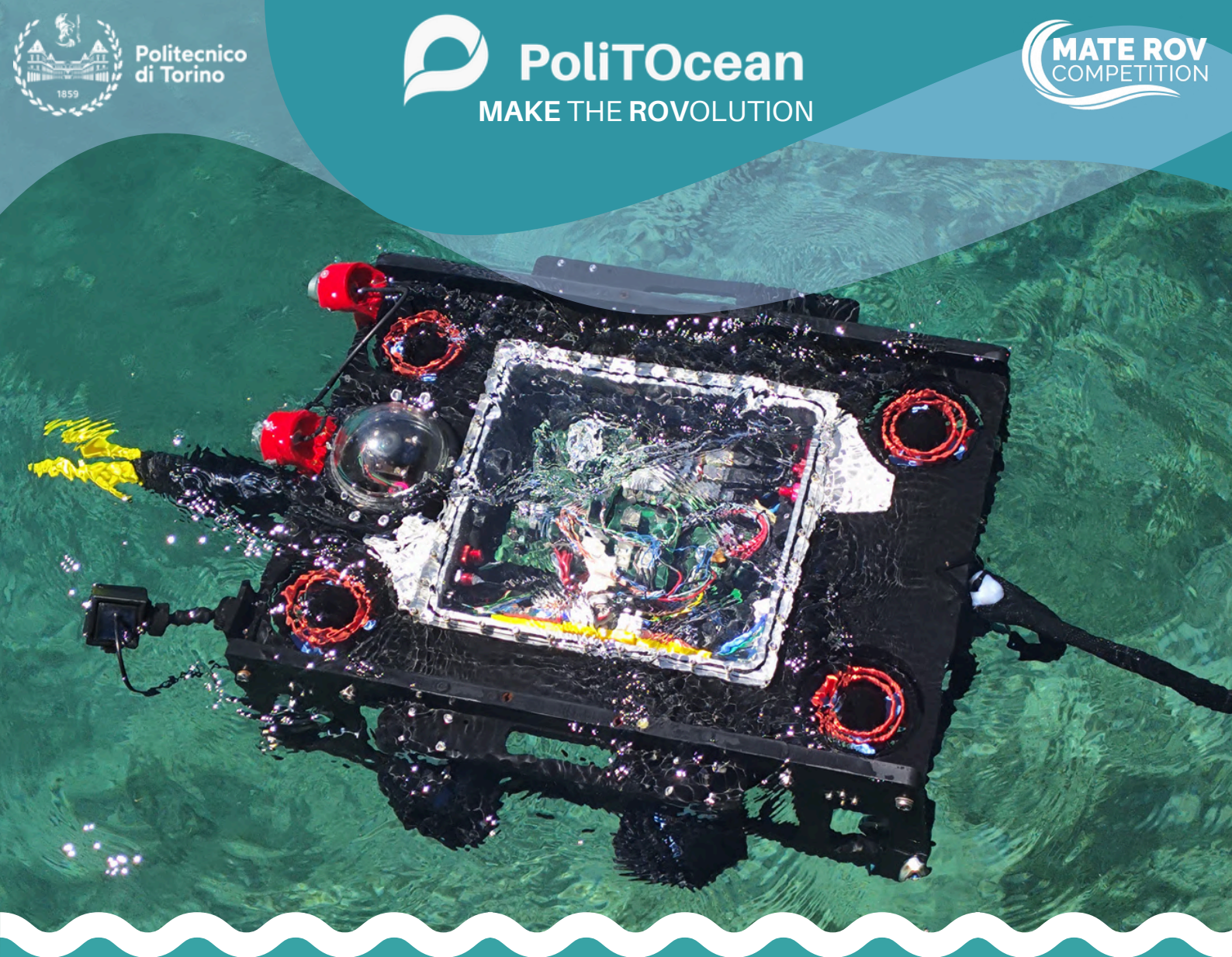




Politecnico
di Torino

PoliTOcean
MAKE THE ROVOLUTION

**MATE ROV
COMPETITION**

TECHNICAL REPORT

PoliTOcean '26

Politecnico di Torino | Italy



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Abstract

This technical documentation presents EVA, a Remotely Operated Vehicle (ROV) engineered by PoliTOcean team. Developed to benefit scientific research, industry, and marine conservation, EVA is the result of over 5,000 hours of rigorous planning, prototyping, and testing.

The report provides an exhaustive, clear summary of the team's work across all organizational and technical divisions. Primarily, the project management structure is outlined, highlighting the collaborative interaction between senior members and new recruits.

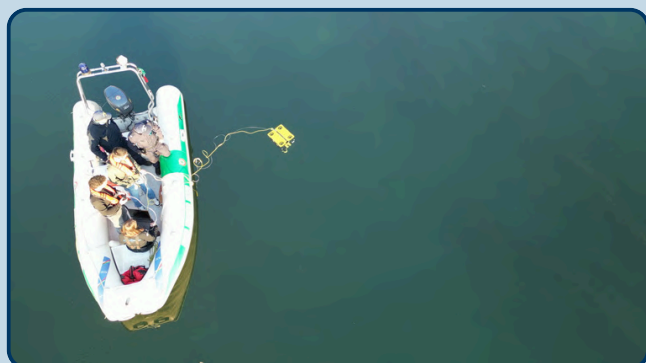
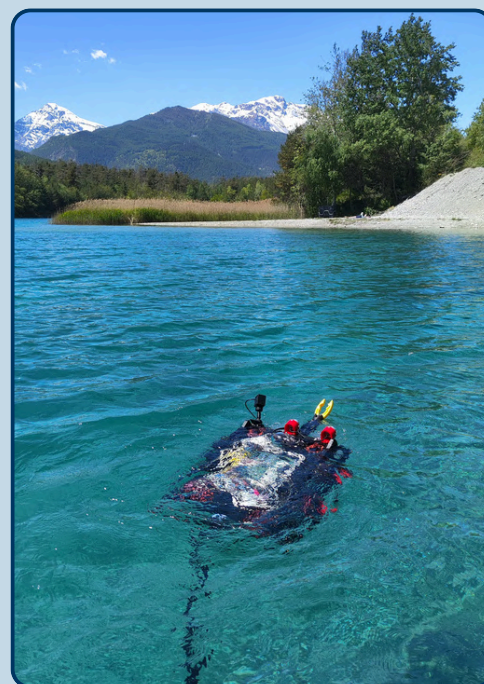
The engineering design rationale sections explore key trade-offs and innovations, demonstrating how the mechanical division optimized the vehicle's structure for efficiency and adaptability. Concurrently, the electronics and software divisions integrated advanced sensors and custom firmware featuring Heave, Roll, and Pitch controllers to maximize maneuverability and task performance. Furthermore, this document elaborates on our comprehensive systems approach, detailing our stringent safety protocols, systematic testing and troubleshooting methodologies, and transparent cost accounting. By documenting our step-by-step problem-solving processes, it is demonstrated how EVA was strategically built to meet complex, real-world underwater mission requirements with optimal precision and reliability.



Team PoliTOcean

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Project Management

Company Structure

PoliTOcean is a multidisciplinary student team of Politecnico di Torino (Italy) consisting of **83 students** from diverse engineering backgrounds. The team is divided into three main areas: the **MATE Competition Department** (Fig.1), the **R&D Department**, and the **C&M Department**. Each of these focuses on specific projects. The **Team Leader (TL)** ensures seamless communication and workflow across all departments, regularly reviewing progress reports. This role holds ultimate responsibility for budget approval; all purchases must receive their final authorization after being validated by the PMs. Each department has its own **Project Manager (PM)** and **Chief Technical Officer (CTO)**. While the PM handles the administrative and organizational aspects of the projects, the CTO oversees the engineering and technical coordination. The departments are further divided into 5 divisions: **Electronics, Mechanics, Firmware, Hydrodynamics, and Control Systems**. The role of dividing the long-term tasks in short-term assignments is given to the **Head of Division (HoD)** helped by the **Technical Head of Division (ToD)**. The detailed breakthrough of the company structure can be found in Appendix A.



Figure 1. MATE Roaster 2026

Mate Department

The **MATE Department** is primarily dedicated to the design, development and optimization of two main projects: a **high-performing ROV** and an **autonomous float**, both engineered specifically for the MATE ROV Competition. Beyond the core vehicle architecture, the department is responsible for developing specialized **payload tools and accessories** required to execute the competition's tasks. Additionally, it manages the comprehensive annual training program for new **ROV pilots**. Alongside the acquisition of technical skills, daily operational sessions are conducted to ensure high capability and precision in task execution. Post-session debriefings are utilized to gather critical pilot feedback, which is essential for troubleshooting system anomalies and implementing iterative design improvements.

Research and Development Department (R&D)

The **R&D Department** focuses on advanced marine engineering simulations and academic research to facilitate technology transfer and strategic collaborations (Fig.2). A primary focus of the department is the evolution of **NEREO**, a legacy ROV currently equipped with an internal battery power system. Expanding on this foundation, this year the department has introduced a long-term project to develop a **high-endurance AUV** capable of sustained underwater monitoring operations, emphasizing power efficiency and reliability.

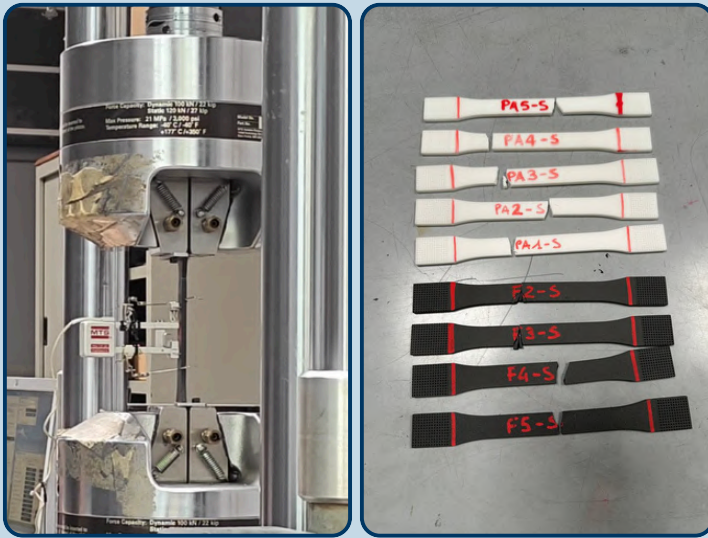


Figure 2. Research of different materials through Failure Tests

Communication and Management Department (C&M)

The Communication and Management (C&M) department drives both public outreach and corporate relations through two distinct workflows. **The Communication unit** acts as the public interface of the organization, overseeing social media channels to ensure consistent content delivery. On a further notice, the department manages the bi-annual **new member recruitment** process held in September and March. Meanwhile, **the Management unit** focuses on corporate strategy. It identifies potential collaborators, fosters partnerships with existing sponsors, and coordinates promotional activities to enhance overall visibility and impact.

