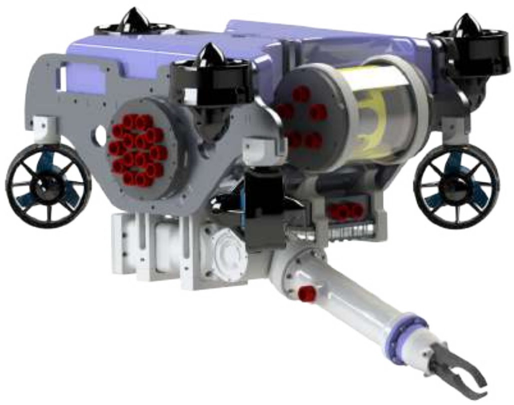
Politecnico di Torino

MATE ROV COMPETITION



AIDA
Technical Report
MATE ROV Competition 2021

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Table of contents

Abstract.....2
Design Rationale.....3
Design evolution.....3
System Interconnection Diagram.....5
Vehicle Core System.....6
Mechanical.....6
Electronics.....8
Software.....10
Mission specific features.....12
Micro-ROV.....12
Seabin.....12
Mapping points of interest.....13
Determine the health of a coral colony.....13
Safety.....14
Company safety philosophy.....14
Lab Protocols.....14
Vehicle Safety Features.....14
Operational And Safety Checklists.....14
Testing and Troubleshooting.....15
Project management.....16
Organization Structure, Planning and Procedures.....16
Budget and Cost Projection.....16
Mechanical.....16
Electronics.....17
Software.....17
Conclusions.....18
Challanges.....18
Lessons Learned And Skills Gained.....18
Future Improvements.....18
Acknowledgements.....20
Appendices.....21
Appendix A: Operational Safety Checklist.....21
Appendix B: Budget and Cost Project.....22

Abstract

AIDA is a prototype of Remotely Operated Vehicle (ROV) developed by team **PoliTOcean** in order to inspect and repair different parts of dams and more general underwater structures. Thanks to its control system and additional tools, AIDA is also suitable for scientific research. It is able to analyze the water and determine the main features of the underwater environment.

The main goal of the company was to develop an innovative product focussing on the dimensions. With a weight of only 14kg the ROV allows the operator to lift up to 120N. This characteristic allows AIDA to get the best in recovery missions. The system is also equipped with an additional micro-ROV, independent from the main body, perfect for pipeline inspection.

AIDA is the result of the cooperation between twenty-six enthusiastic students, who decided to found a student team in 2017. Gathering together Mechanical, Computer Science, Electronics, Mechatronics and Physics engineers was the key for developing an innovative and successful commodity.

Figure 1. PoliTOcean company members

Design Rationale

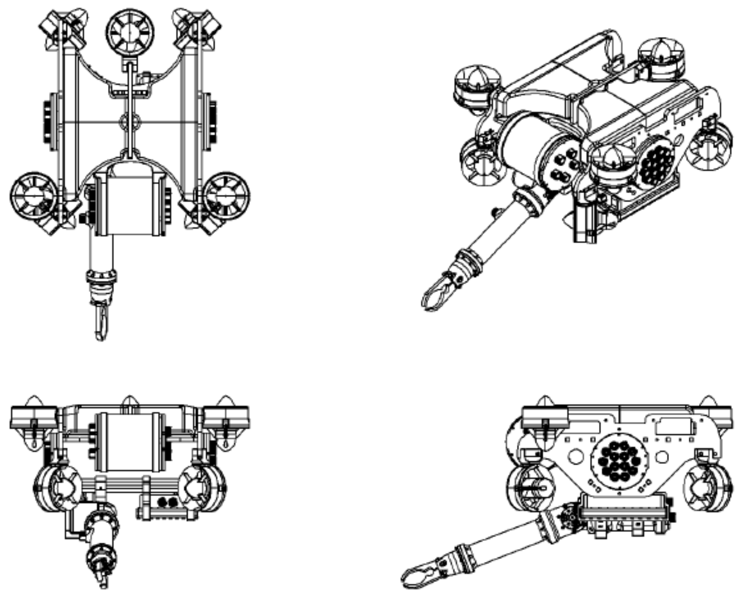
AIDA is the latest company's ROV. It is equipped with seven thrusters and has a lightweight aluminum frame. Its compact shape and reduced weight guarantee an optimal speed and maneuverability in underwater operation.

One of the greatest improvements concerns the power electronics board, which generates a lot of heat. It has a dedicated housing, composed of an aluminum box, designed to maximize the heat dissipation. This allowed the development of a reliable ROV that can guarantee lots of hours of activity without damaging the electronics components.

The electronics consists in a modular system that exploits the advantages of PCB connectors, optimizing the number of the cables inside the main housing, and allows a simpler replacement of components.

The easiness of pilot AIDA is given also by a low-latency HD camera, that can rotate by almost 120°, allowing the operator to see the surroundings.

Moreover, AIDA is equipped with a mechanical manipulator, powered by three electrical motors, giving it 2 degrees of freedom.



Design evolution

PoliTOcean has always proved to strive for the best when underwater robotics comes into play. When starting the design of a new ROV, the main focus of the company is to develop a product that proves not only to be reliable from all the perspectives but also to guarantee the best performance to the user.

