*1

POLITOCEAN
POLITECNICO DI TORINO
TORINO, ITALY
MENTOR: SANSOÈ CLAUDIO

Team members	Role of members
Mauro Foti	Electronic (CEO)
Anastasia Costanza Aiassa	Mechatronic (CFO)
Alessia La Sala	Electronic (CSO)
Alessandro Cellini	Aerospace (CTO)
Agostino Amato	Energetical
Alessandro Di Stazio	Mechatronic
Andrea Franchini	Electronic
Alessandro Marchei	Electronic
Corrado Raiola	Mechatronic
Dora Cristofori	Mathematics
Eduard Andrei Simptea	Electrical
Elena Stivala	Management
Enrico Bravi	Computer
Erik Di Francesco	Communication
Fabio Montenovo	Mechanical
Federica Taglia	Management
Federico Brex	Aerospace
Federico Mele	Computer
Francesca Esposito	Cinema and media
Giovanni Pellegrino	Electronic
Giulia Golzio	Computer

Team members	Role of members
Guerino Valentino	Management
Güney Talgar	Mechanical
Ivano Merendino	Biomedical
Kaliroi Mignone	Mechatronic
Lorenzo Rizzo	Electronic
Lorenzo Strappato	Aerospace
Luigi Puppo	Electronic
Mahdi Nassereddine	Mechanical
Matteo Monticciolo	Computer
Matteo Sala	Cinema and media
Mauro Di Ceglie	Aerospace
Ottavia Chiesa	Mechatronic
Pierluigi Pisconti	Mechanical
Rebecca Bertucci	Electronic
Rita Annunziata	Aerospace
Sara Di Marco	Material
Silvia Bertinetto	Mechatronic
Simone Carena	Computer
Simone Scilletta	Mechatronic
Stefano Giovanni Ruffato	Biomedical
Tommaso Maero	Mechatronic

Politecnico di Torino
1859

POLITOCEAN

ABSTRACT

PoliTOcean consists of forty-two **multicultural** students who are **passionate** about underwater robotics and ocean preservation. The company has developed an innovative solution for a Remotely Operated Vehicle (ROV) to assist in water and light show maintenance, environmental cleanup, and risk mitigation. This year's ROV, EVA, is **built upon successes and failures** of the Team's past ROVs. Extensive **collaboration** between mechanical and electronic division has yielded a compactand elegant ROV with a high degree of serviceability and functionality. The software division also experimented with ROV simulation and sensor filtering for **research and development** of new solutions. With the combined efforts of PoliTOcean's members over thousands of man-hours of planning, development, testing and with its modular frame, expandable electronics, and extensible software platform, EVA is purpose-built to dynamically respond to the ever-changing global environmental challenges. In this technical document, we outline the **design and development journey** of our ROV, highlighting how EVA proficiently tackles a diverse range of tasks and obstacles it faces.

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TEAMWORK

Briefly overview

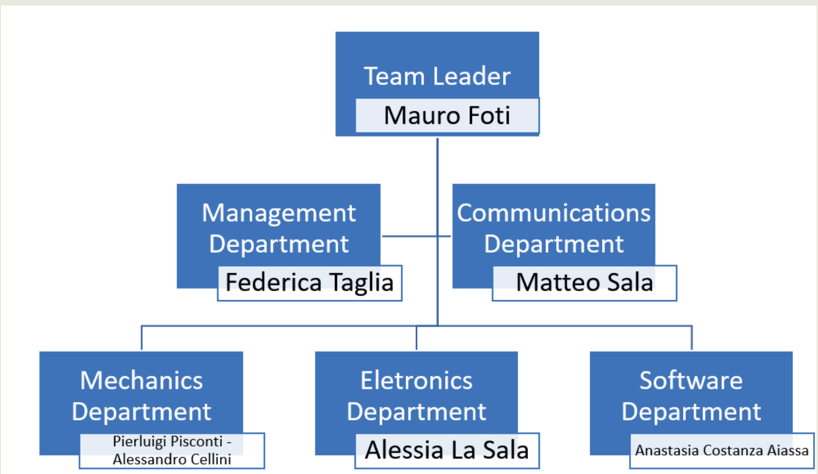
PoliTOcean is an inspiring university student team, made up of talented individuals who are passionate about creating underwater robotics and ROVs. Our team is a unique mixture of engineering and design students from Politecnico di Torino, characterized by a common goal: to create something to be proud of.

Vision, Mission and Values

Our vision is to become an **excellence** student pole in Italy for ROV ideation, being coherent with our mission: raising awareness of underwater pollution and **inspiring** the young generation of high school and university students to be an active part of this social issue and to use our skills to create a better world. We believe in strong **values**: passion, diligence, and mutual respect are the main ingredients of our work environment.

Company Organization

We are a functional organization as shown in the organizational chart below. Our team is broken down into specialized areas: mechanics, electronics, computer science, management, and communications. The members assigned to each area are students with specialized knowledge in that divisionto achieve excellence in our work. The team is coordinated by a **Team Leader** who oversees the general flow of the project and gives support on transversal activities. The departments are split into **technical areas** (mechanics, electronics, and IT) each of them supervised by a **technical lead**, and **support areas** (management and communications) supervised by the **head of the department.** While the technical areas deal with the manufacturing and the research and development of the product, the management area dealswith sponsorship management, inventory management, accounting and budget management, project management, and HR, and the communications area deals with social media and design. We strongly believe that this kind of organization enables us to be more efficient and effective and to optimize our skills. However, to overcome the limits of a functional approach, we organize monthly cross-functional activities that allow us to work together across different departments and gain different insights and skills.



*3 - Organizational chart

Goal Setting and Tasks Management

Official Deadline MATE ROV

Progetto	Stato	Data
Registrare squadra America portale 5	Fatto	apr 30
Video per la qualifica 1	Fatto	mag 15
Technical Report 9	In svolgimento	mag 24

Sotto elemento	Status	Testo
Technical Documentation	Working on it	Responsabili
SID	Done	schema elettrico ROV / Alessia ...
Non-ROV Technical Doc...	Done	ragazzi task 3
Non-ROV SID	Done	
Company Spec sheert	Working on it	anche imapginato da Erik con fo...
Safety Review	Done	Alessia chiude in settimana
JSA	Working on it	Job safety analysis
Corporate Social Respon...	Working on it	Management + Design
Marketing Display (DA P...	Working on it	Matteo
+ Aggiungi Sotto elemento		

Progetto	Stato	Data
Inviare ROV in America	In svolgimento	giu 7
Workshop session MATE (Manageme...	In svolgimento	
Workshop piloti MATE	In svolgimento	
Piano editoriale struttura	Fatto	
+ Aggiungi Progetto		

*4 - Activities Scheduling

At the start of each year, we establish our team **goals** and ideate a **strategy** for achieving them. Our general team goals are then broken down for each department, and we create a general **Gantt Chart** with the main milestones to guide our work throughout the year. For specific activities, we use a **Kanban system** to divide up tasks and assign them to team members. Each task is classified thanks to the **Eisenhower Matrix** which allows us to set the deadline of a task correctly and ensure that we are making the most of our time and resources. Each department meets weekly to check the flow of activities. The software that we use for our activities are **Dropbox** to store our documents and to work on them in collaboration thanks to real-time access, and **Monday.com** to create both the Gantt Chart and the Kanban from a customizable activity schedule. Every month, we hold **all-team meetings** to discuss progress, and each department lead shares updates on their area. This approach allows us to stay on top of our work.