Project Schedule

PoliTOcean recognizes that **effective planning** and **consistent execution** are essential for success. Consequently, at the start of each operational year, the team clearly defines its **primary objectives** for the upcoming competition period. These milestones are mapped out in a **Gantt chart** (Fig.3) and shared during **weekly departmental meetings**, which are essential for tracking progress and collaboratively resolving operational issues.

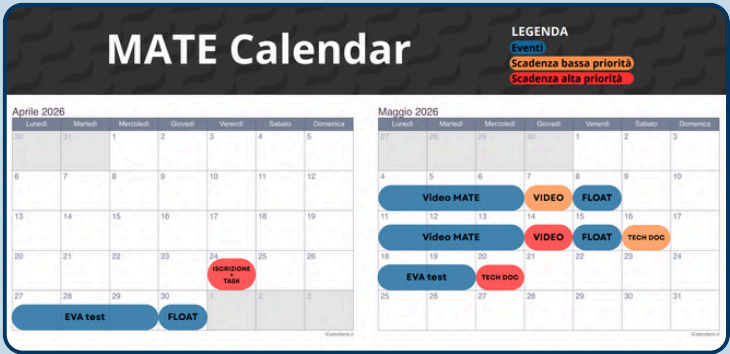


Figure 3. Gantt method example

To ensure that off-site members remain fully integrated, these meetings are consistently broadcasted via **Discord**, facilitating seamless remote participation. To translate this strategic planning into daily action, the team relies on a combination of **rapid communication** and **structured workflows**. Day-to-day internal coordination is driven by **Telegram**, which serves as the primary channel for immediate updates and quick problem-solving across all divisions. Parallel to this, project management is centralized on **Notion**. Within this platform, task allocation (Fig.4) is guided by the **Eisenhower Matrix** evaluating the **urgency** and **importance** of every activity to ensure members strategically focus on high-impact tasks. Task execution follows the **Kanban system**, which is adopted as a core operational principle, promoting a continuous and transparent workflow. By mapping the lifecycle of every activity, it encourages a shared awareness of the **collective workload**, **naturally minimizing bottlenecks** and **ensuring a steady, collaborative production rhythm**.

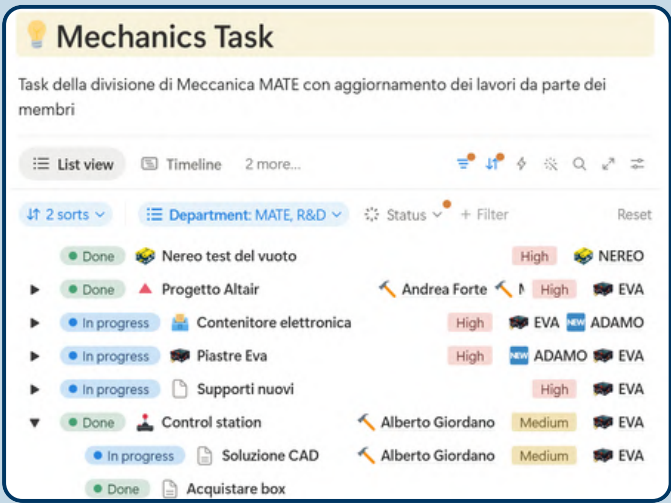


Figure 4. Task assignments

Design Rationale

Engineering Design Rationale

The architectural design of EVA (Fig. 5,6) integrates six subsystems: the structural frame, the electronic enclosure four cameras, eight thrusters, the robotic manipulator, and the connectors housing. The spatial distribution of these components is the direct result of a **trade-off analysis**, in order to optimize payload weight distribution, maximize sensor accessibility, and ensure hydrodynamic stability.

The vehicle features a parallelepiped structural design optimized for modularity and sensor integration. Following a **balanced systems** approach, the upper plate houses the electronics enclosure, three cameras and four vertical thrusters. Conversely, the lower plates are dedicated to the downward-facing camera, the robotic manipulator, and the connectors housing, strategically **lowering the Center of Gravity** to enhance stability. The remaining thrusters are mounted on the lateral plates, ensuring a logical distribution of forces for precise underwater maneuvering. Ultimately, these design choices enable full 6-DoF (degrees of freedom) maneuverability and optimal control during complex mission operations.

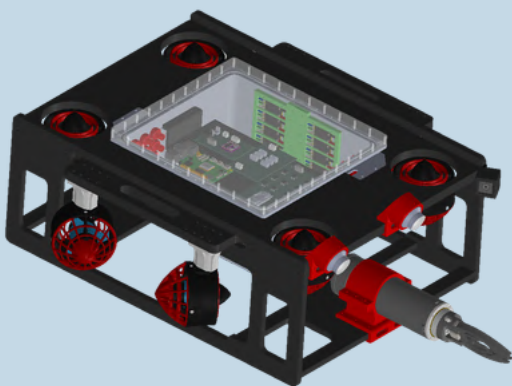


Figure 5. EVA's front view

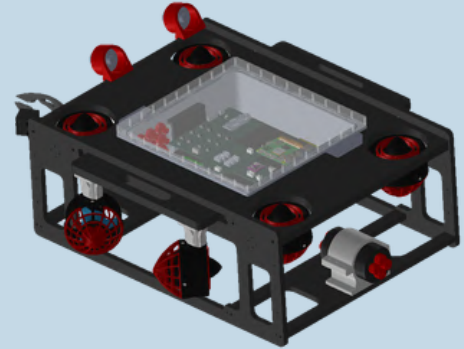


Figure 6. EVA's back view

The engineering process initiated with a systematic **analysis of the MATE 2026 mission tasks**, focusing on three core requirements: **stability, modularity, and cost-efficiency**. This phase utilized an evaluation of the team's previous competition vehicle (EVA) to identify critical areas for redesign or integration.

This analysis enabled the team to establish a step-by-step design process that effectively balanced the integration of high-performance instruments with stringent budget constraints. Consequently, every modification to the vehicle was rigorously justified by specific mission criteria. To maintain this workflow, each department holds **monthly meetings** to define objectives, **troubleshoot issues, and brainstorm innovative solutions**. Components are first designed and simulated using specialized software. Rapid **prototypes** are then manufactured and physically tested to validate the software analyses against real-world performance. This validation sequence is explicitly designed to identify potential failures early, preventing manufacturing mistakes, minimizing material waste, and significantly reducing overall project costs. Once validated, the final components are produced and integrated into EVA.

Innovation and Problem solving

To resolve the low dimensional accuracy and high ongoing maintenance costs associated with the legacy 3D printer, the manufacturing workflow was upgraded with a **Bambu Lab X1** (Fig.7). This upgrade fundamentally improved **component quality** by providing superior dimensional accuracy and significantly **reducing print failure rates**, translating to reduced material waste and lower long-term replacement costs.

The transition to engineering-grade polymers, such as **Carbon Fiber-Reinforced Polyphthalamide (PPA-CF)** for the internal electronics support plate, was the result of a structured problem solving process. During our monthly meetings (Fig.9), we first utilize the **Starbursting method**, analyzing the "5Ws and H" (Who, What, Where, When, Why, and How) to ensure new design ideas are fundamentally sound. We then apply **Reverse Brainstorming** to identify potential failure points and develop mitigation strategies.



Figure 7. 3D printer and filament dryer

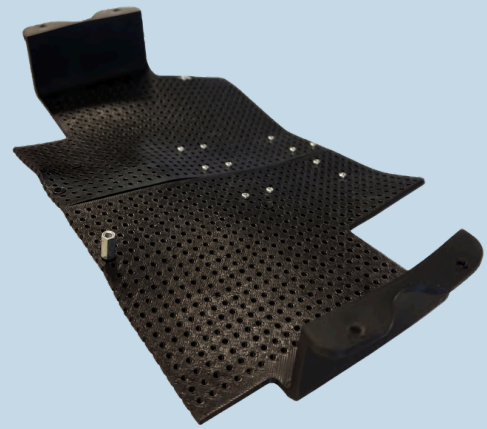


Figure 8. Previous PLA support plane

A primary example of this process occurred when we identified that the previous **PLA support plate** was prone to thermal deformation (Fig.8). While PPA-CF was selected for its exceptional mechanical stiffness and moisture resistance (*Benedetto*), our Reverse Brainstorming sessions revealed a critical issue: PPA-CF is highly hygroscopic. We concluded that without proper moisture control, the structural integrity of the print would fail. Consequently, we integrated a **filament dryer** (Fig.7) into our workflow to ensure the material maintains its engineering properties. This systematic approach demonstrated a balanced systems approach, ensuring the new manufacturing process resulted in higher functionality and a more reliable electronics enclosure.

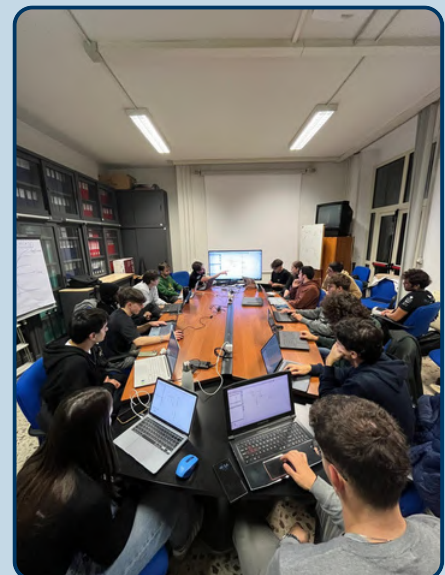


Figure 9. Meeting example

System approach

The development of EVA is rooted in a **holistic system approach**, where the primary objective is to minimize complexity through seamless integration. The **electronics enclosure**, **mounting supports**, and the **vehicle frame** were developed as a **unified system** rather than isolated parts, ensuring total compatibility with all internal components. This design philosophy is the result of continuous, cross-divisional collaboration (Fig.10), ensuring that every subsystem is perfectly integrated and functions in harmony to optimize the ROV's overall operational efficiency.