We carry out each project keeping in mind the requirements necessary to satisfy the customer's needs.

Engineers start the work building on the previous prototypes. They carefully analyse pros and cons in order to take the best from the past experiences and to overcome the spotted weaknesses.

AIDA represents the latest project of the company. It is a Remotely Operated Vehicle thought specifically for recovery and repair missions. The 2020/2021 version presents several improvements with respect to the previous prototypes. The main feature the team has focused on for the current year was to design a machine that could autonomously conduct the majority of the tasks.

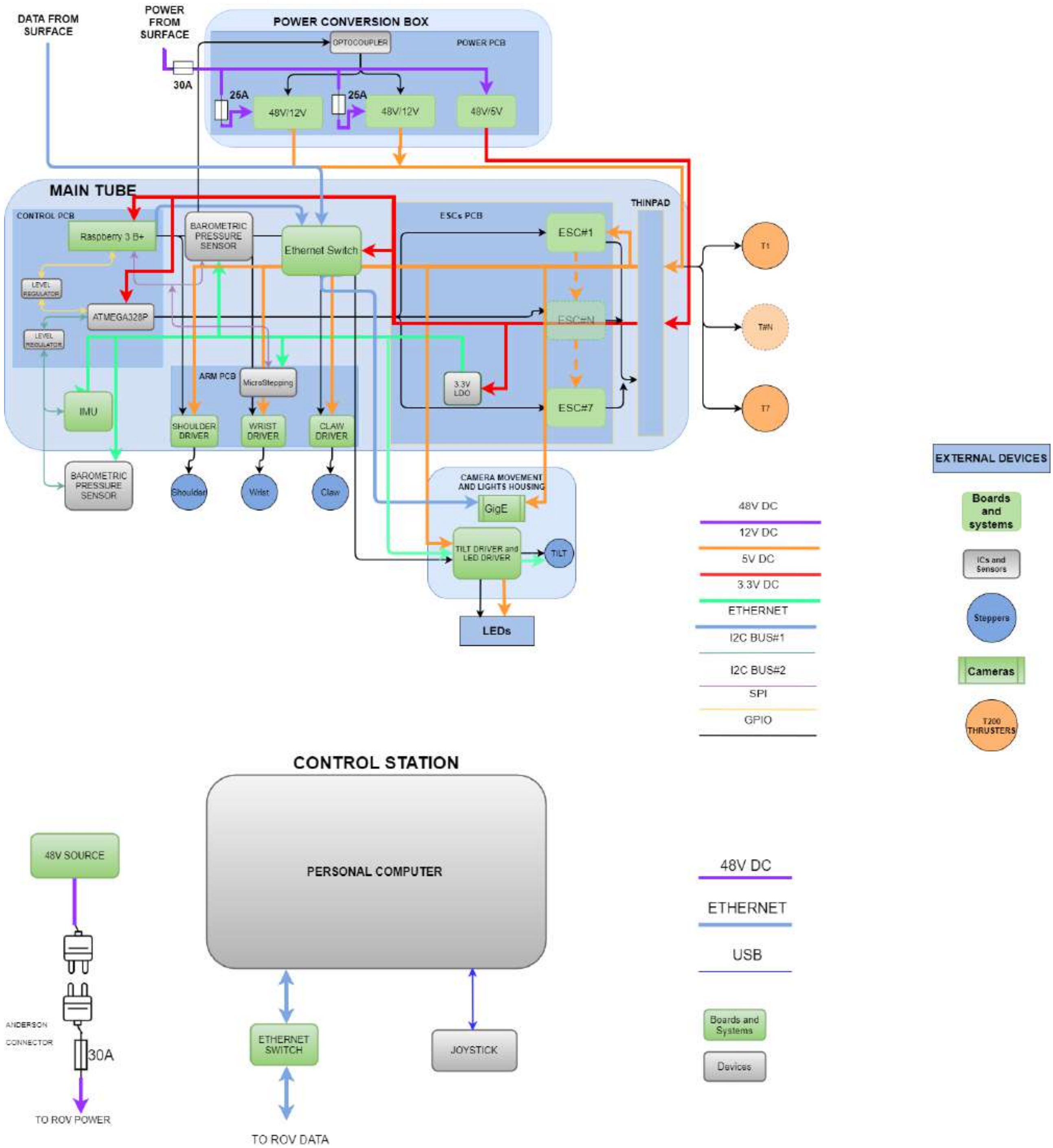
Of particular relevance is the work we did on the camera system. The company decided to use a Blackfly GigE camera, which combines compactness with high resolution. Moreover, the GigE is compatible with the majority of the applications, giving the possibility to Computer Engineers to customize its IT management. Also the tilt camera system went under major enhancements. We installed a stepper motor inside the camera lodging. Now the imaging system can rotate by almost 120°. This new feature allows a drastic improvement of the recorded pictures, which leads also to a more successful machine learning elaboration.

