Politecnico di Torino

# PoliTOcean

MAKE THE ROVOLUTION

MATE ROV COMPETITION

# TECHNICAL REPORT

## PoliTOcean '25

Politecnico di Torino | Italy


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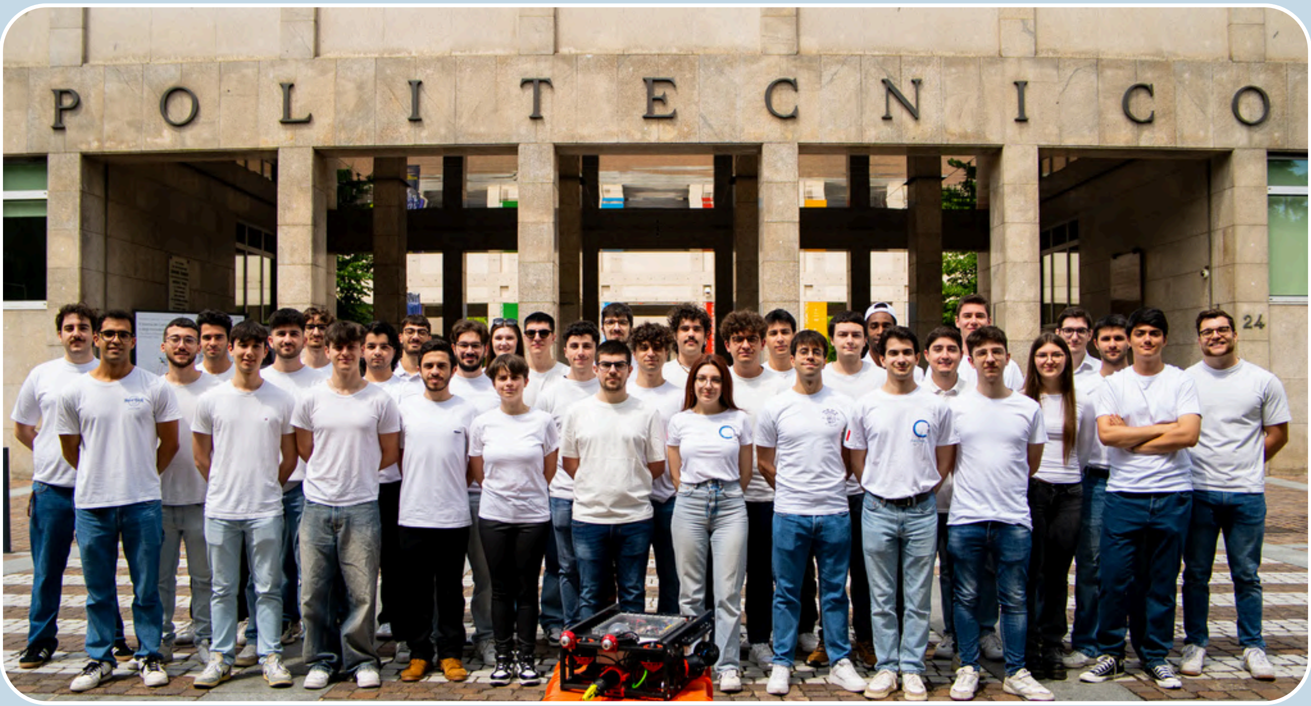
# Abstract

We are proud to present EVA, a Remotely Operated Vehicle (ROV) developed as the result of eight years of experience and over 4000 hours of planning, development and operational testing. EVA is purposefully designed to contribute to the mission of the United Nations Ocean Decade, advancing sustainable ocean science and innovation.

This year, building upon the lessons learned from our previous prototypes, our team has reimagined EVA by combining the technical leadership of senior members with the innovative perspectives of new recruits. The outcome is a redesigned vehicle that fully embodies our team's commitment to Italian maritime excellence and engineering precision. In preparation for the challenges set forth by the Marine Advanced Technology Education (MATE) competition, the mechanical division reengineered EVA's structure to enhance efficiency and adaptability, while the electronics division integrated new-generation sensors to provide superior control and responsiveness across complex underwater operations. Thanks to the software division, the new prototype is equipped with a new firmware that includes Heave, Roll, and Pitch controllers, significantly enhancing its maneuverability and enabling it to perform underwater maintenance and exploration tasks — simulating real-world scenarios — with high performance. As PoliTOcean, this technical document outlines the design and development process of our flagship ROV, EVA, and demonstrates how it effectively addresses a wide range of real-world mission challenges with precision and reliability.



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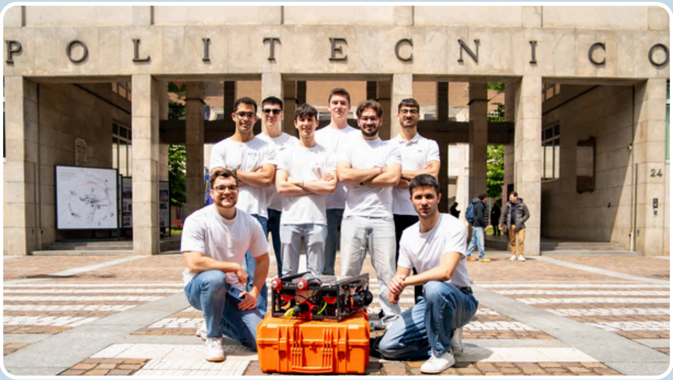
# Company Organization

## Company Structure

PoliTOcean is a team made up of **71 students** from diverse cultural backgrounds and various engineering disciplines, who are dedicated to solving real-world problems by using their knowledge and experience, in alignment with the United Nations' sustainability goals.

The team is divided into three main areas: the **MATE Competition Area**, the **R&D Area**, and the **C&M Area**. Each of these focuses on a specific type of project, all within the field of **ROVs** and **AUVs**.
Each area has its own Project Management team, supported by the Chief Technical Officer. Together with the technical team advisors, they coordinate the projects planned at the beginning of the academic year. The detailed breakthrough of the company structure and the job descriptions can be found in Appendix A.

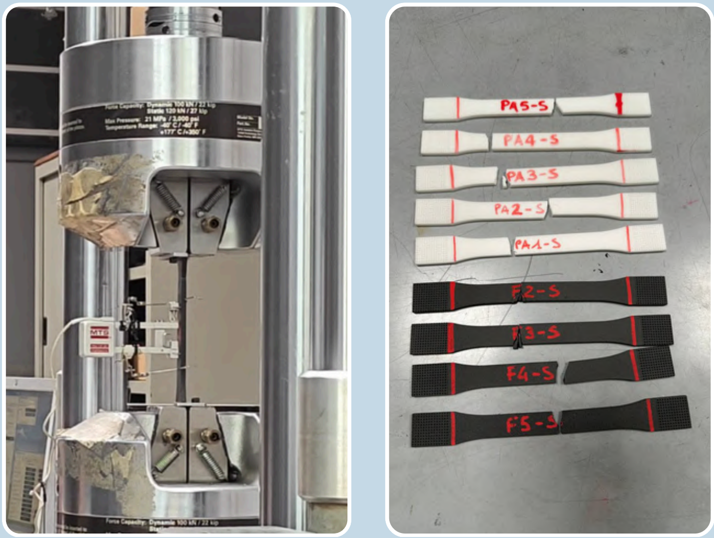



1 - MATE ROV Competition Team Members

New member recruitment occurs twice annually, in September and March. The interview process for new members, their integration into departments, and preliminary training are overseen by the department advisors.
Department meetings are held once a week under the guidance of the department advisors, while the general club meeting takes place once a month. Outcomes or progress from department meetings are reported to the general manager by the department advisors. The team leader's responsibility is to ensure the overall coordination and flow of the team.

## Research & Development Department (R&D)

The Research and Development department (R&D) is divided into six sub-divisions: mechanics, electronics, software, materials, hydrodynamics and control systems. The goal of this department is to carry out **advanced research and simulation** on any field of marine engineering, while also facilitating technology transfer and collaboration with partners. Specifically, it aims to achieve the following objectives: **maintenance of retired prototypes, AUV development, materials engineering**.
Each sub-department maintains continuous communication with one another to identify and implement potential improvements.

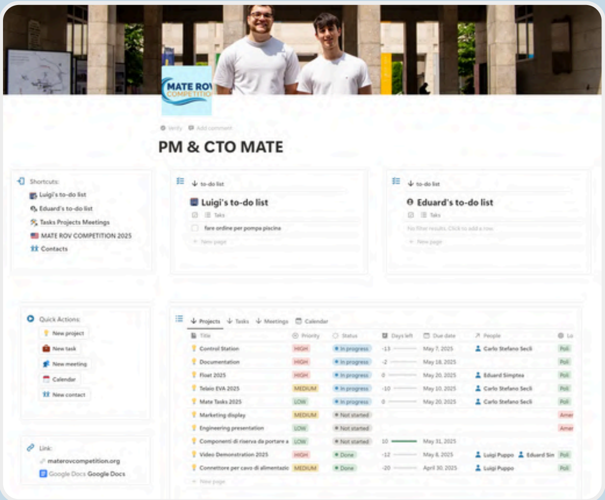


2 - Failure Test of different materials

## MATE Area Department

The MATE area plays a crucial and dynamic role within the team, focused on designing and building the most advanced and high-performing ROV possible for the MATE ROV Competition. Beyond the development of the vehicle itself, the team also engineers a wide range of specialized tools and accessories that are essential to successfully completing the competition's complex tasks.