The **sensor suite** is engineered to be both simple and effective, focusing on the **pilot's situational awareness and intuitive control**. The redundant **multi-camera system** guarantees that the pilot receives continuous and reliable **visual feedback** in any situation.

Furthermore, the integration of **real-time temperature sensors** allows for constant thermal monitoring, justifying the selection of **high-performance materials** for the electronics box to prevent overheating. Finally, the **vehicle's physical balance** was optimized by relocating the robotic arm from a lateral position to the center of the frame. This strategic adjustment ensures a **balanced weight distribution** and **neutral buoyancy**, significantly improving stability and handling during submerged operations.



Figure 10. Members at work

Vehicle Structure and Vehicle System

Frame

EVA's frame (Fig.11) was designed to achieve an **optimal balance of weight, strength, and functionality**. All five plates are securely fastened with M6 screws. This modular, multi-component architecture was deliberately chosen to simplify the **manufacturing process** and facilitate the **rapid replacement** of any damaged parts. The fully assembled structure forms a compact footprint measuring 565mm x 420mm x 220 mm.

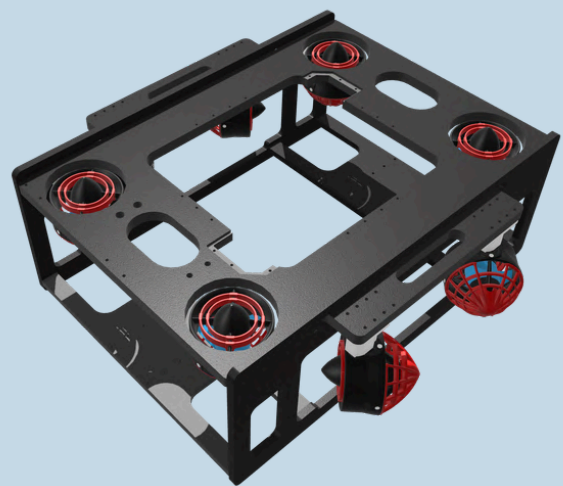


Figure 11. Frame of the ROV

Prior to manufacturing, a **CAD model** of the frame was developed in SolidWorks to evaluate its **resistance to expected operational loads**. During this design phase, several **Finite Element Method (FEM)** analyses were conducted to evaluate different materials. Seeking the ideal compromise among **structural integrity, cost, and weight**, heavier metals such as stainless steel and aluminum alloys were initially excluded. The evaluation then shifted to polymer alternatives, where **HDPE** was selected as the optimal solution. While it exhibits a lower tensile strength than PVC or nylon, HDPE offsets this with a **minimal water absorption rate (Benedetto)**, a significantly lower cost, and a highly efficient strength-to-density ratio.

Electronics Enclosure

The **electronics enclosure** (Fig.12,13) is a critical subsystem that demands absolute **watertight integrity** and highly effective **thermal management**. The unit features a compact rectangular geometry with overall dimensions of 260mm x 280mm x 110mm. To facilitate secure and waterproof cable routing to the external subsystems, both the front and rear panels are equipped with **M10 penetrators**. Furthermore, an **O-ring seal** is positioned along the upper perimeter, ensuring a hermetic seal when the transparent plexiglass top panel is secured in place.

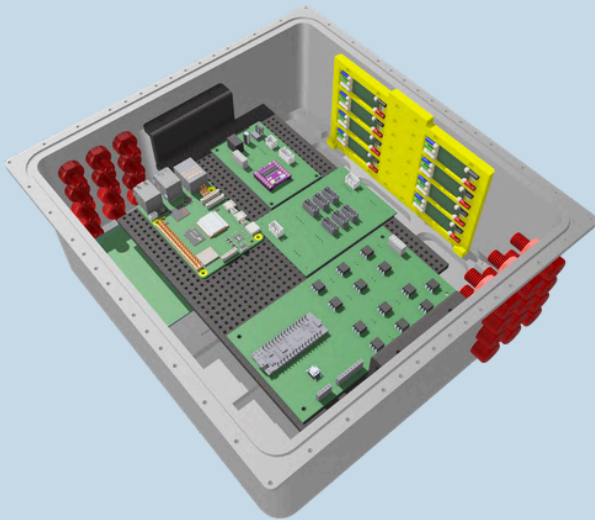


Figure 12. CAD model of electronic enclosure

Aluminum was selected as the primary material for the enclosure body, offering an optimal combination of **low weight, high mechanical strength, and great thermal conductivity**. The enclosure serves a dual purpose: structurally **protecting internal components** while acting as a **passive heatsink** for thermal management. Once the ROV is submerged, it rapidly dissipates internal thermal loads directly into the surrounding water, effectively preventing component overheating. Specifically, the **7075-T651 aluminum alloy** was prioritized over 6000-series alternatives.

While it exhibits slightly lower corrosion resistance an acceptable trade-off for the limited exposure duration typical of competition environments—this 7000-series alloy delivers significantly superior mechanical performance. Internally, the hardware layout was carefully optimized to further **mitigate thermal accumulation**. All electronic components are elevated from the base plate using a custom-designed internal electronics support plate. On the other hand, the components that generate excessive heat are positioned on the sides or bottom of the enclosure.

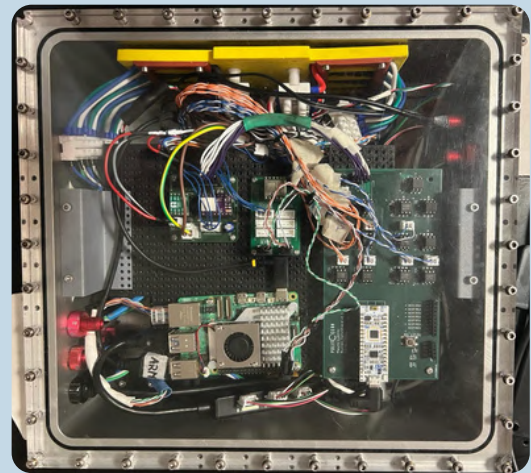


Figure 13. Electronic enclosure

Electrical System

EVA is powered with a **48V/30A supply** from shoreside. The input power is processed by a **custom power PCB**, on which are placed two **QSD(V)W050A0B Barracuda III Series 48V-12V DC-DC converters** working in parallel, providing both up to 600W. There is also a **48V-5V DC-DC converter**. This conversion step is necessary because EVA's electronics needs 5V supply for the logical part and for the Raspberry Pi 5 and the 12V to power on the thrusters/actuators (Fig.14).

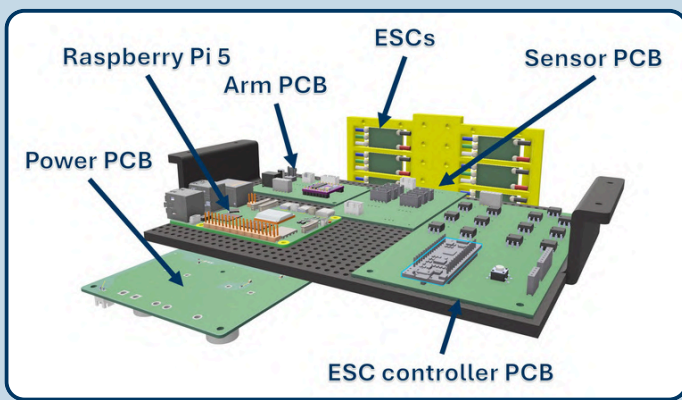


Figure 14. Electronic components layout

An increase in temperature means a reduction in efficiency, therefore to maximize performance is indispensable an effective **heat dissipation**, and our engineers designed the power distribution system to tackle the heat dissipation that leads to extremely high temperatures in electronics enclosures. For this reason the **Power PCB** is housed at the bottom of the electronic case and the **DC-DC converters** were chosen because of their built-in dissipation plates, which are directly touching the aluminium box. Compared to commercial acrylic tubes used as electronic housings, since the aluminium case is directly in contact with the water, it provides a heat exchange with the external environment that leads to a **60% decrease in temperature** compared to other evaluated solutions. So the thrusters can absorb all the delivered power, making the ROV more reliable. The correct heat dissipation is monitored by a **temperature sensor** inside the box. The two **48V-12V DC-DC converters** are connected to the **Raspberry** by an **I2C bus** monitoring activity of the 48V input voltage and absorbed currents at 12V; this solution allows us also to measure the **voltage level, how much current flows** and to **monitor the converter temperatures**, this is a very useful feature in order to gain reliability. All this data are sent to the surface through MQTT. The thinking-core of the ROV is the **Raspberry Pi 5** where all the logic and the computation modules responsible for **balancing, motion, communication** and the **diagnostic** of the machine are implemented.

Other main roles of Raspberry are the video **streaming flow elaboration**, hosting the **MQTT broker** and the **communication with the ESC controller PCB**.

ESC Controller PCB

To establish communication between the Raspberry Pi 5 and both the **thruster** and the **arm control board**, we integrated an **STM32 Nucleo board**. The Nucleo is responsible for generating all the necessary **PWM signals** to control the **thrusters' ESCs**, as well as the **PWM and digital signals** required to operate the manipulator. For this purpose, we designed a **custom shield** for the Nucleo, featuring electrically decoupled outputs. The Nucleo is powered by a 5V supply provided through the micro USB connection, and the PCB itself is powered directly from the Nucleo via the +3.3V and GND pins. System **reliability** and **robustness** were key design priorities (Fig.15).

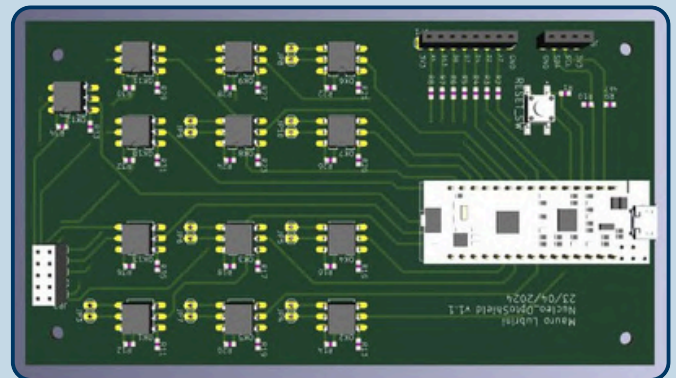


Figure 15. ESC Controller PCB

Particular attention was given to the **electrical isolation** between the low-voltage control circuitry and the high-voltage power electronics, in order to eliminate **ground loops** and minimize **electromagnetic interference (EMI)**, both of which can compromise system performance and safety.