Every time PoliTOcean approaches a new project, the main requirement is to focus on safety. Not only the product itself has to assure the absolute safety for the customer but also the environment where the work is done has to meet specific safety requirements, preventing detrimental injuries for workers. A wide number of tests has been introduced in the prototyping phase. Their main aim is to assure that no water leakage can happen under any circumstances. For this purpose additional security clamps were added to the electronics enclosures. Furthermore, each penetrator through which the cables are delivered inside/outside the ROV is tested against water infiltrations with diligence.
These and other improvements are discussed in further details in the following sections.

During the realization of a project many choices concerning time, costs and reliability have to be done. PoliTOcean tried to take the right decisions by discussing all the problematics and all the possible choices during brainstorm sessions that gathered all the team members. Even though the priorities were safety and efficiency, the costs couldn't be neglected. Every choice is the result of a scrupulous analysis that tries to combine those three ingredients. PoliTOcean strongly believes that all the viable efforts in order to achieve the best of its possibilities were at least tried.

System Interconnection Diagram

These are the system interconnection diagrams of electronics system used in AIDA



AIDA and Control Station SIDs

Vehicle Core System

Mechanical

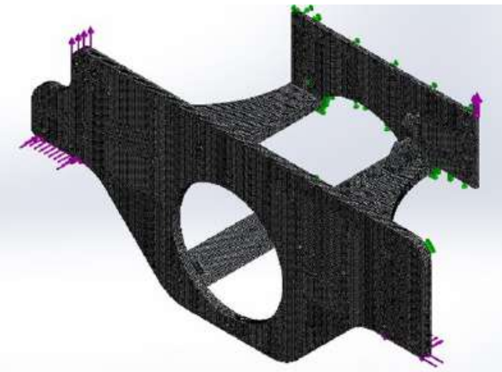
Manipulator

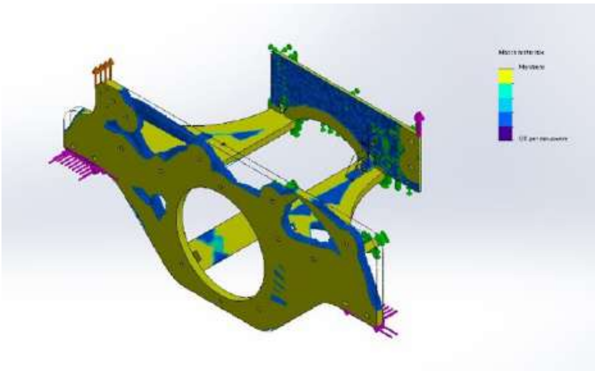
To accomplish servicing and repair underwater structures, AIDA is equipped with a manipulator. The manipulator is an essential device because it allows the operator not only to remove objects, but also to move them and bring them to the surface. The main focus of the company when designing the manipulator was to improve the stability, the maneuverability and to reduce the costs with respect to the one of the previous prototype. Having a modular manipulator allows it to grab objects bending only the arm and avoiding the ROV to take unstable inclinations.

We achieved this goal without having to remove any of the two degrees of freedom. The manipulator's assembly is made by a shoulder fixed to the chassis, an arm, a wrist, and a claw.

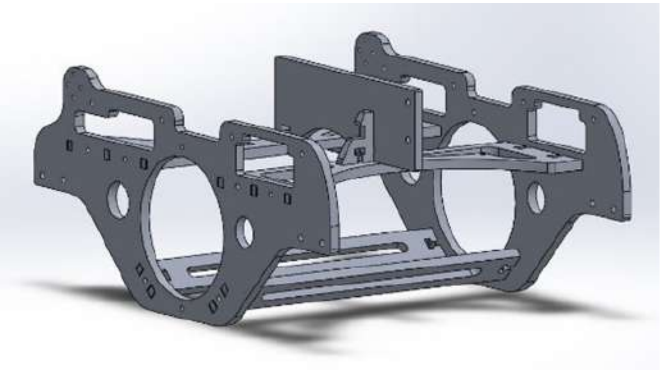
Frame

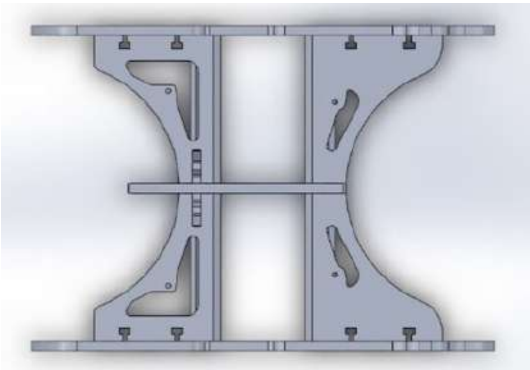
The main characteristic the company required for AIDA's frame was to be lighter with respect to former PoliTOcean's prototypes. To accomplish that, we firstly performed a FEM structural study, to understand how much the decrease in mass would affect the buoyancy and the proper functioning of additional tools, such as the manipulator.





FEM analysis



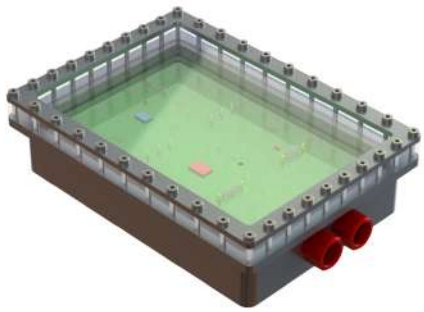


Final result

Our study led to the choice of 8mm aluminum laser-cut plates. Those plates can guarantee both extreme structural strength and a good preservation from damages caused by water, such as oxidation. In addition, drilled plates allow space for off-design accessories.

