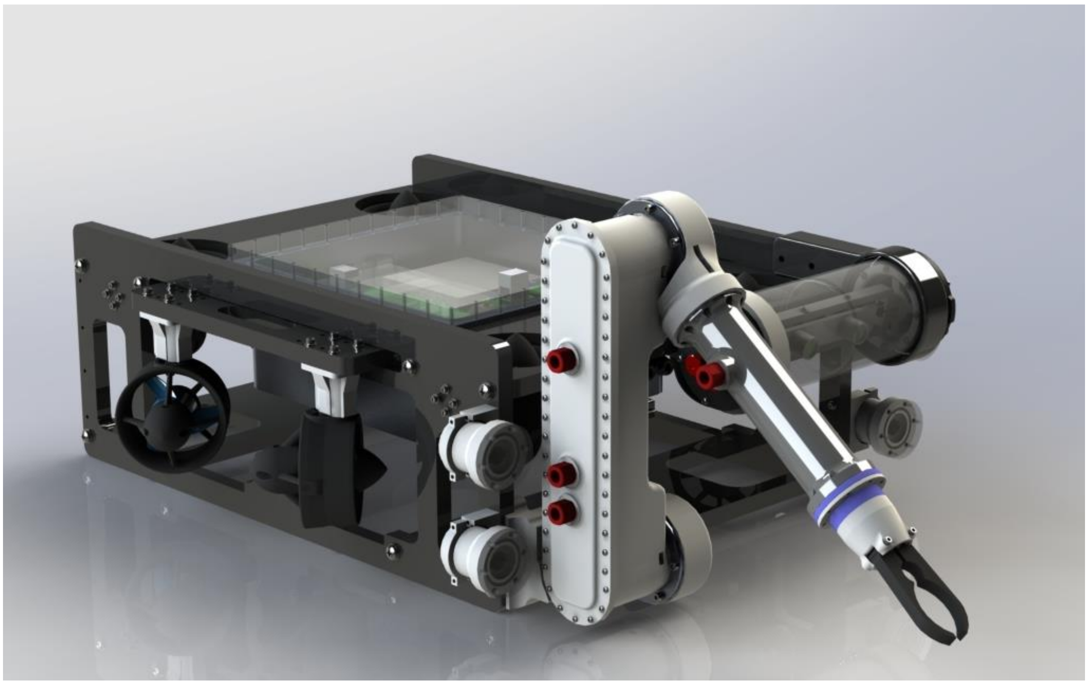
EVA

Technical Report

MATE ROV Competition 2022



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Abstract

EVA is the latest prototype Remotely Operated Vehicle (ROV) developed by the PoliTOcean team for the purpose of inspecting and repairing underwater structures in general. Due to the various mounted devices and its control system, EVA is suitable for marine exploration for scientific research purposes.

The Team's main goal was to develop an innovative product focused on technical specifications and functionality.

Weighing only 20 kg, the ROV allows the operator to lift up to 120N. This feature allows EVA to achieve the best in recovery missions. The ROV is designed to be fully modular, through its frame designed to support numerous loads of all kinds.

EVA is the result of collaboration among 30 enthusiastic students, who decided to found a student team in 2017.

By bringing together every branch of engineering they were able to work to the best of their ability to realize such a project.

Design Rationale

EVA is the company's latest designed ROV. It is equipped with eight thrusters and has an HDPE frame. Its shape allows it to have great stability and optimal maneuverability in underwater operations.

One of the major improvements concerns the power electronics board, which generates a lot of heat. It has been positioned so that it is in contact with the box wall, which is made of aluminum alloy, in order to optimize space and heat dissipation. This made it possible to develop a reliable ROV that could provide many hours of operation without damaging the electronics.

The electronics consist of a modular system that takes advantage of standardized connections, so that electronic boards can easily be rearranged, replaced, and upgraded.

Ease of piloting EVA also comes from the camera compartment, which can accommodate different types of cameras, they can rotate 180°, allowing the operator to view the system easily and widely.

Design evolution

PoliTOcean has always demonstrated that it aims for the best when underwater robotics comes into play. When the design of a new ROV begins, the company's main goal is to develop a product that proves to be not only reliable in all respects, but also but capable of the best possible performance.

Engineers begin the work based on previous prototypes. They carefully analyze the pros and cons to make the best of past experiences and to overcome identified weaknesses.

EVA represents the evolution of nearly a year and a half of study. It is a remotely piloted vehicle designed specifically for recovery and repair missions. The current version has several improvements over previous prototypes. The main feature the team focused on in the current year was to design a machine capable of autonomously conducting most tasks with great stability.

Of note is the work done on the camera system. The team opted for a more versatile choice, to create a system that can accommodate different types of cameras.

Whenever PoliTOcean tackles a new project, the main requirement is to focus on security.

Not only must the product itself ensure absolute safety for the customer, but also the environment in which the work is done must meet specific safety requirements, preventing harmful injuries to workers. A large number of tests are introduced at the prototyping stage. Their main purpose is to ensure that water leakage does not occur under any circumstances.

To this end, additional safety clamps were added to the electronic enclosures.

In addition, each penetrator through which cables are routed inside/outside the ROV is tested diligently against water infiltration.

These and other improvements are discussed in detail in the following sections.