To ensure proper signal isolation, 13 **optocouplers** were implemented. These components effectively decouple the +3.3V control signals generated by the Nucleo from the +12V power signals used by the thrusters and the servo motors in the robotic arm. In particular the PCB implements:

- **A Nucleo LK324KC** used to generate the PWM signals which are used to control the 8 thrusters, and the control signals used to pilot the manipulator.
- **8 octocouplers with a 2 pin output connector** used to send the PWM signal to the 8 thrusters.
- **5 octocouplers** are used to send signals to the arm controller. 8 digital I/O pins and one I2C port.
- **ESC wiring:** 8 BlueRobotics' BasicESCs controller PCB via connectors through which they receive PWM signals. They are secured inside a mechanical support attached on the side of the EB, that facilitates heat dissipation and maintenance.

Sensors PCB

This **PCB** (Fig.16) allows the connection of all required **I2C sensors**, including: an **external barometric pressure sensor**, an **internal barometric pressure and temperature sensor**, and the **WT61 IMU** (Inertial Measurement Unit). All components on the board are powered by either 5V or 3.3V, which are supplied externally through a dedicated power connector. This configuration enables us to power and communicate with up to three sensors operating at 5V and three sensors operating at 3.3V simultaneously.

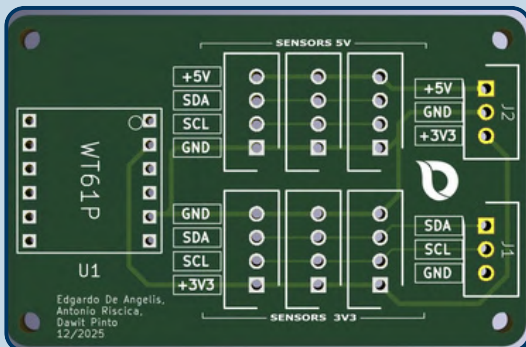


Figure 16. Sensors PCB

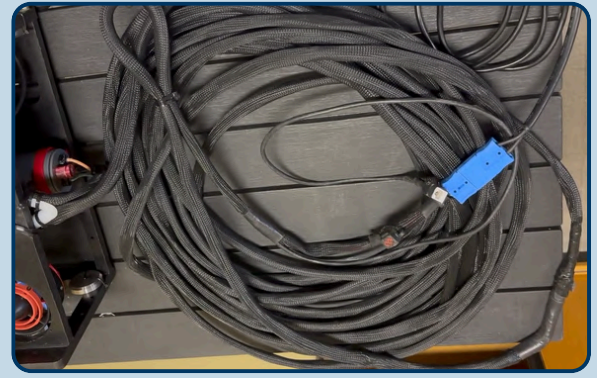


Figure 17. ROV Tether

Manipulator PCB

The **manipulator PCB** (Fig.18,19), as the name suggests, represents the hardware control for the ROV's manipulator. It is responsible for controlling the **wrist**, and the **claw** of our robotic manipulator. Its main components are:

- **2 motor drivers** (DRV8825 and MAX14870) used to control properly the wrist and the claw movement.
- A **10 pin connector** that allow the communication between the drivers and the Nucleo board.
- The **supply of 12V** is provided by an external source and on the board there is a linear DC-DC converter for the generation of 3.3V. When the board is correctly connected to the ROV power, a red LED turns on.

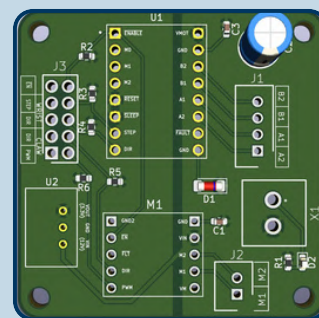


Figure 18. Manipulator PCB

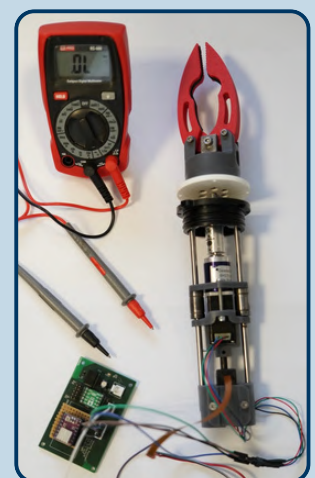


Figure 19. Manipulator connected to the PCB

Tether

EVA's **tether** (Fig.17) is 17m long and designed for efficient, reliable operation underwater. It consists of a **48V power cable** and a **Cat6E** Ethernet cable, bundled together using a **PET braided sleeve** to improve **durability** and **handling**. The power line uses 2.5mm² copper conductors ensuring stable power delivery. The positive wire connects to a **30A fuse** between the ROV and the power supply. The Cat6E cable supports data rates up to 1Gbit/s, enabling **high-bandwidth communication** for video and telemetry. Segments of **buoyancy foam** are attached along the tether to achieve near-neutral buoyancy.

To prevent tangling and ensure safety, a dedicated **tether manager** is assigned during missions. Their tasks include carefully **deploying** and **retrieving** the tether keeping the cable away from moving parts or pilot paths. Before deployment, the tether is neatly coiled and positioned to avoid tripping hazards.

Control System

The **control system** of the vehicle was designed to ensure maximum **stability** and **precision** during mission tasks. The system is entirely software-based. Initially, a **Model Predictive Control** (MPC) strategy was considered for implementation to improve the dynamic response of the ROV. It was hypothesized that a predictive approach could better compensate for the non-linear hydrodynamic forces and the umbilical cable disturbances. However, during experimental tank trials, several critical issues were identified.

High computational overhead on the Raspberry Pi 5 led to control loop latencies, and the **unpredictable forces** from the tether proved difficult to model accurately in real-time. Consequently, the design was pivoted back to a verified **Grey-box model** (Fig.20). This approach allowed for the tuning of the control system based on empirical data rather than purely theoretical predictions.

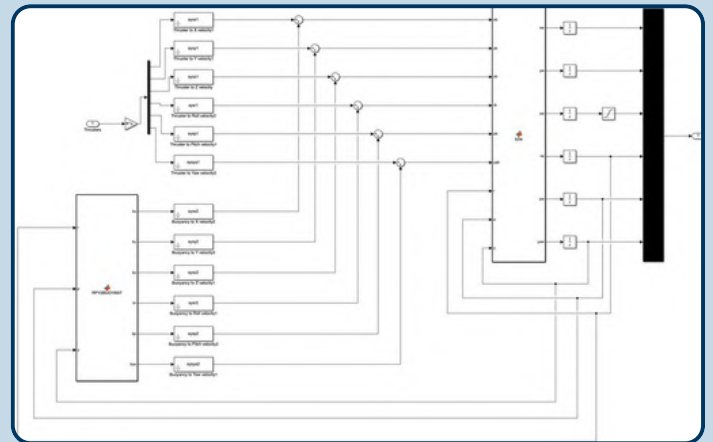


Figure 20. Grey box model

Work Mode

The **Work Mode** function was incorporated to facilitate fine manipulation tasks. When enabled, the **dynamic response** of the ROV is limited in terms of **velocity** and **acceleration**, allowing for more **precise movements** during interaction with task-related objects (*Antonelli*).

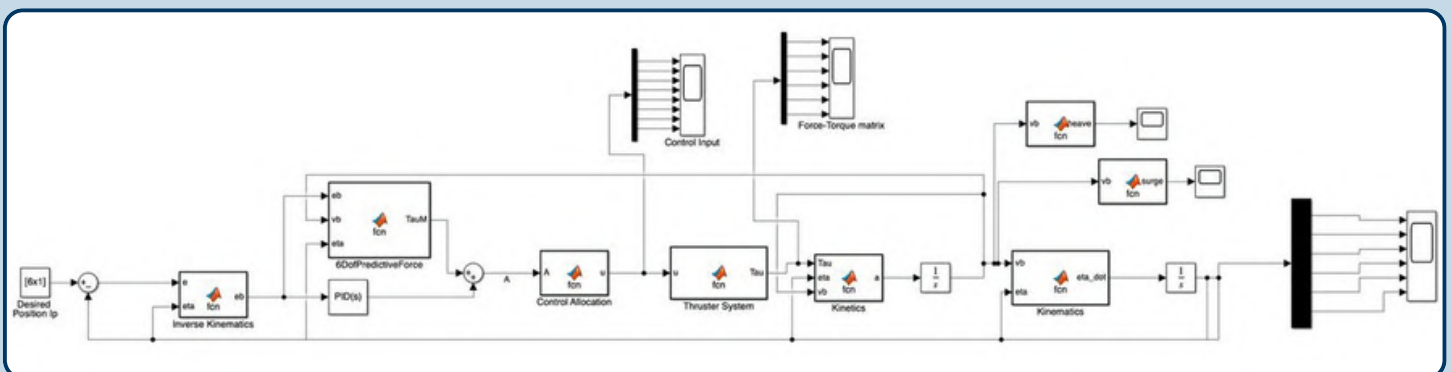


Figure 21. ROV Simulink model

Automatic Control

A robust **automatic control system** was implemented to dynamically **reject external disturbances** while **maintaining the desired depth and attitude**. This system utilized a data-driven identification approach based on a Grey-box model, combining physical equations of motion with parameters estimated from input-output measurements collected during field tests. As demonstrated in the **Simulink model** (Fig.21), the dynamic behavior is simulated by coupling **thruster forces** with **buoyant forces**. The controller operates on **6 Degrees of Freedom** (DoF): **Depth, Roll, Pitch**, and position coordinates to automatically stabilize the vehicle (**Wu**). **Horizontal maneuvers** remain under direct pilot control to preserve **responsiveness** during complex missions. This closed-loop configuration successfully rejects disturbances and improves overall precision during manual operations.

Software System

The ROV's software stack integrates three components communicating via **MQTT, I²C**, and serial protocols: **NEXUS** (control station) provides real-time video, telemetry, and pilot control; **Oceanix** (Raspberry Pi 5) manages mission logic, sensor fusion, and thrust allocation; and the STM Nucleo firmware executes low-level motor control via low-cost, PWM-capable GPIOs.

The **Raspberry Pi 5** was chosen over the NVIDIA Jetson Nano for its efficiency, lower power, and cost-effectiveness, as its CPU is ideal for real-time control and networking rather than GPU-heavy AI. Combined with the STM Nucleo, this architecture ensures **low latency**, robustness, and **easy scalability** for future upgrades.