Electronic Housing

After facing a serious accident in 2018 due to overheating, a priority for our designers consisted in isolating the Printed Circuit Board devoted to the process of the delivered power supply from the PCBs handling the logic system. This solution allows a better heat dissipation, enhancing both structural strength and ROV's security.



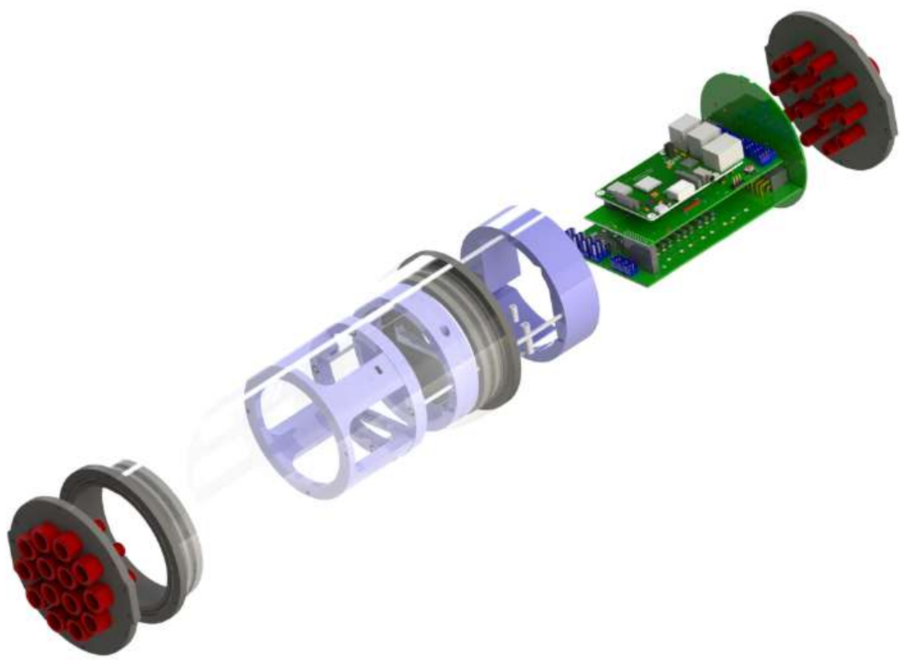
Power electronic enclosure

Furthermore, to ease the serviceability and the safety inspection designers chose to realize the bottom side of the Power PCB enclosure with plexiglass. This solution allows the user to see the status LEDs that signal the correct delivery of the power supply and its correct processing.

Main Tube

The electronics PCBs devoted to logic purposes are stored inside the Main Tube (MT). It is an acrylic tube with a diameter of 4'', produced by BlueRobotics.

To assure greater safety, the company decided to equip AIDA's MT with additional locks. This upgrade allows to prevent unexpected opening of the MT due to rise in pressure inside the logic electronics enclosure. The security clamps are placed in correspondence of the flange where connection cables are plugged.



Main Tube explosion

Camera motion system

Camera motion system

Display a great maneuverability was of crucial importance for our newest product. Considering this requirement, our engineers developed a new camera motion system. It has not only allowed to reduce the number of seal shafts but also it has permitted to increase the range of motion and the angle of view of the camera.

The gear train mechanism, which replaced the previous pulleys and belt system, permits the use of a smaller stepper motor, enabling it to meet some of the previously quoted demands of the company: lightness and low heat/power consumption.

Electronics

Power distribution

AIDA 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 48-12 DC-DC Converters working in parallel, providing both up to 600W. In addition, there is also a 48-5 DC-DC Converter.

This conversion step is necessary because AIDA's electronics needs either a 12V or a 5V supply to operate.

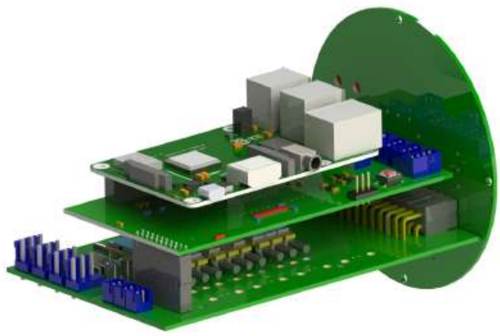
Our engineers designed the power distribution system to tackle the heat dissipation that leads to extremely high temperature in electronics' enclosure. An increase in temperature means a reduction in efficiency, therefore, to maximize performance is indispensable an effective heat dissipation.

For this reason, the power PCB is housed in a dedicated aluminum enclosure. In addition, DC-DC converters were chosen because of their built-in dissipation plates, which are directly touching the aluminum box. Being the aluminum 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. In this way the thrusters can absorb all the delivered power contributing to make the ROV faster. The correct heat dissipation is monitored by a temperature sensor inside the box.

Moreover, we added a custom designed in-built trimmer to regulate the output of the 48/5 DC-DC, allowing to ease the troubleshooting phase. It is important to notice also that the 5V supply is always on, therefore the 48-5 DC-DC is never switched off, allowing the logic part to be always on.