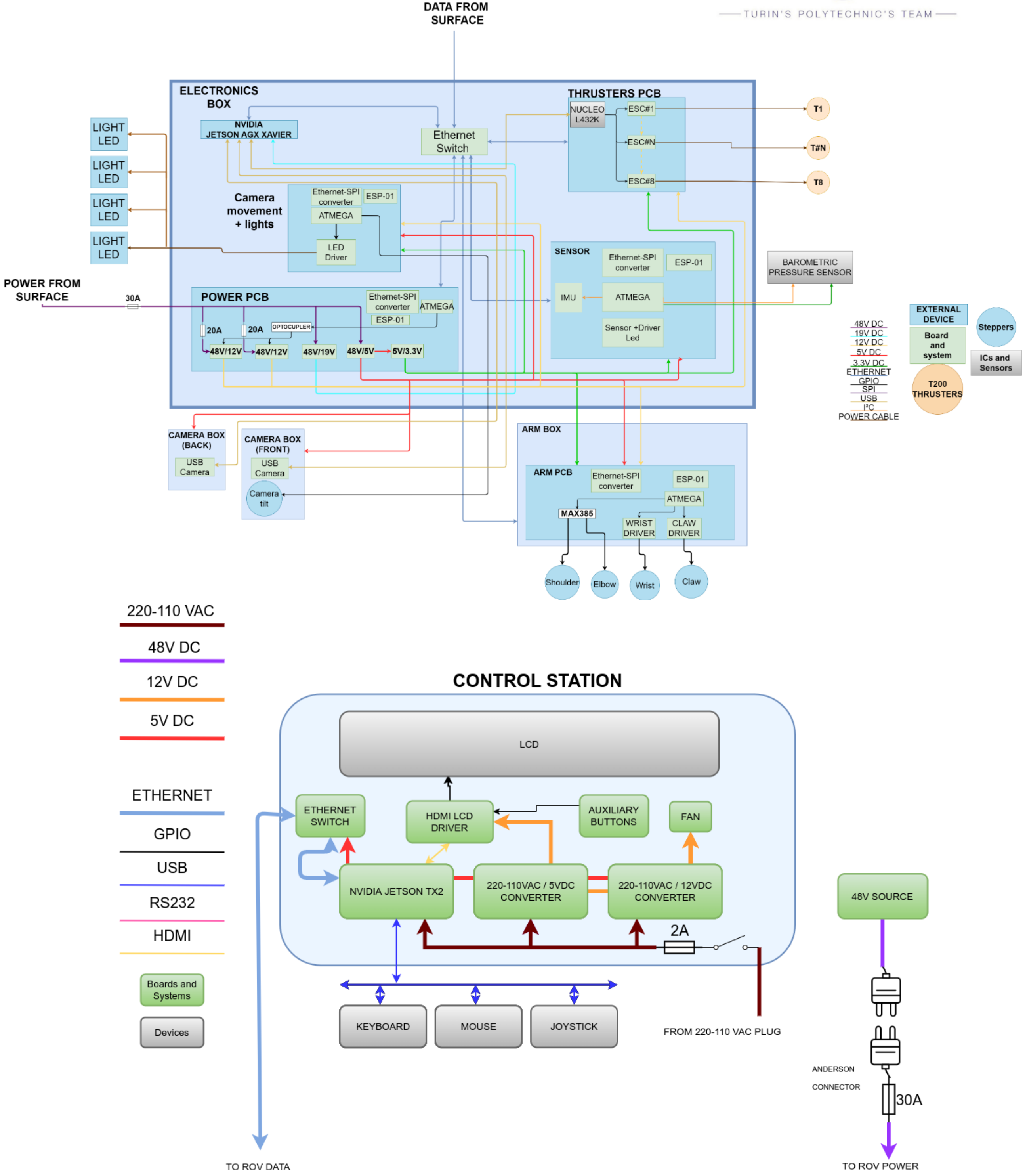
Many choices must be made during the implementation of a project in terms of time, cost, and reliability.

PoliTOcean tried to make the right decisions by discussing all issues and all possible choices during brainstorming sessions.

Although the priorities were safety and efficiency, cost could not be overlooked. Each choice is the result of painstaking analysis that seeks to combine these three ingredients. PoliTOcean firmly believes that all possible efforts to achieve the best of its possibilities have at least been attempted

System Interconnection Diagram

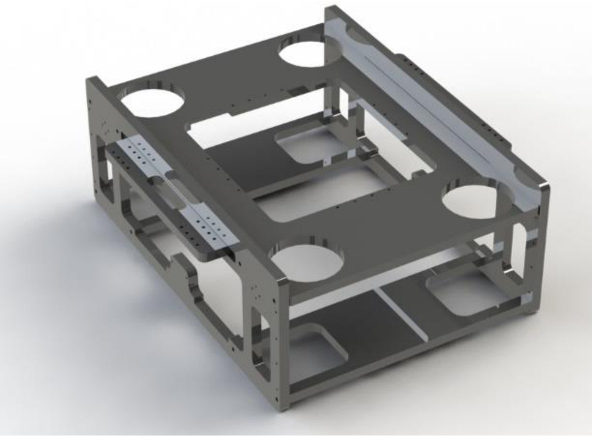
These are the system interconnection diagrams of electronics system used in EVA.



Vehicle Core System

Mechanical

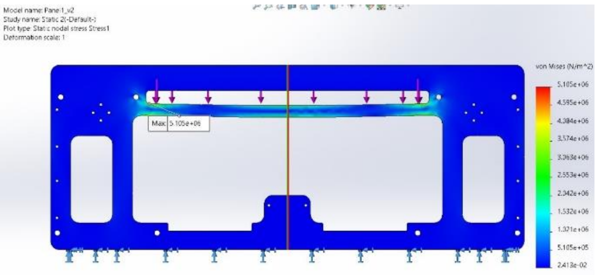
Frame



Eva's frame was designed in such a way as to achieve a stable and strong structure with a good weight to footprint ratio.

The design of the various components of the frame was done by Solidworks, this allowed us to perform several FEM simulations so that we could choose the most suitable material for our needs, minimize disturbances in the flow of the thrusters, and reduce the weight of the structure.