An other innovative and complex project is the float, which receives particular attention in both its design and performance optimization.
Moreover, this area is responsible for training the next generation of ROV pilots, ensuring they are equipped with the technical skills and confidence needed to operate the vehicle under challenging conditions. The MATE team combines engineering excellence, strategic planning, and hands-on experience to push the boundaries of underwater robotics year after year.




3 - General Notion Page

## Communication and Management Department (C&M)

Our "Communication and Management" department is divided into two subdivisions: Communication and Management. The Communication team, which represents the public face of our organization, oversees the team's social media presence, ensuring consistent and engaging content. In addition, it manages the application process for new member recruitment, which takes place in September and March. On the other hand, Management division identifies potential companies for collaboration, nurtures partnerships with existing sponsors, and organizes promotional activities to boost the team's visibility and impact.

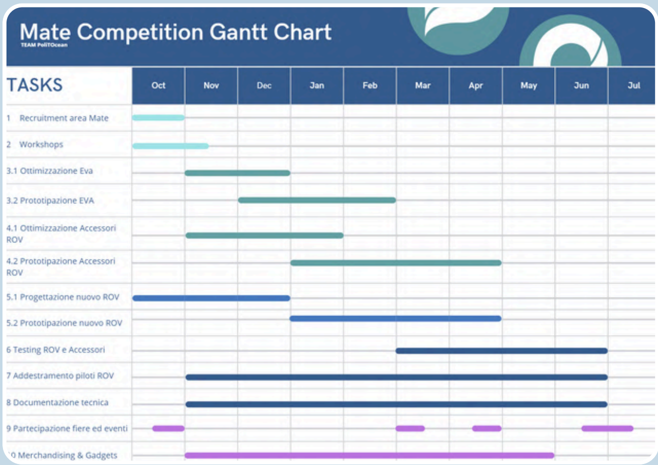
## Mission and Values

As PoliTOcean, we recognize that effective planning and consistent discipline are essential for achieving success. Therefore, at the beginning of each operational year, we define our primary objectives for the competition period using a comprehensive Gantt Chart.

## Project Management

At the beginning of the academic year, the board defines the main objectives the team aims to achieve and plans the best strategy to reach them.
Good planning is essential to lead a large team like ours, which sets ambitious goals involving new challenges, events to attend, and collaborations with companies in the tech sector.
For this reason, our entire organization is managed using the Notion project management software, supported by additional communication platforms such as Telegram and Discord, as well as social media platforms like Instagram, LinkedIn, and YouTube.

To stay organized and always have a clear overview of the general situation, we use Gantt Charts. At the beginning of the year, a dedicated chart is created for each macro area of the team (Competition, R&D, C&M), and we try to follow them as closely as possible. When we encounter unforeseen issues during the process, we adapt the sub-tasks each member is working on in order to stay aligned with the planned vision for that specific team area.




4 - Gantt Chart

## Project Schedule

To organize all the projects planned in the Gantt Chart, we use the Kanban system. This system is essential within the team, as it allows the breakdown and delegation of minor responsibilities from the board to the advisors of each area.

Within a macro-project, there are several tasks to be carried out with varying priorities (LOW, MEDIUM, HIGH), and by applying the Eisenhower Matrix, we are able to schedule higher-priority tasks by assigning more personnel to them or increasing the effort dedicated to their execution.

# Design Rationale

5 - Front-side and back-side ROV

**EVA** is our latest designed ROV and has already taken part in **three** competitions, demonstrating its high **reliability** and **modularity**, which have been top priorities since its inception.
The starting point was identifying the necessary sistems and looking for a structure that could accommodate them all.
The **chassis**, made of HDPE (High density polyethylene, is a compromise of lightness and performance achieved through topological optimization techniques. The choice to mount 8 motors makes all degrees of freedom available to us and at the same time allows effective and refined operation of the controller to regulate stability.

The **heart** of EVA, inserted centrally in the frame, is the rectangular pod made by CNC in metal.
The position balances the structure and the type of material allows us to have optimal thermal relief of the boards.

To interact with the environment we chose a **centered arm** equipped with rotating grippers.
It is a simple, effective, lightweight and **easy to control** solution. 5 cameras, 3 front, 1 top and 1 bottom, allow you to properly visualize your surroundigs and carry out any activities involving graphic shots.

7 - EVA is happy to be photographed

This construction solution was the result of a long work of improvement and choice of the best solutions, in order to create a product that is not only high-performing and reliable but it also has a simple operating logic.


6 - EVA is happy to be photographed

# Design Evolution

The vehicle's design has been carefully developed to enhance its efficiency. Each area advisor focuses on improvements applicable to the ROV, relying on studies, calculations, and past experiences. Together with the CTO and the PM, they meet to discuss and decide on new proposals to pursue for the project.

For example, from a mechanical point of view, two domes for the 180° cameras have been added, along with mounts for the remaining three front-facing cameras. The new 1-degree-of-freedom aluminum-milled arm is fixed to the frame with its dedicated support, and thanks to the ROV's stable structure, it is capable of performing tasks involving the lifting and transport of moderately heavy loads.

The electronics are fully modular, a design choice made to easily upgrade the boards to newer versions or enable quick replacements when necessary.

To highlight the evolution, a full 3D model of both last year's and this year's ROVs is shown, clearly showing the main changes in layout and design.

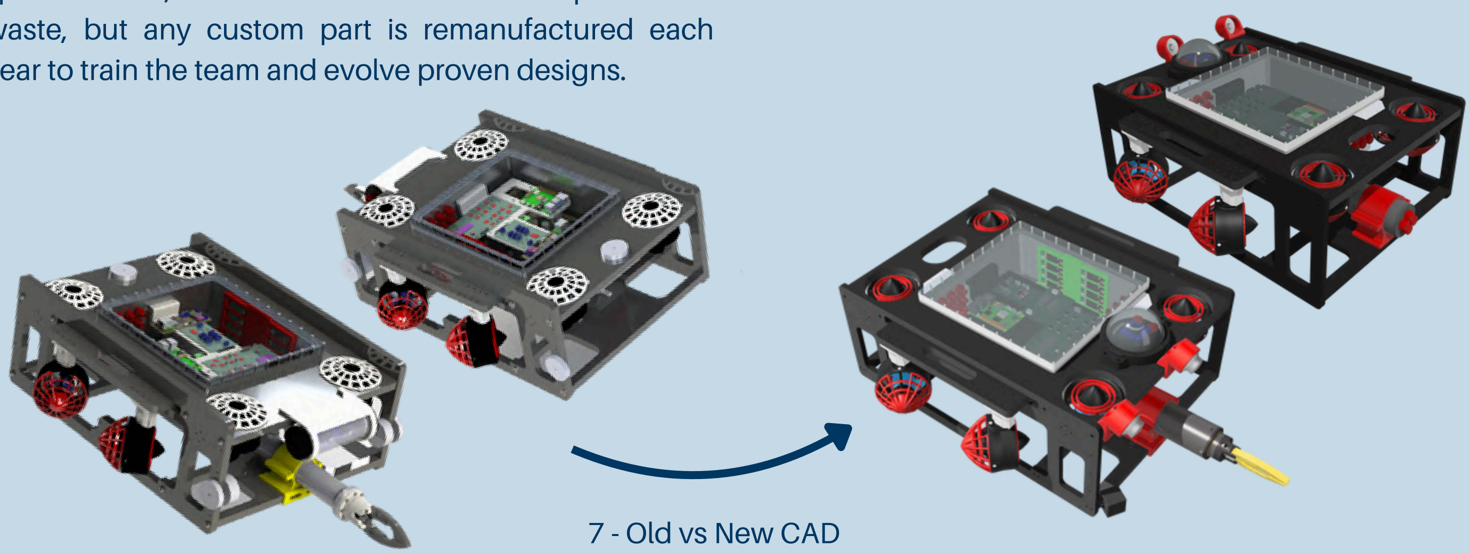
Some components from previous years that were still fully functional have remained unchanged. On the mechanical side, the chassis, the electronics enclosure, and the motors were retained as-is, while on the electronics side, some boards were also left unmodified. In these cases, the decision to reuse was driven by the fact that these parts continued to meet the current mission specifications, while also helping to reduce both costs and waste.

## Build vs Buy, New vs Used

PoliTOcean's "build vs. buy" and "new vs. reuse" philosophy is driven first by mission needs and second by our commitment to hands-on learning. Whenever our workshop can meet the requirements, we opt to design and manufacture in-house-retaining control over custom features, honing our skills, and ensuring that any new member gains experience on every part. Only when an off-the-shelf solution clearly outperforms our in-house option in cost, performance, or reliability do we choose to buy. Likewise, we rigorously assess whether a purchased component can be carried over from prior seasons: if it still meets the current specifications, we reuse it to reduce both expense and waste, but any custom part is remanufactured each year to train the team and evolve proven designs.

This year's manipulator exemplifies our approach. We deliberately built a brand-new gripper assembly from the ground up-outsourcing only the aluminum tubular frame-while 3D-printing every moving component and housing to improve both waterproofing and field reparability. In contrast, our arm-pointing camera was deemed suitable for reuse; we simply resin-potted it for underwater service, sidestepping the cost of a new unit.

For the core vision system, the performance requirements forced us to buy new ExploreHD USB cameras (waterproof and H.264-encoded) to reliably stream five feeds on a Raspberry Pi 5 an off-the-shelf choice that clearly outmatched anything we could build or integrate on the Pi 4B. Similarly, the top and bottom PiCam360 modules were purchased new, but we built their waterproof housings ourselves to maintain flexibility and keep costs down. Finally, our frame, while based on last year's proven geometry, was freshly machined in lighter materials to meet this season's weight limits. In every case, we've balanced in-house innovation against strategic buying, and judiciously reused components whenever they still satisfied our rigorous mission requirements.