Printed Circuit Boards

Our electronic engineers designed AIDA's electronic system paying special attention not only to operational stability but also to space optimization and serviceability. Except for the Power PCB, almost all the electronics is stored in the Main Tube (MT).



Control, ESCs and ThinPad PCBs

The thinking-core of the ROV is the Control PCB, where we find all the logic and the computation modules responsible for balancing, motion, communication, and the diagnostics of the machine. The low-level real time computation is performed by an *ATMega328P* microcontroller, which is attached through an appropriate socket at the bottom of the Control Board. This connection allows a quick replacement of the microcontroller in case of failure. The ATMega uses its own I^2C network to communicate with the two components that handle the ROV's motion: an external barometer and the *IMU* (*Inertial Motion Unit*).

The main software runs on a Raspberry Pi 3B+, which is placed on the top side of the PCB. The Raspberry Pi performs the diagnostics by collecting data about the temperature of the housing (for power circuitry) and the pressure inside the MT. The pressure is measured through a *BMP280* sensor directly integrated on the board. Furthermore, the Raspberry also generates the control signals for all the other PCBs, including the control signals for the arm and the 12V power-up signal.

The ESCs PCB embeds 7 BlueRobotics' Basic ESCs, a 5-3 DC-DC voltage converter and three status LEDs. The status LEDs allow the user to understand if all the power delivered arrives correctly and is properly converted. The ESC Board is connected directly with the Control PCB and the ThinPad. It provides to the Control PCB the necessary power supply and receives from it the signal needed for ESCs' management. The ESCs PCB has also 7 JST connectors used to provide the power supply to the rest of the electronic components in the MT, such as the arm PCB, the ethernet switch and external devices (camera and its tilt mechanism and lights). The displacement of those connectors, as well as all the other connectors that can be found in the MT, was carefully planned in order to ease the servicing and make them more accessible for quick repair.

The ThinPad PCB connects the converted power coming from the power box with the phases of the 7 T200 thrusters.

The Arm and "Camera and Lights" PCBs complete the electronic set. The latter is placed outside the MT with the functionality of managing the main camera tilt movement and lights. The Arm PCB has an 'L' shape, which optimizes the space inside the main tube. On this board there are three drivers, one for each engine of the arm, and an IC connected on the I^2C bus that allows setting the resolution of the steppers.

We want to stress that the routing on all the PCBs were designed carefully, trying to avoid tight corners which could have increased the reflection coefficient of the lines. We paid particular attention to the I2C lines because of their high frequency protocol and their relevance in the functioning of the whole thing.

Tether

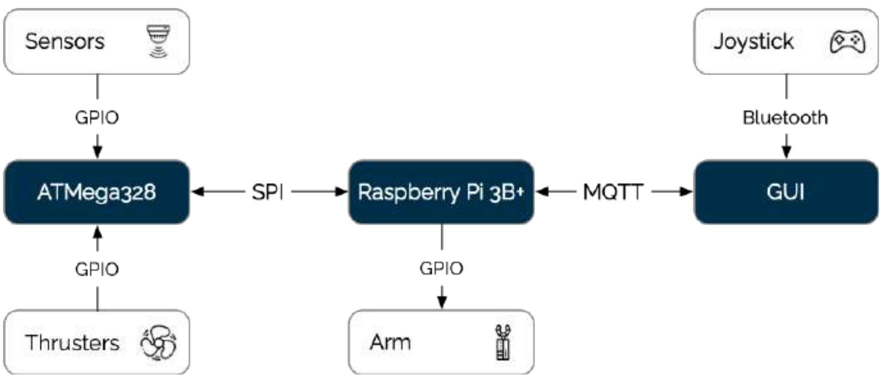
A small Gigabit ethernet switch connects multiple devices with a single cable to the surface. The Raspberry Pi 3 and the IP camera are connected to the switch, leaving an additional slot for another camera if needed. The main tether is composed of two cables wrapped together with a cable sock, one for the power from the surface and one for the data communication. We chose the power cable 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

We chose as main camera a Blackfly GigE BFLY-PGE-03S3C-CS. This results in a significant upgrade from previous implementations. In fact, the GigE camera allows retrieving the frames uncompressed, reducing the video stream delay, and allowing the shoreside control unit to perform image processing process, without losing in quality of the image.

Software

AIDA'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. AIDA's whole system consists of an **ATMega328** and a **Raspberry Pi 3B+**. The two communicate via *SPI*, with the Raspberry acting as the Master and the ATMega as a Slave. A **GUI** allows the operator to control the ROV. The communication between the Raspberry Pi and the GUI takes place via *MQTT*, an extremely lightweight publish/subscribe messaging transport over network protocol.