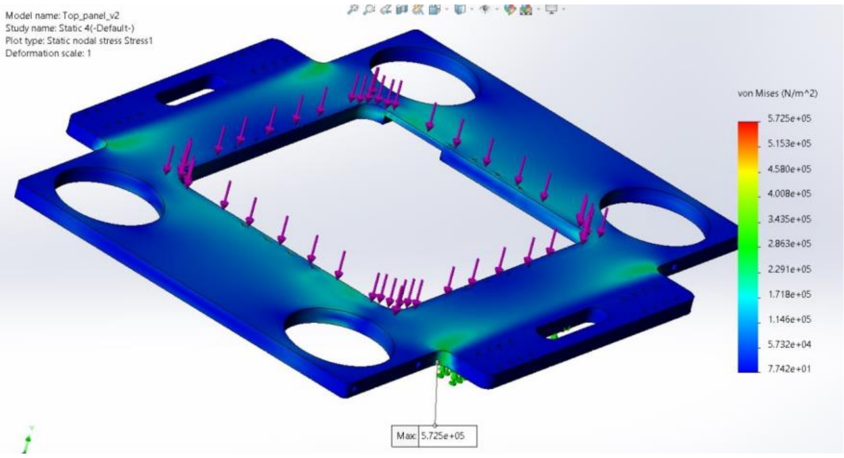
After a series of tests, with different materials, HDPE was chosen, it is in fact an easily machinable material, presents a lower tensile strength than other materials such as PVC or nylon, but unlike the latter HDPE has a lower percentage of water absorption, and a significantly lower cost.



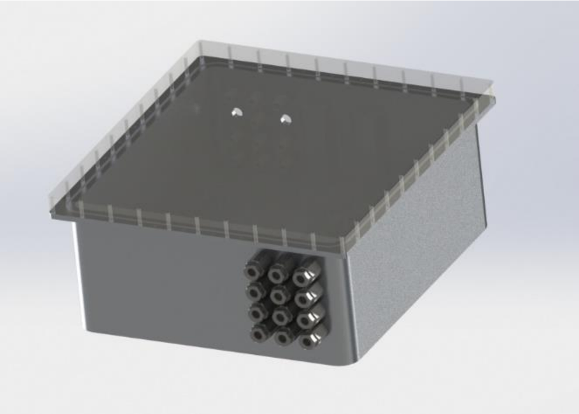
The structure was machine-made by using HDPE panels, creating 5 parts: One top panel, two side panels, and two bottom panels. They are connected to each other by screws (M6) and threaded inserts.

The overall footprint of the frame is a length of 565mm, a width of 498mm and a height of 220mm, each panel is 15mm thick to maintain the integrity of the structure.

The frame has two gripping areas, finished to avoid any damage, also there are several attachment holes, which allows the attachment of the 8 thrusters, the box containing the electronics and additional devices.

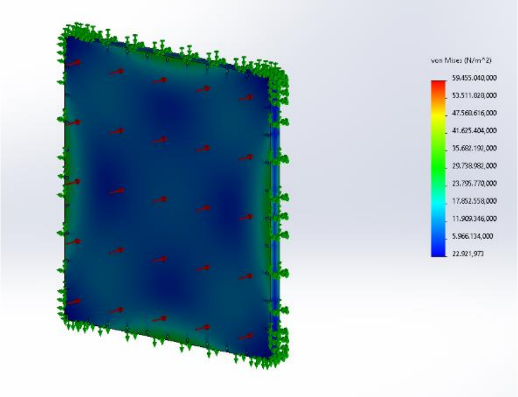


Electronic housing



EVA's electronics enclosure was designed to accommodate all the electronic components necessary for its operation.

In contrast to previous years, a customized solution was chosen that could allow easy access to the various boards and better connection to the chassis. The box was made of aluminum alloy 7075 T651 by milling. It was designed with the use of SolidWorks software through which several FEM simulations were carried out, which allowed us to obtain the best relationship between structural strength and cost.

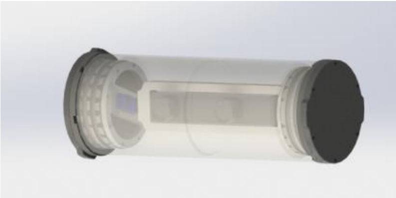


The box also has 24 holes that can accommodate as many penetrators as possible for the passage and connection of cables. The top flange has both holes for anchoring to the frame and clamping holes for the cover. There is also a seat for O-ring, which is also custom made.

the Printed Circuit Board for the power supply was placed in contact with the box itself, using thermal paste, to promote better heat dissipation, while the other boards were placed inside the box through the use of additive manufacturing supports.

The lid was made of Plexiglass and has holes for anchoring it to the box. It too was designed using FEM analysis to ensure its structural strength. In addition, given the transparency of the material, it is possible to view the status of the LEDs to verify the proper operation of the electronic boards inside the box.

Camera motion system



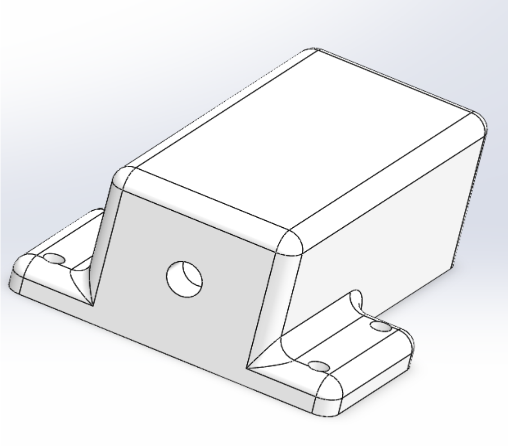
During the design stage of the new camera motion system, our engineers wanted to satisfy two main demands: lightness and great range of motion. After some trials to find the best compromise between reliability and the requirements mentioned above, the final product shows a great maneuverability. The camera housing was 3D printed using ABS filament, which is moved by a small servomotor, enabling low heat/power consumption. Due to the coupling with an Allen key, the range of motion was increased (180°) compared to the previous models and its design allows the camera's power cable to pass through, reducing space requirements.