7 - Old vs New CAD

# System Design

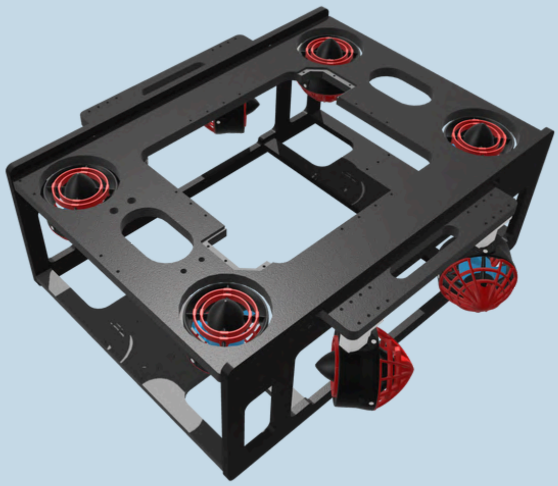
## Mechanical Systems

### Frame

Eva's frame has been designed to obtain a stable and robust structure. The design of the various components was done in Solidworks (*6).

This allowed us to perform several **FEM simulations** to choose the material that met our requirements, minimized disturbances in the thruster's flow, and reduced the weight of the structure. After testing with different materials, we found that **HDPE** was the best solution.

Although it has **lower tensile strength** than materials like PVC or nylon, HDPE has a lower water absorption rate, a large strength-to-density ratio, and a significantly lower cost.
The frame was made by machine due to the material's ease of processing. The **structure** consists of five parts: an upper panel, two side panels, and two lower panels. These were then connected to each other by screws (M6) and threaded inserts.
The overall footprint is **565 mm long**, **498 mm wide**, and **220 mm high**, with each panel being 15mm thick to maintain frame integrity, the complete ROV has a weight of **18.9 kg**.



8 - Frame of the ROV

### Electronics Enclosure

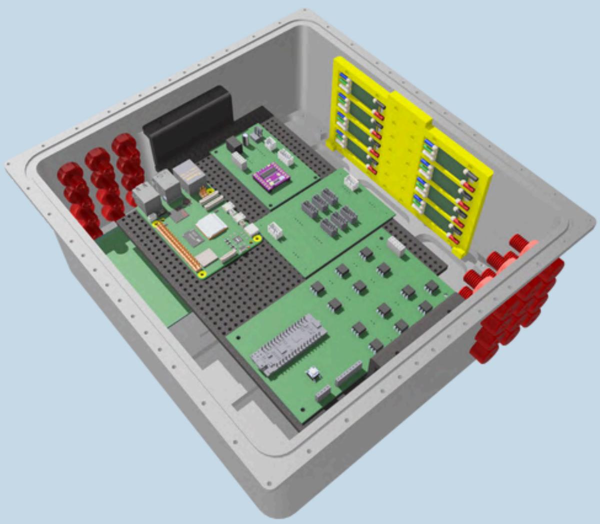
EVA's electronic box consists of a box-shaped enclosure (260x280x110mm) made of 7075 T651 aluminum alloy milled into shape. It has 24 holes placed symmetrically on the front and rear, divided into two groups of 12.

The holes are equipped with M10 penetrators that allow cables to pass from the box to the utilities, including thrusters, cameras, and the power source.

The upper closure of the box is made of a flange and a 15 mm-thick plexiglass panel, with 56 and 40 M3 holes respectively. The flange is used to seal the box to the chassis through 16 M3 screws, while the panel is attached to the box through 40 M3 holes.

Aluminum 7075 was chosen for its high mechanical properties and ability to dissipate heat generated by electronic boards' operation. The inner bottom of the box has tappings suitable to house M2 screws for the two largest electronic boards, while a PLA support with M2 holes is available for positioning the other three boards.

Compared to previous models of circular boxes, the simple and functional design allows easy installation, maneuverability, and replacement of any damaged parts, as well as better internal cable management.
The box and closure in plexiglass have been designed to ensure safe handling through the joint of the edges.



9 - Electronic box

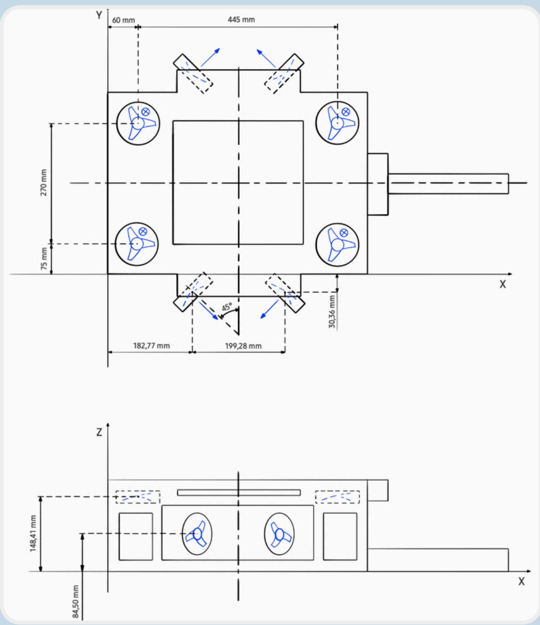
Hydrodynamic Systems

# Propulsion

EVA is equipped with **8 T200 thrusters** manufactured by Blue Robotics, designed with tough polycarbonate casing and marine-grade 316 stainless steel hardware to ensure durability in underwater environments. The propulsion system is arranged to guarantee complete control over all six degrees of freedom (surge, sway, heave, roll, pitch, and yaw). The configuration consists of:

- 4 thrusters mounted horizontally at a 45° angle relative to the main axes (XY-plane) to provide precise control in planar motion (forward, backward, sideways, and rotational movements).
- 4 thrusters mounted vertically to control the heave motion (ascending and descending).

The horizontal thrusters are positioned with alternating rotation directions (2 clockwise, 2 counterclockwise) to balance torques and improve yaw control efficiency. Similarly, the vertical thrusters are arranged symmetrically to ensure stability during vertical maneuvers. The propulsion system operates at 12 V, chosen based on two main factors: 1. 2. The voltage conversion from the 48 V main supply to 12 V is highly efficient, achieving a 92% conversion efficiency. For the thrust requirements of EVA (approximately 2.9 kgf per thruster), 12 V provides the optimal balance between thrust output and energy consumption, improving overall endurance and reducing the thermal load on electronic components. This configuration allows EVA to perform agile and stable maneuvers necessary to accomplish all mission tasks with minimal power expenditure.



10 - Thrusters Relative Position


11 - Render Thruster

# Buoyancy and Float Systems

The buoyancy system of EVA was designed to achieve a **slightly positive** net buoyancy, ensuring that the vehicle naturally ascends to the surface in the event of a system failure. This safety feature eliminates the need for manual retrieval through the tether and is based on Archimedes' principle, which ensures that the vehicle floats even with all systems powered down. Rather than relying on additional external flotation modules, the design leverages the aluminum electronics housing as a critical structural and functional component.

Despite aluminum being denser than water, the large internal volume of the housing is filled with air, which is considered massless in the buoyancy calculation. This allows for a significant reduction in the overall density of the ROV, compensating for the mass of the electronics and other components housed within.
However, due to the conservative safety margin and design constraints, EVA initially presented a greater positive buoyancy than desired. To fine-tune this and bring the system closer to neutral buoyancy, a set of small ballast elements were added. These consist of metal discs, strategically placed along the structure of the ROV. Their location and mass were selected to:

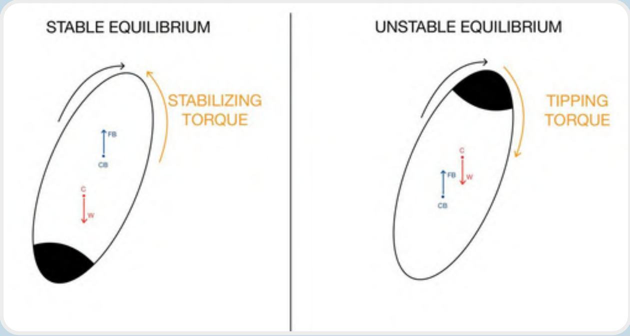
- Precisely control the net buoyancy,
- Maintain a stable orientation during motion
- Allow for easy adjustments in future iterations or different mission scenarios.

# Static Stability Considerations

A critical aspect of the buoyancy design is the relative positioning of the center of gravity (CoG) and the center of buoyancy (CoB). In EVA:

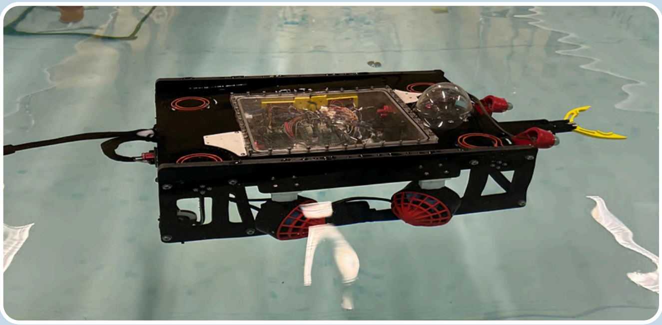
- The CoB lies vertically above the CoG, and both are aligned along the same principal axis of the vehicle.

- The buoyant force acts upward through the CoB, while the weight force acts downward through the CoG.