Software System Interconnection Diagram

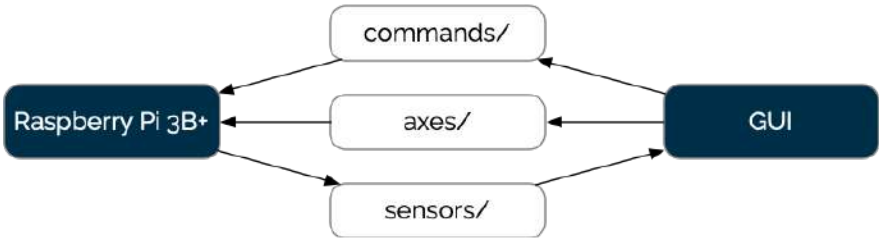
ATMega328

The ATMega is devoted to the analog world. It sends to the Raspberry the values read by sensors and controls the thrusters to move the ROV.

The control system resides on the ATMega microcontroller. It is currently based on PID 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.

Raspberry Pi 3B+

The Raspberry Pi is devoted to the digital world. It handles arm movements, and it acts as a broker: it sends to the ATMega controller the inputs for the thrusters via SPI received by the GUI via MQTT; on the other side, it forwards the sensors' values to the GUI via MQTT.



MQTT Communication Diagram

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…). We developed it using the Python programming language and the Qt Framework as a cross-platform Desktop application, focusing 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 Raspberry Pi via MQTT. It reads the reference from the joystick and it sends it to the Raspberry Pi, while it listens from the Raspberry Pi the sensors' values.

Mission specific features

Micro-ROV

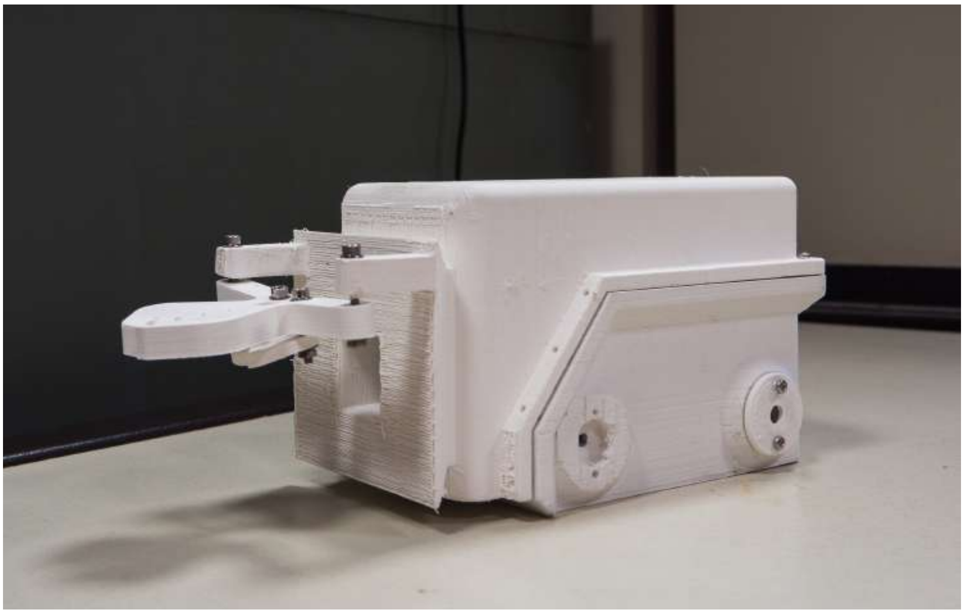
One of the main tasks that a ROV has to tackle when leading underwater expeditions is the analysis of samples. It is useful to have a tool that allows the customer to study the presence of contaminants and other dangerous substances in collected specimens.

AIDA is able to deal with this assignment thanks to the presence of a micro-ROV. It is a small external device, which is able to move independently from the main system. Thanks to its rectangular shape and small size it can move along a pipeline without losing stability. The strong point of the micro-ROV is its simplicity, which allows to minimize the chances of errors and makes the serviceability easier.

There is only a single PCB on which an *Arduino Nano* is placed. This microcontroller manages the *Adafruit DRV8833 DC/Stepper Motor driver*. The last one is needed in order to control the two double shaft engines, which move the continuous tracks allowing the displacement. The Arduino Nano also manages a claw mechanism. It is a magnetic switch that closes an external claw when an object gets in touch with the front side of the micro-ROV.

Once the claw closes, the system inverts direction of displacement and the micro-ROV returns to AIDA.

The whole system is power supplied using two 9V alkaline batteries that allow the device to function up to 1h.



Micro-ROV prototype

Seabin prototype

Seabin

The Seabin power connector is an AIDA's external tool which consists of a 3D printed waterproof frame that has inside an inductive power connector, capable of giving 12 Volts, the control electronics board and the alcaline battery. Our engineers designed its shape to achieve the best fit possible with AIDA's grippers.

Mapping points of interest

AIDA is able to autonomously map six points of interest during a fly over a transect line over a coral reef:

- One larger coral colony (occupying two adjacent squares)
- Two designated area for outplanting coral fragments
- Two crown of thorn sea stars
- One sponge

It creates a map of grid squares and places those points of interest in the appropriate grid squares autonomously.

To achieve this goal, our computer scientists trained a **YOLO** (*You Only Look Once*) neural network to detect the six points of interest. Then, using Computer Vision algorithms and techniques, it recreates the grid, replacing the points of interest with the corresponding colored circles.