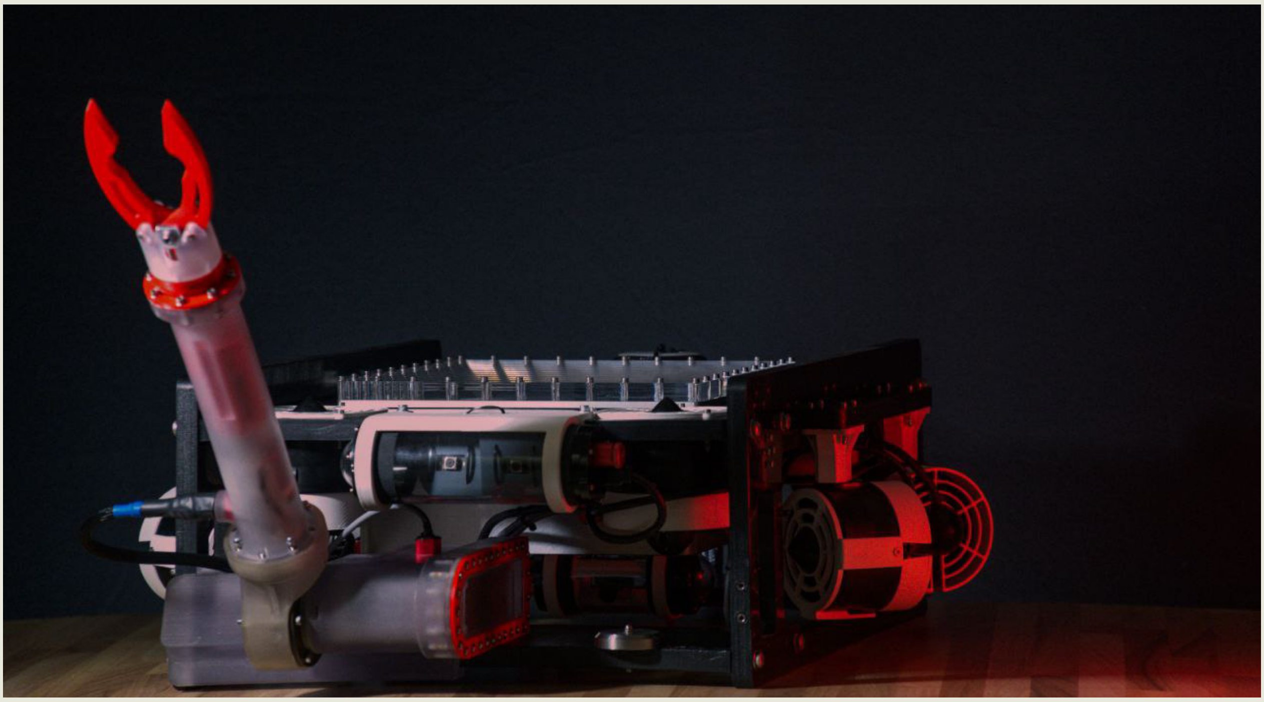
HR

As a university team with over forty members, HR management has an important role. The HR department organizes monthly individual meetings with all members to check the level of **stress** and the way tasks are organized to ensure the wellness and satisfaction of all team members. In addition, we make consistent investments in formation and skills development. Periodically, workshops are organized with external guests, one example being a seminar on ROV design with Andrea Bellizzi, Manager of Abel, an Italian company specializing in sea technologies.

DESIGN RATIONALE

EVA, our latest designed ROV, showcases significant advancements. It boasts eight thrusters and is constructed with an **HDPE** frame. Its unique shape grants it exceptional stability and optimal maneuverability during underwater operations. Notably, one of the key enhancements pertains to heat dissipation. We have strategically positioned all our boards in direct contact with the **aluminum alloy** box wall, enabling efficient heat dissipation. This crucial improvement has resulted in the development of a reliable ROV that can operate for extended periods of time without causing any damage to the electronics.

The electronic components of EVA are structured as a **modular system**, utilizing standardized connections. This design facilitates easy rearrangement, replacement, and upgrading of electronic boards. Moreover, the ease of piloting EVA is further augmented by the camera compartment, which accommodates various types of cameras. These cameras are capable of rotating **180°**, providing the operator with a comprehensive and convenient view of the system.



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DESIGN EVOLUTION

PoliTOcean has consistently demonstrated its commitment to excellence in the realm of underwater robotics. When embarking on the design of a new ROV, the company's primary objective is to create a product that excels in **reliability** and **performance**. Engineers leverage insights from previous prototypes, meticulously analyzing their strengths and weaknesses to optimize past experiences and address any identified shortcomings. EVA is the culmination of nearly two years and a half of study and represents a remotely piloted vehicle specifically tailored for recovery and repair missions. The current version incorporates numerous improvements over its predecessors.

One of the team's main focuses in the current year was to develop a machine capable of **autonomously** executing tasks with remarkable stability. Notably, significant efforts were invested in enhancing the camera system. The team opted for a versatile design to accommodate different types of cameras. Safety remains a paramount concern for PoliTOcean in every project undertaken. It is not only crucial for the product itself to ensure absolute customer safety but also imperative for the working environment to meet specific safety requirements, safeguarding workers against potential harm. Rigorous testing protocols are introduced during the prototyping stage, particularly aimed at preventing water leakage under any circumstances. Additional safety clamps were incorporated into the electronic enclosures, and meticulous testing of each penetrator, through which cables are routed inside and outside the ROV, was conducted to ensure water leakage prevention. These and other improvements are discussed in detail in subsequent sections.

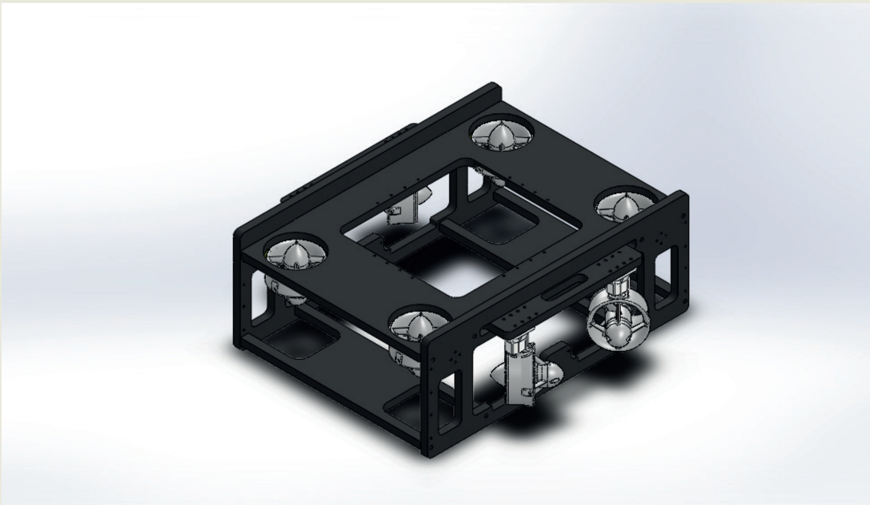
Throughout the implementation of a project, numerous decisions must be made concerning time, cost, and reliability. PoliTOcean strives to make well-informed choices by thoroughly discussing all issues and exploring various alternatives during **brainstorming sessions**. While prioritizing safety and efficiency, cost considerations are also taken into account. Each decision is the result of meticulous analysis, seeking to strike the right balance among these three elements. PoliTOcean firmly believes in making every possible effort to leverage its capabilities and achieve the best outcomes.

MECHANICAL SYSTEMS

Vehicle Structure

1 - 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** (*7-8) 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 **565mm** long, **498mm** wide, and **220mm** high, with each panel being **15mm** thick to maintain frame integrity, the complete ROV has a weight of **19.75kg.** The frame features two gripping areas finished to avoid any damage, several attachment holes to allow the attachment of the **eight thrusters**, and the box containing the electronics and additional devices.



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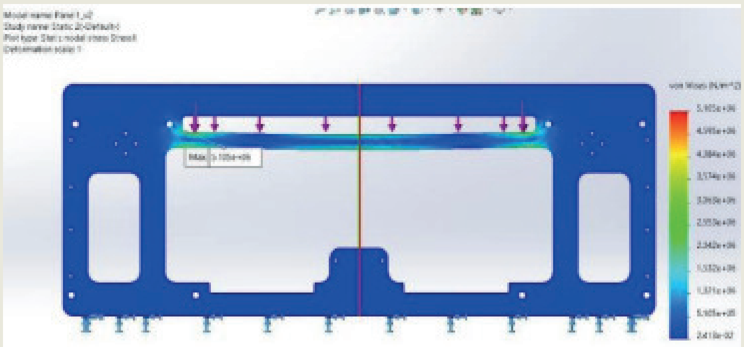

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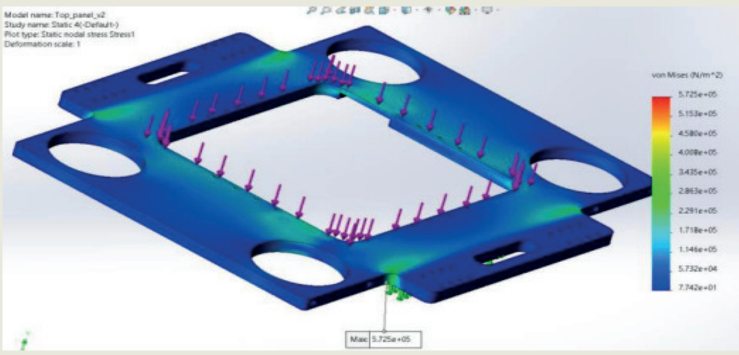

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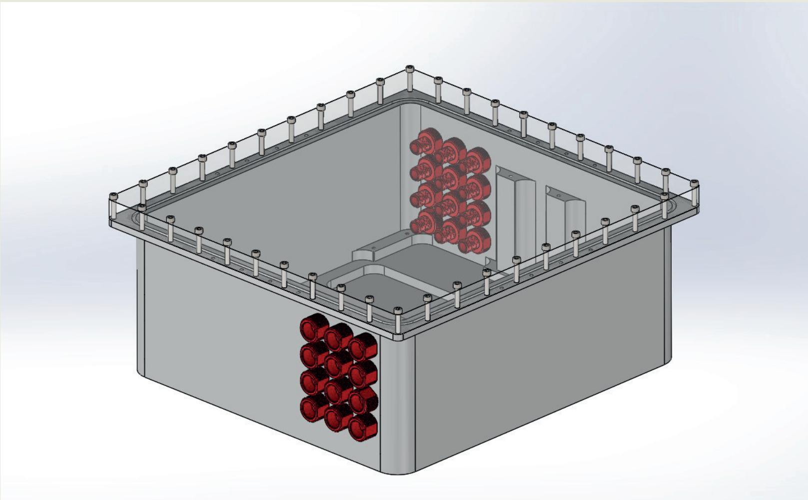
2 - ELECTRONIC HOUSING

EVA's electronic housing consists of (*9) 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 15mm-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. The hermeticity of the box is ensured by an O-ring system on the flange. The transparency of the plexiglass allows easy monitoring of the internal components (*10) proper functioning through the LED lights. 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.