NEXUS GUI

The ROV software stack is organized around **NEXUS** (Fig.22), a Python/Flask backend that acts as the integration layer between **onboard services, telemetry, video streaming**, and the **operator interface**. The new user interface is implemented as a modular React/Type Script web dashboard,

designed to provide pilots with a centralized real-time view of vehicle state, camera feeds, controller status, and mission controls.

For EVA operations, the dashboard provides a primary live camera view with selectable secondary streams, **WebRTC/Janus-based video** integration, connection health indicators for **NEXUS, MQTT, Janus**, and the **controller**, and **dedicated telemetry panels** for depth/height, attitude, pitch reference, and mission timing. A **floating attitude panel** visualizes **roll, pitch**, and **yaw** in real time, while the joystick status panel reports the state of arming, work mode, torque mode, and the depth, roll, and pitch controllers.

Telemetry and control data are exchanged as **JSON messages** over **MQTT**: pilot commands are routed from the UI through NEXUS to Oceanix, while live status updates are published back to the dashboard to update telemetry, controller states, and mission indicators in real time.

The **FLOAT interface** follows the same design system and provides dedicated controls for float testing, PID tuning, pressure/depth monitoring, and experiment execution. Both EVA and FLOAT share reusable UI components, consistent connection monitoring, and light/dark theme support, ensuring a coherent operator experience across subsystems.

Video streams from the Raspberry Pi 5 are delivered through **WebRTC**, enabling low-latency browser rendering and compatibility with onboard **H.264** encoding. Where required, the video pipeline can apply real-time correction and processing before presenting the feed to the pilot.

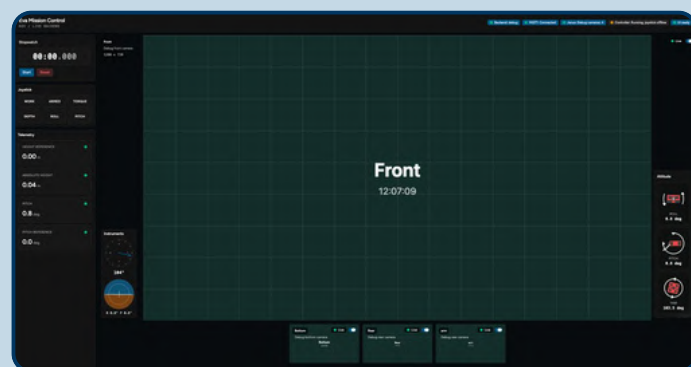


Figure 22. Nexus GUI

Oceanix

Oceanix is our C++ application running on the Raspberry Pi5, structured in an object-oriented paradigm to isolate sensors, controllers and communication services. The Pi hosts a **Mosquitto MQTT** broker that relays messages between NEXUS, the debug tool and Oceanix itself. Joystick inputs arrive on the command topic, the **resulting force** and **moment vectors** feed a thrust allocation algorithm that computes individual **PWM setpoints** for eight thrusters (Fig.23). These setpoints are forwarded over a high-speed **UART link** to the **STM Nucleo** board. Simultaneously, Oceanix polls the onboard **IMU** and **Bar02 sensor** at 200Hz via I²C, combining **accelerometer**, **gyroscope** and **pressure** data in a complementary filter to estimate depth and attitude (*Wu*).



Figure 23. Python tool main window

STM Nucleo Firmware

On the **NUCLEO-L432KC board**, a bare-metal C application built on **ST’s HAL libraries** listens on **UART** for a continuous stream of **PWM duty-cycle** values and servo positions sent by Oceanix at 100Hz. Each packet includes a **CRC** to verify integrity; in the event of a **CRC** failure, the firmware retains the previous command until valid data resumes.

Hardware timers generate PWM signals with 1 μs resolution, which drive optocouplers feeding our motor driver **MOSFETs**. For manipulator control, a specially designed packet is received to regulate the **actuator** and **driver**, including their speed and direction. The firmware’s emphasis on deterministic timing and minimal interrupt jitter guarantees that high-frequency control loops run reliably, enabling both precise thrust control and smooth manipulator operation.

CRAB Detector

To solve the invasive species task (Fig.24,25), which requires identifying and counting European Green Crabs within a 50x50 cm quadrant, we developed an **automated object detection pipeline**. We leverage a custom-trained **YOLOv8 model** that processes the live feed from the ROV’s front cameras in real time to detect and classify each specimen. This automated workflow eliminates human counting errors under stressful competition conditions and ensures rapid execution to save valuable mission time. By processing the data programmatically, the system automatically formats the results for the required reporting form. This approach fully satisfies the high-scoring criteria for autonomous recognition, bypassing the slower and less reliable manual operator assessment.



Figure 24. Crabs on seabed

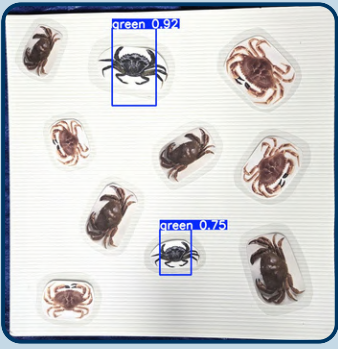


Figure 25. Invasive crabs detected

Propulsion

EVA is equipped with eight **Blue Robotics T200** thrusters (Fig.27), featuring **polycarbonate casings** and **marine-grade 316 stainless steel** hardware to ensure durability in underwater environments. The propulsion system is engineered to provide full **6 DoF: surge, sway, heave, roll, pitch, and yaw**. The configuration consists of **four horizontal thrusters** mounted at a **45°** angle to the XY-plane for planar and rotational control, and **four vertical thrusters** for heave maneuvers (Fig.26). The horizontal thrusters are positioned with alternating rotation directions (2 clockwise, 2 counter-clockwise) to balance torques and enhance yaw stability (*Ferraresi and Raparelli*). The operating voltage for each thruster is 12 V, strategically selected to both maximize step-down efficiency from the 48 V main supply, achieving a high conversion efficiency of 92%, and optimize the thrust-to-power ratio; at 12 V, each thruster delivers approximately 28.5 N (2.9 kgf) of force. This provides an ideal balance between vehicle maneuverability and energy endurance, while simultaneously minimizing the thermal stress on power distribution components.

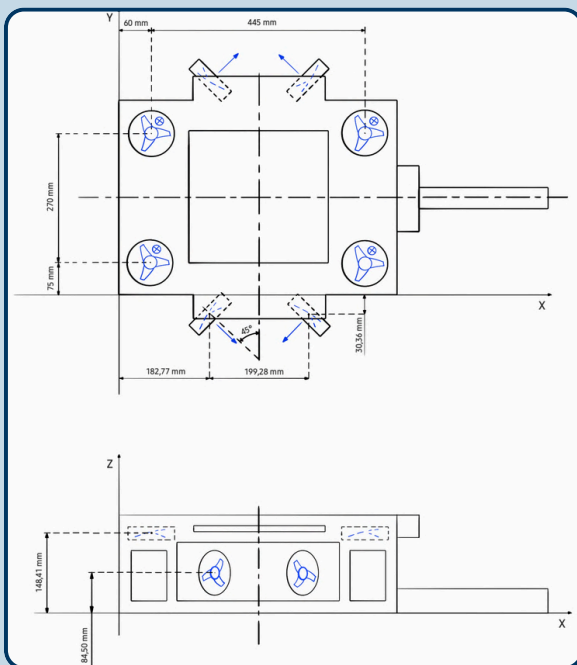


Figure 26. Thrusters Relative Position



Figure 27. Render Thruster

Buoyancy and Ballast

EVA's **buoyancy system** is fundamentally designed around the physics of its main **electronic enclosure**. Because this watertight container holds a **large volume of air**, it generates significant upward force and is strategically mounted on the vehicle's top plate. To counterbalance this, the heaviest electronic devices are placed at the bottom of the enclosure, and dense components (robotic manipulator and connector housing) are mounted on the bottom plates. This deliberate distribution of mass and volume ensures that the **ROV's Center of Buoyancy (CB)** is located securely above its **Center of Gravity (CG)**. This arrangement provides the vehicle with excellent static stability, creating a natural righting moment that prevents EVA from rolling over in the water (Fig.28) (*Ferraresi and Raparelli*).

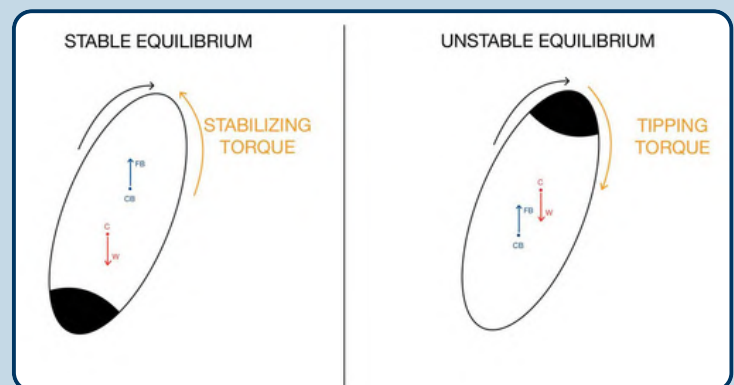


Figure 28. Stable Equilibrium of EVA

Furthermore, material selection played a key role in the vehicle's passive buoyancy profile. In point of fact, **HDPE** was chosen for the frame specifically because its density is close to that of water, making the frame itself nearly **neutrally buoyant** (Fig.29). Because the combined volume of the enclosures makes EVA slightly positively buoyant overall, it can be put **removable weights** secured to the bottom of the frame. This modular approach allows the team to precisely tune the vehicle's resting trim and adjust the degree of positive buoyancy to match specific mission requirements and pilot preferences.