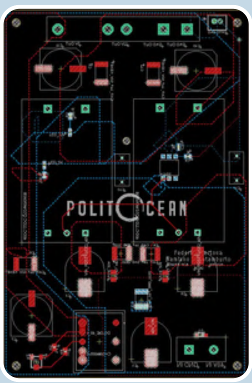


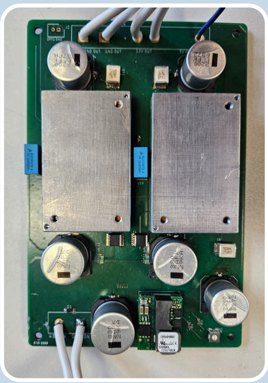

12 - Stable Equilibrium of EVA

This configuration guarantees static stability: when the ROV is perturbed from its equilibrium position, the misalignment of the two forces generates a restoring moment that tends to return the system to its original orientation. If the CoB and CoG were reversed — with the CoG positioned above the CoB — any disturbance would generate a destabilizing torque, leading to uncontrolled rotations or capsizing. The careful positioning of these two centers is therefore not only essential for passive stability, but also fundamental to the design and tuning of the control system, which benefits from a naturally stable dynamic baseline



13 - Buoyancy of EVA

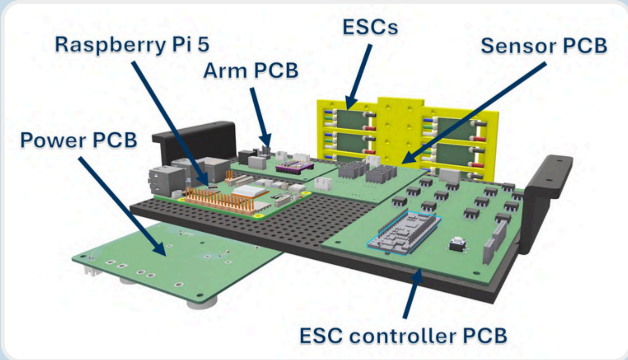


14 - Power PCB

## Electronic Systems

The electronic system of our ROV is basically composed of many PCBs in a modular structure that work seamlessly to perform the tasks. All the circuit-boards get through 3 phases: Schematic Design, Board Design, Assemblying and Final Testing. Once certified they are ready to be attached to the ROV.



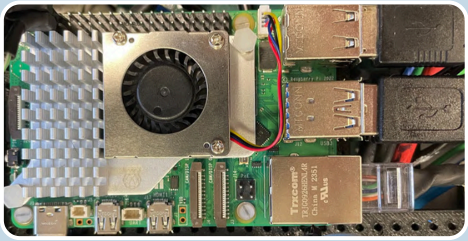

15 - Model of Electronics Stack

# Power Distribution

EVA is powered with a **48V/30A supply** from shoreside. Before reaching the overall electronics, 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. In addition, 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.

Our engineers designed the power distribution system to tackle the **heat dissipation** that leads to extremely high temperatures in electronics enclosures. An increase in temperature means a reduction in efficiency, therefore, to maximize performance is indispensable an effective heat dissipation. For this reason, the power PCB is housed at the bottom of the electronics case. In addition, DC-DC converters were chosen because of their built-in dissipation plates, which are directly touching the aluminium box. Being the aluminium case directly in contact with the water, it provides a thermal exchange with the external environment that leads to a decrease in temperature of **60%** with respect to other solutions evaluated (for example use a commercial acrylic tube as electronic housing). In this way, 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.

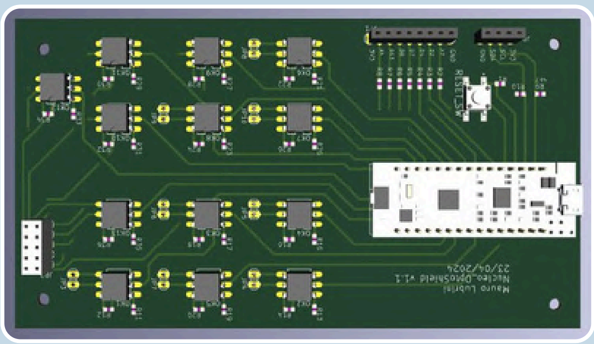


16 - Raspberry Pi 5

Our electronic engineers designed EVA's electronic system paying special attention to operational stability and space optimization and serviceability. Almost all the electronic boards are mounted in the Electronic Box (EB). 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 diagnostics 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 thrusters 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 arm.

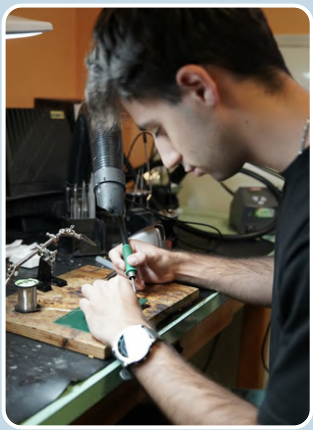


17 - ESC Controller PCB

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.

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 arm.
- **8 optocouplers** with a 2 pin output connector used to send the PWM signal to the 8 thrusters.
- **5 optocouplers** are used to send signals to the arm controller. 8 digital I/O pins and one I2C port.
- **ESC wiring**: 8 BlueRobotics' BasicESCs that drive the thrusters are wired to the ESC 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**.



18 - Soldering Station

19 - Pick & Place Station

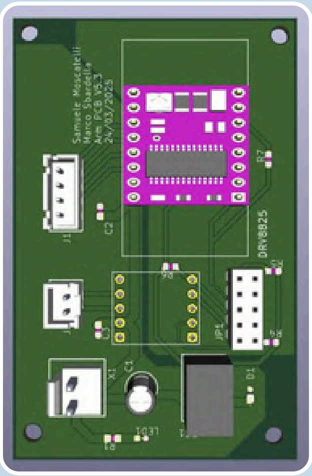
# Sensors PCB

This PCB 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.

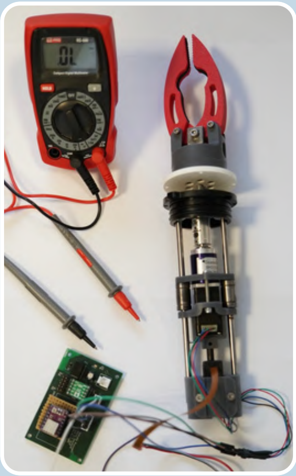
# ARM PCB

This board, as the name suggests, represents the hardware control for the ROV's arm. 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 alow 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.



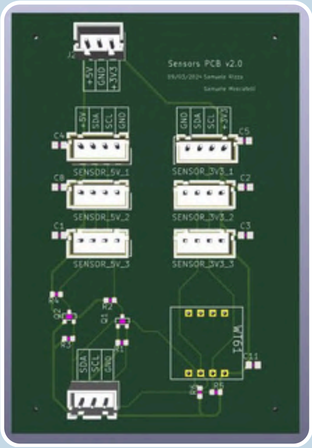
20 - ARM PCB



21 - ARM connected to the PCB

# Tether

EVA's tether is **17 m** long and designed for efficient, reliable operation underwater. It consists of a 48 V power cable and a Cat6E Ethernet cable, bundled together using a PET braided sleeve to improve durability and handling. The power line uses 2.5 mm² copper conductors ensuring stable power delivery.



22 - Sensors PCB

23 - ROV Tether

The positive wire connects to a **30A fuse** between the ROV and the power supply. The Cat6E cable supports data rates up to 1 Gbit/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.
See **Appendix C** for the tether management protocol.

# Cameras Compartment

Our ROV is equipped with **five** USB digital cameras, selected after comparing SPI and IP options. SPI cameras were ruled out due to their need to be physically close to the main board, impractical given our layout, while IP cameras required an onboard Ethernet switch, adding cost and bulk. USB cameras offered the best compromise between flexibility, image quality, and integration effort. At the front, two high-resolution waterproof **DWE exploreHD 3.0** units provide a sharp, low-distortion image, ideal for precise manipulator operation and stereo-based depth estimation during tasks like shipwreck inspection. A top and a bottom **PiCam360** module, each equipped with ultra-wide 180° fisheye lenses, offer full vertical coverage for navigation, mapping, and capturing immersive 360° photo spheres, as required in Task 1.1. Finally, a fifth **wide-angle USB camera** below the arm to eliminate a blind spot that previously prevented us from completing certain manipulation tasks.

## Software System

The ROV's software stack is built around **three integrated components: NEXUS, Oceanix**, and **STM Nucleo firmware**. NEXUS, running on the control station, delivers real-time video, telemetry, and control to the pilot. Oceanix, hosted on a Raspberry Pi 5, handles mission logic, sensor fusion, and dynamic thrust allocation. The STM Nucleo executes low-level motor and actuator control via lightweight firmware, offering additional GPIOs with PWM support at very low cost. These components communicate via MQTT, $I^2C$ and a custom serial protocol, ensuring modularity, low latency, and robustness.

The decision to adopt the **Raspberry Pi 5** over alternatives like the NVIDIA Jetson Nano was driven by its **efficiency**, **lower power consumption**, and **cost-effectiveness**. While the Jetson's GPU acceleration benefits AI workloads, our architecture prioritizes **real-time control**, sensor polling and network communication (tasks where the Pi 5's CPU is more than sufficient). Similarly, the STM Nucleo adds PWM-capable GPIOs and supports a *modular architecture at minimal cost*. This design allows us to upgrade sensors or control logic with minimal effort, supporting rapid development and scalability.