The camera motion system is placed in a PMMA tube, enabling low image distortion. The support mechanism was 3D printed using ABS filament and it was designed with the aim of not hindering the movement of the robotic arm and, at the same time, allow a good visual of the camera. Another challenging aspect during its project phase was to prevent the risk of rupture of one of the two supports in case of impact.

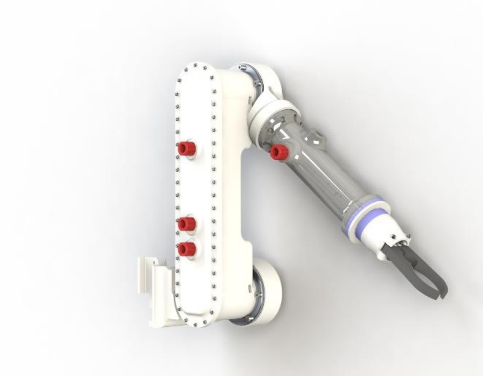
Lower Camera

A valuable additional accessory is the lower camera frame.

Our engineers have created a small, ergonomic stand. The design has been conceived to optimize space and to be able to mount it in the lower part of the EVA to have a perfect view of the area below. The support was made using a latest generation 3D printer. The material used is Tough 2000 Resin, a resin with characteristics similar to ABS plastic and which has excellent resistance to effort and stress. This support is completely waterproof thanks to the presence of a penetrator that allows the entry of cables for the camera and a plexiglass cover closed with gaskets.



Manipulator

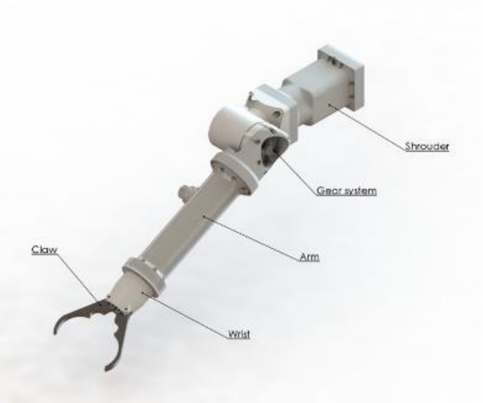


The manipulator (figure 1) is a three-degree-of-freedom device that allows the ROV to reach objects relatively far from the frame and move them without having to act on the thrusters, thus avoiding damage to the samples or raising sediment and compromising visibility.

To design the new manipulator, we started from previous models (Figure 2), so that all the positive factors were retained and optimized.

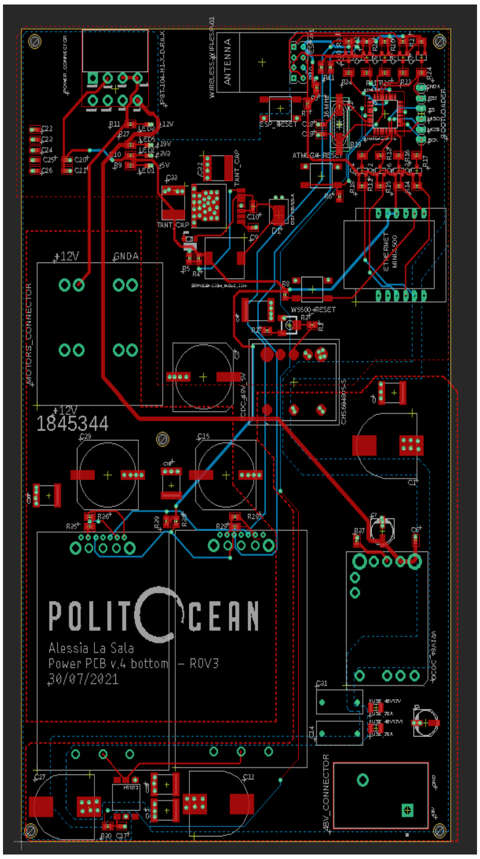
The manipulator's large working space is particularly useful in picking operations, which are commonly required of the ROV.

The chassis and transmission are made of plastic and produced by additive manufacturing; all electronic components are incorporated into the chassis.



Electronics

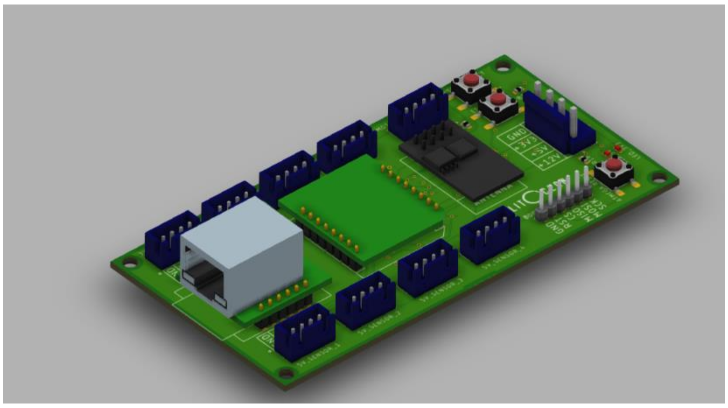
Power distribution



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, 48V-19V DC-DC converter and 5V-3.3V DC-DC converter. This conversion step is necessary because EVA's electronics needs the 19V, 5V and 3.3V supply for the logical part 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. 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 and 19V supplies are always on. In particular, 19V is 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 convertors 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 in order to gain reliability. All this data are sent to the surface through MQTT.

Printed Circuit Boards

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 Electronical Box (EB). The thinking-core of the ROV is the Nvidia Jetson AGX Xavier 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 AGX Xavier are the



video streaming flow elaboration, MQTT broker, computer vision, and Machine learning algorithm elaboration.