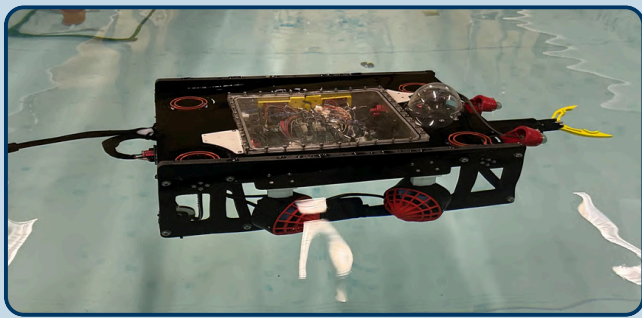


Figure 29. Buoyancy of EVA

Payload and Tools

Cameras Compartment

The core of the ROV's forward vision relies on factory-sealed **DWE ExploreHD 3.0 cameras**. Requiring no dedicated external housing, they are secured within **3D-printed cylindrical mounts** angled at 19° (Fig.30), an inclination calculated to optimize both the framing of the robotic arm and general navigation visibility. To further assist manipulation tasks, a **supplementary camera** (Fig.31) is strategically positioned lower on the frame, directly at the manipulator's height. As this specific camera is not natively waterproof, it is encased in a **custom micro-housing** and permanently potted with sealing resin, ensuring a watertight and highly compact solution without the bulk of a dome. While the forward-facing setup proved highly effective, the vertical vision system underwent a strategic overhaul for this year's competition.

Previous iterations utilized **top and bottom 180-degree PiCam360 cameras**, which required voluminous Blue Robotics acrylic domes and custom caps. To optimize the vehicle's weight, the top camera assembly was permanently removed; eliminating this module significantly reduced the ROV's overall weight and hydrodynamic drag, as upward panoramic visibility is no longer required for the current tasks. Conversely, the bottom 180-degree camera was replaced with an additional **DWE ExploreHD 3.0 unit**. Its focused optical characteristics are far better suited to the precision required by this year's specific underwater operations, entirely eliminating the need for bulky panoramic enclosures.

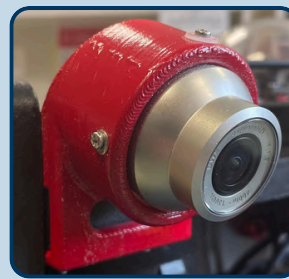


Figure 30. Front camera



Figure 31. Manipulator-focused camera

EVA Manipulator

Our multifunctional electronic **robotic manipulator** (Fig.32,34) features a **single degree of freedom** and has been entirely redesigned to overcome the structural and functional flaws of previous models. Measuring 340 mm in length and weighing just 792 g, the manipulator consists of two interconnected subsystems: the **End-effector** and the **transmission system**. Internally, the transmission was completely re-engineered. In older versions, direct friction between moving parts wasted a great amount of the actuator's force. To solve this, two **linear guides** with **bearings** were introduced to assist the internal movement, allowing the **PQ12 linear actuator** to deliver power smoothly and efficiently (*Antonelli*). Additionally, all internal components are now designed for **quick removal**, drastically improving maintenance accessibility.



Figure 32. CAD model of EVA Manipulator

Another significant upgrade is the manipulator's external housing. Abandoning the previous 3D-printed **SLA resin** which suffered from limited mechanical strength and poor pressure resistance an **EN AW-6082 T6 aluminum tubular structure** with a black anodized finish. This material providing a highly durable body has been adopted, such that it guarantees superior watertight sealing through **O-rings**. Finally, the **End-effector** (Fig.33) compartment relies on a simplified **three-hinge** mechanism to optimize assembly and reduce failure-prone parts (*Ferraresi and Raparelli*). The gripping jaws are 3D-printed in **PLA**, a choice deliberately made to ensure rapid and cost-effective replacements; furthermore, operational testing showed minimal surface wear, confirming the material's excellent durability for this application. These jaws are driven by an **ERGAL 7075-T6 shaft**, while a **NEMA8 motor** precisely manages the **wrist rotation**, ensuring a stable and reliable grasp.



Figure 33. CAD model of Eva End-effector



Figure 34. EVA Manipulator

Connector Housing

To improve modularity and simplify transport and maintenance operations, the ROV features a dedicated **Connector Housing** (Fig.35). This cylindrical enclosure is mounted on the vehicle's frame next to the main electronics box. Its primary function is to serve as an **intermediate interface** between the external tether (umbilical cable) and the internal electronic systems. By routing the main cable through this module, connection and disconnection procedures become **faster** and **safer**, reducing the need to handle the main electronics enclosure directly. This design facilitates easier access during assembly and testing, while protecting the main box by minimizing mechanical stress on its penetrators. While previous versions used **Formlabs Tough 2000 Resin**, the new housing adopts a fully **transparent case**. This simple but effective upgrade allows us to instantly verify the internal connections and intervene promptly in case of maintenance.



Figure 35. Connector Housing

Build vs. Buy, New vs. Used

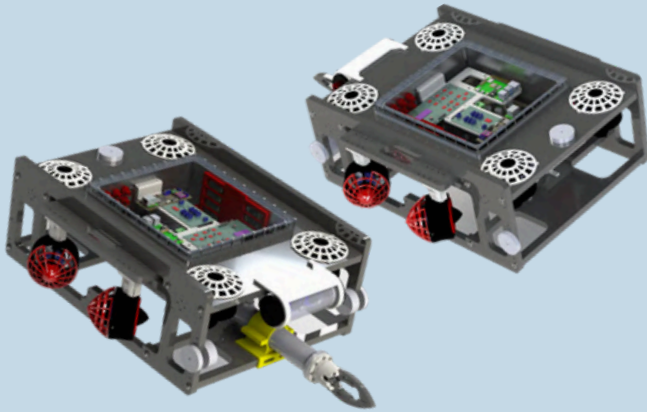


Figure 36. EVA's first configuration

PoliTOcean's engineering philosophy is driven first by **mission requirements** and second by a commitment to hands-on learning. Whenever workshop capabilities meet the technical specifications, components are designed and manufactured in-house. This approach ensures custom **functionality**, allows the team to improve **engineering skills**, and guarantees that new members gain **practical manufacturing experience**. Commercial off-the-shelf (COTS) solutions are purchased only when they definitively outperform in-house capabilities in cost, performance, or reliability. For example, the frame is custom-manufactured from HDPE plates that are cut using the team's **CNC machine**. Conversely, because machining aluminum requires specialized tooling beyond the team's current capabilities, the electronic enclosure is custom-designed in-house but manufactured by an external vendor. All other structural supports are 3D-printed by the team. To maximize spatial efficiency within the electronic enclosure and tailor the hardware perfectly to our mission requirements, we design all of our specific PCBs in-house (Power, Sensors, Arm, and a custom carrier board for Nucleo). On the contrary, for the core computing and processing hardware, we utilize **COTS solutions**.

Specifically, a **Raspberry Pi 5** was purchased as the main single-board computer and an **STM32 Nucleo board** for low-level hardware control. Similarly, components from prior seasons are rigorously evaluated against the 2026 mission specifications. If a legacy component still meets all current requirements, it is reused to minimize both financial expense and material waste (Fig.36,37). This is the case for both the **frame** and the **electronic enclosure**, which successfully passed evaluation for this year's tasks. On the other hand, most of the 3D-printed internal supports were redesigned and manufactured using an **upgraded material**. This decision was made not only to optimize the physical design but also to prevent thermal softening and structural deformation during operation. All of the custom-designed **PCBs** still fully meet this year's power distribution and signal processing requirements. For the vision system, a strategic mix of new and inherited components was adopted to balance **budget** and **performance**. Three of the cameras are being reused, as their frame rates and resolutions remain perfectly suited for general navigation and manipulator control whereas the downward-facing camera is a brand-new acquisition for this season.



Figure 37. EVA's current configuration

Safety

Safety is regarded as a keystone of responsible engineering and organizational excellence. In line with this commitment, the team has established a structured safety **management framework** that applies to all departments and operational levels. From the outset, every team member undergoes mandatory **safety orientation** and **periodic refresher training**, tailored to both general laboratory practices and task specific hazards.



Figure 38. Carlo and Lucrezia are Safe

Working in a laboratory requires strict observance to specific **safety protocols** to ensure a **secure work environment** (Fig.38,39). When assembling electronic equipment, personnel are required to wear specialized **gloves** and **safety glasses**, and to utilize the **chemical ventilation** systems located at each workstation. Over time, we have also developed a rigorous electrical safety protocol to prevent **electrocution** and mitigate the **overheating of devices**. For mechanical fabrication processes, a specific **dress code** is mandatory, which includes the use of protective **coveralls**, **safety goggles**, and **heavy-duty gloves**. Whenever hazardous materials are handled, adequate ventilation is strictly enforced. All of these procedures are detailed in **PoliTOcean's Safety Data Sheet (SDS)**, which is readily accessible to all personnel and serves as a vital complement to our mandatory new-member training.

Furthermore, to guarantee procedural compliance, our team utilizes comprehensive **safety checklists** for both the **vehicle's construction** phase and the **on-site operational phase** (see Appendix C).



Figure 39. Carlo is Safe

Safety also plays an integral role in the final design of the vehicle itself. Each electronic enclosure features a **temperature sensor** to monitor for **overheating** and prevent electrical malfunctions. Inside the main electronics housing, a **pressure sensor** provides early warnings of potential water ingress, allowing the team to prevent catastrophic leaks. Another critical safety feature is the ability to remotely cut power to the 12V output, which drives all of the ROV's thrusters and actuators. This **kill-switch** functionality is achieved using an **optocoupler**, guaranteeing safe optical isolation. As a fail-safe mechanism, EVA was engineered with a slightly **positive buoyancy profile**, ensuring the vehicle naturally returns to the surface in the event of a total power failure. Finally, **physical thruster guards** (Fig.40) have been implemented to prevent any direct contact between the operator's fingers and the spinning propellers.

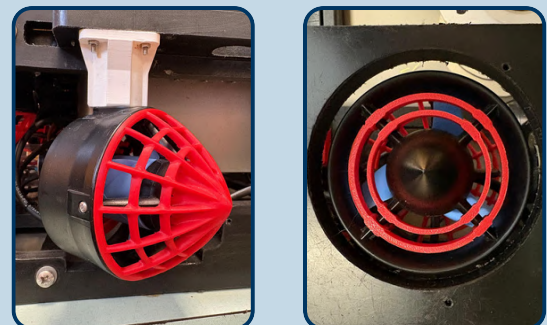


Figure 40. Side-thruster and top-thruster covers

Testing and Troubleshooting

Testing is a fundamental part of the development of the ROV, as it helps identify any problems that may have been overlooked. PoliTOcean's workflow involves testing each individual component through **dry testing** before assembling and evaluating the ROV as a whole. For the Mechanical Division, both the electronic enclosure and the frame are subjected to **FEM analysis** (Fig.41) to verify their behavior under stress. In the Electronics Division, the preliminary step involves examining each individual PCB with a **multimeter** and **oscilloscope** to ensure correct soldering and assembly. For the Software Division, the entire software stack is tested using a **Software-in-the-Loop (SITL)** simulation environment with simulated sensor data and virtual camera feeds. In the Hydrodynamics division, the frame and the electronic enclosure are subjected to **CFD analysis** to evaluate fluid dynamic coefficients, which are implemented in the Control system. **Prototyping** and **testing** are also heavily utilized to evaluate design options before finalizing the vehicle. A perfect example of this method is the substitution of the internal electronic support plate, since physical thermal testing revealed the original PLA plate retained a excessive amount of heat, leading us to substitute it with a PPA-CF plate for ensure the ROV's integrity before full water testing, we verify the absence of **insulation loss**, especially around penetrators, which are key points where cables enter the watertight containers.

