2025 TECHNICAL DOCUMENTATION

SEAFOX-VIII

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SEAFOX INVENTIVE 2025

CETYS UNIVERSIDAD MEXICALI, B.C., MEXICO

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ABSTRACT

SeaFox Inventive, a multidisciplinary company from the School of Engineering of CETYS Universidad, Mexicali Campus, proudly presents SeaFox-VIII—our latest underwater remotely operated vehicle (ROV) developed for the MATE ROV 2025 World Championship. Founded in 2016 and guided by the expertise of our mentors Dr. Luis Básaca, M.C. Mario Ramos, and M.I. Leonardo Ortega, SeaFox Inventive transformed a vision into reality over a rigorous academic year.

Our vehicle design harmonizes robustness, precision, and mission adaptability, enabling it to tackle complex underwater tasks with agility. Six Blue Robotics thrusters empower SeaFox-VIII with six degrees of freedom, while a reimagined Newton Gripper—modified for wider dexterity—ensures versatile object manipulation. The journey to SeaFox-VIII was paved with challenges that became catalysts for innovation. Each obstacle—from buoyancy calibration to tether strain management—was met with ingenuity, such as repurposing swimming kickboard foam for neutral buoyancy and leveraging 3D-printed mounts to reduce weight.

SeaFox-VIII reflects a season-long effort of coordinated design, prototyping, and testing among the company's mechanical, electrical, software, and administrative departments. With a focus on robustness, safety, and mission versatility, the vehicle is built to meet the technical and operational challenges presented by this year's competition tasks.

Fig. 1: SeaFox Inventive Company Photo

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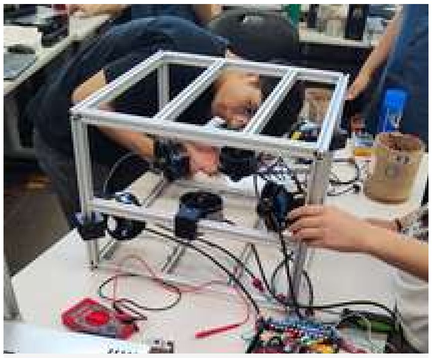

Fig. 2: Company members working on the frame

Fig. 3: Company weekly meeting in action

Fig. 4: Company members testing cameras

PROJECT MANAGEMENT

COMPANY PROFILE

SeaFox Inventive is a dynamic and innovative company based at CETYS Universidad, composed of 19 members from a wide range of academic backgrounds. Our mission is to develop innovative and high-performance underwater robotic systems tailored to meet the demanding requirements of the MATE ROV Competition and broader marine applications.

The company operates under a structured leadership hierarchy. The Chief Executive Officer (CEO) oversees the entire project and operation. The Chief Technical Officer (CTO) is responsible for managing the technical departments: mechanical, electrical, and software. The Chief Financial Officer (CFO) leads administrative, logistical, and financial efforts. Each technical department has its section lead, ensuring clear communication and specialized focus.

We place a strong emphasis on mentorship and sustainable growth. Each year, a new cohort of members is recruited and trained through hands-on activities and supervised learning. Our mentors, Luis Carlos Básaca, Mario Ramos, and Leonardo Ortega, provide guidance throughout the season.

PROJECT MANAGEMENT

The season begins with the appointment of company leads, who are responsible for setting objectives within their departments and establishing timelines for deliverables.

Progress is monitored through weekly meetings held every Saturday, where section leads present updates, discuss challenges, and propose solutions. These meetings ensure company-wide alignment and accountability. Cross-functional coordination is especially emphasized in areas like Mechanical-Software integration and Electrical testing.

To effectively manage communication, task delegation, and documentation across the company, we use the following tools:

- Google Drive for shared files and collaborative writing,
- Trello for Kanban-style project and task tracking,
- WhatsApp, Zoom, and Facebook Messenger for online meetings and urgent communication,
- GitHub for version control, collaborative coding, and managing contributions across development branches.

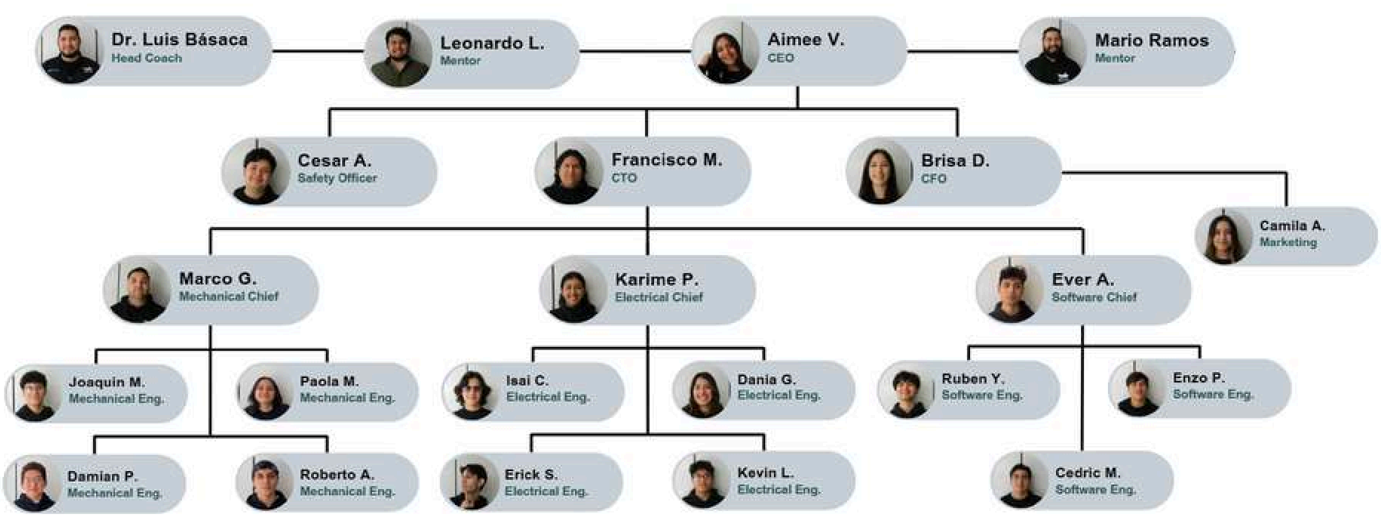

Fig. 5: Company Organizational Chart

Appendix A: Challenges & Lessons Learned Table provides a summary of key organizational and technical challenges and lessons learned during development.

Fig. 6: Tasks from the software section of the company's Trello.

OPERATIONAL STRATEGY & RESOURCE ALLOCATION

To meet mission requirements and maintain cost-effectiveness, we have developed strategies for efficient resource use and streamlined operations, as seen in Figure 7.

Procurement and Budgeting	Handled by the CFO, using cost estimates based on previous seasons and adjusted for inflation and sponsorship inputs.
Tool and Material Selection	Done collaboratively, ensuring alignment between availability, budget, and functional requirements.
Quality Assurance processes	Includes continuous peer-review of mechanical assemblies, electrical safety validation, and simulation-based software testing.
Safety Protocols	Standardized across all departments, and all work sessions require compliance with PPE and risk mitigation checklists.

Fig. 7: Company strategies for efficient resource use.

BUILD SCHEDULE

Our company follows a build schedule that spans the academic year and is broken into five main stages: Recruitment & Training, Design Phase, Prototyping Phase, Integration, and Final Testing & Optimization.
Each phase includes review milestones and internal deadlines aligned with competition targets. See Figure 8 and Figure 9 for additional information.

PHASE	DESCRIPTION
Recruitment & Training	• Class visits • First meeting and role assignments • Safety training • Software, mechanical and electrical training • Design Thinking workshop
Design	• Competiton manual Requirements Review • Design ideas brainstorming • Electronic arrangement brainstorming • Software architecture planning • Adjustments based on cost, weight, size and feasibility
Prototyping	• Mechanical, electrical, software prototyping • Dry runs of subsystems, debugging and replacement
Integration	• Mechanical assembly • Electrical Integration • Snyc controls with hardware, camera and interface test • Initial pool tests
Final Testing & Optimization	• Full mission tasks simulations • Fine-tuning and improvements • Documentation

Fig. 8: Build Schedule phases description.

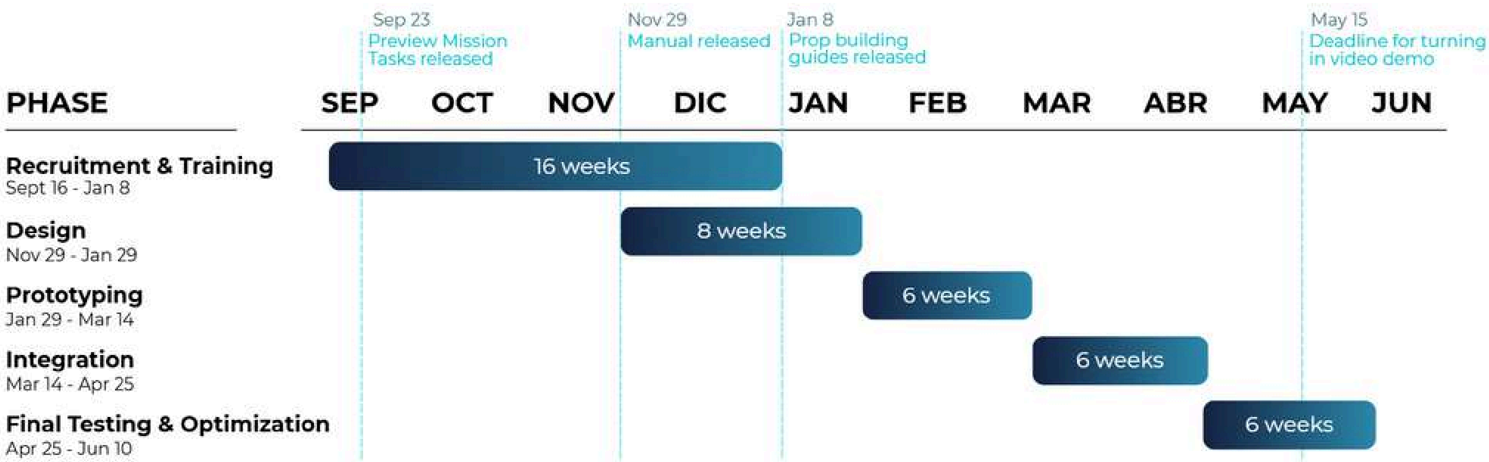

Fig. 9: Build Schedule

DESIGN RATIONALE

VEHICLE OVERVIEW

SeaFox-VIII was designed with a compact, modular frame optimized for maneuverability, neutral buoyancy, and precise control across six degrees of freedom. It integrates a Blue Robotics gripper, which was modified to allow for a wider opening range, enabling more versatile manipulation tasks. Custom PCBs consolidate power distribution, sensor interfacing, and real-time current monitoring, all housed in a watertight enclosure positioned at the vehicle's center of mass.