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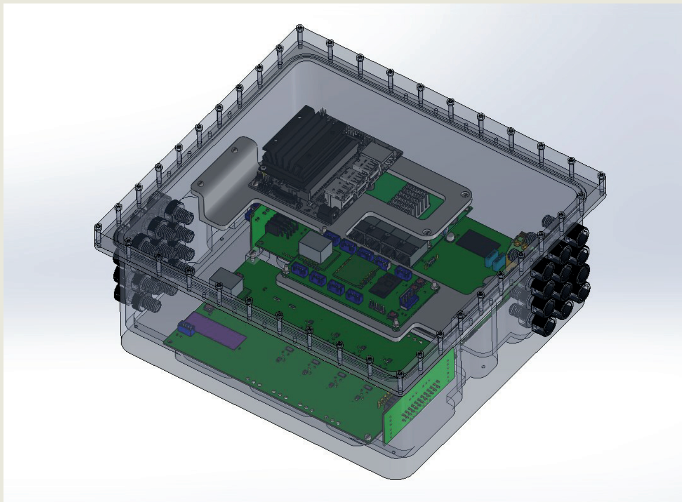

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3 - PROPULSION

EVA is equipped with **8 T200 Blue Robotics** thrusters made from tough polycarbonate plastic and marine grade 316 stainless steel. In order to achieve a stable motion and control four thrusters (2 clockwise, 2 counterclockwise) are set in the corners (for Z DOF) and the others four (2 clockwise, 2 counterclockwise) on the sides with a **45° angle inclination** (for XY DOF).
The T200 are the most efficient, powerful and best value for money thrusters from Blue Robotics.
The T100 is not suitable for long high trottle performances and for rapid movements due to the total thrust / EVA's weight ratio. Voltage usage is set at **12 V** for two different reasons:
1) From 48 V power supply to 12 V usage we have a 92% conversion efficiency
2) For our thrust requirements (2.9 kgf) 12 V is the most efficient voltage/power ratio.
Thruster's guards are **3D PLA** printed and mounted on both sides of each T200 in order to ensure a safe and efficient functioning.

4 - BUOYANCY

Our goal when designing our ROV is to achieve a **near-neutrally buoyant** state. Not only does this allow the ROV to dive to greater depths, increase payload, and reduce energy consumption, but it also maintains a stable working condition underwater. To achieve this result, we have developed a flotation system capable of counteracting the negative buoyancy effect of materials heavier than water on the ROV, with lighter than water materials. Despite the frame being built with HDPE, which is itself a floating material with a low percentage of water absorption, the ROV is heavier than water due to other components, such as the electronic housing, cameras, lights, and especially the manipulator. This creates an imbalance that we addressed by designing and adding two buoyancy modules to the frame. We studied the appropriate sizing and location to ensure a neutrally buoyant state and maintain stability during underwater motion. The buoyancy modules are made of a **3D printed PLA** case filled with syntactic foam, a composite material widely used for ROVs, AUVs, and deep-sea exploration due to its low density, low water absorption, and high strength, which makes it resistant to the effects of hydrostatic pressure.

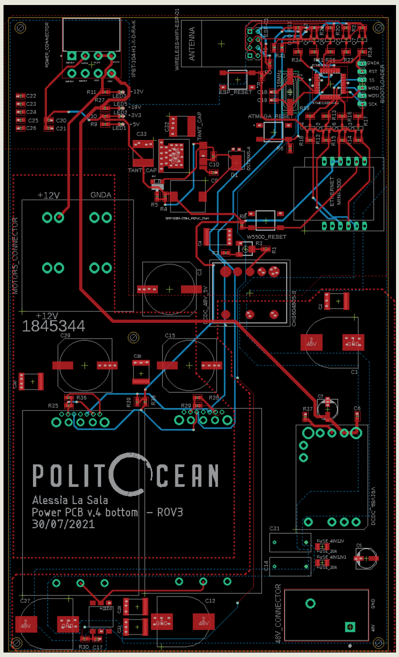
5 - TOPSIDE CONTROL UNIT

The control station consists of a watertight XYZ-sized **suitcase**, on the bottom of which a reticular structure has been fixed. The support prevents the movement of electronic components during transport and use. The control station is compact and easy to handle thanks to the careful selection of small and carefully chosen components. Inside the box, there is an additional support that holds the keyboard used to interface with the control station. It allows the installation of the fan and the mounting of. This support has been designed to not interfere with the closure of the lid integrated in the suitcase and its watertight seal. Two notches have been applied in the side walls of the lid, in which the screen mounted on an additional cross support is kept stable to allow the monitor to be mounted without interfering with the **waterproofing** and the closure of the case.

ELECTRONIC SYSTEM

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 and 5V-3.3V DC-DC converter. This conversion step is necessary because EVA's electronics needs 5V and 3.3V supply for the logical part and for the Jetson 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 enclosure. An increase in temperature means a reduction in efficiency, therefore, to maximize performance is indispensable an effective **heat dissipation**.



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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. It is important to notice also that the 5V, 3.3V are always on. In particular, 5V is also used to supply the **Nvidia Jetson**. This power PCB has its own logical part that consists in a **ATmega328 µC**. This core controls the two 48V-12V DC-DC converters through an **optocoupler** that allows them to be remotely turned on or off. This has two goals: first, it is a security measure: in case of short-circuit or the need to security shutdown; and second, it is made for energy saving, for turn off the converters when they are not needed and avoid wastes. These two converters are also connected to the µC by an **I2C** bus monitoring activity of the 48V input voltage and absorbed currents at 12V; this solution allows us also to monitor the converter temperatures, this is a very useful feature to gain reliability. All this data is sent to the surface through **MQTT**.

Printed circuit board

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 **Nvidia Jetson Nano** 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 Nvidia Jetson Nano are the video streaming flow elaboration, hosting the MQTT broker, computer vision and Machine learning algorithm elaboration.

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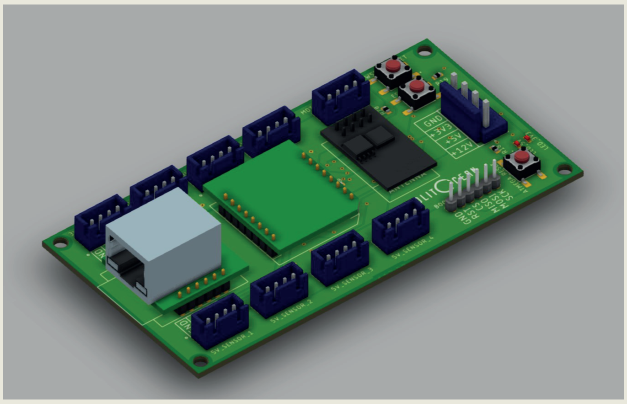


All the main operational blocks of the ROV were designed based on a **modular architecture** in fact each board has its own Microcontroller (ATmega328) connected to an **SPI/Ethernet Converter** that allows the MQTT communication (in both direction) and three LEDs that indicate the status of the power supply useful to check the cable's integrity. The interface between each component inside the EB and the surface is managed by an 8-port 100-1000 Mbit/s Ethernet switch.

Furthermore, on each board there is an **ESP** which is a Wi-Fi module connected to the serial port of the µC allowing the board to be remotely reprogrammed and debugged. The main advantage of this modular architecture is that each component of the board is **independent** from the others. It can be easily redesigned or replaced without affect the design of the entire system. The team developed this solution thanks to the previous experience, indeed in the previous ROV it was necessary to redesign the entire system if a new payload was needed to be implemented.

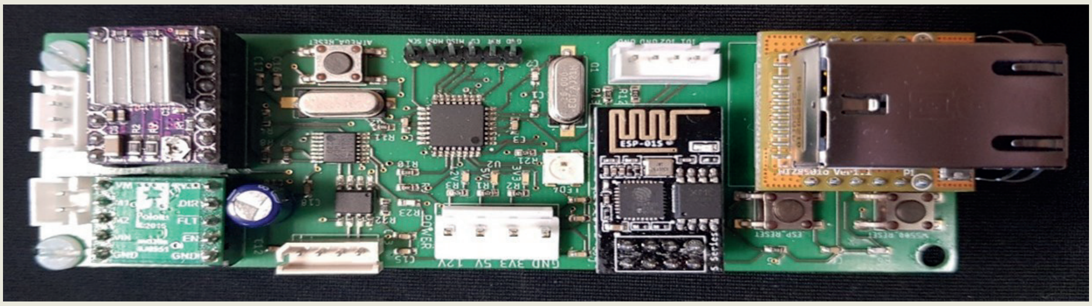
Description of the modules:

- **Power PCB**: previously described.
- **ESCs PCB**: it embeds 8 BlueRobotics' Basic **ESCs** and a **STM32 Nucleo L432K** insteadof an ATmega328 because it was necessary to have more computational power for the control system. The Nucleo is connected directly with the Nvidia Jetson Nano to be reprogrammed and to the thrusters.
- **Arm PCB**: This board, as the name suggests, represents the hardware control for the ROV's arm. It is responsible for controlling the **shoulder** movement, the **wrist**, and the claw of our robotic manipulator.