# NEXUS GUI

**NEXUS** is implemented as a Flask-based Python application that delivers a desktop-style web interface to the ROV pilot. Within the browser window, operators see **five live feeds** from the Raspberry Pi 5. This year, we upgraded the streaming system to **WebRTC**, enabling **GPU-accelerated rendering** of the video directly in the browser. This allowed us to reduce latency by up to 200 ms and add **real-time lens distortion correction** for improved camera visualization, while fully leveraging the onboard H.264 encoding of the two front cameras. Alongside the video panels, dynamic charts visualize the **ROV's attitude** (roll, pitch, yaw) and depth readings from the Bar02 sensor. **Float functions** are accessed through a dedicated section. **Commands**, from joystick movements to arm actuation, are serialized as JSON and sent over MQTT to Oceanix. For deeper analysis and tuning, we maintain a companion Python/Tk debug tool that connects via MQTT to display *raw sensor dumps, per-motor thrust values, live logs* and *adjustable control-loop parameters such as controller gains.*


24 - NEXUS main window

# OCEANIX

**Oceanix** is our C++ application running on the Raspberry Pi 5, 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.

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 200 Hz via $I^2C$, combining accelerometer, gyroscope and pressure data in a complementary filter to estimate depth and attitude.

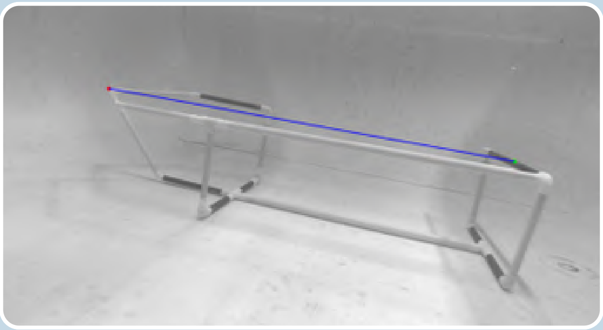

25 - Python tool main window

## STM Nucleo Firmware

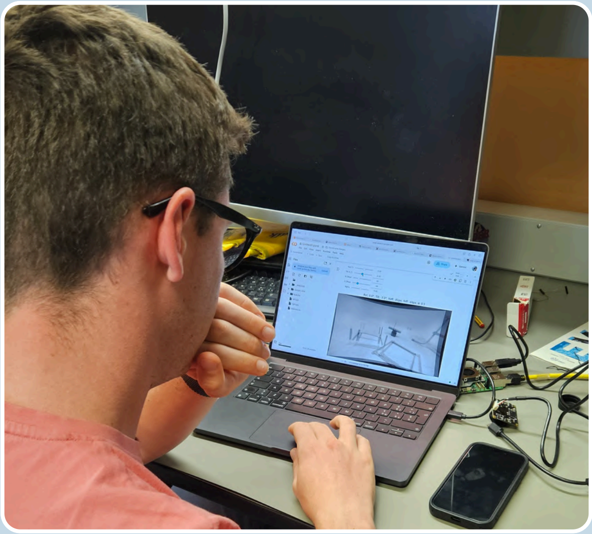
On the **NUCLEO-L432KC board**, a bare-metal C application built on ST's HAL libraries listens on UART for a continuous stream of PWM duty-cycle values and servo positions sent by Oceanix at 100 Hz. Each packet includes a CRC to verify integrity; in the event of a CRC failure, the firmware retains the previous command until valid data resumes. Hardware timers generate PWM signals with 1 µs resolution, which drive optocouplers feeding our motor driver MOSFETs. **For arm 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.

## Length Measurement

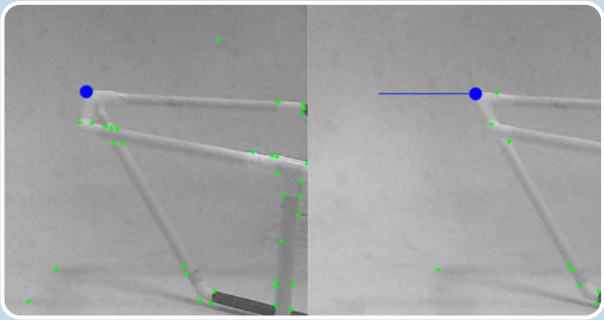
To solve the shipwreck task, which requires measuring the wreck's length for proper classification, we focused on a solution that minimizes in-competition execution time, we use our two front-facing cameras in stereo mode to **triangulate points in 3D space**. First, we perform underwater stereo calibration with a chessboard, capturing dozens of images to extract each camera's intrinsic and extrinsic parameters. In competition, operators mark points of interest on the left image. A feature-matching algorithm then finds their counterparts in the right image, yielding precise pixel correspondences. From these correspondences we compute a **disparity map**, convert it to a depth map, and project the selected pixels into 3D. Finally, we calculate the **Euclidean distance** between the 3D points to obtain an accurate length measurement. This semi-manual workflow bypasses unreliable disparity estimation in turbid water and ensures rapid, reliable results.



26 - Measured segment visualization



27 - Simone is working



28 - Left and right images used for point matching

### Control System

**Efficient motion** is a key requirement for any underwater robotic application, especially when performing tasks that demand precision and stability. This led us to design a new, modular motion control system tailored to the challenges of underwater manipulation and navigation.

The control pipeline consists of **four** main stages:

1. **Kinematic mixing**
2. **Pilot commands** (either from joystick or autonomous logic) are translated into individual thruster setpoints using a 6-DOF kinematic model that accounts for the physical layout and orientation of each thruster.
3. **Automatic control activation**
4. On request, the pilot can activate the **automatic control system**. This controller maintains the ROV at a fixed depth while keeping roll and pitch angles close to zero, stabilizing the platform during manipulation or inspection tasks.

## Work Mode

Manually enabled by the pilot, **work mode** is designed for fine manipulation tasks. It reduces the dynamic response of the ROV by limiting velocity and acceleration, allowing for **more precise movements**.

## Slew Rate Limiting

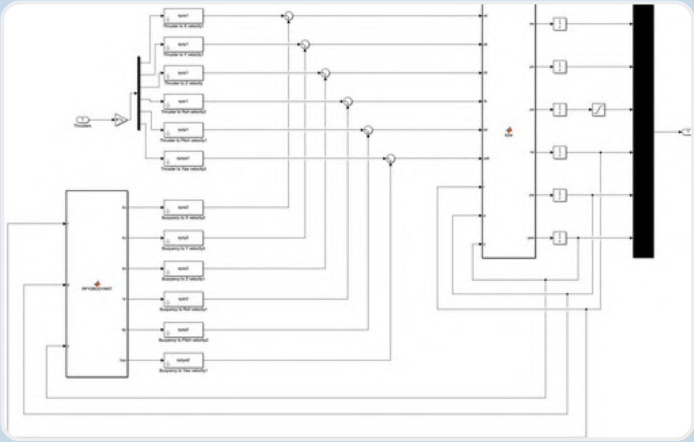
Thruster speed commands are passed through a rate limiter to **prevent sudden current spikes** that could cause voltage drops on the power board. Since our brushed DC thrusters can draw high peak currents at large speed deltas, this mechanism is essential to ensure electrical stability and avoid brownouts or undesired resets of onboard systems.

## Automatic Control

To effectively perform underwater tasks with accuracy and precision, such as object manipulations and trajectory tracking, the EVA ROV needs a **robust control system** designed to dynamically reject external disturbances while maintaining the desired depth and stable attitude.

To find a realistic plant model and to improve system performance, we employed a data-driven system identification approach. Specifically, the **grey box model** allowed us to combine the equations based on physics with the parameter's estimations based on input-output measurements collected from field test.

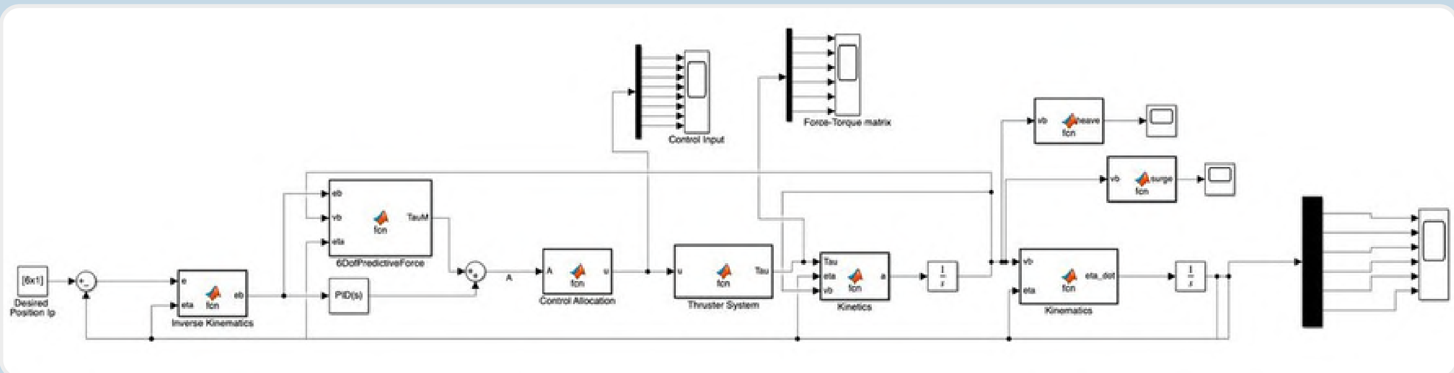
**Autoregressive models** have been identified and employed to build and simulate discrete-time transfer functions. Moreover, filters were estimated directly by experimental input-output data.



29 - Grey box model

As it shown in the **Simulink** model presented, the dynamic behaviour of the ROV is **simulated** by coupling the forces generated by the thrusters with the buoyant forces. These total forces and moments are used as inputs to the equations of motion, which determines the ROV's position and orientation over time. Then, the state variables constructed are received by the control system. The controller computes the error with respect to the desired trajectory, processing it through a control algorithm, and allocating thrusters, so it estimates the individual thrust commands necessary to achieve the desired.