Key sensors include the Bar30 pressure sensor, ACS-712 current sensor, BlueRobotics SOS leak detection system, and PH-4502C sensor for water sample analysis. These are complemented by an Intel RealSense D455 depth camera, which provides real-time vision and measurement. Communication and power are delivered via a streamlined tether, supported by integrated strain relief and management protocols. Figure 10 shows the SeaFox-VIII vehicle fully assembled, highlighting its compact design, sensor placement, and modified gripper configuration.

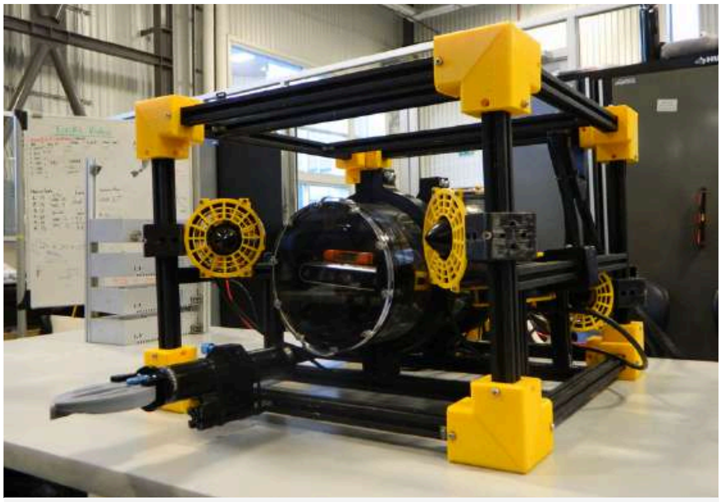

Fig. 10: SeaFox-VIII

MECHANICAL SYSTEMS

MECH. DESIGN EVOLUTION

The mechanical design evolved through a balance of functionality, manufacturability, and mission-specific constraints. We began by reviewing the MATE ROV 2025 competition manual to extract requirements such as six degrees of freedom, neutral buoyancy, and payload integration. Early concepts were modeled in CAD to validate component placement, weight distribution, and spatial clearance, which helped identify design conflicts before fabrication.

Lessons learned from past seasons were reviewed to retain successful strategies and improve weak points, allowing faster development with fewer errors. Key trade-offs included downsizing the electronics enclosure from 8 to 6 in to improve buoyancy and shifting from a dual-arm manipulator to a single-arm setup to streamline integration under time and budget limits.

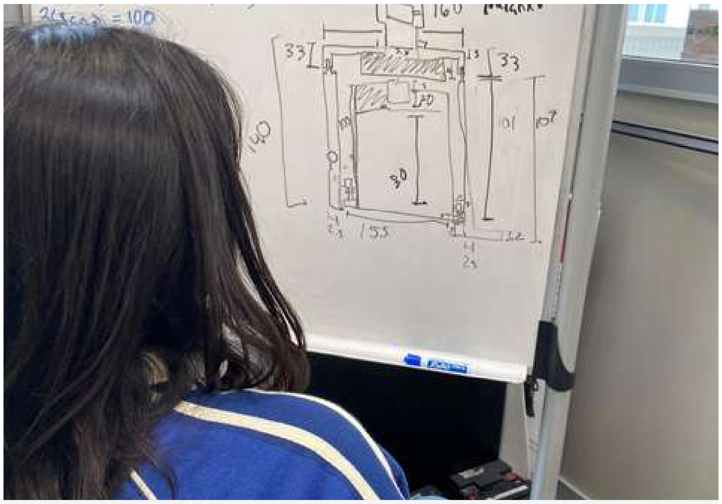

Fig. 11: Mechanical department member brainstorming

FRAME AND STRUCTURAL DESIGN

The primary structure is built from 20 × 20 mm anodized-aluminum extrusion profiles, selected for their high strength-to-weight ratio and inherent corrosion resistance in marine environments. These profiles, generously provided through a sponsorship from Modular Assembly Technology, form a rigid yet lightweight framework that supports all major subsystems, including propulsion, electronics, and mechanical tools. The modular nature of the extrusion system enabled company members to rapidly iterate, reconfigure, and repair the frame during prototyping and testing stages, reducing downtime and improving system flexibility. The open-frame design (Fig. 12) was chosen to minimize water resistance and allow efficient hydrodynamic flow through the vehicle's body.

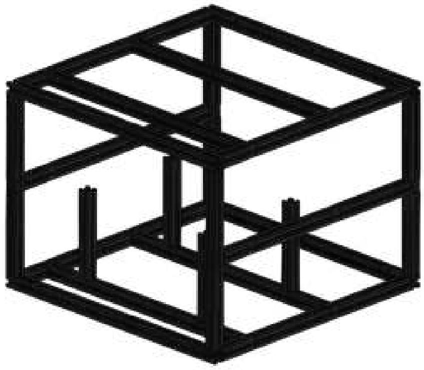

Fig. 12: Frame.

ELECTRONICS ENCLOSURE

A commercial Blue Robotics 6-in watertight enclosure (pressure-rated), as the one in Fig.13, was selected to house the ROV's control system, power regulation, and sensor interface electronics. This decision was made after originally considering an 8-in enclosure. The smaller unit reduced overall weight and volume, which in turn minimized the amount of buoyancy material required and enabled finer control of the vehicle's center of mass. The enclosure's IP68 sealing provides protection against water ingress during underwater operation, ensuring uninterrupted function of sensitive systems. Positioned at the geometric center of the ROV, the enclosure plays a critical role in maintaining balance and achieving neutral buoyancy. Internally, a custom-designed carrier plate organizes electrical components and connections, improving modularity and simplifying maintenance. This centralization of electronics supports efficient cable routing, thermal isolation, and physical separation between high- and low-voltage domains, while reducing the overall footprint of the system.

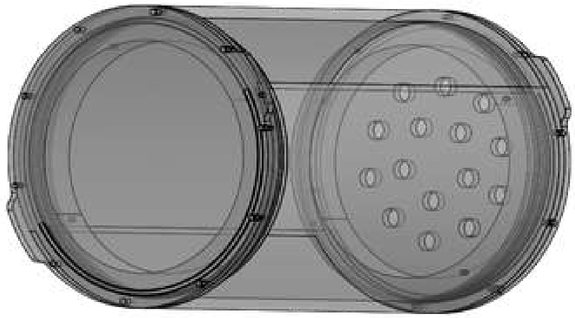

Fig. 13: Electronics enclosure.

CUSTOM MOUNTS AND MECHANICAL INTERFACES

To improve component integration and reduce overall vehicle mass, all mechanical supports for the ROV's main subsystems were designed and manufactured in-house using 3D printing with filament material donated by Polymaker. This approach allowed for rapid prototyping and customization while maintaining low weight and sufficient structural performance for underwater use.

ENCLOSURE MOUNT

The main electronics enclosure is secured to the ROV's frame using custom-designed 3D-printed clamps (Fig. 14) that interface directly with the 20 × 20 mm aluminum profiles. These mounts were engineered with an internal anti-slip rail to prevent axial displacement during movement or retrieval operations. Rather than fully printing the entire clamp assembly, the design was optimized to leverage the modular aluminum frame geometry, reducing material usage and improving mechanical robustness.
This hybrid approach simplified installation and adjustment during integration. The electronics enclosure is inserted into place before tightening the mounts together, and once the enclosure is inside, everything is securely fastened using M6 × 35 mm screws.

Fig. 14: Enclosure mount.

Fig. 16: Watertight Enclosure RAILS, Blue Robotics.

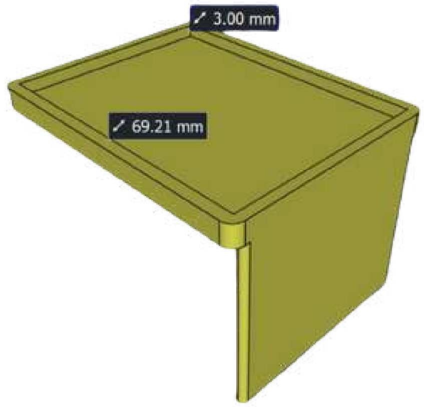

Fig. 17: USB hub case, in-house design.

THRUSTER MOUNTS

Custom 3D-printed mounts were designed to attach the six thrusters to the aluminum frame with precision (Fig.15). Each mount has two parts: one connects to the frame, allowing angle adjustment 90°, 45°, or 35°, while the other holds the thruster in place, secured with M3 screws. Each mount then clamps to the profile with M4 screws that press the parts together and lock them in place. This design ensures accurate alignment, easy installation, and quick adjustments.