Its main components are:

o An ATmega328p microcontroller that is the core module, generating the proper signals to drive all the 3 motors depending on the commands sent by the remote **joystick**.
o An **ESP-01** microcontroller used for programming the ATmega328p OTA (wirelessly), to avoid removing all the screws to flash the code
o 2 motor drivers (**DRV8825** and MAX14870) used to control properly the wrist and the claw movement.
o A **w5500** ethernet module to allow communication between the ATmega328p and the JETSON via Ethernet. The NVIDIA JETSON NANO within the ROV sends periodic instructions via Ethernet using the MQTT protocol.

As you can see in the two pictures below the external sources are 3.3V, 5V and 12V with their respective LEDs. On the board there are 3 pushbuttons allowing external resets of the ATmega328p, the ESP01 and the ETHERNET shield, plus a programmable RGB LED to indicate the status of the arm.



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- **Sensors PCB**: in this PCB can be connected the all **I2C sensors** needed: external barometric pressure sensor, internal barometric pressure and temperature sensor and **IMU** (Inertial Measurement Unit). The sensors data are sent to the source through MQTT.

Tether

The tether from the surface is composed by a 48V supply cable put together with an Ethernet cable using a protection sleeve, in order to reach an optimal tether management. The power cable was chosen looking for an adequate copper size, while for the data cable was essential the data transmission rate. The former has a copper size of 2.5mm that guarantees a proper power transmission, and the latter is an **Ethernet cable Cat6E**, which allows data transmission up to 1Gbit/s. In addition, both cables feature excellent flexibility.

Camera

There are three **USB cameras** connected to NVIDIA Jetson Nano: the first one facing the arm, the second one facing the front in order to have a good view of all the space in which Eva is moving, the last one on the bottom to control the vertical movement. Cameras are managed by a **Motion server**.

Control station

The control station is compact powerful thanks to the careful selection of small and carefully chosen components. The **NVIDIA Jetson Xavier AGX**, powered by a 12V 4.2A power supply, was chosen for its computational speed, compactness and versatility for the image recognition needed to complete the tasks. A **Raspberry Pi 4** SBC, connected to an HDMI Monitor Controller Board (Rtd2556_Edp_1h) for interfacing with the **LCD screen**. Using a USB hub, the Raspberry communicates with the mouse, keyboard and monitor, which are the main components accessible to the user. The ethernet is used to communicate directly with the ROV via RJ45 Keystones connectors. To avoid high temperatures, a fan has been inserted near the Jetson, which is the warmest element. Each component has been mounted inside the control station, by supports designed and produced by us, which keep everything stable, making the structure safe and suitable for transport. For the safety of users, clearly visible warning labels have been added.

SOFTWARE SYSTEM

Introduction

EVA's software is written mostly in C/C++ and Python. **Code modularity** and **object-oriented programming** allow for better code maintenance and fast prototyping and development. EVA's whole system consists of a Jetson Nano, an STM NUCLEO board and several ATmega, allowing for the best **flexibility and reliability** with dedicated hardware for each part of the ROV. All the board communicate over MQTT, with the Jetson acting as the broker. This system allows us to integrate an arbitrary number of boards with a plug and play solution. A GUI allows the operator to control the ROV. Even the communication between the Jetson and the GUI takes place over MQTT, an extremely lightweight publish/subscribe messaging transport over network protocol, with the GUI sending commands from the joystick and visualizing data from the ROV.

Jetson Nano

The Jetson Nano hosts the **MQTT broker**, MQTT is the communication protocol used on our boards. Each board communicates via Ethernet. Every board subscribes and publishes in various topics, which can be mainly divided in command and status one. The topics are handled by the MQTT broker that is hosted on the Jetson. The Jetson also controls three cameras, via a Motion server we stream the cameras to the GUI. Motion is a service for streaming video cameras on an http page. We noticed some instabilities on the 5V power line that power the Jetson. To solve this, we implemented a board to stabilize the voltage supply and prevent the voltage drops. The Jetson is also responsible for all machine learning tasks due to its capable GPU which allows for the best performance in computer vision.

STM Nucleo Board

The Nucleo L432KC is a development board which mounts an **STML432KCU6U microcontroller**. The Nucle board controls the thrusters based on the commands received from the control station and the values read from the **IMU** (Inertia Measurement Unit). The IMU readings, along with the control station inputs, are processed by a PID controller, which is employed to make the z-axis stable. While the PID only controls the z-axis, the inputs from the joystsick move the ROV along all the three directions.

ATmegas

Several Atmega microcontrollers are employed in the ROV, each one with their own dedicated board, to increase modularity. The first microcontroller is used to **read data** from the IMU and the various sensors onboard. This information are dispatched through MQTT to the control station and the Nucleo board, for them to be processed. Another ATmega is used to **toggle the lights**, in order to provide better visibility of the surrounding. The third one is used to **manage the power unit**, based on the messages sent by the control station. The last ATmega is used to manipulate the arm. The arm is operated via the joystick, whose inputs are dispatched by the control station.

Board Communication

Each board communicate with each other indirectly via **MQTT**. MQTT is a publisher/subscriber-base protocol, where one entity, known as the broker, is in charge of dispatching the messages sent between the other participants to the communication. The communication is based on the concept of topics, which are a class of messages all related to the same argument. When an entity wants to receive messages from a topic, it has to communicate it to the broker, which will forward it the messages related to that topic. Entities can publish and subscribe to **different topics**, even at the same time. Within EVA the role of the broker is played by the Jetson Nano, and all of the other boards communicate through it. The connection between the boards and the Jetson in made via Ethernet cables. The control station also communicates via MQTT to send commands for the thrusters and to receive the ROV data, like video from the cameras and sensors readings.

Sensor Board

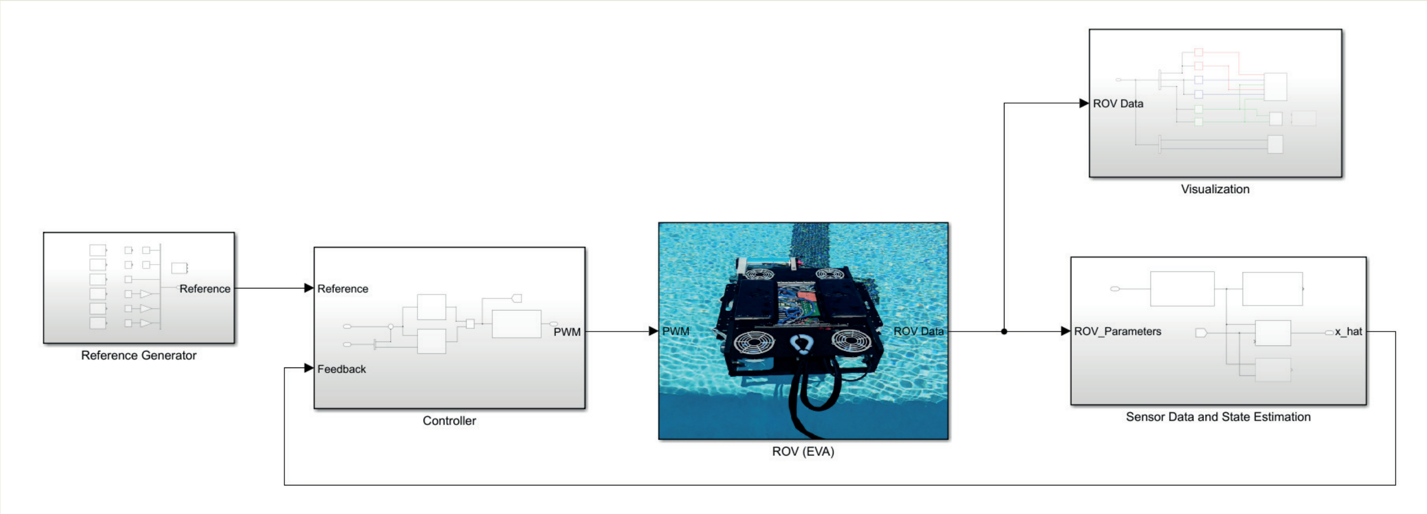
Sensor board is a board that counts **IMU**, **ATmega**, two **depth sensor**, **temperature**, **humidity** and **internal pressure** of the ROV. It has eight B4P connectors and each of them has a I2C line. Each sensor communicates by I2C protocol. The ATmega collects data acquisition from the sensors and publishes data on the sensor MQTT topic. Due to the fact that the ATmega memory is not large enough (32Kb Flash memory), we had to prune the library in order to fit in the limited memory.

GUI

The Graphical User Interface (GUI) is used by the operator to **remotely control the ROV** and to monitor the sensors (e.g. temperature, depth, etc...). It was developed in Python, using the Qt Framework as a cross-platform Desktop application. The graphical user interface (GUI) on the Raspberry Pi starts up, featuring distinct sections. In the center, you'll find the camera interface, where you can view multiple cameras simultaneously or individually using a dedicated button. On the right-hand side, there is a designated area for error messages, displaying the current error status and the corresponding light indicators.