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 cables integrity. The interface between the each component inside the EB and the surface is managed by an 8-port Ethernet switch. Furthermore on each board there is an ESP which is a WiFi 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 and it can be easily redesigned 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 instead of an ATMega328 because it was necessary to have more computational power for the control syste,. The Nucleo is connected directly with the Nvidia Jetson to be reprogrammed and to the thrusters.
- Camera Movement and Lights PCB: the functionality of this PCB regards the control of 4 LEDs and the tilt engine for the front camera. The control is managed by a micro-controller ATMega328 and LED drivers.
- Arm PCB: this PCB is internal to the arm. Its functionality is the control of 4 engines moving the arm, in particular: the movement of the wrist and the claw is realised by a stepper motor for the first and a linear actuator for the other. Otherwise the control of the elbow engine and shoulder engine is using two servo motors interfaced with a 485 serial bus.
- 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 sock, 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 1Gb/s. In addition, both cables had to display good flexibility.

Camera

There are two USB cameras: the first one is a Zed Mini stereoscopic camera, employed as main view, thanks to its characteristic can be used also for surrounding reconstruction, the second one at the bottom of the ROV is used for line path following tasks. This results in a significant upgrade from previous implementations, in terms of image quality, surrounding view and data that can be retrieved by the cameras.

Control Station

This year control station is composed by an Nvidia Jetson TX2. This extra computational power is required to process vision’s tasks. This computing unit is placed inside a waterproof box, which incorporates a 15.6 inches LCD monitor and an ethernet switch that enables to connect to the ROV up to four technicians at the same time. This feature was very useful in the software development and debug phase to allow working on different devices simultaneously. All components of the control box have been mounted to the external case by using 3d printed frames.

Software

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 Xavier AGX, an STM NUCLEO board and several AT Mega, 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 allow 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.

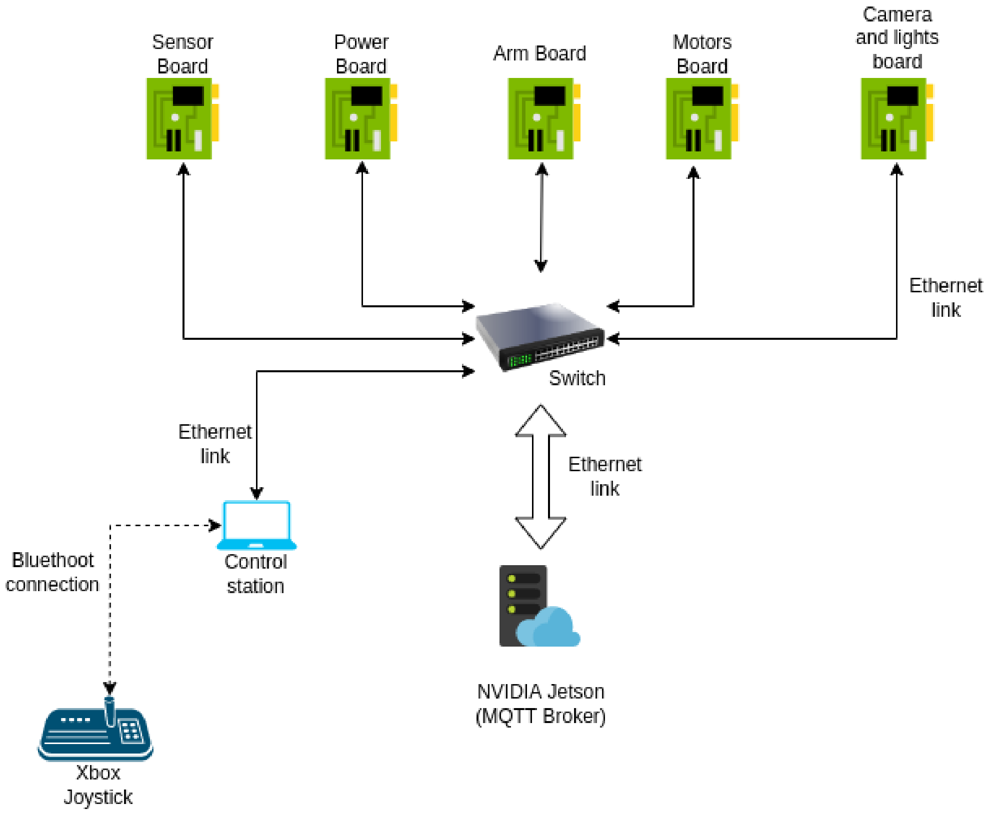


Figure 1. Software System Interconnection Diagram

JETSON XAVIER AGX

The Jetson Xavier AGX is the host of the MQTT broker and it acts as a streamer for our camera image sending them to the base station. The Jetson is also in charge of every machine learning tasks thanks to its capable GPU that allows for the best performance in computer vision.

On the Jetson we perform the computation to extract the paths to be followed by our ROV in the autonomous driving task.

STM NUCLEO

The NUCLEO board is devoted to the control system tasks. It controls the thrusters to move the ROV according to the value received from the GUI and from the sensors.

The control system resides on the NUCLEO microcontroller. It is currently based on LQR control of the depth axis providing auto-quote. This feature allows the operator to be more precise in completing tasks that require greater stability or to operate at fixed depth.

The complete control is the integration between the position, the speed control system and the auto-quote. The auto-quote start its work when we don't supply speed commands on the z axis. In order to provide a more reliable positioning for what concern the quote, we use the pressure sensor BMP30 that allows low variational measurement.

ATMegas

One ATMega is used in order to retrieve date from IMU, pressure sensor and temperature sensor , such data are analyzed, filtered and sent through MQTT to the NUCLEO and the GUI respectively for the control system and for displaying the position of the ROV. The temperature sensor is crucial in order to prevent faults and monitor the system. Further effort in this sense has been spent providing a system that analyze the temperature of the core on the Jetson.