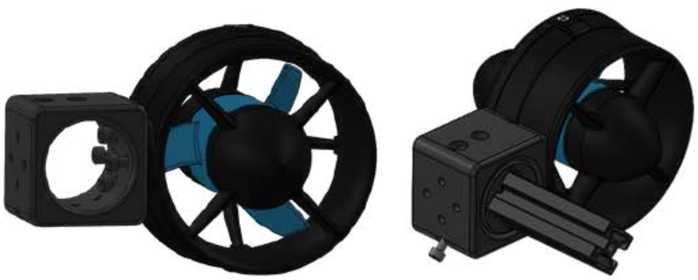

Fig. 15: Thruster mount.

ELECTRONICS CARRIER PLATE

We adopted the Watertight Enclosure RAILS design published by Blue Robotics (Fig. 16) and adapted it for printing in PETG ESD filament provides high strength, dimensional stability, and electrostatic-dissipative properties that protect electronics from static discharge. By retaining the original geometry of the tray and its compatibility with the RAILS system, we ensure a flawless fit with standard hardware, eliminate alignment errors, and significantly reduce assembly time. In addition to this rails system, in-house designed parts were made and printed for the optimization of the enclosure's space, ensuring the best placement for each component.

DC VOLTAGE CONVERTER HOLDER

We designed and 3D printed a custom holder for a DC voltage converter (Fig.18) using Polymaker's ESD-safe filament due to its electrostatic-dissipative properties. The part includes drilling holes that match the layout of the existing thruster mounts, allowing it to attach directly to the structural profile without any modifications. It also features four dedicated drilling holes for M5 screws to securely fasten the converter to the printed mount, ensuring stability and resistance to vibrations. This custom solution offers a reliable and clean integration of electrical components into our system.

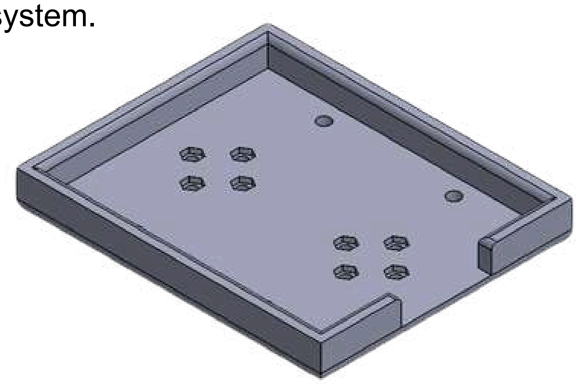

Fig. 18: DC voltage converter holder.

CFD

A CFD analysis was conducted on the ROV, as shown in Fig. 19, to estimate hydrodynamic drag at 0.75 m/s. The simulation resulted in an estimated drag force of 5.259 N, which was used to optimize the ROV's design for underwater stability and efficiency.

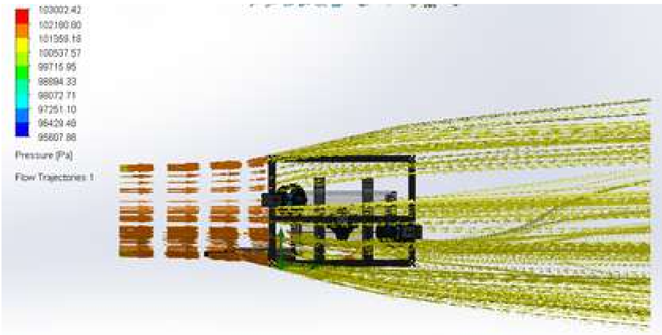

Fig. 19: CFD

BUOYANCY AND BALLAST

The buoyancy system was developed by analyzing the combined material properties of its structural components—primarily anodized aluminum and 3D-printed mounts. We calculated the total vehicle weight in conjunction with its available internal volume, most notably that of the central electronics enclosure, to assess its initial buoyant state.

Preliminary analysis indicated that the ROV had negative buoyancy, meaning it would sink under normal conditions. To correct this, closed-cell, low-density foam was strategically integrated into the design to provide positive buoyancy without significantly increasing drag. In our case, we used foam from swimming kickboards because its low density offers high volume with minimal added weight. To protect and secure the foam , , we will enclose it in custom 3D-printed cases affixed to the frame

To determine the required volume of foam, werearranged the buoyancy equation based on the ROV's total weight. From this, we obtained the total displacement volume needed for neutral buoyancy. By subtracting the existing internal volume from this value, we calculated the exact foam volume to be added.

Applying Archimedes' principle, we then adjusted both the quantity and placement of the foam to ensure the ROV remains stable and easily maneuverable during underwater operations.

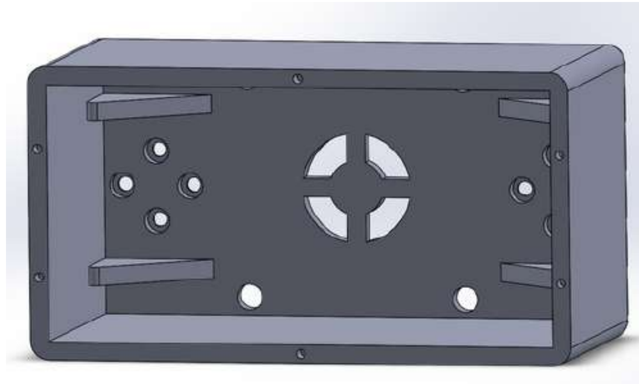

Fig. 20: Foam case.

PROPULSION AND MOVEMENT SYSTEM

A total of six Blue Robotics T100 thrusters were selected to provide precise control across six DOF: surge, sway, heave, roll, yaw, and pitch. The propulsion layout was optimized for compactness and precision, matching the vehicle's small form factor and the need for highly maneuverable motion in tight spaces. Two vertical thrusters are located at opposite ends of the vehicle along the Y-axis, enabling smooth heave (vertical) movement. The remaining four thrusters are mounted at 45° angles relative to the X and Z axes—two in the front (pointing to X+Z+ and X−Z+ respectively), and two in the rear (pointing to X+Z− and X−Z−).

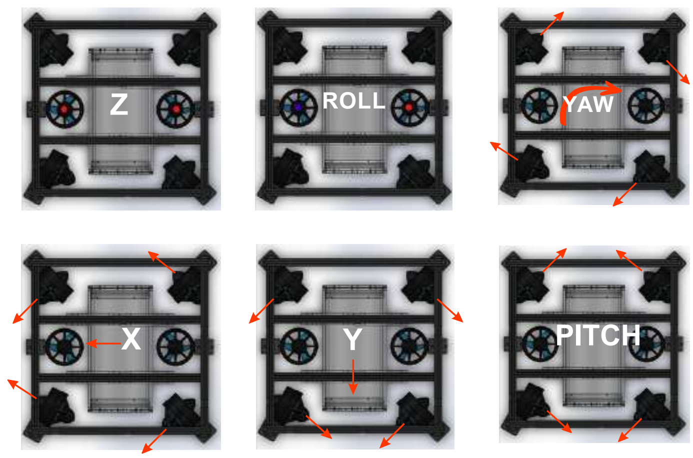

Fig. 21: Degrees of freedom.

TOOLS & MANIPULATORS PROTOTYPES

GRIPPER EVOLUTION

Robotic Arm Design V1.0

The first version of the robotic arm featured three degrees of freedom, each actuated by 40 kg high-torque waterproof servos from ROVMAKER, powered at 12 V. The design included revolute joints, consisting of a 360-degree rotating wrist, a 275-degree elbow joint moving along the Y-axis, and a linear gripper for object manipulation. The entire mechanism was designed in-house and 3D-printed in resin, and it was mounted at the front-bottom section of the ROV.

However, due to the high sensitivity and cost of the servos, the system proved to be fragile; a slight over-tightening of the gripper could lead to damage. For this reason, the design was ultimately discarded in favor of a more robust solution.

Fig. 22: Robotic Arm Design V1.0

Robotic Gripper Design V2.0

The second gripper design featured a single degree of freedom using an IP68-rated linear actuator, inspired by Blue Robotics' Newton Gripper When activated, the actuator pushed an internal rod that caused the jaws to open through a pivot mechanism.

Although mechanically simple and robust, the system had several drawbacks. The actuator weighed over 1.5 kg, which shifted the center of mass forward and required repositioning the buoyancy system. Additionally, it lacked position feedback and could not operate reliably underwater for extended periods. These limitations ultimately led us to discard the design.

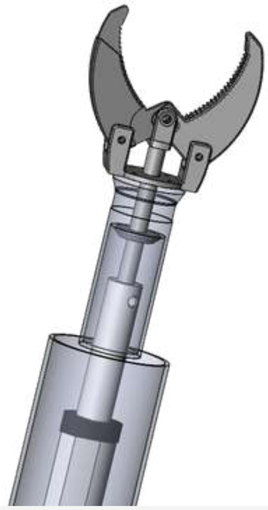

Fig. 23: Robotic Gripper Design V2.0

Robotic Gripper Design V3.0

The final version of the manipulator uses the Newton Gripper from Blue Robotics, chosen for its reliability, compact design, and watertight construction. To adapt it to our specific needs, the original claw was modified to open slightly wider, improving its ability to grasp larger or irregularly shaped objects underwater. This decision allowed the team to save time and resources by avoiding a fully custom design, while still achieving better performance. The modification preserved the gripper's mechanical integrity and ensured continued ease of integration and maintenance in the field, as shown in Fig 24.

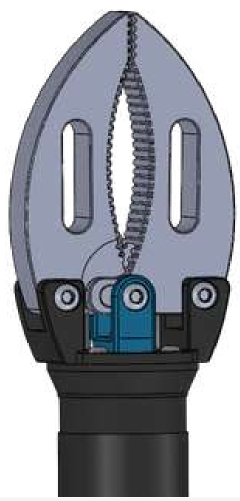

Fig. 24: Robotic Gripper Design V3.0

NET ATTACHMENT

An additional accessory was incorporated on top of the ROV, mounted on a base angled at 45 degrees to optimize its usability, as seen in Fig. 25. The base is 3D printed, allowing for a custom fit and lightweight design. A pool net, which was purchased commercially, measuring 35.5 × 45 × 37.9 cm, as you can see in Fig. 26, is attached to this base. The net is made from durable materials such as nylon and polypropylene, combined with an aluminum handle, resulting in a lightweight yet robust structure that is highly resistant to water exposure and corrosion. Its primary purpose is to assist with various tasks that require collection or manipulation of objects in the underwater environment, complementing the capabilities of the main manipulator system. The angled mounting allows for easier access and improved ergonomics during operation, enhancing the overall versatility.