Control System

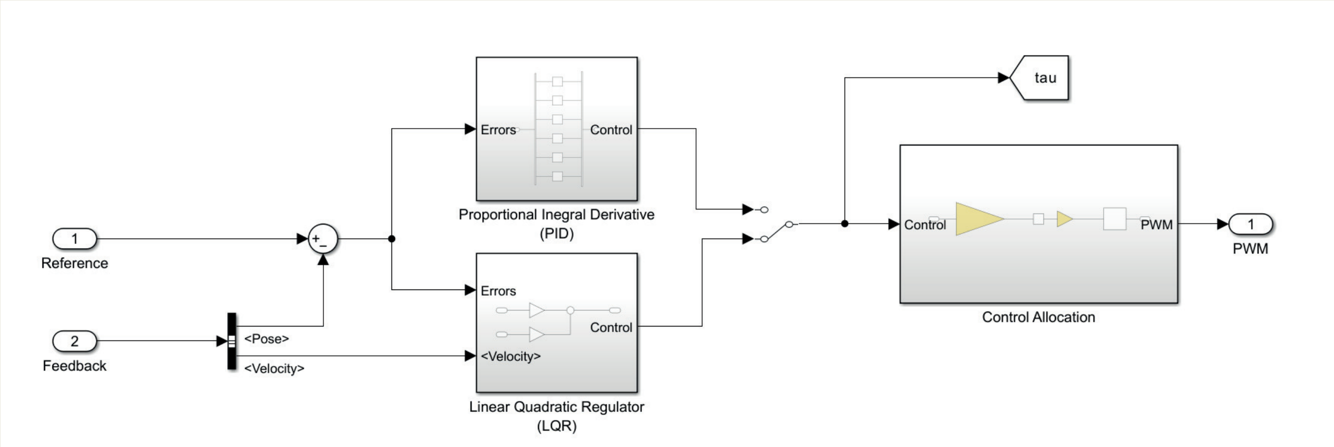
To control the system, we have developed a **PID controller** for each degree of freedom. However, since the ROV system is controlled remotely using a joystick, we just need the **z-axis control**. To implement the control action, we ended up with the following simulator:



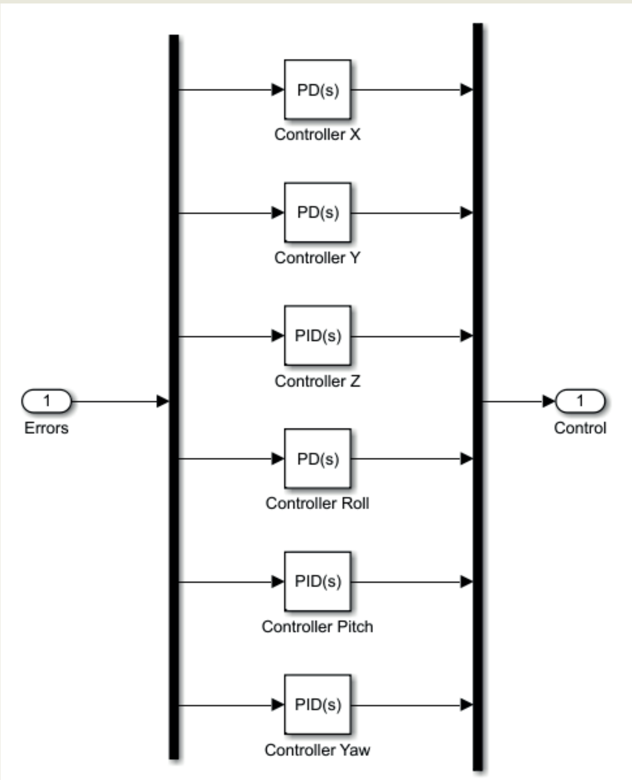
*14 - Overall Control System of EVA

As depicted in the picture, the simulator consists of five blocks: Reference Generator, Controller, ROV (EVA), Sensor Data and States Estimation and Visualization. **The Reference Generator** block provides the references to be tracked. The Controller block uses the error between the reference and the feedback to generate the PWM input signals. Even though we just used the PID controller for the z-axis, we designed also an LQR controller for future implementation. Indeed, even though a LQR controller is more appropriate and precise to use, is more complicated to implement. This is the reason why, for this competition, we are going to use a PID controller, willing to use a LQR controller in the next competition. A Linear Quadratic Regulator (LQR) controller is an optimal control technique used in control systems design.It computes control inputs that minimize a quadratic cost function. LQR controllers are designed based on a linear model of the system and assume known system parameters. They provide a feedback control law that adjusts the control inputs based o,n the system's current state, optimizing the trade-off between control effort and desired performance.

*15 - Controller Block of the ROV



Inside the **Proportional Integral Derivative (PID)** block there are 6 PIDs whose coefficients have been tuned using a specific tool of a simulation's software. The z-axis PID take as input the difference between the reference and the feedback and provide as output the forces in Newton needed to control the heave. The Control Allocation uses such forces and convert them into a PWM signal.



*16 - PID Controller for 6 DoF

The **ROV (EVA)** block contains the dynamics of our system which is divided into two parts: **kinematics**, which treats only geometrical aspects of motion, and **kinetics**, which is the analysis of the forces causing the motion. The equations that describe the dynamics are the following:

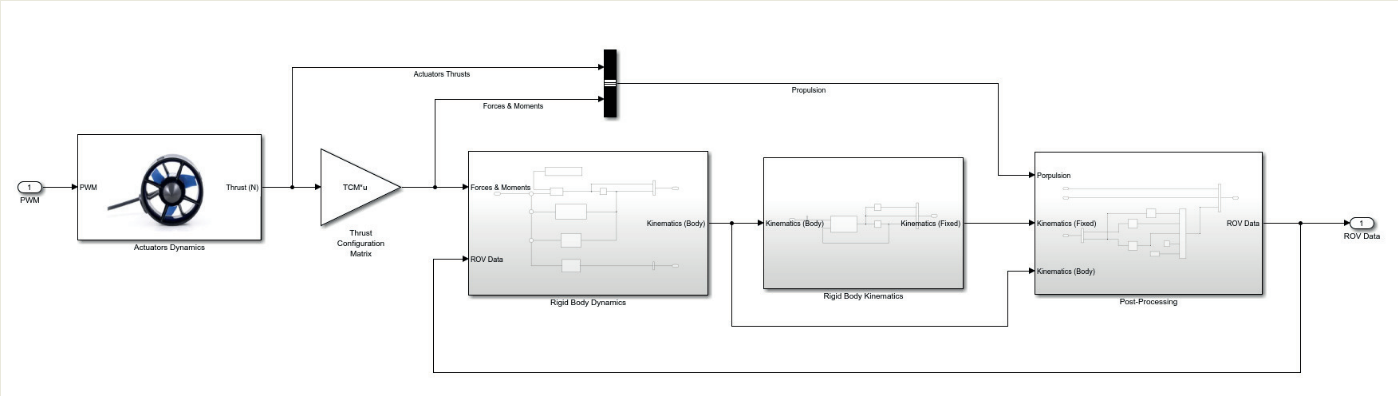
$$\dot{\eta} = J(\eta)\nu$$

$$M\dot{\nu} + C(\nu)\nu + D(\nu)\nu + g(\eta) = \tau$$

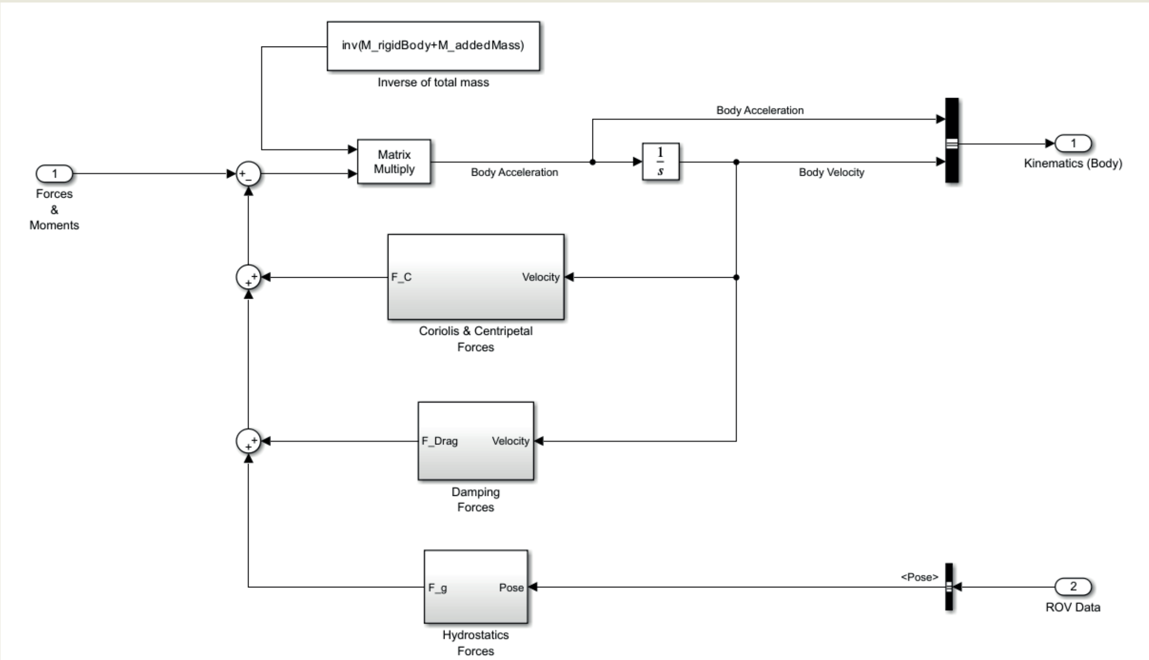
*17

The first equation is the kinematics term where η is the pose in the fixed frame, v is velocity vector in the mobile frame and J(η) is the matrix that convert the kinematics variables from the mobile to the fixed frame. The second equation is the dynamics term where M is the mass matrix composed by the sum of the rigid body mass matrix and the added mass matrix, C(v) is the Coriolis and Centripetal matrix, D(v) is the damping matrix, g(η) is the vector of the hydrostatic forces and moments and τ is the vector of the external forces and moments. To simulate such equations in Simulink we implemented the Rigid Body Dynamics block and Rigid Body Kinematics block.