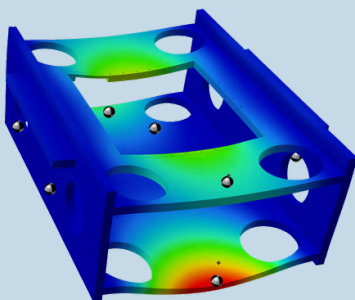


Figure 41. FEM analysis of the frame

To inspect this, the team developed a custom system consisting of a **vacuum pump** (Fig.42) and a sealed cylinder equipped with a **pressure gauge** and **penetrators**. This cylinder is connected to EVA's containers through tubes with appropriate fittings at each end. This system allows us to test whether the entire device is watertight and to precisely identify any possible leak points.



Figure 42. Vacuum pump



Figure 43. Robotic manipulator test

Once all preliminary steps are successfully completed, **in-water testing begins**, during which the full system and firmware are verified. We utilize a dedicated **testing pool**, which offers a controlled environment for initial buoyancy balancing and maneuverability trials. To account for real-world mission conditions, we further validate the ROV through field testing in **lakes** and **rivers**. If any issues are encountered, we apply technical troubleshooting strategies, such as systematically **isolating** electronic subsystems or utilizing software **debuggers**, in order to identify the root cause; for example, the robotic manipulator PCB is tested separated from the ROV to verify signal integrity before integration (Fig.43). Because it is inevitable to encounter unforeseen issues during a project of this scale, we pair these technical strategies with our established action plan: **assessing the critical path, breaking the problem** down into parallel subtasks for specific team members, and **smoothly integrating** the individual contributions to resolve the issue efficiently.

Accounting

Budget

Financial planning for the 2026 season prioritized **resource optimization**. Since EVA's most important components remained unchanged, **manufacturing expenditures** were significantly reduced. To minimize waste, existing components are only replaced if they are **damaged beyond repair** and can no longer be used. This **cost-saving** measure allowed the remaining budget to be redistributed toward **system maintenance** and **travel expenses** for representation and competition missions. Primary funding is provided by the **Politecnico di Torino**, supplemented by critical material donations received from **corporate sponsors**. Total **travel expenses** are estimated at around €23,000 (\$26,930.93 USD), with €20,000 (\$23,418.20 USD) specifically allocated for the **MATE ROV Competition**. An overview of all the expenses is shown in Figure 44.

Cost accounting

To ensure accurate **financial tracking**, a clear distinction is maintained in the budget between **purchased, reused, and donated items**. Furthermore, a strict **procurement protocol** prevents overspending: all purchases require preliminary authorization from Project Managers and final approval from the Team Leader before processing by the C&M division.

While institutional regulations from the Politecnico di Torino prohibit the team from accepting **direct monetary sponsorships**, the company effectively leverages in-kind donations to offset operational costs. This includes several **professional software licenses**, such as SolidWorks, Siemens, and Notion, which are essential for vehicle design and project management. The total fair market value of these donated services is estimated at around €11,000 (\$12,880.01 USD), ensuring that our accounting reflects the true cost of the project and the effective use of all available resources.

Descrizione Spesa	Cronoprogram	Tipologia di sp	Coan	Budget	Budget in USD	Provenienza Fc	Provenien	azienda o Enti	Sub-categori
gadget per fiere ed eventi	02/11/2025	Materiale di con: A.C.B.A.01.060	€ 700,00	\$819,00	POLITECNICO DI				merchandising
Visita all'Università di Firenze al team che costruisce A	01/04/2026	Spese per missio A.C.A.A.04.020	€ 1.800,00	\$2.106,00	POLITECNICO DI				missioni
JEC World Parigi, 4 persone tre notti	09/03/2026	Spese per missio A.C.A.A.04.020	€ 1.400,00	\$1.638,00	POLITECNICO DI				missioni
Telai prototipi	02/02/2026	Altre attrezzature A.I.B.B.02.030	€ 2.000,00	\$2.340,00	POLITECNICO DI				eva, nereo, rov, auv, float
elettronica generale	02/02/2026	Altre attrezzature A.I.B.B.02.030	€ 1.000,00	\$1.170,00	POLITECNICO DI				laboratorio
DPI	19/10/2025	Spese per sicure: A.C.B.D.02.010.0	€ 300,00	\$351,00	POLITECNICO DI				laboratorio
filamenti stampante 3D	02/11/2025	Altro materiale d A.C.B.A.01.060	€ 1.500,00	\$1.755,00	POLITECNICO DI				laboratorio
stepper, attuatori, servomotori	30/11/2025	Attrezzature info A.I.B.B.02.010	€ 1.640,00	\$1.918,80	POLITECNICO DI				eva, nereo, rov, auv, float
attrezzatura varia da laboratorio (viti, punte saldatura, 25/09/2025	25/09/2025	Altro materiale d A.C.B.A.01.060	€ 1.450,00	\$1.696,50	POLITECNICO DI				laboratorio
sensori (radar, barometro, ph-metro, termometro,...)	08/12/2025	Attrezzature info A.I.B.B.02.010	€ 3.500,00	\$4.095,00	POLITECNICO DI				eva, nereo, rov, auv, float
attrezzatura informatica (microcontrollori, jetson, rast 18/01/2026	18/01/2026	Attrezzature info A.I.B.B.02.010	€ 2.300,00	\$2.691,00	POLITECNICO DI				eva, nereo, rov, auv, float
Fiera MECSPE tre persone due giorni a Bologna	04/03/2026	Spese per missio A.C.A.A.04.020	€ 600,00	\$702,00	POLITECNICO DI				missioni
MATE rov competition	14/06/2026	Spese per missio A.C.A.A.04.020	€ 20.000,00	\$23.400,00	POLITECNICO DI				missioni
pezzi in metallo realizzati da aziende con lavorazioni r	03/05/2026	Prestazioni di ser A.C.B.C.04.040.0	€ 5.500,00	\$6.435,00	POLITECNICO DI				eva, nereo, rov, auv, float
pezzi blue robotics (strutture e penetraori)	01/03/2026	Altre attrezzature A.I.B.B.02.030	€ 1.950,00	\$2.281,50	POLITECNICO DI				eva, nereo, rov, auv, float
PCB x37	02/11/2025	Altre attrezzature A.I.B.B.02.030	€ 3.700,00	\$4.329,00	POLITECNICO DI				eva, nereo, rov, auv, float
abbonamenti (canva e overleaf)	05/10/2025	Licenze software A.C.B.C.05.050.0	€ 1.120,00	\$1.310,40	POLITECNICO DI				software
telecamere x8	05/10/2025	Attrezzature info A.I.B.B.02.010	€ 2.080,00	\$2.433,60	POLITECNICO DI				eva, nereo, rov, auv, float
materiali per control statio(mouse,tastiera, schermo, t	05/04/2026	Attrezzature info A.I.B.B.02.010.0	€ 400,00	\$468,00	POLITECNICO DI				control station
magliette, felpe	02/11/2025	Materiale di con: A.C.B.A.01.060	€ 2.500,00	\$2.925,00	POLITECNICO DI				merchandising

Figure 44. Side-thruster and top-thruster covers

Acknowledgements

PoliTOcean extends its sincere gratitude to the individuals and organizations who supported our journey in the 2026 MATE ROV Competition.

We would like to thank the MATE ROV Competition for fostering an environment of innovation, sustainability, and educational growth. We are immensely grateful to the Politecnico di Torino for their generous financial support, without which this project would not have been possible. Additionally, we thank the Department of Electronics for providing essential logistical and technical resources.

A special thanks goes to our mentor, Professor Sansoè, for his unwavering technical guidance and moral support, constantly keeping the team motivated and on track.

Finally, we proudly acknowledge the invaluable contributions of our corporate partners: Subsea LED for LED samples, SolidWorks and Siemens for software licences, Dewesoft for data acquisition and testing campaigns, Officine Massola for

production of machined parts, Notion for workspace organization, Projectstudio for 3D-printing some components, CX Lab for their generous contribution of official team clothing, Pompadour for providing a selection of herbal tea.