An other ATMega is used to switch on the lights, in order to allow an improved vision from our cameras, and to move the frontal camera. The cameras are interchangeable in order to provide the maximum flexibility.

Finally one ATMega is used for powering the power unit and another one for moving the arm.

Graphical User Interface

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 mostly in Python using the Qt Framework as a cross-platform Desktop application, focussing on software portability and on maximizing its pilot's ease of use through intuitive controls and the predisposition to mission specific tasks.

The application layout is organized in four sections with specific purposes:

- Control, in the left, to call mission specific tasks
- Monitor, in the right, to report sensor values, status indicators and activity logging
- Camera, in the center, to stream the video from the ROV camera
- Trend, in the top-center, to build graphs reporting the time trend of the sensors during the diving time

It communicates with the other boards via MQTT. It reads the reference from the joystick and it sends it to the NUCLEO, while it listens from the ATMega the sensors' values.

Safety

Company safety philosophy

We here at PoliTOcean strongly believes that a safe workplace is an essential requirement in order to succeed in the realization of a project. Our responsibility is to guarantee a safe work environment that prioritizes the protection of people and surroundings. However, the employees have also to cooperate in order to prevent accidents. For this reason, there are mandatory training, safety procedures, and safety protocols.

Lab Protocols

The work in the lab has to follow specific safety protocols, in order to ensure a safe work environment. When dealing with electronics assembly, the employees have to wear special gloves and turn on the chemical vent placed in proximity to the benchwork. In addition, we developed an electrical safety protocol to avoid electrocutes and burn out of devices. For mechanical processes there is a special dress code that imposes a specific coverall along with glasses and gloves. Furthermore, when handling hazardous materials the protocol requires the room to be well aired. These procedures may be found in PoliTOcean's Safety Data Sheet (SDS) accessible to all the employees. However, the SDS is only an additional tool that allows to quickly check the correct procedure and which comes after a mandatory training for all new employees.

Vehicle Safety Features

Safety plays an important role also when dealing with the final product. For this reason EVA is equipped with several safety features consisting of a combination of both sensors and actuators. Every electronic housing of EVA is equipped with a temperature sensor, to monitor possible overheating that could lead to electrical failures. Inside the Main Tube it is also placed a pressure sensor giving indications about the pressure inside the housing. Monitoring this parameter is useful to avoid detrimental water leakages. Another important safety feature of EVA is the possibility to remotely turn on and off the 12V output, which feeds all the thrusters and actuators of the ROV. This was accomplished using an optocoupler, which also provides galvanic insulation.

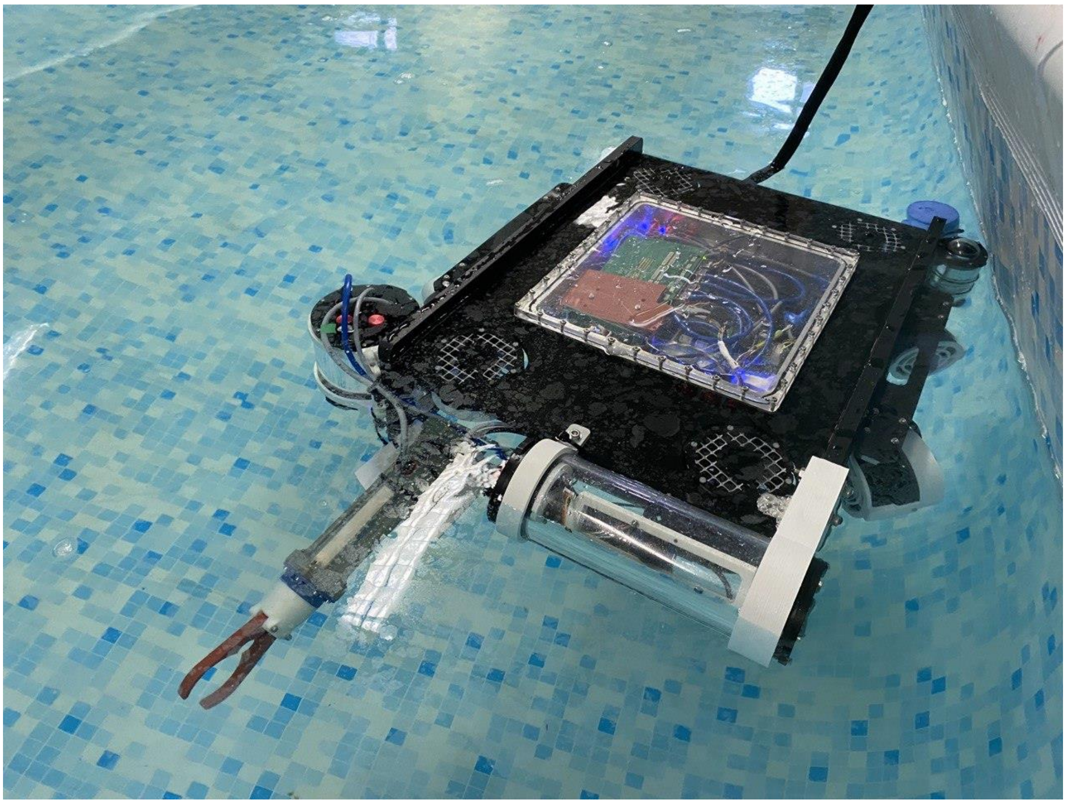
Operational And Safety Checklists

Safety protocols and checklists (Appendix A) are diligently followed before, during, and after ROV functioning. Employees have also to respect specific procedures for ROV launch, recovery, and waterside safety.