*18 - ROV(EVA) Block

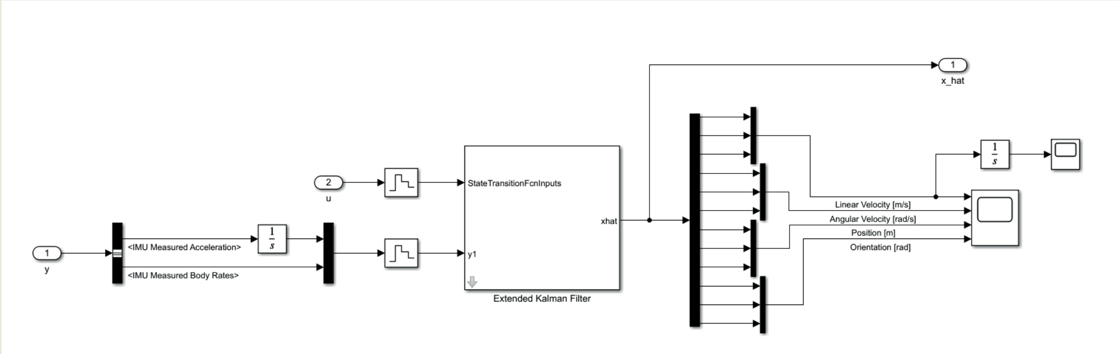


Furthermore, we have added the **Actuators Dynamics** Block, that converts the input signal PWM in thrust forces. These are then processed with the **Thrust Configuration Matrix (TCM)** to obtain forces and moments applied to the ROV. Finally, we have implemented the **Post Processing** Block that allows us to have the ROV Data.



*19 - Rigid Body Dynamics Block

The **Sensor Data and State Estimation** is the block used for estimating the state of the system and to know the data of the ROV, such as position and velocity. Initially, our intention was to apply an internal filter to the simulated output data from the IMU by integrating the IMU values. Unfortunately, this approach brought us to unsatisfactory results due to poor integration, since to get the position of the system we had to double integrate the acceleration, which leads to many calculations. For this reason, we tried to implement a Kalman filter, which is widely recognized as a prominent observational technique. Despite implementing it using a tool within the simulation software, as depicted in the picture, we have encountered persistent issues. Then, we were not able to reach correct data.



*20 - Kalman filter Block

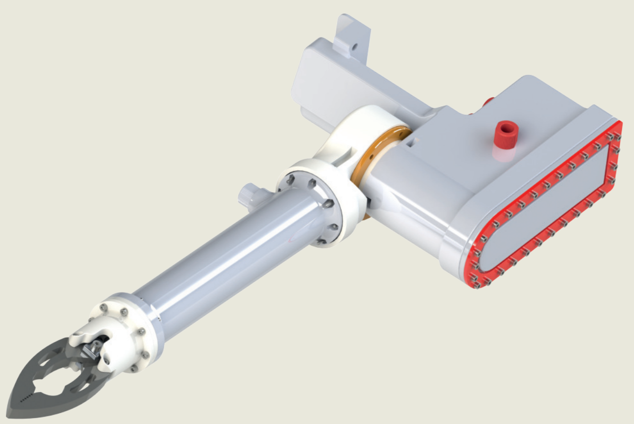
Finally, we have chosen to use a PID controller since we have faced many of the previous problems. Moreover, at the beginning, we encountered several challenges in identifying an appropriate mathematical model. However, with the aid of some research, we managed to successfully incorporate it. To facilitate the simulation, we arranged meetings with PhD students who provided invaluable guidance on the correct approach. Although this is our first attempt at implementation, we acknowledge the possibility of encountering some issues. Nonetheless, this marks a **promising start towards developing a more robust and dependable solution** for next year.

PAYLOAD AND TOOLS

EVA MANIPULATOR

1 - Working Principle

Our multi-functional manipulator (*21) is an electronic robotic arm designed to have a total of **two degrees of freedom**. It is designed in such a way as to adapt to structures and parts of previous models, with the addition of improvements regarding materials and operation. It allows us to pick up several types of objects of varying shapes and sizes thanks to the use of **grasping jaws.** The different possible joint rotations of the arm allow us to facilitate movements to reach objects even in unfavorable positions. The total footprint of our manipulator is **L=595mm** (23.43 inches), with an operating radius of **437mm** (17.2 inches), **W=233mm** (9.2 inches), and **H=94mm** (3.7 inches). The manipulator has a weight of only **2kg** and a total volume of **1571 cm^3** (95.8683 cubic inches) (*22). The manipulator is composed of three very different systems, interconnected in such a way as to make the ROV optimal. These three systems are called MANO, AVAMBRACCIO, and SPALLA.



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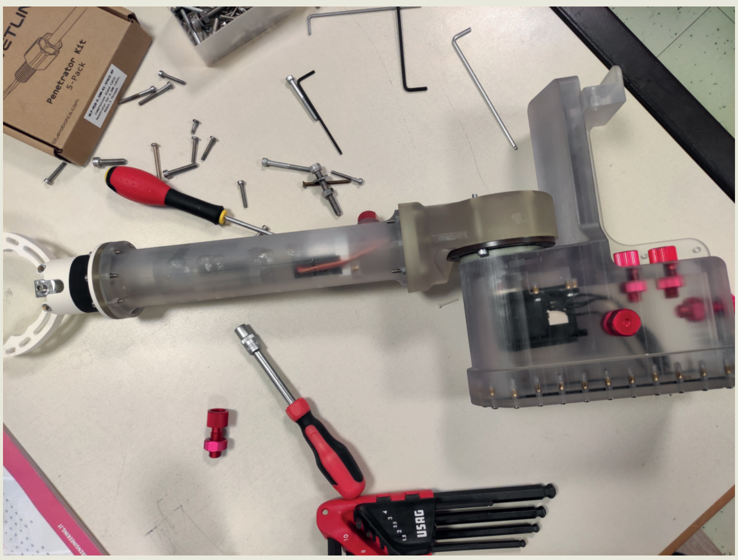
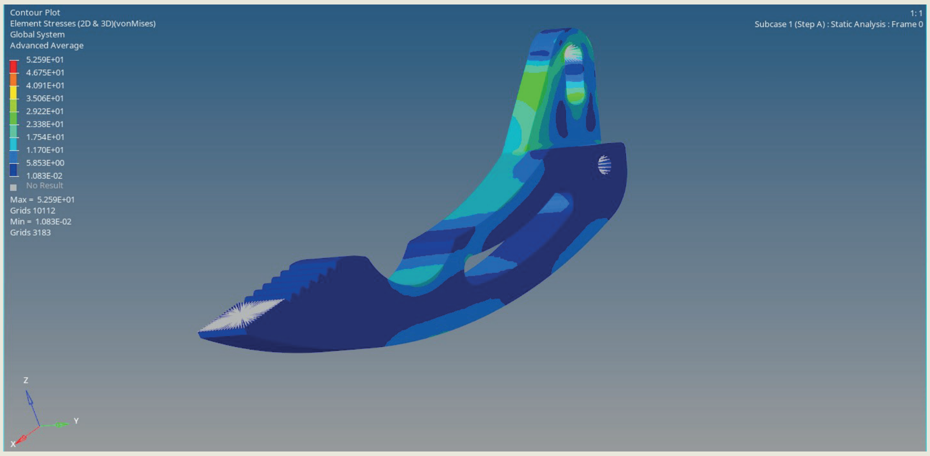


*22

2 - Mano *(Hand)*

The MANO compartment includes a **3-hinge mechanism** (2 fixed hinges, 1 movable) (*23). This choice was made to optimize and simplify the assembly method, and to reduce the number of components at risk of breaking. This mechanism binds **2 jaws**, made by 3D printing in **metal** (*24), to allow only the opening and closing movement, using only the simple motion of a shaft made of **ERGAL Al 7075-T6**. It is machined with multi-axis machines and connected to a linear actuator (pq12-etc...). The structure that holds the clamps is called the POLSO mechanism and consists of a set of fifth wheel couplings created by 3D filament printing (**ALFAOPRO material**). Thanks to a NEMA8 motor, it allows the rotation of the wrist. The union of the MANO and AVAMBRACCIO system is called BRACCIO (ARM).