Determine the health of a coral colony

AIDA is able to detect the differences between two images of the same coral colony shot in two different moments using an object detection approach. AIDA treats the two images as if they were one, which results from the sum of the differences between them. So, it can solve an object detection problem using a YOLO neural network, previously trained by our Computer Scientists.

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 AIDA is equipped with several safety features consisting of a combination of both sensors and actuators.
Every electronic housing of AIDA 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 AIDA 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 taken into account.

The PoliTOcean's workflow begins with dry tests. If they are successfully passed, then the water tests starts. In the first place all the single components are separately checked.

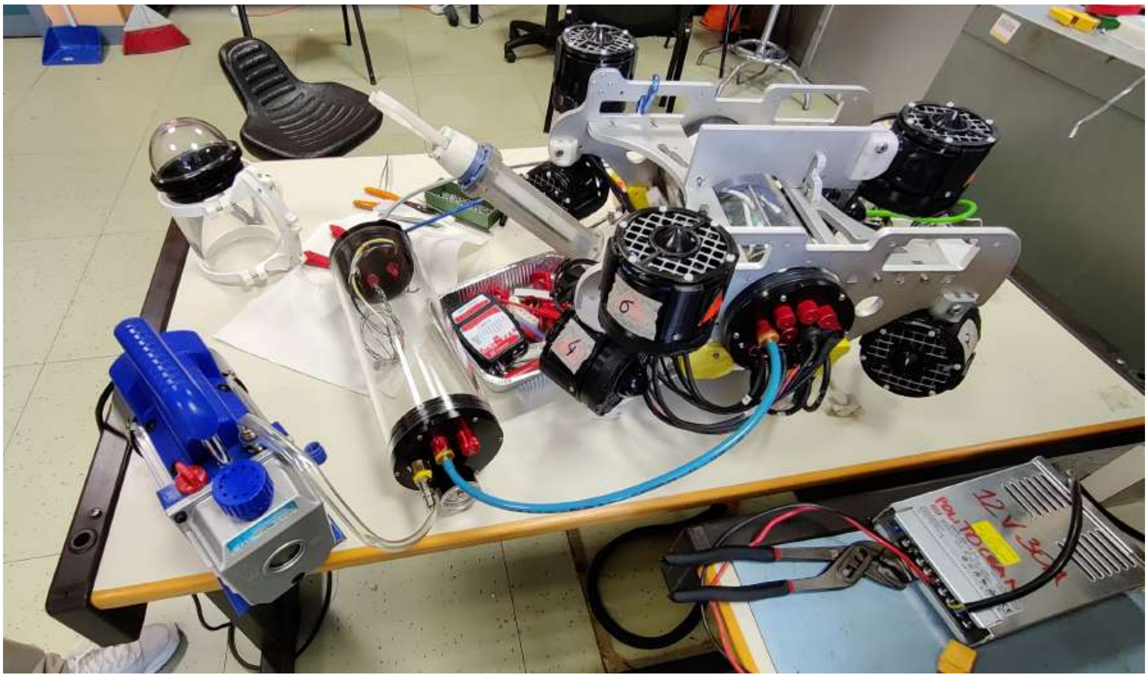
As far as the electronics is concerned, the preliminary step is to examine if every single PCB was correctly soldered using a multimeter. This tool is fundamental also for localizing the matters in further checks. Once we are sure that all the boards are properly working they may be connected together 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 quasi-vacuum 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 out of 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.

Furthermore, the diameter of the tube is the same as the one of the Main Tube (MT) and the Camera Tube (CT). This allows to check the waterproofness of the system as a whole.

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. As a consequence, 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.



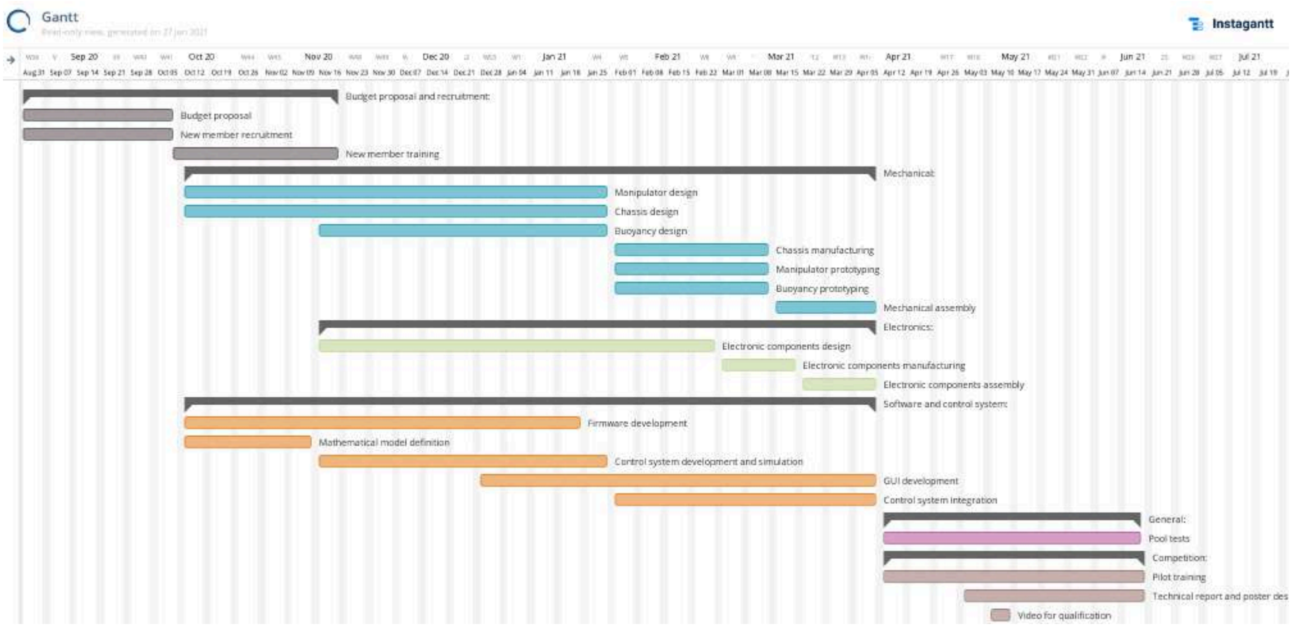
Testing the high pressure condition of electronics MT using the pressure pump and gauge