Fig. 25: Removable net base.

Fig. 26: Removable net.

MECHANICAL SAFETY

To comply with safety guidelines and protect both company members and the vehicle, several mechanical safeguards were implemented. Rounded corner caps (Fig. 27) were integrated into the aluminum frame to eliminate sharp edges that could pose a risk of cuts or impact injuries during handling and transport. Additionally, protective thruster guards (Fig.28) were installed around the propellers to prevent accidental contact during close-range operations and reduce the risk of entanglement with external objects. These guards were engineered to meet IP-20 standards, providing solid particulate protection against objects larger than 12.5 mm, thereby enhancing safety near moving components.
See Appendix B for warning label design for thrusters.

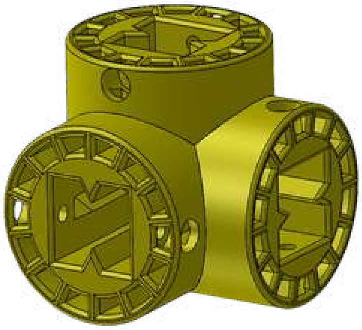

Fig. 27: Rounded corner caps.

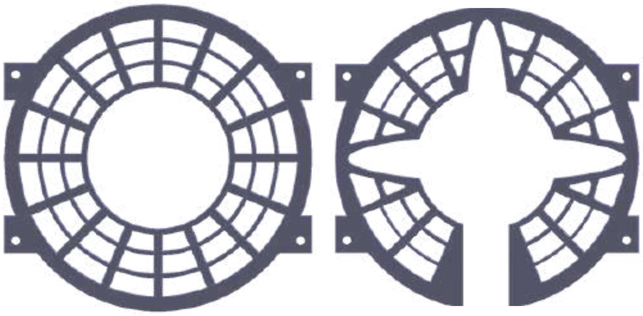

Fig. 28: Thruster guards.

ELECTRICAL SYSTEMS

ELEC. DESIGN EVOLUTION

The electrical system evolved through a structured, iterative process informed by prior seasons and updated MATE requirements. Early planning involved analyzing last year's shortcomings, such as bulky third-party modules, which led to the design of custom PCBs aimed at improving space efficiency and subsystem integration. Nevertheless, due to time and testing constraints, the PCBs were ultimately not implemented in the final system. Collaboration with other departments guided the separation of

power and control systems, while safety and diagnostic needs shaped the inclusion of current sensing and robust connectors. Company members received training in PCB design and safe handling practices, enabling in-house development.
This evolution resulted in a modular, efficient, and competition-aligned architecture.

POWER DISTRIBUTION

Power is supplied from an external topside source at 48 V, then passes through a step-down converter that lowers it to 12V. This 12V output is then transmitted to the ROV through two 10 AWG wires. Inside the enclosure, dedicated buck converters further step the 12V line down to rails required by critical subsystems. An early priority was providing a stable 5V rail to the onboard Jetson Nano— the vehicle's main processing unit. This step established the electrical foundation for the rest of the system and guided the subsequent integration of sensor and actuator interfaces.

Terminal blocks and parallel buses distribute power efficiently across all loads, with hardware rated for the expected current and voltage. Propulsion is managed by electronic speed controllers (ESCs) driven directly from the ESP32-S3, providing precise motor control while maintaining galvanic isolation between logic and power domains.

A power-budget analysis of nominal and peak currents guided connector selection and AWG sizing. Components such as thrusters and servos were specifically evaluated for current stability and peak handling to ensure system reliability.

POWER CONSUMPTION

While designing the vehicle electrical system, we considered both nominal and peak power consumption of all components. The configuration includes six T100 BlueRobotics thrusters—each controlled by a separate ESC—which are the primary power consumers. In this context, power consumption is analyzed in two parts: nominal usage and maximum (full load) consumption.

The following chart (Fig. 29) shows the nominal power consumption of the components integrated into the vehicle, providing an overview of typical power usage relative to the system's 1,440 W available power. For fuse selection, however, we based our calculation on full-load underwater conditions, using datasheet values and peak current estimates. This resulted in a calculated current draw of 27.75 A at 48 V, leading us to select a 30 A fuse, in accordance with MATE ROV safety requirements.

Component	Power consumption (ROV)
48-12 V	+1440 W
Jetson Nano	-30 W
T100 Thrusters (x6) + Basic ESC (x6)	-417.6 W
Newton Gripper	-72 W
USB HUB	-0.45 W
Total power used	520.05W
Remaining power	919.95 W

Fig. 29: Power Consumption Table, based on a dry run.

CUSTOM PCBS AND INTEGRATION

To improve internal organization and reliability, custom PCBs were developed to handle power regulation, signal routing, and sensor interfacing within compact modules mounted to the carrier plate. These in-house designs replaced bulkier off-the-shelf solutions used in previous seasons, simplifying wiring and debugging.

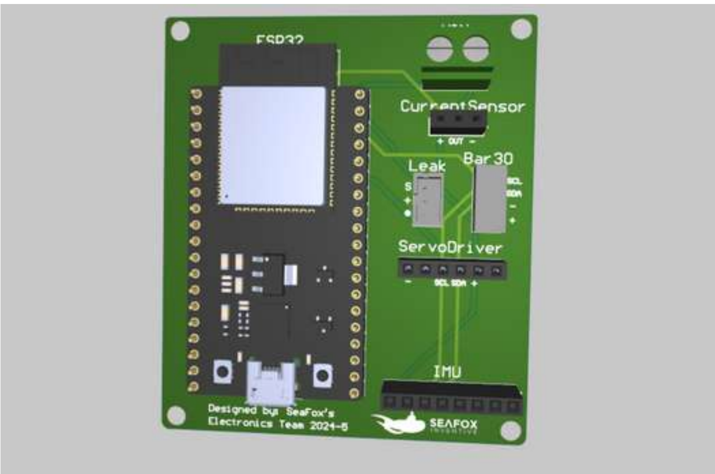

Fig. 30: 3D Model for ROV'S PCB.

SENSOR SUITE

PRESSURE SENSOR

The Bar30 pressure sensor provides depth data and serves as the primary reference for the IMU-based odometry, closing the navigation control loop. It also aids the software team in coordinating depth-based motion and automation.

Fig. 31: Blue Robotics depth pressure sensor.

CURRENT SENSOR

The ACS-712 current analog sensor enables real-time power monitoring to prevent overloads and supports MATE ROV compliance by tracking consumption and behavior under different loads. It helps balance the electrical system and improve reliability by monitoring high-demand components. In this design, the sensor measures currents up to 30 A.

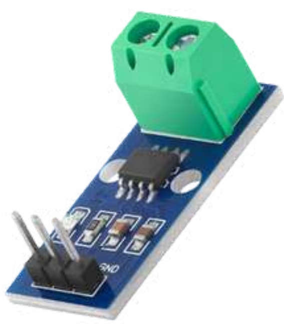

Fig. 32: ACS-712 30A current sensor.

LEAK DETECTION SENSOR

The SOS Leak sensor ensures safety, detects water ingress inside the enclosure, triggering an emergency routine. It is also used during dry-run diagnostics to confirm enclosure integrity before deployment.

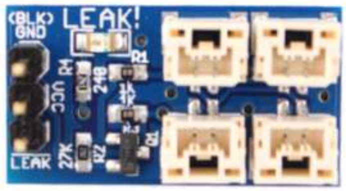

Fig. 33: Blue Robotics Water leak sensor.

INTEL REALSENSE

The Intel RealSense D455 delivers real-time stereo depth data, enhancing navigation and manipulation accuracy. Unlike standard USB cameras, it generates spatial data that enhances control algorithms and complements the Bar30 and IMU for 3D situational awareness.

pH SENSOR

The pH-4502C sensor offers real-time pH measurement via its analog output and built-in probe, fulfilling water analysis tasks for MATE. It’s securely mounted and interfaces with the ESP32-S3 for efficient data handling.

Fig. 34: pH measurement sensor.

TETHER MANAGEMENT: ELECTRICAL INTERFACE & PROTOCOL

The tether design was based on two essential functions: power delivery and data communication. It includes two 10 AWG power cables for reliable current transmission and a single Ethernet cable for high-speed data transfer between the surface control station and the onboard computer. These cables were selected for their electrical robustness and mechanical flexibility, ensuring reliable performance while minimizing drag and buoyancy imbalance. To manage strain and prevent connector damage, strain-relief fixtures were installed both at the ROV's frame and at the surface station. The tether routing and attachment were coordinated with the mechanical team to secure penetrators and waterproof connectors, mitigating water ingress and electrical-failure risks.

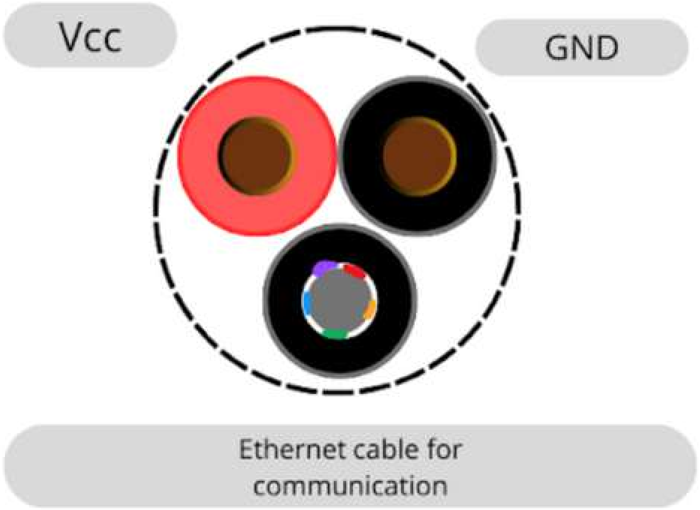

Fig. 35: Tether

A structured tether management protocol was followed throughout the development and testing phases (see appendix C).