This model served as the basis for a **custom controller**, integrated into our simulation framework and deployed in the ROV software stack. The controller operates on **6 DOFs**, depth, roll, pitch and the three position coordinates, automatically stabilizing the vehicle during operation. Horizontal movements remain under direct pilot control to preserve full manoeuvrability and responsiveness during complex tasks. The final closed-loop system reliably rejects disturbances and improves precision during manual operations, particularly where smooth manipulation is required.




30 - ROV Simulink model

## EVA manipulator

Our multifunctional manipulator is an **electronic robotic arm** designed to have a single degree of freedom.
It has been developed to adapt to structures and components from previous models, while incorporating improvements in materials and functionality.

It allows us to grasp various types of objects with different shapes and sizes, thanks to the use of gripping jaws.
The arm has a total length of approximately **34 cm** and weighs only **791 g**.
The manipulator consists of two interconnected parts: HAND and ARM.

31 -Eva gripper

The **HAND** compartment features a three-hinge mechanism (two fixed and one movable).
This configuration was chosen to optimize and simplify assembly while reducing the number of components prone to failure.
The mechanism connects two jaws, 3D-printed, and allows only opening and closing motions through the rotation of a shaft made of **ERGAL Al 7075-T6**.
The shaft is machined with multi-axis CNC tools and connected to a linear actuator (**PQ12**).
The structure supporting the jaws is called the WRIST mechanism, composed of a set of rotating joints made with 3D printing.
Thanks to a **NEMA8** motor (model to be confirmed), the wrist can rotate

32 - EVA Manipulator

The ARM system features a tubular structure made from **Aluminum Al-6082 T6** with a light black anodized finish.
This material allows for a solid and durable body with a high surface definition, ensuring excellent sealing performance through the use of gaskets and o-rings.
Each internal component of the forearm has been designed for easy and quick removal, improving accessibility over previous models.
Two linear guides with bearings, have been added to assist the movement of internal structures and to prevent the actuator's force from being wasted overcoming friction.
The forearm houses all the motors internally, which ,through a connecting joint, enable the proper functioning of the HAND system (mainly the NEMA8 motor and the linear actuator).

33 - EVA ARM

## Cameras Compartment

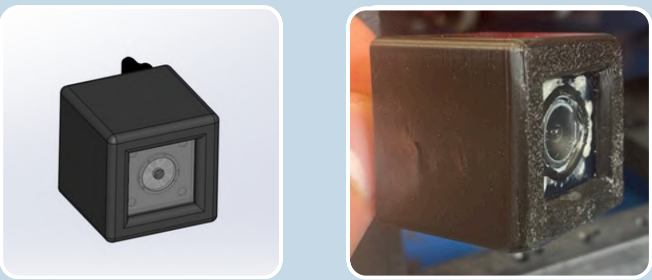
For the top and bottom cameras (PiCam360), a **waterproofing system** based on an acrylic dome provided by Blue Robotics has been adopted, coupled with a custom-made cap. The cap features two holes for the insertion of penetrators and supports, through adhesive bonding, a frame for securely mounting the camera. The use of the dome allows for a panoramic view with minimal optical distortion underwater, ensuring high-quality images.

For the front cameras (DWE ExploreHD 3.0), which are factory-sealed and already waterproof, a dedicated housing is not necessary. In this case, the camera is mounted inside a 3D-printed cylindrical support, angled at 19°, an inclination designed to optimize the framing of the robotic arm and ensure good visibility during ROV navigation.

Additionally, a fifth camera is mounted on the frame at the front but positioned lower, at the height of the robotic arm. This strategic placement provides an alternative point of view during tasks. Since this camera is not waterproof, a compact solution was implemented: it is encased in a small **custom-made case** and sealed with resin, avoiding the need for a bulky dome structure.

34 - front cam

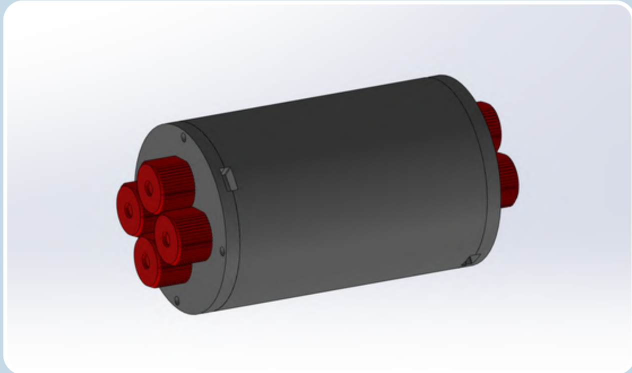
35 - Pi cam 180°



36 - Fifth camera

## Connector Housing

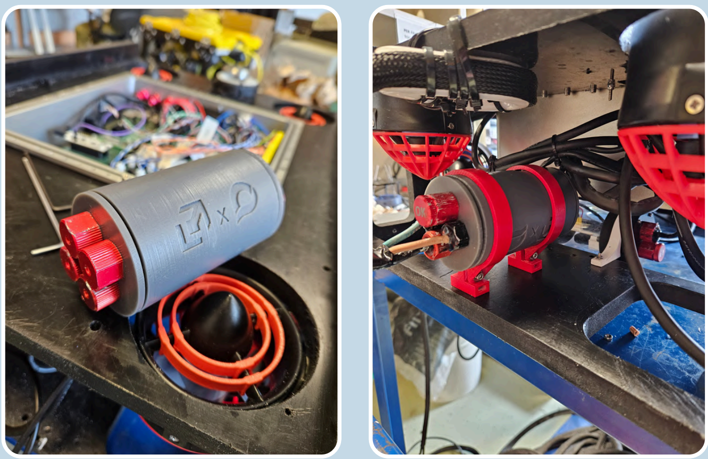
To improve **modularity, simplify transport** and **maintenance operations**, the ROV features a dedicated Connector Housing. This component is a cylindrical enclosure made of **Formlabs Tough 2000 Resin**, mounted on the vehicle's frame next to the main electronics enclosure.



37 - Connector housing CAD

Its primary function is to serve as an **intermediate interface** between the external tether and power supply (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 box directly.

This design choice facilitates easier access during assembly, testing, and deployment, while also protecting the integrity of the electronics enclosure by minimizing mechanical stress on its penetrators and connectors. The Formlabs Tough 2000 Resin construction ensures a lightweight yet robust solution, and the compact cylindrical shape optimizes space usage on the ROV frame.

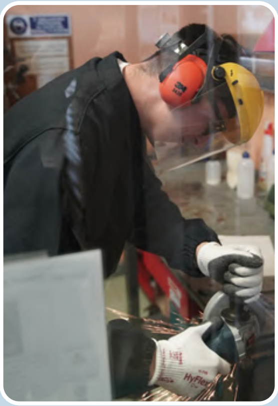


38 - Connector housing

# Safety

## Safety Philosophy

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



39.1 - Carlo is Safe

## Laboratory Protocols

Working in a laboratory requires adherence to specific safety protocols to ensure a safe work environment. When it comes to assembling electronic equipment, employees are required to wear special gloves and eye protection and to turn on the chemical ventilation system, which is located near each workstation. Over time, we have developed an **electrical safety protocol** to prevent electrocution and overheating of devices.

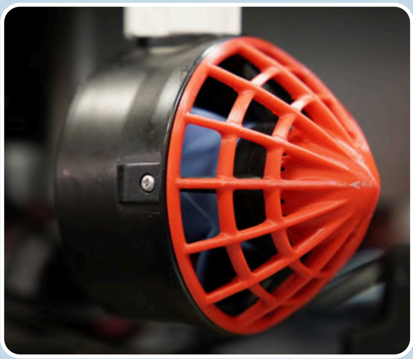
For mechanical processes, a specific dress code is mandatory, which includes the use of a suit, goggles, and gloves. In case hazardous materials are being handled, adequate ventilation must be ensured. All these procedures listed so far are included in PoliTOcean's Safety Data Sheet, which is accessible to all employees. We remind you that the SDS is just an additional tool that complements mandatory training for all new employees.


39.2 - Carlo is Safe

## Vehicle Safety Features

Safety plays an important role in the production of the final product. To this end, EVA is equipped with several safety features consisting of a combination of sensors and actuators. Each electronic enclosure in EVA is equipped with a temperature sensor that monitors possible overheating to prevent possible electrical malfunctions. Inside the main box, a pressure sensor has been installed to monitor the pressure inside the enclosure. Control of the pressure inside the enclosure is necessary to prevent water leaks. Another important safety feature present in EVA is the ability to remotely turn on and off the 12V output, which powers all the propellers and actuators of the ROV. This has been achieved thanks to the use of an optocoupler, a component capable of ensuring galvanic isolation.

To enhance safety, **protective engine covers** have been designed to prevent direct contact between a finger and the motor's propellers.This version maintains clarity while sounding more polished and professional for a report. Let me know if you'd like any further refinements!



40 - Thruster cover

# Critical Analisys

## Testing Metodology

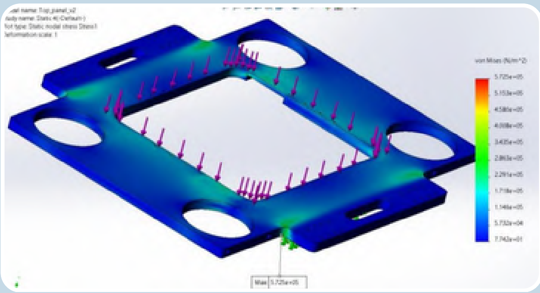
Testing is a **fundamental part** of the development of the ROV as it helps to identify any problems that may have been overlooked.