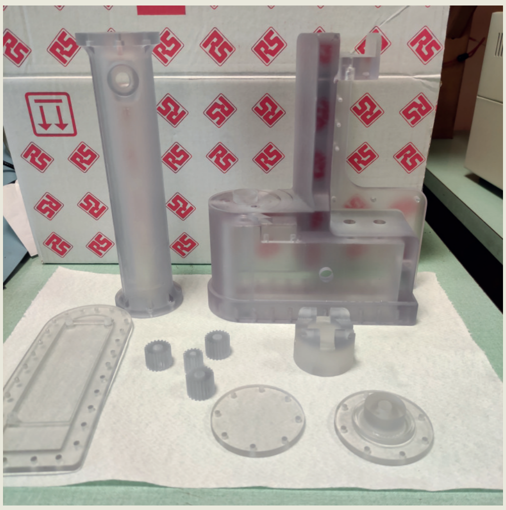

*23

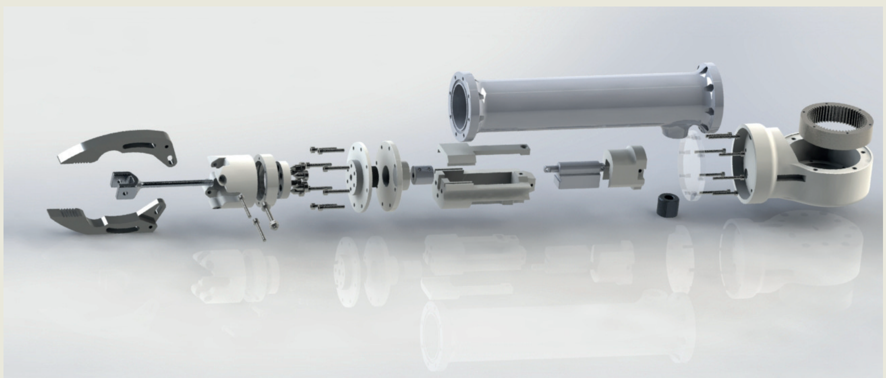


*24

3 - Avambraccio *(Forearm)*

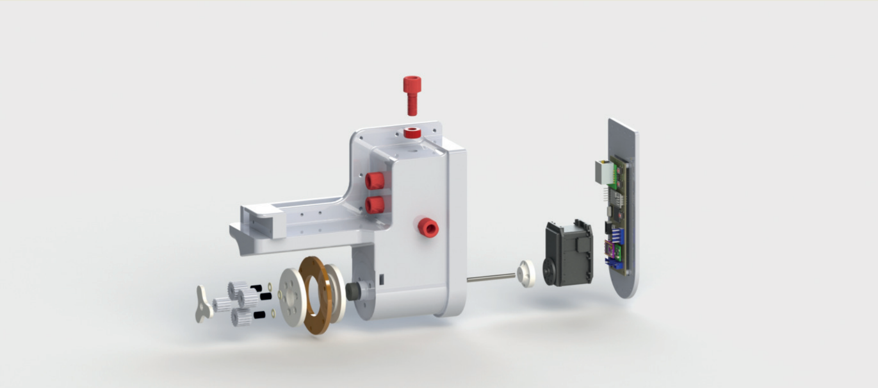
The AVAMBRACCIO system consists of a tubular design 3D printed in resin (**VisiJet Armor M2G-CL MJP**) (*25). This type of printing has enabled us to obtain a solid and resistant body with a high surface definition that allows, thanks to the use of gaskets and o-rings, an excellent seal. Each internal component of the forearm has been designed in such a way that it can be removed **quickly** and **easily**, compared to previous models. The forearm contains within it all the motors, which, by means of a connecting joint, allows the correct functioning of the MANO compartment (mainly the **NEMA8** and the **linear actuator**) (*26). The connection linking the AVAMBRACCIO to the SPALLA allows, thanks to a crown wheel, a 180° excursion from the body of the manipulator. The union of the MANO and AVAMBRACCIO system is called the BRACCIO.

*25



*26

4 - Spalla *(Shoulder)*

The SPALLA (*27) system is the main component that connects our ROV to the manipulator. This component is composed of a 3D resin printed case (**VisiJet Armor M2G-CL MJP**), which not only protects but also supports the BRACCIO control board and motor, allowing the BRACCIO to move. The motor is connected to the BRACCIO through an **epicycloidal system**(*28) , which comprises of a planetary gear with three satellites and one solarium. This gear system effectively reduces the motor speed by around **3.8 times**, and as a result, amplifies its torque. Due to high torque, the planetary gear system was made from 3D printed metal material for reliable stability. To ensure smooth maintenance inside the shoulder compartment, an easily removable sealing cover was created with an o-ring. Finally, electronic communication is safely transmitted via cables that are sealed using **bluerobotics penetrators**.



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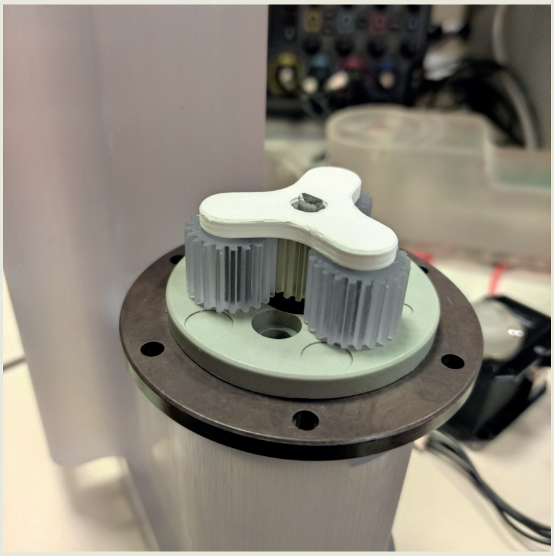
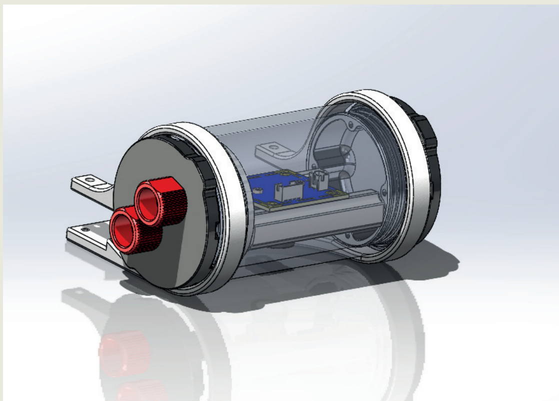


*28

CAMERA COMPARTMENT

The ROV is equipped with **three cameras**, two in the **front** position and the other in the **rear** position. The frontal ones (*29) allows a view of the arm and the direction to which the ROV is moving. Moreover, their characteristics allow for a three-dimensional reconstruction of the environment through stereoscopy. The rear camera is placed at the base of the ROV frame and allows a view of what is below it (*30). Both the front and rear cameras are inside watertight tubes supplied by Blue Robotics. They are equipped with o-rings and steel penetrators to communicate the video signal. The cameras are fixed inside by internal supports consisting of two non-rotating suspended rods. Due to the unfavorable position of the screws on the tube, the internal supports have notches to allow the use of offset head screws. The tubes containing the cameras are fixed to the ROV through external supports that are cut in half to make realization easier. Both internal and external supports are built using **3D printing** with Alpha Pro filament supplied by Filoalfa.