CONTROL STATION

The control station integrates the topside power supply and communication link via a tether with dual 8-AWG power leads and Ethernet. Power and signal interfaces are securely routed through stress-relief fixtures on the table to prevent disconnection or strain during operation. A USB hub on the Jetson Nano handles real-time data transfer from cameras and sensors, while the surface operator monitors and controls the vehicle through a laptop-based interface. This setup ensures reliable connectivity, efficient power delivery, and safety during deployment.

ELECTRICAL SAFETY

Protective components such as heat-shrink tubing, terminal blocks, and real-time monitoring sensors reduce electrical hazards. Leak and current sensors provide early fault detection, ensuring safe operation.

SOFTWARE SYSTEMS

SOFTWARE DESIGN EVOLUTION

The SeaFox-VIII software stack was developed in-house from scratch, giving us full architectural control and allowing modules such as sensor acquisition, actuator control, and vision to be tailored to the new hardware. Key components—a PyQt5 GUI, the migration from ROS 1 to ROS 2 nodes, and a custom serial protocol for the ESP32-S3—were built in-house, with external libraries like OpenCV used selectively based on control, complexity, and timeline. While this custom approach enabled tight integration, it also posed debugging and support challenges.

SOFTWARE ARCHITECTURE

MIDDLEWARE

To support scalability and reliable task execution, the software department transitioned from ROS 1 to ROS 2.

ROS 2 was selected after reviewing official documentation and community comparisons, which confirmed its suitability for the company's goals in the 2025 competition. Its improved node communication and task orchestration enabled more robust integration of real-time safety logic and autonomous control systems.

FEATURE	ROS 1	ROS 2
Communication Backend	Custom (ROS TCP/UDP)	DDS (Data Distribution Service, real-time ready)
Node Lifecycle Management	Basic	Advanced (managed lifecycles)
Real-Time Capabilities	Limited	Improved support for real-time applications
Security Features	Minimal	Built-in security mechanisms
Long-Term Support	Slower updates	Active support with LTS versions
Scalability & Modularity	Less modular for large systems	Better suited for complex, distributed systems
Autonomy Support	Manual integration	Nodes support autonomous/semi-autonomous control

Fig 36. Key architectural differences between ROS 1 and ROS 2 guide middleware migration.

CUSTOM SERIAL COMMUNICATION INTEGRATION

To ensure efficient integration between the onboard sensors and the main computing unit, we developed a fully custom serial communication protocol from scratch. Instead of relying on micro-ROS or middleware layers, a structured and lightweight solution was created specifically to optimize compatibility with the ESP32-S3 microcontroller.

The ESP32-S3 is responsible for reading sensor values—including the IMU, leak sensor, pressure sensor (Bar30), and current sensor (ACS-712)—and transmitting this data over a UART serial link to the onboard Jetson Nano. Several communication formats were tested during development until a stable configuration was identified. The final protocol minimized data overhead while supporting reliable parsing within a ROS2 environment.

A dedicated ROS2 node on the Jetson Nano receives this data stream, decodes the messages according to the custom format, and republishes the values as ROS topics. This modular approach enables seamless communication across the full software stack while preserving low latency and flexibility for future sensor expansion.

OBJECT DETECTION AND VISION SYSTEM

For visual object detection, several AI models and frameworks were evaluated, including YOLO and Moondream. We ultimately selected YOLOv11 Nano via Roboflow due to its lightweight architecture, high detection accuracy, and low computational demand—ideal for real-time inference on the Jetson Nano.

In parallel, a custom computer vision pipeline was developed to detect geometric shapes and color patterns aligned with mission task requirements. These routines were implemented as ROS2 nodes and optimized to operate under the lighting and distortion conditions found in underwater environments.

Multiple USB cameras were mounted facing different directions to provide the pilot with complete visual coverage.

USB was chosen over SPI because of compatibility and stability issues with the Jetson Nano and the required Ubuntu version. USB cameras offered easier integration with OpenCV and ROS2, and their resolution and framerate can be adjusted dynamically from software. A custom system was programmed to switch between active cameras as needed, optimizing processing load by disabling unused streams during tasks.

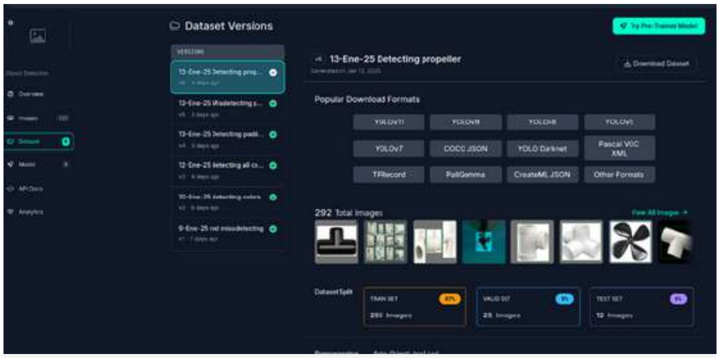

Fig. 37: Custom dataset on roboflow.

All camera feeds are processed using OpenCV, with ROS2 integration handled via the cv_bridge library. This setup enables real-time capture, recording, and distribution of video data across vision-related subsystems.

A front-mounted Intel RealSense depth camera supplements this vision system by providing stereo depth perception, essential for object manipulation and distance estimation. It complements 2D object detection by enabling spatial awareness and assisting the software department with depth-based control logic.

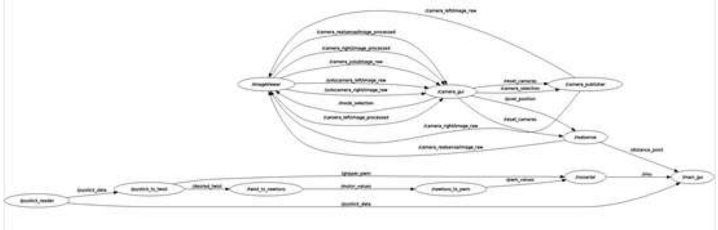

Fig. 38: Camera handler system

CONTROL SYSTEM

The control system was architected as a distributed network of ROS2 nodes, each responsible for a critical operational domain. One node receives commands from the GUI, another processes sensor data, and a dedicated control node computes motor outputs using PID algorithms and kinematic transformations to manage the vehicle's six degrees of freedom.

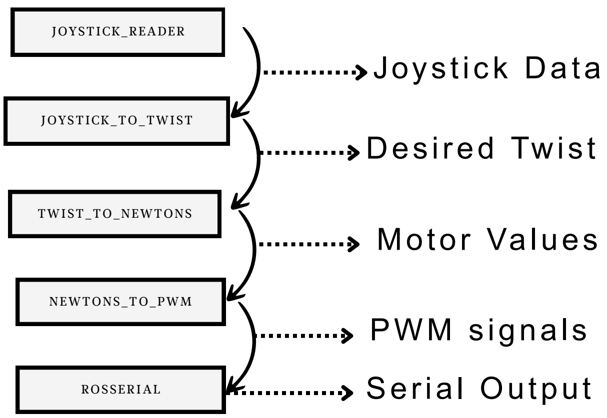

Fig. 39: Control System overview.

To maintain responsiveness during complex tasks, the system includes logic to dynamically reduce camera resolution or disable inactive feeds, minimizing frame loss and reducing CPU load. A dedicated camera manager node enables the pilot to switch views based on situational needs, improving system stability during high-demand operations.

A custom inverse kinematics (IK) module translates position goals into actuator commands, supporting precise manipulator control. This ROS2 node enables intuitive interaction by abstracting raw motor control, ensuring tool movement remains constrained and accurate, even in tight underwater spaces.

All subsystems—thrusters, sensors, cameras, and safety protocols—are managed in real-time by the control software. Embedded safety logic within the actuator control node monitors for critical conditions such as leaks, overcurrent, and IMU faults, triggering alerts or automatic responses when necessary.

USER INTERFACE

The graphical user interface (GUI) was developed using PyQt5, selected after evaluating alternatives such as web-based interfaces (e.g., HTML/React). Though used in prior seasons, the web-based approach proved unstable under competition conditions. PyQt5 was chosen for its native ROS2 compatibility, lightweight performance, and ease of integration with Python-based backends. (Fig. 40).

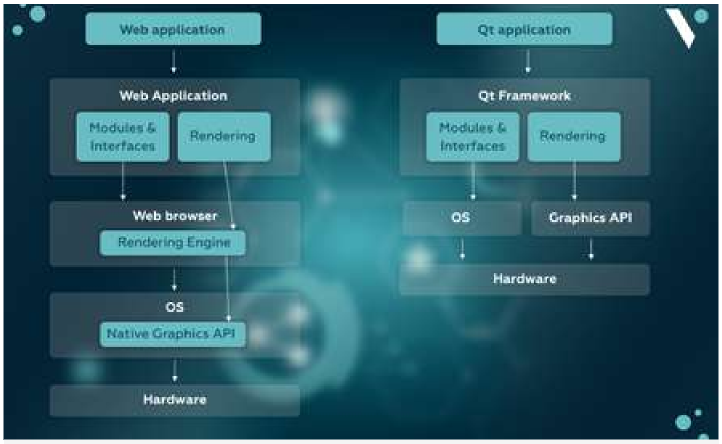

Fig. 40: Comparison of abstraction layers between PyQT5 and web-based applications.

