more predictable low-speed control and more reliable maneuvering during task execution.

Overall, this testing-centered process transformed *FinsROV* from a functional prototype into a **robust and competition-ready** system.

Accounting

As a first-year team, **Blue Fins** allocates its budget primarily to two needs: building a complete competition ROV from scratch and transporting the team and equipment to the event. Because we do not have inherited hardware, reusable stock, or prior competition logistics, the projected budget reflects the full cost of an initial platform rather than incremental upgrades to an existing system. Detailed budget estimates and cost breakdowns are provided in the tables below.

Production Expenses Estimate		
Items	Description	Price(USD)
ROV Surface Station	Computer, Xbox Controller, Manipulator Controller	500
ROV Structure	3D Printed Mounts, Bouoyancy Equipments,	1000
ROV Electronics	Thrusters, PCB, MCU, Jeston Orin NX, Camera, Wiring, Pressure Sensor	1600
ROV Teather & Connectors	Teather, Connectors	800
Manipulator	Joint motors, Aluminum alloy frame, FOC drive board	1000
Floats	PCB, MCU, DCDC, Motor Driver, ESP32, Battery, Sersors, etc.	400
Total		5300

Table 4. Budget estimate for vehicle production.

Travel Estimate		
Items	Description	Price(USD)
Airfare	Round-trip economy airfare for team members traveling to the competition location	6000
Accommodation	Lodging costs (hotel / short-term rental) for the team during the competition period	1200
Taxi Fare	Local ground transportation including airport transfers, venue shuttles, and other necessary trips	500
Visa Processing	Visa application fees, service charges, and related administrative costs for international travel	1110
Robot Shipping	Shipping or excess baggage fees for transporting the ROV and equipment to the competition site	615
Competition fees	Official registration fee for the MATE ROV Competition (or equivalent competition)	1610
Total		11035

Table 5. Budget estimate for competition travel.

Production Expenses Costing		
Items	Description	Price(USD)
ROV Surface Station	Computer, Xbox Controller, Manipulator Controller	453.05
ROV Structure	3D Printed Mounts, Bouoyancy Equipments,	922.38
ROV Electronics	Thrusters, PCB, MCU, Jeston Orin NX, Camera, Wiring, Pressure Sensor	1657.7
ROV Teather & Connectors	Teather, Connectors	708.28
Manipulator	Joint motors, Aluminum alloy frame, FOC drive board	934.06
Floats	PCB, MCU, DCDC, Motor Driver, ESP32, Battery, Sersors, etc.	229.52
Total		4904.99

Table 6. Costing for vehicle production.

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Appendices: Safety Checklists

ROV Construction:

Assembly:

- ☐ Turn off the power to the ROV and all related equipment to ensure the system is de-energized
- ☐ Inspect all tools and equipment to confirm they are in good condition and suitable for operation
- ☐ Confirm that the workbench and the interior of the hull are completely dry, with no water stains or moisture
- ☐ Inspect the penetrators and cable connections to ensure they are secure and that there are no exposed wires
- ☐ Operators must wear protective gear
- ☐ If welding or work involving toxic gases is required, ensure operations are conducted in a well-ventilated area
- ☐ Place all tools in their designated locations and maintain a clean work environment
- ☐ Before installing electronic hatches or components, verify that O-rings and sealing surfaces are clean, undamaged, and lubricated
- ☐ When installing electronic hatches or components, maintain proper alignment to avoid pinching wires or damaging seals
- ☐ After assembly is complete, check that all fasteners are tightened and confirm that the housing and components are securely and reliably fastened

Disassembly:

- ☐ Ensure the work surface is clean and free of debris, metal shavings, hair, or other foreign objects
- ☐ Turn off all relevant power sources to ensure the equipment is de-energized
- ☐ Wipe the chamber lid and external surfaces dry, paying special attention to the edges to prevent water from entering the electronics compartment
- ☐ Release the latches on the electronics compartment to ensure a safe working space
- ☐ Carefully disconnect the cables inside the enclosure and the wall bushings, taking care not to pull or damage the cables
- ☐ Place the enclosure lid gently to the side to avoid collisions or scratches
- ☐ Inspect the electronics enclosure and work surface to ensure they are completely dry and free of residual moisture

Before Closing:

- ☐ Inspect the pressure hold and backplate end cap to ensure there is no fogging, cracking, or other damage

- ☐ Verify that internal components are positioned horizontally to prevent tilting or shifting
- ☐ Check that all wire connections are secure and ensure there are no loose or disconnected wires
- ☐ Verify that there are no exposed wires or wires trapped between components or the walls of the pressure hold
- ☐ Double-check that the interior of the pressure hold is completely dry

After Closure:

- ☐ Verify that the O-ring is intact and shows no signs of damage or displacement
- ☐ Verify that internal components are positioned horizontally, with no tilting or misalignment
- ☐ Check that all fasteners are tightened to ensure the end cap and chamber are securely fastened
- ☐ Verify that the robotic arm is locked in its initial position
- ☐ Visually inspect the entire chamber to confirm that the seal is intact and there is no risk of leakage