PoliTOcean's workflow involves testing each individual component through dry testing before assembling and evaluating the ROV as a whole.

For the Mechanical Area, each piece is subjected to FEM analysis to verify its behavior under stress.

In the Electronics Area, the preliminary step involves examining each individual PCB through a multimeter and oscilloscope to ensure correct soldering and assembly.

For the Software Area, the entire software stack is tested in simulation using "fake" sensors and cameras. This allows us to evaluate output behavior, system stability, and the integration between different software components.



41 - FEM analysis on the frame

To ensure ROV's integrity before water testing, we verify the absence of **insulation loss**, especially around penetrators, key points where cables enter the watertight containers. To inspect this, the team developed a system consisting of a vacuum pump and a sealed cylinder equipped with a pressure gauge and penetrators. This cylinder is connected to EVA's containers to be tested through PVC tubes with appropriate fittings for the penetrators at each end. This system allows us to test whether the entire device is watertight and also to identify any possible leak points.

Once all the necessary steps have been successfully completed, **testing in water** can begin, during which any problems at the firmware level are verified. If any issues are encountered while piloting the ROV, developers attempt to find solutions.

## Troubleshooting

During the development of a project of this scale, it is inevitable to encounter issues that were not foreseen during the earlier planning phases. As engineers, we are used to solving problems in the classroom, but when it comes to practical implementation, it's a completely different story. However, we have a clear **action plan** for addressing the problems we face along the way.

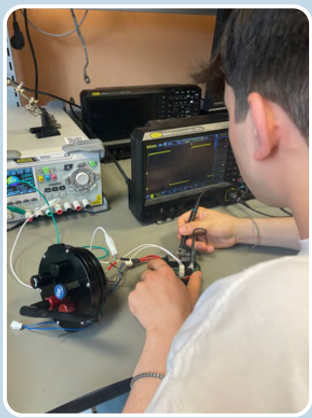
The first step is to assess the situation. Understanding the most **critical aspects** that need to be addressed, whether related to construction timelines or delays in material procurement.

The second step is breaking the problem down into **subtasks**. These tasks are then assigned to the members responsible for each area of the team, who work in parallel while maintaining communication to minimize the technical time required to fix the issue.

Afterward, we regroup and, once the individual work is verified, we integrate all the separate contributions to **resolve** the initial problem.

This practice has helped us a lot in overcoming challenges, and thanks to the dedication of the team members, who spend countless hours in the lab, we've always managed to resolve issues in record time.

42 - Vacuum pump



43 - Electronic tests

# Finances

## Accounting

Politocean estimates the cost of the project and the expenses done at the start of the year to manage its budget.

For the year 2025, our expense table was heavily reduced due to recycling of the 2024 ROV. With this decision our team decided to use the budget mainly for representation missions and fixes.
Our income source is heavily given by Politecnico di Torino, in addition to that our sponsors' support is very important to us when it comes to material donations.

All of our purchases must be approved in advance by the Project Managers and then finally approved by the Team Leader. Then they are processed by the internal division of C&M division. Our expenses are regularly checked to ensure that they match with our records.

| Category | Description | Type | Budget(USD) | Spent(USD) | Worth(USD) |
|---|---|---|---|---|---|
| Mechanical | | | | | |
| Electronics box | Raw material and mechanical processing | Re-used | 2825 | 0 | 2380 |
| Frame | Raw material and mechanical processing | Purchased | 565 | 470 | 470 |
| Thrusters | 8 BlueRobotics T200 thrusters + ESC | Re-used | 2712 | 0 | 2235 |
| Manipulator | Raw material and mechanical processing | Purchased | 960,5 | 720 | 720 |
| 180 cameras enclosure | BlueRobotics Watertight Enclosure Dome | Purchased | 169,5 | 124 | 124 |
| Connector housing | Raw material and mechanical processing | Donation | 169,5 | 0 | 135 |
| Tools | Filaments for 3D printing. | Purchased | 1525,5 | 1200 | 1200 |
| Electronics | | | | | |
| PCBs | PCB fabrication and components | Re-used | 791 | 0 | 675 |
| Tether | Tether | Re-used | 226 | 0 | 154 |
| Tools | Multimeters, components, wires | Purchased | 960,5 | 738 | 738 |
| Stepper and linear actuato | Motors for the manipulator and the Float devi | Purchased | 339 | 236 | 236 |
| Software | | | | | |
| Cameras | 360 cameras, front cameras, lateral camera | Purchased | 1130 | 870 | 870 |
| Raspberry | Raspberry pi5 | Purchased | 113 | 80 | 80 |
| External monitor | Additional monitor for the Control Station | Purchased | 282,5 | 220 | 220 |
| Control Station | Laptop for the control station | Re-used | 1017 | 0 | 865 |
| Administrative expenses | | | | | |
| Pool tests | Pool tests | Donated | 452 | 0 | 400 |
| MATE ROV registration fees | Registration fees | Purchased | 678 | 600 | 600 |
| MATE ROV accomodation | Accomodation expenses for 8 members | Purchased | 4520 | 3700 | 3700 |
| MATE ROV travel | Travel expenses for 8 members | Purchased | 11300 | 9500 | 9500 |
| Non-ROV Device | | | | | |
| Float | Electronics | Purchased | 282,5 | 120 | 120 |
| Float | Mechanical | Re-used | 169,5 | 0 | 150 |
| RnD Division | | | | | |
| Nereo | Electronics, Mechanical, Software | Purchased | 3616 | 2700 | 2700 |
| Proteo | Electronics, Mechanical, Software | Purchased | 2599 | 1000 | 1000 |
| TOTAL | | | 37403 | 22278 | 29272 |

Table of costs


## Aknowledgements

A plunge of gratitude to those who have illuminated our path in the ocean of the MATE ROV Competition and underwater robotics!

A special thank to the **MATE ROV Competition** for offering us this incredible adventure in the underwater world of growth and competition. Your commitment to encouraging innovation and sustainability education is the current that guides us towards the future.
Immense gratitude to the **Politecnico di Torino** for their generous financial support, their contribution was essential in bringing our project to the surface.

A special thanks goes to **Professor Sansoè**, our mentor, for his constant support in every aspect. Whether it's technical suggestions or words of encouragement, he always backs us up and keeps our motivation high.

A warm thank you to the **Department of Electronics**, for their logistical and technical support.