SOFTWARE SAFETY

The ROV's software includes multiple safety mechanisms integrated into ROS2 nodes, which continuously monitor system parameters like current, temperature, humidity, and leaks. When abnormal readings are detected, the system can trigger alerts, shut down affected modules, or initiate a mission abort.

Emergency routines also allow the operator to manually deactivate systems or command a surface return, ensuring real-time protection and fault response during operation.

TESTING METHODOLOGY

ROV-VIII's validation followed a modular and iterative approach across all departments. Electrical sensors—including the ACS-712, Bar30, IMU, and leak detector—were individually bench-tested and calibrated using external instruments before integration. Mechanical systems like the gripper and thruster mounts were tested in dry runs and water trials to verify stability, fit, and motion control.

Software modules (ROS2 nodes, GUI, serial protocol) were validated in isolation and later integrated incrementally into the system. Vision and control subsystems were tested using synthetic and real inputs, ensuring accurate message flow and system responsiveness. GUI visualizations and sensor data displays were tested live to verify correct behavior. System-wide field tests were used to evaluate integration, flotation, and full operational workflows.

TROUBLESHOOTING TECHNIQUES

We used real-time logs, serial output, and modular ROS2 architecture to isolate and diagnose software issues. GUI visualizations and sensor alerts helped identify anomalies like overcurrent or communication delays. Resolution adjustments and dynamic camera switching were implemented after testing revealed dropped frames in high-load conditions.

Mechanical and electrical failures—such as leaks or unstable buoyancy—were caught through immersion testing and pre-dive checklists. Debugging involved multimeter validation, connector inspections, and reviewing logs. Cross-functional meetings allowed for the fast identification and resolution of integration issues. All failures were documented to support future improvements.

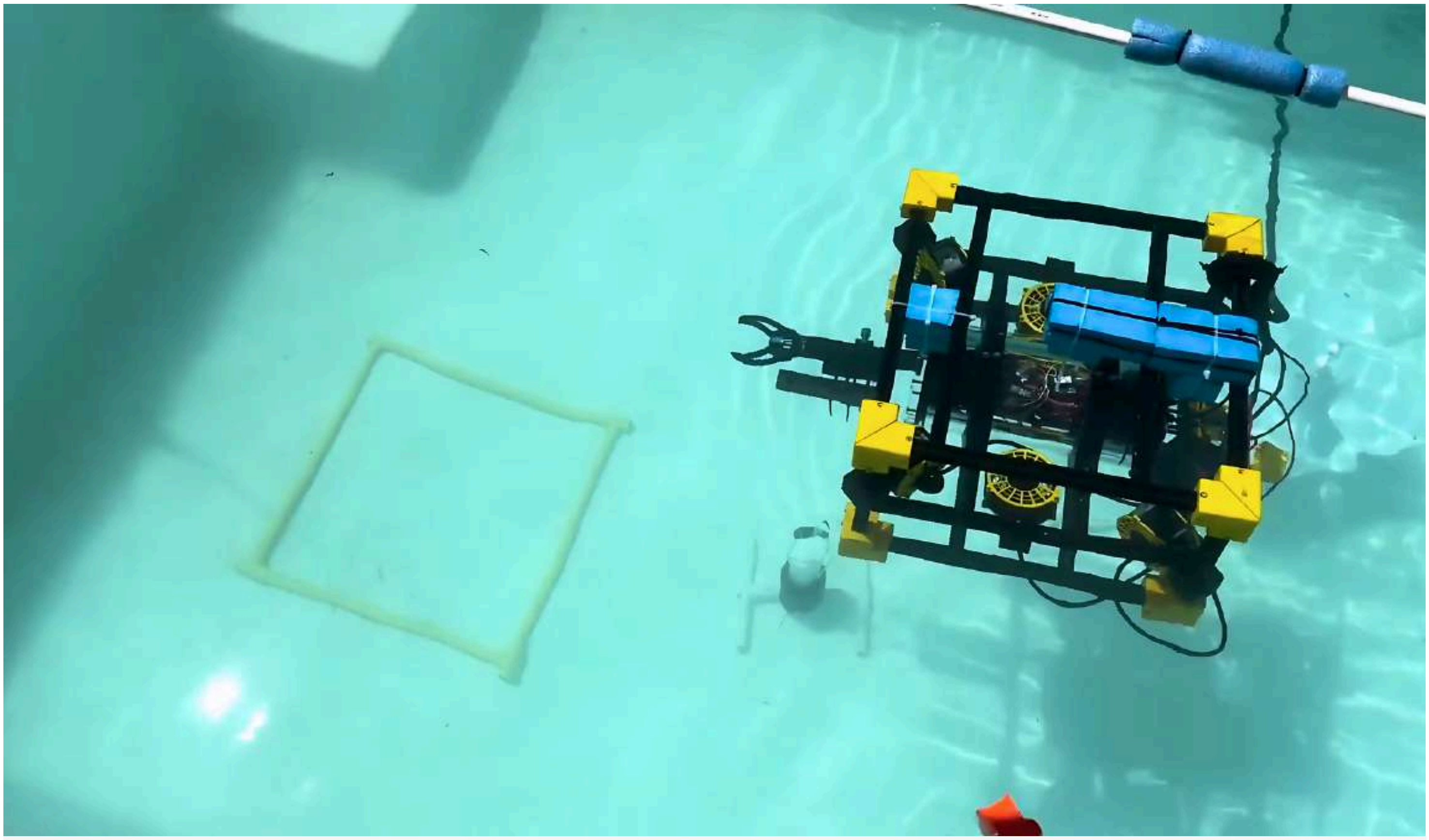

Fig. 41: Water Trial

BUDGET & RESOURCE MANAGEMENT

Budget planning prioritized efficiency through strategic reuse, sponsor collaboration, and a structured acquisition process. A preliminary audit of legacy components identified reusable materials, minimizing new purchases and directing funds toward mission-critical items. Financial oversight was led by the CFO, in coordination with department leads.

COMPONENT SOURCING STRATEGY: BUILD VS BUY

Decisions on in-house fabrication versus commercial procurement were guided by feasibility, safety, and cost. Custom components, such as a redesigned microcontroller module, were built internally to optimize internal space, enable personalized connectors, and improve traceability. Conversely, off-the-shelf items like voltage converters, underwater servos, and camera systems were selected for their proven waterproof ratings and electrical reliability, verified through simulation and early-stage testing.

NEW VS REUSED COMPONENT PROTOCOL

A systematic review process was applied to legacy parts from the 2024 ROV to determine their suitability for reuse. Components such as ESCs, tether cables, and select microcontrollers were approved after passing mechanical inspections and electrical reliability tests. Testing involved checking for corrosion and voltage stability. Items showing degradation or electrical instability were flagged and replaced to maintain overall system safety.

This reuse strategy not only reduced lead times and material costs but also aligned with sustainable engineering practices by minimizing electronic waste and extending the life cycle of components. Kind donations from sponsors like Polymaker (filament) and Modular Assembly Technology (aluminum profiles) further reduced the project's environmental footprint and material costs. High-value purchases were supported through corporate partnerships, allowing the team to invest in essential new hardware while maintaining a responsible, efficient, and sustainable approach.

BUDGET LIST 2024 - 2025					
Category	Component Description	Quantity	Acquisition Type	Worth Per Unit	Total Cost (USD)
ROV Expenses					
Electrical - Component	ACS712 Current Sensor	1	Purchased	$6.00	$6.00
Electrical - Component	Hyper Tough 80-Piece Electrical Connectors	3	Purchased	$7.50	$22.50
Electrical - Component	SB850 Anderson Connectors	1	Purchased	$9.00	$9.00
Electrical - Component	MPU6050 IMU	1	Purchased	$10.00	$10.00
Electrical - Component	Littelfuse 30 AMP Fuse	1	Purchased	$10.00	$10.00
Electrical - Component	Fermerry 22 AWG Wire Rolls	1	Purchased	$10.00	$10.00
Electrical - Component	TICONN 120Pcs Heat Shrink Wire Connectors	1	Purchased	$10.00	$10.00
Electrical - Component	6 Position Terminal Blocks	2	Purchased	$11.00	$22.00
Electrical - Component	12 Position Terminal Blocks	2	Purchased	$12.50	$25.00
Electrical - Component	TOBSUN Stepdown Buck Converter, 12V to 5v	2	Purchased	$15.00	$30.00
Electrical - Component	Waterproof 48V to 12V 30A Stepdown Converter	1	Purchased	$15.00	$15.00
Electrical - Component	Freenove ESP32-S3 Breakout Board	1	Purchased	$15.00	$15.00
Electrical - Component	Fermerry 20 AWG Wire Rolls	1	Purchased	$15.00	$15.00
Electrical - Component	M10 6.5mm wetlink penetrators	4	Purchased	$16.00	$64.00
Electrical - Component	M10 8.5mm wetlink penetrators	4	Purchased	$16.00	$64.00
Electrical - Component	Freenove ESP32-S3-WROOM Board Lite	1	Purchased	$17.00	$17.00
Electrical - Component	Littelfuse Fuse Holder	1	Purchased	$18.00	$18.00
Electrical - Component	12V 30A Switching Power Supply	4	Purchased	$19.99	$79.96
Electrical - Component	30ft. CAT6 Ethernet Cable	1	Purchased	$21.00	$21.00
Electrical - Component	BlueRobotics SOS Leak Sensor	1	Purchased	$35.00	$35.00
Electrical - Component	BlueRobotics Basic ESC	6	Re-used	$38.00	
Electrical - Component	BlueRobotics BAR30 Depth Sensor	1	Re-used	$85.00	
Electrical - Component	Marine Grade 10 AWG wire	1	Re-used	$135.00	
Electrical - Component	ROVMaker Waterproof Micro Servos	3	Purchased	$140.00	$420.00
Electrical - Component	BlueRobotics T100 Thrusters	6	Re-used	$258.00	
Electrical - Component	BlueRobotics Newton Subsea Gripper	1	Purchased	$760.00	$760.00
Electrical - Component	BlueRobotics 6" Watertight Enclosure	1	Re-used	$786.00	
Mechanical - Component	Underwater Servo Motor ROV Maker	4	Purchased	$160.81	$643.24
Mechanical - Machine	3D Printer	3	Re-used	$300.00	
Mechanical - Machine	Resin 3D Printer	1	Re-used	$350.00	
Mechanical - Material	Pre-ser Nut-6-M4	16	Donation	$8.80	
Mechanical - Material	Black Paint	3	Purchased	$12.44	$37.32
Mechanical - Material	M4 Screws for 20x20 Profile	16	Purchased	$12.44	$199.04
Mechanical - Material	ANYCUBIC 3D Printer Resin	1	Purchased	$19.99	$19.99
Mechanical - Material	Polymaker Poly-Lite PETG 3D Printer filament	6	Donation	$21.99	
Mechanical - Material	Polymaker PETG ESD 3D printer filament	1	Donation	$32.99	
Mechanical - Material	90° Profile Joints	64	Donation	$33.00	
Mechanical - Material	Polymaker Poly-Lite TPU 3D Printer filament	2	Donation	$45.00	
Mechanical - Material	Meter of 20x20 Anodized Aluminum Extrusion Profile	6	Donation	$75.90	
Mechanical - Material	Screws for 90° Profile Joints	42	Donation	$130.20	
Mechanical - Tool	Measuring Tape	2	Purchased	$4.76	$9.52
Mechanical - Tool	Allen Key Set	3	Purchased	$5.08	$15.24
Mechanical - Tool	Level	1	Purchased	$7.61	$7.61
Mechanical - Tool	Phillips Head Screwdriver	2	Re-used	$10.00	
Mechanical - Tool	Angle Grinder (Buffer)	1	Re-used	$48.98	
Software - Control	Gamepad (Xbox controler)	1	Purchased	$50.00	$50.00
Software - Control	Jetson Nano (Onboard computer)	1	Re-used	$250.05	
Software - Vision	USB cameras (HBV-W202012HD)	3	Purchased	$17.50	$52.50
Software - Vision	Intel Realsense (Depth camera)	1	Re-used	$419.00	
Total					$2,516.78