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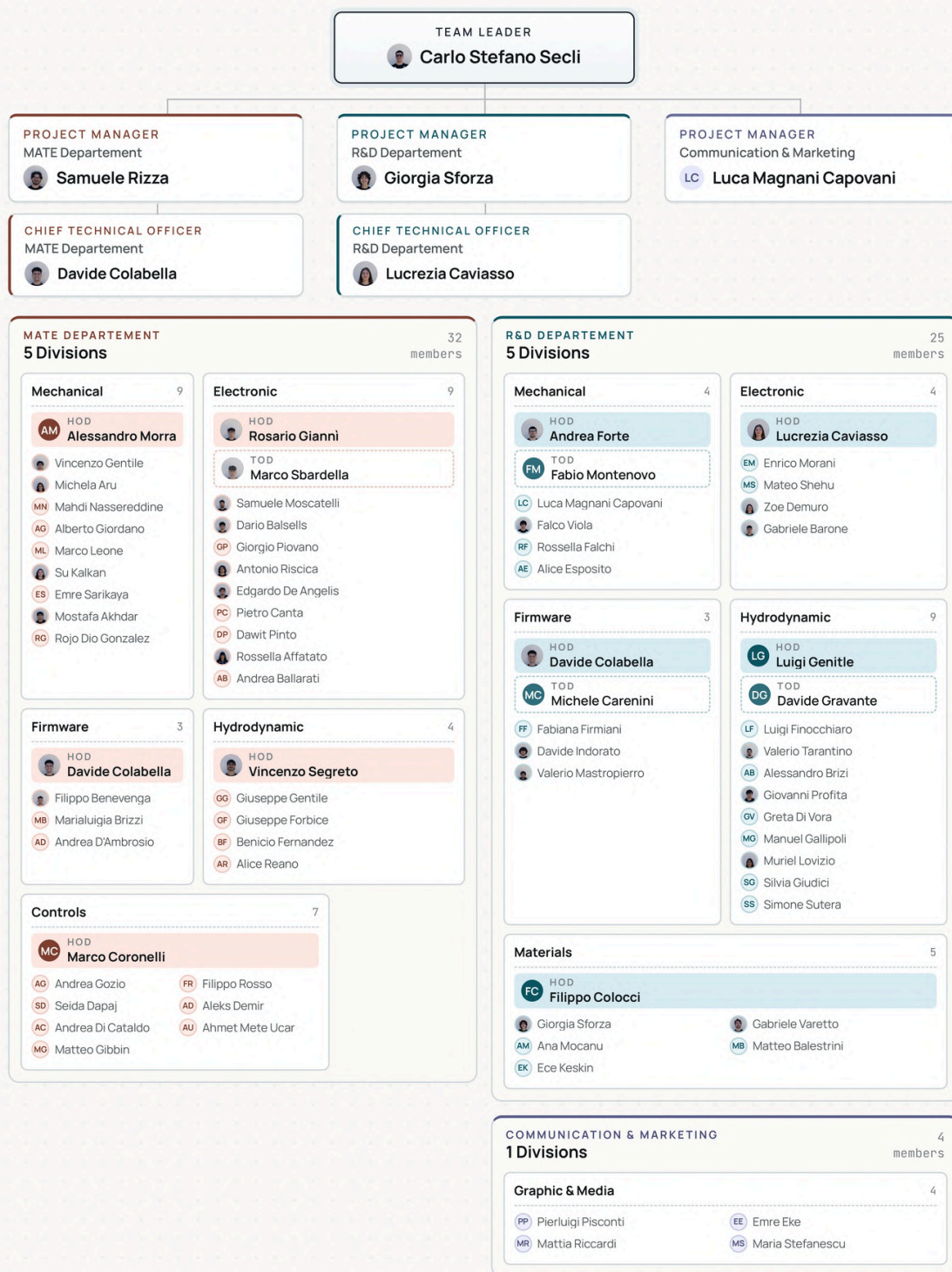


Appendix A

ACADEMIC YEAR 2025 / 2026

Team Organization Chart

Format A4 · Portrait
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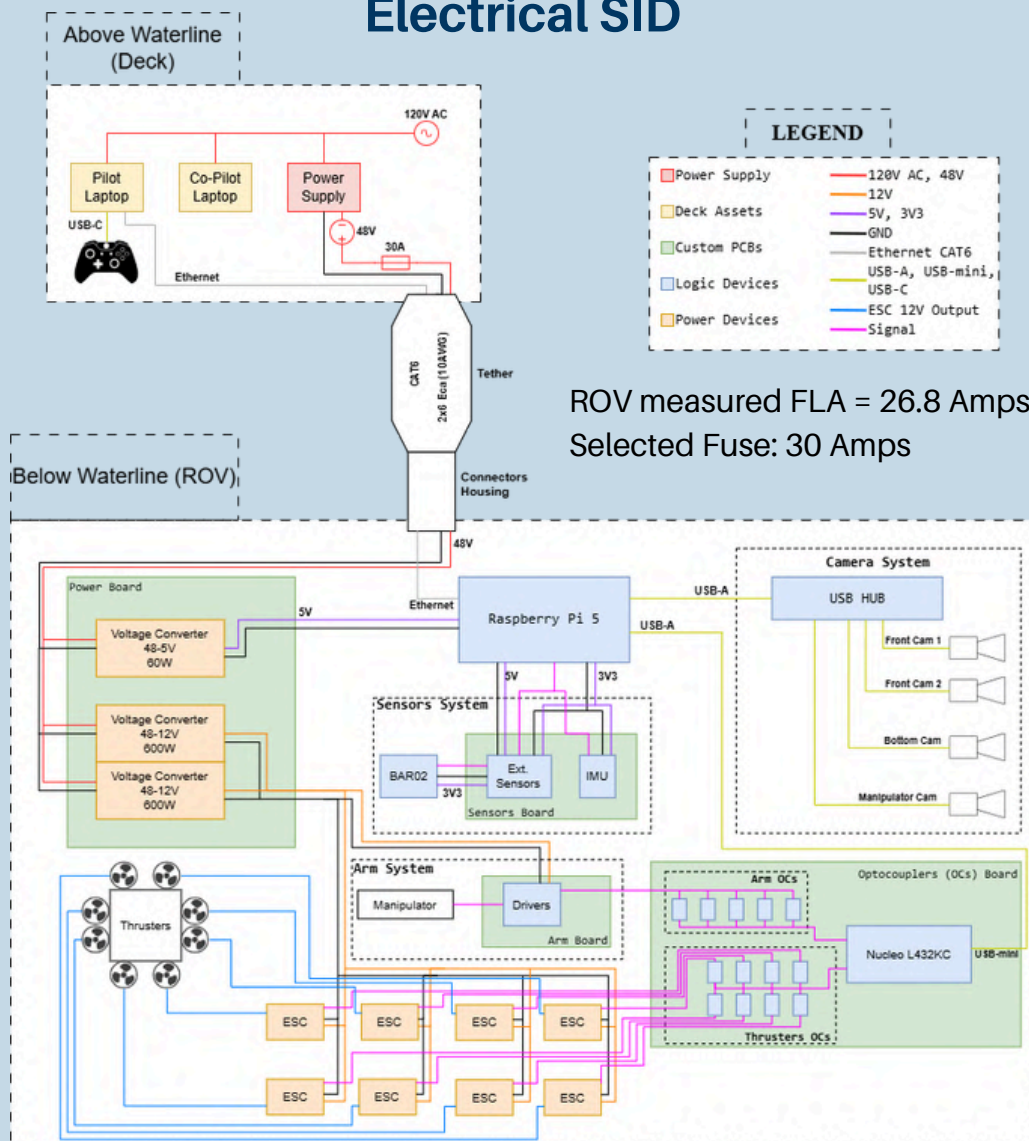


■ MATE Departement ■ Research & DeveLopment Departement ■ Communication & Marketing

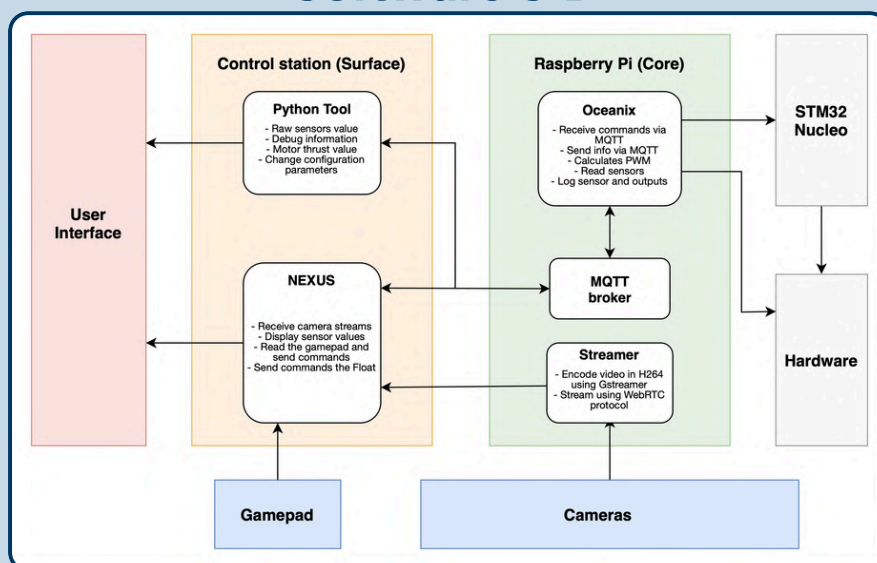
81 people · 11 divisions

Appendix B

Electrical SID



Software SID



Appendix C

Safety Checklist

Personal Protective Equipment

- ☐ Ensure non-slippery, closed-toe shoes are worn
- ☐ Ensure non-loose clothing worn
- ☐ Ensure protective work gloves are worn

Transport & Set-up

- ☐ Verify ROV is secured to wheeled carts with tie-down straps
- ☐ Enforce "two-person lift" protocol for heavy items
- ☐ Ensure ROV is placed on a stable, flat surface
- ☐ Check that walking paths are clear of obstacles
- ☐ Route tether away from traffic
- ☐ Flake tether in a figure-eight pattern
- ☐ Verify strain relief devices are secured at ROV and surface ends
- ☐ Verify main power switch is OFF before connecting cables
- ☐ Ensure surface control station is strictly dry
- ☐ Inspect cable connectors visually for moisture before mating

Pre-Dive & Launching

- ☐ Inspect penetrators and O-rings
- ☐ Perform a vacuum test with the pump to verify sealing
- ☐ Check that fasteners and thruster guards are securely installed
- ☐ Ensure hands are completely clear of thrusters
- ☐ Verify manipulator range of motion is clear of personnel and obstacles
- ☐ Lower ROV using a two-person lift via structural handles only

In-Water Operations

- ☐ Continuously manage tether slack to prevent entanglement
- ☐ Maintain a strict "No-Step" zone over the active tether line
- ☐ Keep the pilot station perimeter clear of unauthorized personnel and distractions

Recovery & Demobilization

- ☐ Drain ROV for 10 seconds while partially submerged
- ☐ Use a two-person lift to move the ROV directly to the transport cart
- ☐ Disconnect and unplug main power completely BEFORE touching ROV connections
- ☐ Dry the ROV exterior completely with a towel
- ☐ Verify ROV is secured to wheeled carts with tie-down straps

Emergency Retrieval, Post-Dive & Pit Maintenance

- ☐ Cycle TCU power to reboot ROV
- ☐ If no comms: disarm thrusters and power down system
- ☐ Pull ROV gently to pool edge via tether
- ☐ Use 2-person lift (handles only) to remove ROV
- ☐ Disconnect main power BEFORE touching any connections
- ☐ Towel-dry hands, connectors, and ROV exterior
- ☐ Inspect thrusters for debris or damage
- ☐ Check tether for cuts, abrasions, or kinks
- ☐ Check the electronics enclosure for water ingress or moisture
- ☐ Inspect the ROV frame and structural handles for physical damage