We would love to thank other amazing companies that have collaborated with us: Subsea LED, Altair, Dewesoft, Officine Massola, Notion, Projectstudio, Italstrass.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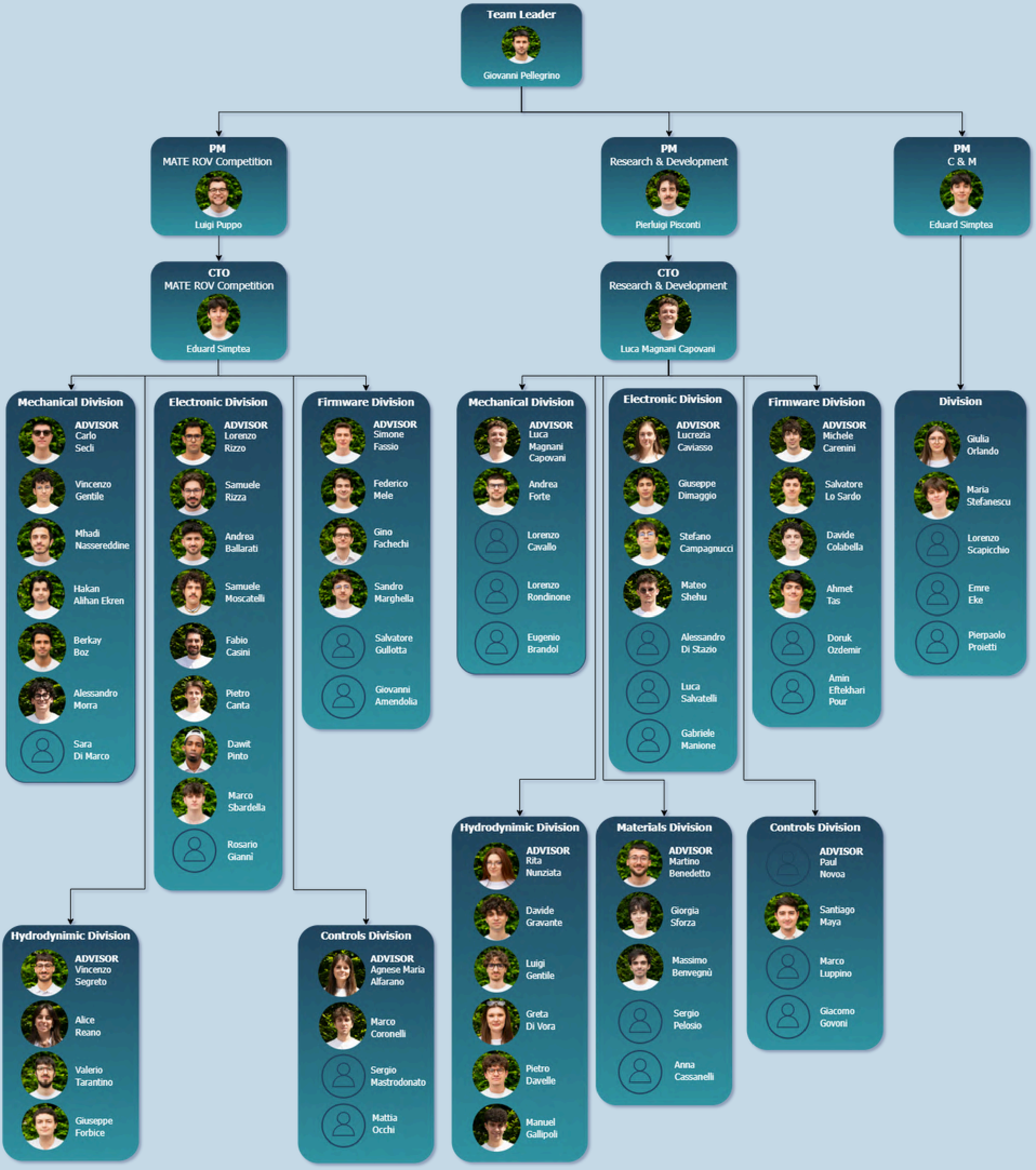
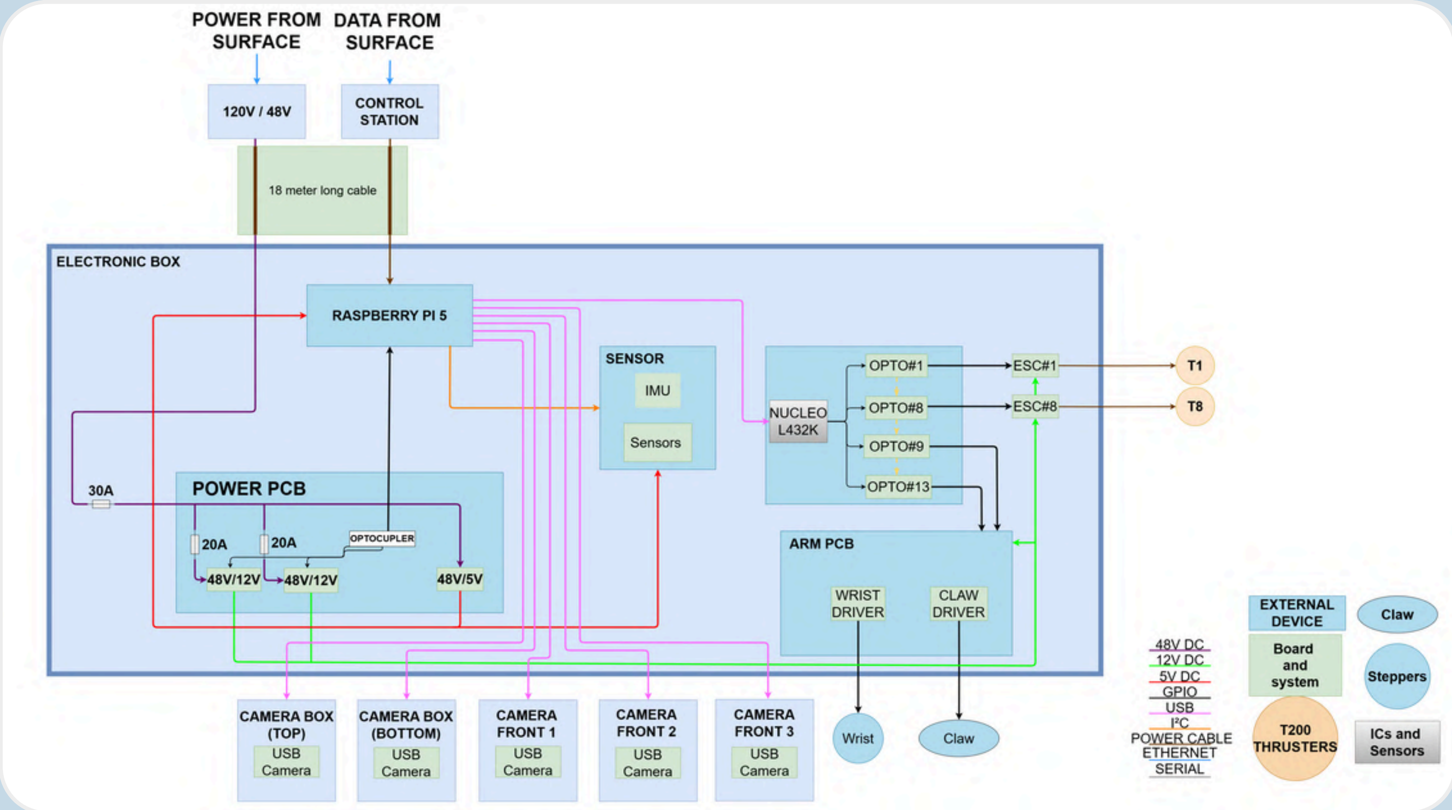
# Appendix A

## Company Organizational Chart

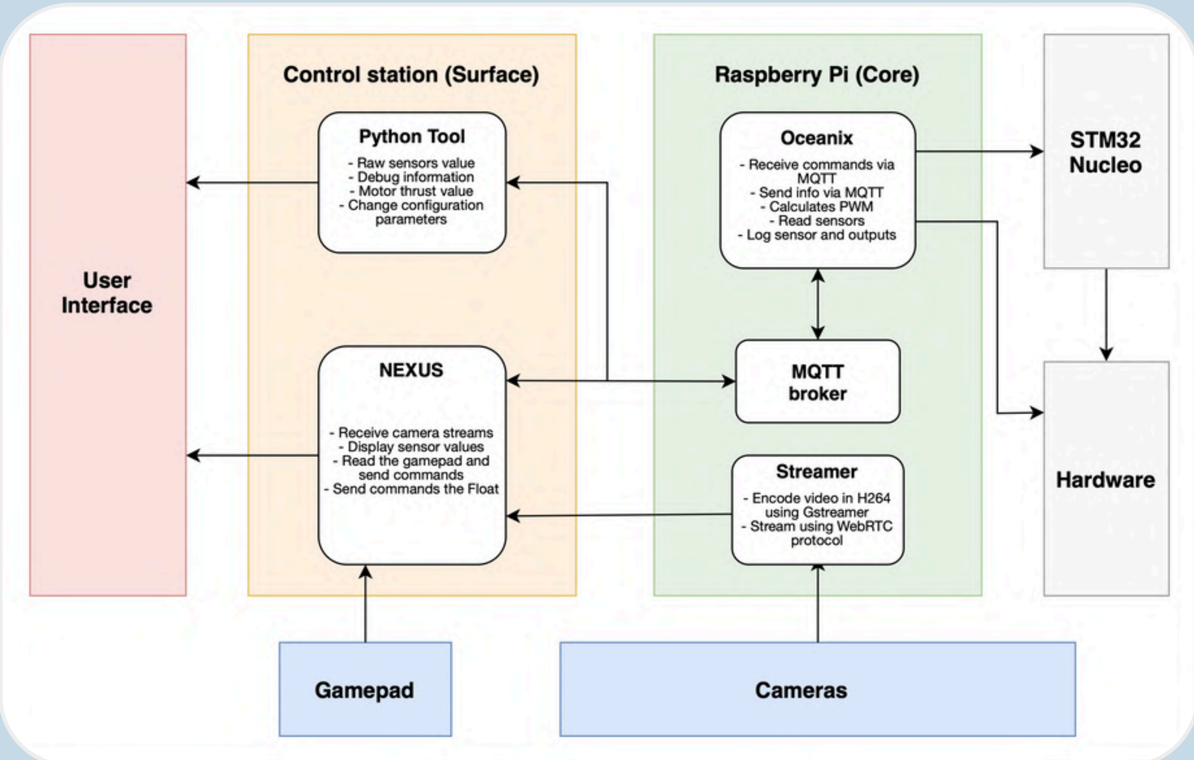


# Appendix B

## Electrical SID




## Software SID



# Safety Cecklist

## Pre-Power Procedure

- ☐ The ROV is not powered
- ☐ All electronics connections are secured
- ☐ No items in the way
- ☐ Stain relief connected to the ROV
- ☐ Surface station tether strain relief is connected
- ☐ Tether connected to the ROV
- ☐ Electronics box is sealed
- ☐ Visually inspection the ROV frame
- ☐ Thrusters free from obstructions
- ☐ Theter is flaked out without knots

## Power-Up Procedure

- ☐ Power on TCU
- ☐ Power on 48V
- ☐ Turn on the GUI
- ☐ Verify cameras are working properly
- ☐ Verify joypad movements correspond with thruster activity
- ☐ Test the manipulator is working

## Deployment procedure

- ☐ Place ROV in water
- ☐ Check for bubbles, if excessive remove ROV from water
- ☐ Check for water leaks
- ☐ Arm thrusters and begin tasks
- ☐ Ensure there is sufficient tether deployed in the water
- ☐ Test the manipulator is working
- ☐ Continuously monitor tether tension during operation to prevent overloading

## Loss of communication

- ☐ Cycle power on TCU to reboot ROV
- ☐ If no communications, power down ROV
- ☐ Retrieve ROV via tether
- ☐ Check Communication services
- ☐ If communication restored, resume operations
- ☐ If communication not restored, begin troubleshoouting
- ☐ Document failure cause and add to fix list

## Rov Retrival Procedure

- ☐ Drive ROV side of the pool
- ☐ Disarm thrusters
- ☐ Retrieve the tether systematically, avoiding twists

## Pit Maintenance

- ☐ Examine thrusters for debris or damage
- ☐ Check strain relief and termination integrity
- ☐ Inspect camera domes for cracks
- ☐ Inspect tether for cuts, abrasions, or kinks
- ☐ Check frame for structural damage
- ☐ Visual inspect for leaks
- ☐ Organize a list if anything is needed for repair

## Safety checklist executed by:

Name: ____________________

Date: ____________________

Signed ____________________