*29



*30

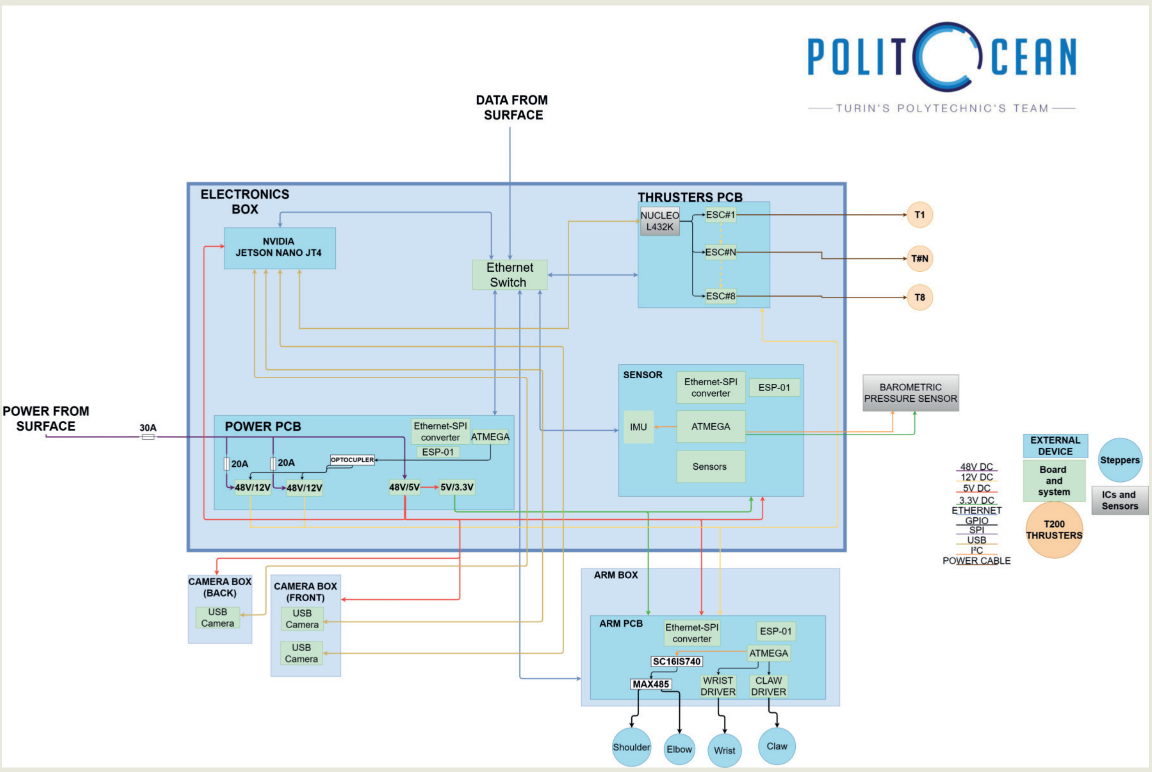
EXTRACTION TOOL

The "**Syringe tool**" is made of **five components:** motor case, motor case support, binary, syringe support, LED case. Each component has a simple and functional design which has been designed using **CAD Solidworks.** Various FEM analyses were carried out to choose the components' materials. The "motor case" and the "led case" were made to be waterproof and tough, therefore the **Visijet Armor M2G-CL*** resin was chosen. For the rest of the components, PLA (Alpha Pro filament supplied by Filoalfa) was used, a lightweight material that is easy to process. All elements have been produced by 3D printing. The components were fixed to the chassis with a screw-nut system in a position that does not interfere the hydrodynamic flow of the engines. A led is placed inside the LED case, which is located on the opposite side of the frame. The motor block (case + support) and the syringe block (binary + support) are connected through a threaded rod to allow the plunger of the syringe to flow. The overall dimensions, considering each component, is about **400x66x66 mm**, with a total weight of about **0.5 kg**.

Build vs. Buy, New vs. Used

In comparison to the previous year, we used the same electronic system but with some modifications. Specifically, we encountered issues related to the roots on the thruster's PCB traces being too thin to handle the required power. Then, we addressed this problem by enlarging the traces, and printing on a PCB with a heavier copper base (70μm instead of 30μm). Another improvement we made from the previous year was the substitution of the Jetson Xavier with a Jetson Nano. This change was motivated by the Nano's lighter weight and ease of placement. Additionally, the previous Jetson necessitated the conversion of 19V from the 48V power supply specifically for the Xavier, whereas the Nano alleviates this requirement and is still powerful enough for all the necessary tasks. Furthermore, our focus shifted towards developing a control system, which was absent in the previous year. Initially, we encountered difficulties in determining the correct mathematical model. However, after conducting some research, we managed to obtain a satisfactory model. We implemented this model using software such as Matlab and Simulink. Despite achieving a good mathematical model, we opted to utilize a PID controller as it remains an effective choice. Nonetheless, in our ongoing pursuit of advancement, we aim to improve upon this work in the coming year.

SID



*31

SAFETY

Company Safety Philosophy

At PoliTOcean, we strongly believe that a **safe work** environment is an essential requirement for the success and realization of a project. It is our responsibility to ensure a safe work environment that prioritizes the protection of people and the surrounding environment. However, we recognize that employees must also collaborate to prevent accidents. To this end, we have chosen to implement mandatory **training**, **safety procedures**, and **safety protocols**.

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.

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 tube, 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.

Operational and Safety Checklists

Safety protocols and checklists are diligently followed before, during, and after operations. Employees are required to follow specific procedures for the launch, recovery, and water safety of the ROV.

TROUBLESHOOTING AND TESTING TECHNIQUES

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** to ensure correct soldering and assembly. Once the cards are confirmed to be functioning properly, they can be placed in the ROV. To ensure the integrity of the ROV, it is necessary to verify any loss of insulation that may be harmful to it before testing it in water conditions. Attention must be paid to the penetrators through which the cables connecting the electronic parts to the ROV pass. To inspect these, the company has developed a system using a **pressure pump** with a pressure gauge and an acrylic tube inserted into one of the penetrators. 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.
When the ROV performs all assigned tasks correctly, testing ends.

ACCOUNTING

PoliTOcean develops its **annual budget** estimate at the beginning of September in order to prepare for a pitch in front of the "Commissione contributi e progettualità studentesca" of Politecnico di Torino, from which we receive funding. To be able to do a right estimation, we analyze our previous year's work and expenses, as well as any new initiatives we plan to execute in the current year to form a **projection of our costs**. Our primary source of revenue comes from the funds provided by the Politecnico di Torino, though we also receive some minor economical support from our sponsors. Furthermore, our Project cost chart provides an in-depth look into how we have allocated our budget across various areas.

2022-2023 Project Summary	Description	Amount
Income		
School fund	Politecnico di Torino	$ 31.450,52
Sponsors	Massola/Witted/STMicroelectronics	$ 607,67
Total Income		$ 32.058,19
Expense		
Project Cost	Production of ROV/	$ 12.701,75
Operation Expenses	Transportation/ Meal/ Accomodition	$ 10.400,02
Total Expense		$ 23.101,77
Balance		$ 8.956,42
EUR/USD	Date: 19/05/2023	≈1,08

*32 - Project Summary Excel Sheet

*33 - Project Cost detailed Excel Sheet

Expenses	Description	Type	Budget	Cost	Balance
ROV Production					
Frame		Purchased	$ 1.956,73	$ 1.590,93	$ 365,80
Thruster		Purchased	$ 2.159,72	$ 1.981,41	$ 178,31
TCU	Case/ NUC	Purchased	$ 1.835,76	$ 1.643,49	$ 192,27
Tether & Connectors	Subcon/ Strain Relief/ Sheathing	Sponsor&Purchased	$ 1.330,42	$ 764,11	$ 566,31
Electronics & Connectors	Wires/ Connectors/ HAT PCB/ DSQs/ Controller	Sponsor&Purchased	$ 4.055,23	$ 3.647,65	$ 407,58
Pneumatics	Valves/ Fittings/ Tubing/ Gauges	Purchased	$ 95,00	$ 85,44	$ 9,56
Mission Tools	Gripper/ Float/ ROV Cameras/ Lasers	Purchased	$ 1.295,83	$ 1.033,66	$ 262,17
Pilot Controls	Joystick	Purchased	$ 45,00	$ 35,42	$ 9,58
Raw Materials	Plastics/ Metals/ Hardware/ 3D Filament/ Consumable	Purchased	$ 2.114,72	$ 1.917,46	$ 197,26
ROV Total			$ 14.888,42	$ 12.701,75	$ 2.186,67
Operation Expenses					
Accomodition	Place to Stay/ Meal/ Transportation of team	Purchased	$ 12.958,32	$ 7.100,00	$ 5.858,32
Mission Props	MATE Mission Props	Purchased	$ 647,92	$ 324,00	$ 323,92
MATE ROV Entrance Fee	Entry fee	Purchased	$ 431,94	$ 453,54	$ -21,60
Transportation of ROV	Transfer of ROV from Italy to America	Purchased	$ 2.699,65	$ 2.267,00	$ 432,65
Other Expenses	Report/ Broucher/ Lab supplies: Consumable, plastic, glue, hand tools	Purchased	$ 300,00	$ 230,48	$ 69,52
Operation Total			$ 17.169,77	$ 10.400,02	$ 6.769,75
Total Expenses			$ 31.926,25	$ 23.076,77	$ 8.849,51

ACKNOWLEDGEMENTS

- We would like to express our gratitude to MATE Center and Marine Technology Society.
- A special thanks to St. Vrain Valley School District in Longmont, CO for hosting the 2023 MATE ROV World Championship.
- We extend our heartfelt appreciation to Politecnico di Torino for their generous financial support and the invaluable buildings they have provided us.
- We are grateful to Head Professor Claudio Sansoè for his support and invaluable guidance.
- We would like to thank SolidWorks for providing us with CAD software.
- Our gratitude goes to Matlab and Simulink for providing simulation software.
- We express our appreciation to Github for serving as a repository for our code.
- Eagle deserves our thanks for providing PCB design capabilities.
- MORE Energy Lab has been instrumental in assisting us with the controller, and we are grateful for their support.
- We extend our thanks to mentor Andrea Bellizzi for his continuous support and guidance.
- Mentors Riccardo Ruggiu, Dario Sciortino and Massimo Balvis, who founded PoliTOcean and have been a constant presence.
- We are deeply grateful to our families for their unwavering support and love.
- Special thanks to our sponsors FiloAlfa, Altair, 3DCompany, and Officina Massola for their support.

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