ROV Operation:**Before Deployment:**

- ☐ Ensure there are sufficient personnel on-site to guarantee the safe operation of the ROV
- ☐ Clear the deck and poolside areas, removing debris and tripping hazards to ensure a safe working environment
- ☐ Inspect the ROV frame and pressure hold for cracks, fogging, or damage
- ☐ Confirm that all ROV attachments (propeller guards, buoyancy and ballast systems, propellers) are securely fastened
- ☐ Inspect the interior of the pressure hold to ensure there are no loose connections
- ☐ Confirm that the hatch is properly sealed and that power sources remain dry to prevent water ingress or electric shock risks
- ☐ Lay out and inspect the tether to ensure it is neat, free of knots and tangles, and kept away from passageways or areas where personnel are active
- ☐ Start up the control station to ensure the computer, power supply, and control box are functioning normally and connections are stable
- ☐ Inspect all electronic connections to confirm they are secure, properly connected, and have no exposed wires
- ☐ Confirm that all camera threaded caps are tightened and the cameras are securely mounted
- ☐ Inspect the thrusters and robotic arm to ensure smooth operation
- ☐ Prepare recovery equipment (long poles, nets, etc.) in case of an emergency retrieval

Pre-Initialization:

- ☐ Verify that the power supply is not connected to the ROV control system to ensure safe operation
- ☐ Check that all components inside the hull are securely fastened, and confirm that no parts are loose or detached
- ☐ Inspect all cables, penetrators, and connectors to ensure they are secure and that there are no exposed wires
- ☐ After completing the above checks, confirm that the hatch is securely locked

Deployment:

- ☐ Confirm that all tools and payloads are correctly installed and secured on the ROV
- ☐ The pilot announces "Ready to take over," notifying the ROV operator to prepare for operation
- ☐ The ROV operator grasps the ROV's frame and hovers it in the water at the deployment zone
- ☐ After confirming the ROV's stable condition via the camera and data, the pilot announces "Ready to release"
- ☐ After ensuring the ROV is in a stable state, the ROV operator releases the ROV and announces "Releasing"

ROV Operation:**During Operations:**

- ☐ The mooring line supervisor at the poolside inspects the mooring line layout to ensure there are no tangles, knots, or obstructions
- ☐ The operator maintains constant communication with the poolside team, promptly reporting the ROV's position, mission status, and any abnormalities
- ☐ Inspect the surrounding work area to ensure that no personnel are walking or running in the path of the tether or the ROV
- ☐ In the event of an emergency (such as tether entanglement or loss of ROV control), immediately call for an "emergency stop," and the operator shall execute the shutdown procedure

Surfacing after Operation:

- ☐ The pilot maneuvers the ROV toward the deployment area, taking care to avoid collisions with surface obstacles or other equipment
- ☐ As the ROV approaches the water's surface, call out "Ready to take over" to notify the poolside operator to prepare to take control of the ROV
- ☐ After confirming the location is safe, the operator grasps the ROV frame and suspends the ROV steadily in the water
- ☐ Once the operator confirms the ROV has been safely handed over, call out "Handover complete" and deactivate the ROV's thrusters
- ☐ The operator positions the ROV at the designated location, ensuring it is placed securely

Post-Deployment:

- ☐ Check that all components are securely fastened and free of damage or foreign objects
- ☐ Check that cables, lanyards, and connectors are dry and intact, and ensure there is no wear or exposed wiring
- ☐ Apply corrosion protection to components prone to corrosion
- ☐ Document any abnormalities or damage

Communication Interruption / Camera Signal Loss:

- ☐ Perform a power cycle on the ROV to attempt a system restart
- ☐ If communication is still unavailable, power down the ROV and retrieve it using the umbilical cable
- ☐ If communication is restored and there is no water ingress or leakage in the ROV, resume operations
- ☐ If communication is still unavailable, initiate the troubleshooting procedure to identify the root cause of the problem
- ☐ Record the time of the communication failure, the cause, and the actions taken

Water Ingress:

- ☐ Immediately shut off the ROV's power supply and retrieve the ROV to a safe area using the tether
- ☐ Inspect the interior for water ingress and check all electronic components for signs of corrosion or damage
- ☐ Re-seal all water-exposed interfaces with water-repellent grease to ensure complete waterproofing
- ☐ Thoroughly dry the internal components
- ☐ Conduct functional tests on the system to verify that all equipment is operating normally
- ☐ Document the cause of the leak, its location, and the corrective actions taken

Maintenance Area:

- ☐ Clean the work area to ensure that the floor and work surfaces are tidy and free of debris and tripping hazards
- ☐ Check that all tools and equipment are neatly stored and returned to their designated locations
- ☐ Inspect power cords, plugs, and extension cords to eliminate any potential electrical hazards
- ☐ Check that lanyards and electrical connectors are intact and properly secured
- ☐ Inventory supplies; if any items are needed for repair or maintenance, compile a procurement list
- ☐ Prepare for the next mission