Fig. 42: Budget List 2024-2025 ROV Expenses

BUDGET LIST 2024 - 2025					
Category	Component Description	Quantity	Acquisition Type	Cost Per Unit	Total Cost (USD)
Float Expenses					
Electrical - Component	BlueRobotics 3" Watertight Enclosure	1	Purchased	$332.00	$332.00
Electrical - Component	Sensors (BAR02, current, IMU, Leak sensor, each)	1	Purchased	$150.00	$150.00
Electrical - Component	Threaded shaft	5	Purchased	$10.00	$50.00
Electrical - Component	Microcontroller (ESP32-C3)	2	Purchased	$20.00	$40.00
Electrical - Component	RC module	2	Purchased	$20.00	$40.00
Electrical - Component	Custom PCB Board	1	Purchased	$27.00	$27.00
Electrical - Component	DC MOTOR with encoder	1	Purchased	$15.00	$15.00
Electrical - Component	AAA batteries	6	Purchased	$2.00	$12.00
Electrical - Component	Motor Driver	2	Purchased	$5.00	$10.00
Electrical - Component	3 AMP Fuse	1	Purchased	$5.00	$5.00
Electrical - Component	Fuse Holder	1	Purchased	$3.00	$3.00
Total					$684.00
Administrative Expenses					
Administration - Logistics	Air Transportation San Diego - Detroit	16	Purchased	$558.38	$8,934.01
Administration - Logistics	Days Inn by Wyndham Alpena (4 nights)	6	Purchased	$875.60	$5,253.60
Administration - Logistics	Ground Transportation	2	Purchased	$1,126.90	$2,253.80
Administration - Image	Team Uniforms	16	Purchased	$55.76	$812.16
Administration - General	World Championship Registration	1	Purchased	$650.00	$650.00
Administration - Marketing	Camera Battery	12	Purchased	$1.40	$16.80
Administration - Marketing	Mobile Phone Microphone	1	Purchased	$10.85	$10.85
Administration - Marketing	Professional Camera	1	Re-used	$450.25	
Total					$17,931.22
Incomes					
Initial Fund	Remaining funds from previous administration				$2,166.66
Fundraising - Donation	Centro de Enseñanza Técnica y Superior, CETYS University				$7,614.21
Fundraising - Events	Fundraising events such as weekly and specials sales				$4,225.00
Fundraising - Donation	IAMSA Development Group				$1,522.84
Fundraising - Donation	Molinos del Sudeste, La Moderna				$1,522.84
Fundraising - Donation	Tecnologias Internacionales de Manufactura, TIMSA				$1,522.84
Fundraising - Donation	Miura Logistics				$1,522.84
Fundraising - Donation	Alejandro Novoa				$507.61
Fundraising - Donation	Sialia Karina Mellink Mendez				$507.61
Fundraising - Donation	Rheem Mexicali				$507.61
Fundraising - Donation	Instituto Municipal de la Juventud de Mexicali, IMJUM				$406.09
Fundraising - Donation	RUBA Residencial				$253.81
Fundraising - Donation	Gruas Cimarron				$253.81
Fundraising - Donation	Honda Optima				$101.52
Total					$22,635.29
Surplus					$1,603.29

Fig. 43: Budget List 2024-2025 Non - ROV Expenses

SAFETY FEATURES

To ensure safe operation across all subsystems, we integrated safety features spanning electrical, mechanical, and sensor domains (See Appendix D).

TRAINING

To promote cross-functional knowledge and safety, all company members were encouraged to attend training sessions across mechanical, electrical, and software areas, regardless of their primary role. This ensured a well-rounded understanding of the ROV's systems during integration and testing.

Mechanical Training covered safe tool use, frame assembly, and buoyancy element installation, with emphasis on PPE and mechanical hazard awareness.

Electrical Training included soldering, PCB design, multimeter and oscilloscope usage.
Members learned safe procedures for working with high-current systems, cable management, and component testing.

Software Training introduced version control, microcontroller programming, and sensor integration. Sessions also included debugging protocols (I²C, UART) and setup of the Jetson Nano runtime environment.

LAB SAFETY PROTOCOLS

At the start of the season, safety briefings were held to orient new and returning members on the proper use of tools, emergency procedures, and personal protective equipment (PPE). The lab is equipped with clearly marked safety infrastructure, including a fire extinguisher, a first aid kit, an eye wash station and PPE charts.

Each tool in the workspace is associated with specific PPE requirements. The safety officer is responsible for verifying tool readiness and instructing members on safe usage based on task type (cutting, soldering, drilling, etc.). For detailed safety procedures and checklists, see Appendix E.

TASK TYPE	REQUIRED PPE
Soldering	Safety glasses, heat-resistant gloves
Cutting tools	Safety glasses, cut-resistant gloves
Drilling and machining	Safety glasses, ear protection, gloves
Frame assembly	Safety boots, gloves

Fig. 44: PPE requirements of tasks

Fig. 45: Some of the gloves and glasses available to company members.

ACKNOWLEDGEMENTS

ACKNOWLEDGEMENTS

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CETYS Universidad
For fostering innovation, providing institutional support, and being the academic home that allows SeaFox to grow and thrive.

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Family, Friends, and Community
We thank our families and local supporters and companies for their encouragement and involvement in our fundraising efforts.

MATE ROV Competition
Special thanks to the MATE Center for providing the platform that drives innovation and collaboration in marine robotics.

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REFERENCES

Our project has been informed and supported by a variety of resources, including academic publications, industry standards, and previous research in the field of underwater robotics. Below is a list of references that have been instrumental in our project development.

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APPENDIX

A - CHALLENGES & LESSONS LEARNED

CHALLENGE	LESSON LEARNED
No reusable code from past seasons	Developed full in-house software system, reinforcing understanding and ownership.
Sensor-actuator integration issues	Switched to modular ROS2 nodes and validated each module iteratively.
Incompatible or degraded components	Enforced strict pre-integration testing and refined sourcing criteria.
Vision system overload from high-res streams	Implemented dynamic resolution and camera toggling for system stability.
Buoyancy/layout imbalance from enclosure redesign	Validated CAD models early to ensure hydrodynamic and structural balance.

Fig. 46: Challenges and Lessons Learned Table

B - WARNING LABELS ON THRUSTERS

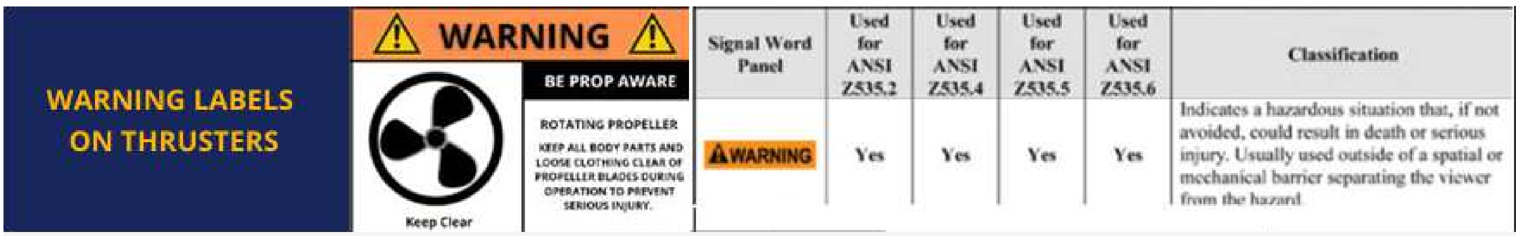

Fig. 47: Warning label design for thrusters: ISO 7010 – Standard for safety symbols used in ISO 3864. ANSI Z535 – Corresponding American standard for safety signage, product warning labels and product instructions.