Testing and Troubleshooting

The testing and troubleshooting phases represent the most important parts in the development of a product, to reveal all the problems that were not considered. The PoliTOcean’s workflow begins with dry tests. If they are successfully passed, then the water tests start. In the first place all the single components are separately checked. As far as the electronics is concerned, the preliminary step is to examine if every single PCB was correctly soldered using a multimeter. This tool is fundamental also for localizing the matters in further checks. Once we are sure that all the boards are properly working, they may be connected and allocated in their final case. If the electronics properly works, wr recreate a scenario 10 meters beneath the sea surface to check for functioning in quasivacuum conditions. Before starting any test in water, it is important to verify that no detrimental water leakages are allowed. We pay special attention to the penetrators through which the cables are delivered inside/outside the ROV. For this purpose, the company has developed a system made from a pressure pump with a pressure gauge and an acrylic tube. The tube is attached on one side to the pump while on the opposite side is inserted a cork where the single penetrator can be plugged allowing its inspection.

Once those steps are revealed to be successfully accomplished, we begin the water tests. This phase represents the true troubleshooting of the firmware. The pilot reports the main struggles spotted during the ROV drive. Therefore, the software developers try to find solutions to these difficulties in real time. In this way the pilot can immediately give feedback. The tests end when the ROV accomplishes favorably all the requested tasks.

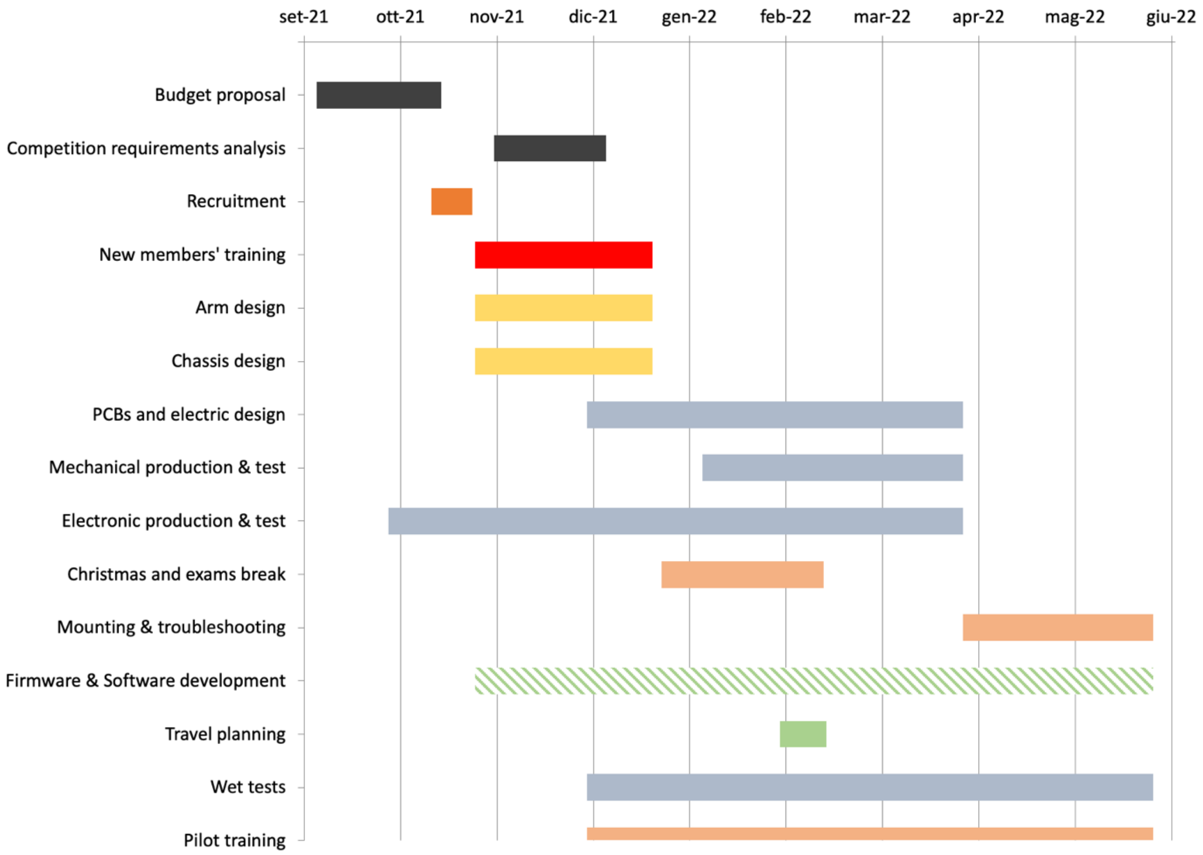


Project management

Organization Structure, Planning and Procedures

PoliTOcean is made up of multidisciplinary teams with employees from different countries and cultures. This key strength allows the company to consider different points of view during development and prototyping that, analyzed together, lead to the best Minimum Viable Product (MVP). Ideas and decisions are made according to majority criteria, during brainstorming sessions or general meetings, in which everyone is encouraged to speak up.

The company is organized in three sub-teams: Mechanical, Electronics and Software. We planned the design and the prototyping of EVA using a Gantt chart to have an overall view of the roadmap and the deadlines. Internally, each Team (Mechanical, Electronics and Software) are self-organized, and they proceed in parallel to converge, at the end, to the best MVP.



Budget and Cost Projection

Our company is entirely founded by the University Politecnico di Torino. The majority of EVA’s development budget was allocated for electronics and mechanical parts.

Mechanical

The Mechanical Section works on a flexible schedule. The ROV is divided into several subsystems, which are designed by small groups of two or three students. The number of members depends on the complexity of the project.

Each subsection must work on the design, simulation, and prototyping of the assigned component. Weekly meetings are held to have an up-to-date overview of the work done.

These meetings are also useful for solving problems that may arise during the drawing and design phases.

3D printing allows for faster prototyping. It takes place only after the design has been completed.

Testing represents the final stage. During this final stage, members of the mechanical team come together in the lab and workshop to manually assemble the prototypes first and the ROV later.