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 AIDA 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.



Gantt chart for project planning

Budget and Cost Projection

Our company is entirely founded by the University Politecnico di Torino. The majority of AIDA's development budget was allocated for electronics and mechanical parts. Tables with incoming and outgoing budget are reported in Appendix B.

Mechanical

The Mechanical Section works with a flexible schedule. The ROV is divided into several subsystems, which are designed by small groups made up by two or three students. The number of members depends on the complexity of the project. Each subsection has to work on design, simulation and prototyping of the assigned component.

Weekly meetings are held in order to have a constantly updated overview of the work done. Those meetings are also useful in order to solve problems that may arise during the draw and planning stages.

3D printing allows faster prototyping. It takes place only after the project has been completed. Testing represents the very last step. During this final phase, Mechanical Team members gather in the laboratory and workshop to manually assemble the prototypes first and the ROV last.

Electronics

The first step taken in order to successfully develop the electronic system is the division of responsibilities among each section member. Every electronics engineer is in charge of 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.

Conclusions

Challanges

The previous year with the breakthrough of the pandemic has revealed to be very demanding not only for the project development but also for employees' perseverance and motivation.

The company had to find new ways of working, allowing effective research and design despite the challenging times and the distance that took the team members apart. For this reason we planned a strict schedule, which consisted mainly of weekly meetings. Having such close deadlines allowed the team to not lose the focus on the company's goals.

The main consequence of such an extraordinary situation was the impossibility to meet assembly, testing and troubleshooting deadlines. Due to the confinement, the workplaces were not accessible. This caused a major delay in the project realization.

In addition, the closure of the factories exacerbated the production delay because the majority of the raw materials and of the components were not delivered.

Lessons Learned And Skills Gained

Despite all the challenges, 2020 revealed to be a very useful time in order to make personal and company improvements. The qualities that team members were able to acquire are team working abilities and time management skills.

As far as team working is concerned, being able to rely on colleagues and trust in the validity of their work showed up to be fundamental. Organizing and splitting the workload turned out to be an asset. The cooperation of many employees on the same project allows the company to find solutions to sudden problems quicker.

Taking into account time management skills, frequent meetings played a crucial role. Having to present systematically the work done introduced an additional motivation for the employees to carry out their tasks.

In addition, the acquired financial management competences have not to be underestimated. It was a priority for the company to involve all the team members in the purchase process. Many students had the possibility to get in touch with different suppliers. As a consequence, they learned how to close business deals and how to bureaucratically employ funds provided by a third party.

Future Improvements

AIDA represents the best prototype that the company has realized until now.

However, PoliTOcean constantly challenges itself and tries to start projects that overrun its comfort zone.

It is for this reason that the company has started to work on a completely new prototype based on radically different concepts.

In contrast to AIDA, the new ROV will give priority to stability over lightness. It is for this reason that a further thruster will be mounted, bringing them to a total number of eight. Owing to the uneven disposition of the thrusters, the team has experienced some problems during the piloting of AIDA. For this reason it was a common decision to have an even number of thrusters: there is no room for drive errors when it comes to repair and recovery missions.

Moreover, the ROV will be designed in such a way to have the possibility to transform itself into an AUV (Autonomous Underwater Vehicle). It will be crucial to have the possibility to quickly switch from external shoreside power supply to battery power supply. Hence, modularity is the key concept of the new project. Each component (arm, sensors, camera, lights, thrusters, power) will have their own microcontroller in order to be independently handled via MQTT.

From the standpoint of organization structure, the Scrum method was revealed to be more efficient with respect to the Gantt one. Because of that, the company wants to use this way of managing the workload not only in the software section but also in other PoliTOcean's departments.

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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

- 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	1.160,00 €
	Thrusters	2.990,00 €
	Consumer electronics	4.920,00 €
	Mission tools	850,00 €
	Services and mechanical	1.900,00 €
R&D	Prototyping and 3D printing	490,00 €
Mission	MATE Entry Fee	400,00 €
Total		**12.710,00 €**

Incoming	Budget (EUR)
University fundings	10.260,00 €
Previous year funding residual	17.340,00 €
Total	**27.600,00 €**