C - TETHER MANAGEMENT PROTOCOL

PHASE	PROTOCOL
Preparation	Visual inspection for tension, twisting, or wear; implementation of strain relief.
Implementation	Secure routing through the ROV structure, proper connector locking, and final verification.
Testing	Monitoring buoyancy behavior and resistance during field tests.
Post-use	Cleaning, drying, and maintenance review with the safety team to ensure long-term reliability.

Fig. 48: Tether Management Protocol

D - CROSS-SYSTEM SAFETY FEATURES

CATEGORY	COMPONENT/FEATURE	FUNCTION
Electrical	ACS-712 Current Sensor	Prevents overcurrent damage to high-demand systems
Electrical	Thermo-fit & Terminal Blocks	Prevent loose wires and shorts
Electrical	Parallel Power Distribution	Minimizes risk of bottlenecks and voltage drops
Mechanical	Tether Stress-Relief Mounts	Protects connectors and reduces risk of strain or failure
Mechanical	Cable Routing & enclosure Layout	Prevents tangling, interference, and overheating
Electrical	SOS Leak Sensor	Detects water ingress and triggers emergency protocols
Electrical	Bar30 Pressure Sensor	Assists in safe vertical control and depth-limit enforcement
Electrical	IMU	Enables stable navigation and collision avoidance
Mechanical	Material Choice for Mounts (Filament)	Ensures electrical insulation and secure internal support
Mechanical	Edge guards	Prevent injuries by eliminating sharp edges during handling and transport
Mechanical	Thruster guards	Protect company members from accidental contact and reduce entanglement risks.

Fig. 49: Cross-System Safety Features and Functions

E - SAFETY CHECKLIST & LAB SAFETY POLICY

PRE-POWER CHECKLIST
☐ Verify that the ROV's internal wiring is properly connected and clean.
☐ Inspect all cable connectors for damage or looseness.
☐ Confirm that the electronics capsule is fully sealed.
☐ Check that the tether is untangled and free from obstructions.
☐ Use a manual vacuum pump to reach 10 inHg pressure via the vent penetrator.
☐ Wait 15 minutes; if pressure is stable, remove the pump and seal the vent.
☐ Keep battery/power supply dry and safely distanced from water.
☐ Confirm that the surface station (computer, router, monitor) is powered and connected.
☐ All team members must wear PPE: safety glasses, closed-toe shoes, and secure clothing/hair.

Fig. 49: Pre-Power Checklist

POWER-UP CHECKLIST
☐ Connect the tether to the power supply.
☐ Verify successful GUI connection.
☐ Confirm camera feeds are live and stable.
☐ Ensure control system communicates with all thrusters.
☐ Listen for audible cues signaling thruster power readiness.

Fig. 50: Power-Up Checklist

WATER IMMERSION CHECKLIST
☐ Inspect all seals, gaskets, and penetrators for wear or damage.
☐ Submerge the ROV slowly with assistance from two team members.
☐ Watch for abnormal bubbling and verify buoyancy stability. If abnormal bubbling is detected, refer to **ABNORMAL BUBBLING RESPONSE.**
☐ Regularly check the leak detector for signs of intrusion.
☐ Conduct a functionality test to ensure all systems operate correctly after immersion.
☐ Document any issues or anomalies observed during the water immersion check for further assessment and action.

Fig. 51: Water Immersion Checklist

LOST COMMUNICATION RESPONSE
☐ Immediately disconnect power and retrieve the ROV via the tether.
☐ Reboot control systems to attempt reconnection.
☐ Collaborate with the surface station team to troubleshoot.
☐ Log the incident with observed symptoms and recovery steps taken.

Fig. 52: Lost Communication Response Checklist

ABNORMAL BUBBLING RESPONSE
☐ Immediately disconnect power and retrieve the ROV via the tether.
☐ Inspect the leak sensor for water ingress confirmation.
☐ Examine the ROV to identify the point of water entry within the capsule seal.
☐ Use a multimeter to verify the presence of 0V across internal systems.
☐ Log the incident and repair or replace any damaged electronics.
☐ Restore vacuum integrity by resealing the capsule.

Fig. 53: Abnormal Bubbling Response Checklist

1.	**Appropriate Lab Attire:** Wear safety glasses or side-shields, close-toed, non-slip shoes, and appropriate gloves. Avoid loose clothing and secure long hair. Remove rings, watches, and bracelets.
2.	**Clean Workspace:** Keep the workspace clean after each session. Ensure that all tools, equipment, and surfaces are properly wiped down and organized.
3.	**Report Incidents**: Immediately report all injuries or accidents to the Lab Supervisor.
4.	**Seek Guidance:** If unsure about a procedure, stop and ask the Chiefs or CEO for help.
5.	**Address Hazards:** Report any unsafe conditions and correct them if possible.
6.	**Know Your Equipment:** Use only equipment you are trained on and understand fully.
7.	**Proper Tool Use:** Only use tools for their intended purposes.
8.	**Adjust Safely:** Adjust machines only when fully stopped, unless motion is required for adjustment.
9.	**Monitor Machines:** Never leave a running machine unattended unless designed for continuous operation.
10.	**Stop Equipment Safely:** Never use your hands or tools to stop moving parts.
11.	**Handle Sharp Edges:** Deburr or file all machined parts to eliminate sharp edges.
12.	**Secure Workpieces:** Always clamp or secure workpieces properly before working.
13.	**Respiratory Protection:** Use proper protection when working with dust, fumes, vapors, or chemicals.
14.	**Chemical Safety:** Read the Safety Data Sheets (SDS) before using lubricants, resins, adhesives, or other chemicals.
15.	**Stay Focused:** Avoid distractions while using tools or machines.
16.	**Safe Lifting Techniques:** Use proper form and ask for help when lifting or carrying heavy objects.
17.	**Prevent Tripping:** Keep walkways clear of tools and materials.
18.	**Emergency Preparedness:** Know the locations of fire extinguishers, fire exits, and first aid kits.

Fig. 54: SeaFox Inventive Lab Safety Policy

F - ROV SID

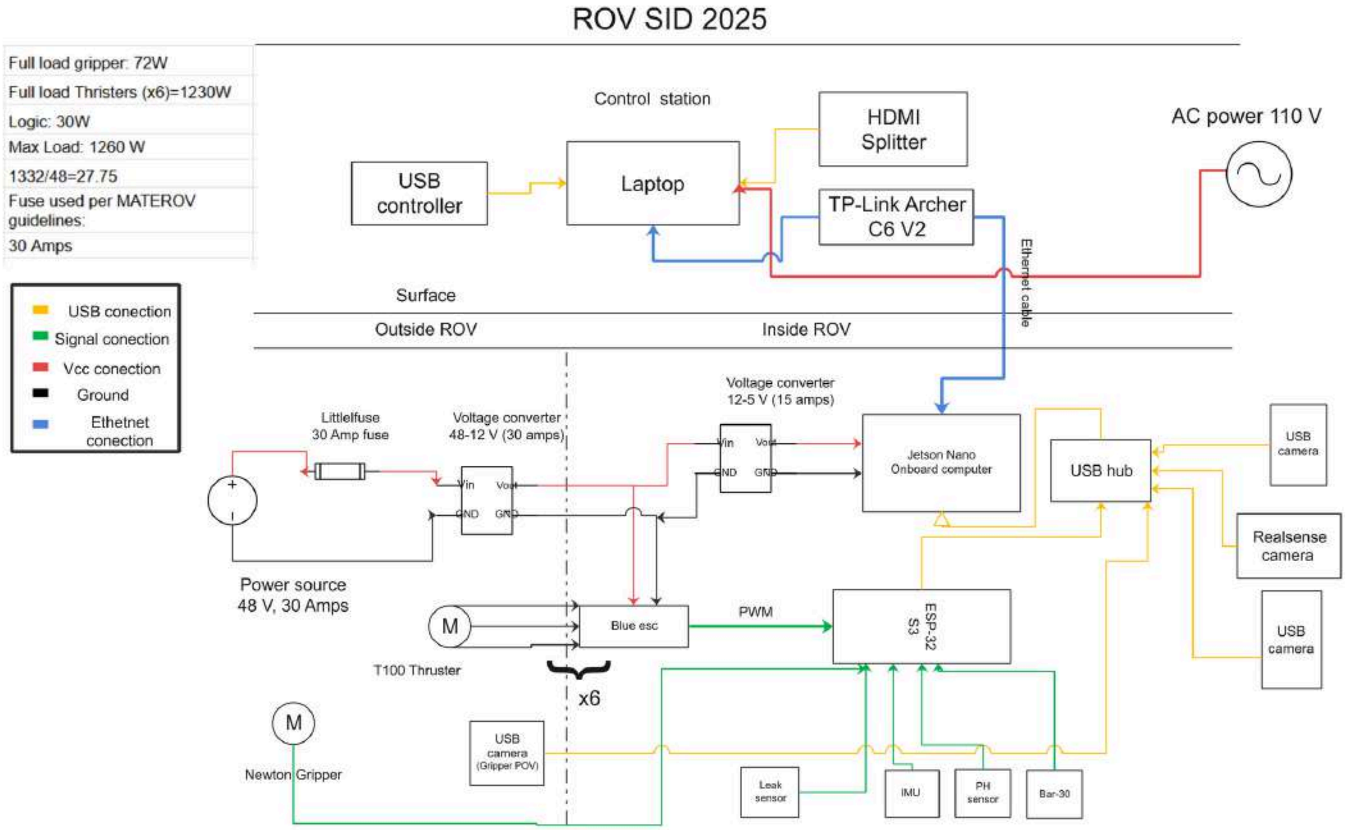

Fig. 55: SeaFox-VIII SID 2025