Electronics

The first step taken to successfully develop the electronic system is the division of responsibilities among each section member. Every electronics engineer oversees designing and soldering a specific PCB, along with its service. Electronic engineers rely on weekly meetings to organize and carry out the work. During those meetings they stay update about how the work proceeds. Those moments represent a suitable time for brainstorming solutions to sudden problems. The company has seen in its previous experiences that a constant update is fundamental for everyone to have a clear overview of how the realization of the project is proceeding. In addition, the employees are requested to write weekly reports, not only to keep track the accomplishments of the week, but also the spotted difficulties. In such a way stems a database of problems and applied solutions, which is useful for future troubles.

Software

The Software Team bases its organization according to the Scrum method. The Gantt chart turns out to be very often unsuccessful and harmful in Software Development. Requirements vary over the course of prototyping to get far from where it was planned, risking missing deadlines. The Scrum method solves this problem with Sprints.

The Scrum method consists of Sprints of fixed length, in our case of 2 weeks. At the beginning of each Sprint, we plan our activity preparing a list of tasks that must be done and completed by the end of the Sprint. The Scrum Master, usually the IT Chief, coordinates the Sprint session. At the end of the Sprint, we organize a Retrospective session to analyze the work done during the sprint and to plan a better Sprint session for the next two weeks.

Moving from Gantt to Scrum resulted in an increase of productivity, having resources always full. Thanks to the Retrospective session, it allows the employee to understand what went wrong and how to improve in the meanwhile, resulting in an increase in the quality of work and in the organization of time.

Challenge

This past pandemic year has proven to be very challenging not only for project development, but also for employee perseverance and motivation.

The company had to find new ways of working, enabling effective research and design despite the difficult times and the distance that separated team members. For this reason, we planned a rigorous schedule, which consisted mainly of weekly meetings both in person and remotely. Having such tight deadlines allowed the team not to lose focus on the company's goals.

Another difficulty was designing every component, which could not be purchased, from scratch. Thus, devoting more time in the design and testing phase.

Lessons learned and skills gained

Despite the challenges, 2022 proved to be a very useful time to make personal and business improvements.

We improved internal team communication among the various members to get a complete picture of the project, which allowed us to improve it and expand the knowledge of each member.

In terms of communication with external entities, 2022 was a fruitful year that created great opportunities for teamwork; the ability to rely on colleagues and trust in the validity of their work proved crucial. Organization and division of workload proved to be an advantage.

The collaboration of many employees on the same project enables the company to find solutions to sudden problems more quickly.

With time management skills in mind, frequent meetings played a crucial role. Having to systematically present the work done on the given dates introduced additional motivation for employees to perform their tasks.

In addition, the skills acquired in financial management should not be underestimated.

It was a priority for the company to involve all team members in the procurement process.

Many students had the opportunity to meet different suppliers. As a result, they learned how to close business deals and how to bureaucratically employ funds provided by a third party.

Future Improvements

EVA represents the best prototype, and the most challenging, that the company has made so far. However, PoliTOcean is constantly challenging itself and trying to initiate projects that go beyond its comfort zone.

That is why the company has started work on a completely new prototype, based on the experience of previous prototypes.

Unlike EVA, the new ROV will favor in both stability and lightness.

In addition, the ROV will be designed in such a way that it will have the ability to transform into in an AUV (Autonomous Underwater Vehicle).

It will be critical to have the ability to quickly switch from external shore power to battery power. Thus, modularity is the key concept of the new project.

In addition to the new ROV, there are several plans for the coming year to optimize EVA and produce a fully battery powered ROV without external cables.

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- Politecnico di Torino for giving us the means and the financial resources needed.
- Mentor Prof. C. Sansoè, providing suggestions in technical fields and, most important one, helping us to deal with the bureaucratic affairs inside the University from four years.
- MATE Center for giving us a goal to aim.

Appendices

Appendix A: Operational Safety Checklist Pre-Power

- Clear communication among the users
- Surrounding area is safe (no running at the pool & no tripping hazard)
- Electronic housing is correctly closed
- Check vacuum port is securely capped
- Visual inspection of electronics for damaged wires, loose connections
- Thrusters free from obstructions
- Proper connection of the data transmission cable with the working station
- Power source connected to the working station
- Check if the ROV is properly connected to the power supply

Power-Up

- Call out “Power On!” • Ensure the correct deliver of 48V
- Check the proper conversion of the power supply to 5V
- Check the GUI’s response • Power 12V supply
- Perform thruster test
- Verify thrusters are working properly following correctly joystick’s instructions
- Verify video feeds
- Test the arm

In Water

- Check if bubbles arise
- Visually inspect for water leaks
- If detected bubbles in water pull to surface and check leaks in dry environment
- Employ thrusters and begin operations

ROV Retrieval

- The pilot calls “ROV recovered”
- Seize the ROV and disable thrusters
- Operation Technician powers down the system
- Operation Technician allows to safely remove the ROV from water
- After placing safely the ROV on shore the team calls out “ROV safely secured on shore”

Leak Detection Protocol

- Recover immediately to surface 21
- Power down
- ROV Inspect
- Remove electronics if required

Loss of Communication

- Reboot the ROV
- If no successful reconnection, switch off the ROV and retrieve via tether
- If the communication is properly restored and there are no leaks, restart Power-Up protocol

Appendix B: Budget and Cost Project

Outgoing category	Description	Budget (EUR)
Production	Frame and housing	1,434.96 €
	Thrusters	2,990.32 €
	Consumer electronics	4,920.50 €
	Mission tools	851.74 €
	Service and mechanical	3,800.00 €
R&D	Prototyping and 3D printing	1,493.00 €
Mission	MATE Entry Fee	400.00 €
Total		**15,890.52 €**

Incoming	Budget (EUR)
University fundings	10,262.42 €
Previous years funding residuals	17,337.58 €
Total	**27,600.00 €**