Technical Documentation

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Robocol
Universidad de los Andes
Bogota, Colombia

Contents

1 Project Management

1.1 Robocol

We are a group of students with a deep motivation for the development of projects and the management of multidisciplinary teams, managing to apply theoretical knowledge to a real engineering problem.

- **Mission**
  Robocol is a student initiative of the Universidad de los Andes, whose purpose is to train its members in the area of technology applied to robotics, with the aim of offering a complementary education that allows them to develop qualities suitable for the requirements of the labour market.
- **Vision**
  We want to be a Latin American benchmark in high-level training in the area of robotics through research, innovation and project creation, being at the forefront of technological change.

1.2 Integrants

Team members		
Team member	Career	Career Level
Gabriela Camargo Moreno	Business Administration	5 semesters
Laura Andrea Hurtado Acosta	Electronic Engineering	3 semesters
Juliana Delgadillo Cheyne	Electronic Engineering	6 semesters
Juan Pablo Santa Arias	Mechanical Engineering	3 semesters
Juan Diego Pinto	Electronic Engineering	2 semesters
Sergio Andrés Oliveros Barbosa	Computer and systems engineering	4 semesters
Daniel Alejandro Castillo González	Electronic Engineering	3 semesters
Felipe Andrés Mesa Niño	Computer and systems engineering	2 semesters
Daniel Hurtado Jiménez	Electronic Engineering	7 semesters
Hernando José Díaz	Electronic Engineering	2 semesters
Gianmarco Javier Rojas Rodriguez	Electronic Engineering	2 semesters
Maria Alejandra Moreno Bustillo	Electronic Engineering	6 semesters
Andrés Santiago Martinez Hernández	Biomedical Engineering	7 semesters
Santiago Usme Martínez	Electronic Engineering and Mechanical Engineering	6 semesters
Daniel Eduardo Contreras Rojas	Electronic Engineering	6 semesters
Tatiana Pérez Suancha	Electronic Engineering	2 semesters
Valentina Echeverri	Electronic Engineering and Computer Science	5 semesters
Santiago Ardila	Mechanical Engineering	6 semesters
Daniel Alvarez	Electronic Engineering and Mechanical Engineering	7 semesters
Jorge Luis Lamprea Barragán	Electronic Engineering and Mechanical Engineering	6 semesters

2 Engineering Design Rationale

In 2021, our team embarked on an ambitious project to create a submarine, drawing inspiration from Colombia's geographical characteristics, being surrounded by two oceans and having an abundant hydric network. The idea of exploring underwater environments motivated us to undertake this endeavor. As we delved into the design process, we were heavily influenced by the work of Blue Robotics and the MATE ROV competition, which served as valuable sources of inspiration and reference for our project.

One of the crucial components of the submarine was its tank, and we carefully considered the choice of material for its construction. After evaluating various options, we opted for acrylic due to its favorable mechanical properties. Specifically, we selected translucent acrylic to ensure easy visibility of the electronic components housed within the tank. This decision would facilitate monitoring and maintenance of the internal systems. To ensure effective waterproofing, we implemented seals made with O-rings, employing an aluminum cap and an acrylic layer at the end. These sealing components were meticulously selected to provide a reliable barrier against water intrusion, safeguarding the sensitive electronics within the tank.

In addition to the tank construction, we devoted significant attention to designing a suitable chassis for the submarine. The chassis served two primary objectives: facilitating tank movement and balancing the gravity center. By meticulously considering these factors, we aimed to create a stable and maneuverable submarine capable of navigating underwater environments with precision. It is worth noting that, in the pursuit of achieving balance and stability, we made the decision to eliminate one degree of movement for the tank. While this prioritization limited the maximum maneuverability of the submarine, it ensured a more stable and controlled experience, aligning with our project goals.

When it came to the electronic components, we aimed to integrate a range of essential sensors to enhance the submarine's functionality and data collection capabilities. These sensors included a temperature and humidity sensor, internal and external pressure sensors, an IMU (Inertial Measurement Unit), and a leak sensor. Additionally, we incorporated motors to enable the movement of the remotely operated vehicle (ROV). To ensure efficient integration and management of these components, we expertly connected them on a printed circuit board (PCB) using best practices in engineering. To control and coordinate all the electronic systems seamlessly, we leveraged the power of ROS 2, a robust and flexible robotic operating system.

Our design process effectively incorporated the innovative ideas and practices from Blue Robotics and the MATE ROV competition. The meticulous consideration of acrylic's mechanical properties, the selection of appropriate materials for effective waterproofing, and the thoughtful design of the chassis all contributed to the successful realization of our submarine. Moreover, the integration of advanced electronic components and the utilization of ROS 2 showcased our commitment to incorporating cutting-edge technologies into our design, enhancing the overall capabilities and performance of the submarine.

In parallel to the development of the submarine, we focused on designing a claw that would serve a crucial role in manipulating objects underwater. Our primary challenges in designing the claw were achieving waterproofing and ensuring modularity to accommodate various tests and objects it would handle. We recognized the significance of addressing these challenges to effectively meet the objectives of our project.

To address the waterproofing issue, we initially considered utilizing seals, similar to what we had done for the submarine. However, upon careful evaluation, we concluded that investing in a waterproof linear drive would offer a more robust and reliable solution. Although slightly more expensive, we believed it was the optimal choice, simplifying the problem and aligning with our goal of achieving consistent waterproofing performance.

The decision to invest in a waterproof linear drive was made after thoughtful deliberation, weighing the advantages and disadvantages compared to using seals. The group recognized that while seals could provide a viable solution, the complexity and time required to achieve an effective seal made the waterproof linear drive a more favorable option. By balancing effectiveness, simplification, and reliable performance, we aimed to optimize the functionality and longevity of the claw.

It is worth noting that the cost implications of choosing the waterproof linear drive were also taken into account during the decision-making process. Despite the slightly higher expense, the group considered the long-term benefits it offered in terms of functionality, durability, and maintenance. The trade-off between cost and performance was carefully evaluated, and the group believed that investing in the waterproof linear drive would yield the best overall outcome for the project.

Additionally, to accommodate the various tests and objects the claw would handle, we conducted thorough research on the types of claws that would be most suitable for catching different objects underwater. Our findings revealed that altering the number of fingers affected the ease of catching specific objects. Recognizing the importance of adaptability, we decided to design a modular claw that would allow us to change the number of fingers based on the object we needed to catch. Furthermore, we ensured that the design facilitated easy interchangeability, minimizing the time required for making these changes.

Another potential option we considered was incorporating a servomotor to provide rotational capability to the claw, offering two degrees of freedom. However, considering the elevated costs associated with a servomotor and our desire to minimize added weight to the design, we ultimately decided on a four-finger claw design. While it lacked rotational capability, this design choice allowed for modularity by removing fingers depending on the object we intended to hold, providing versatility and adaptability to different tasks.

In summary, the design process for the claw involved addressing the challenges of waterproofing and modularity. Through careful consideration of various options, we made the decision to invest in a waterproof linear drive, guided by a thoughtful evaluation of trade-offs and prioritizing effectiveness, simplification, and overall project goals. The incorporation of a modular design for the claw further enhanced its versatility and adaptability, enabling us to optimize its performance for different objects and tests.

Furthermore, given the requirements of the MATE ROV competition, we undertook the design of a vertical float that would utilize a variation in density to control its flotation. Our objective was to develop a float that would have a lower density than water when empty, allowing it to float, and could increase its density by sucking in water to submerge effectively.

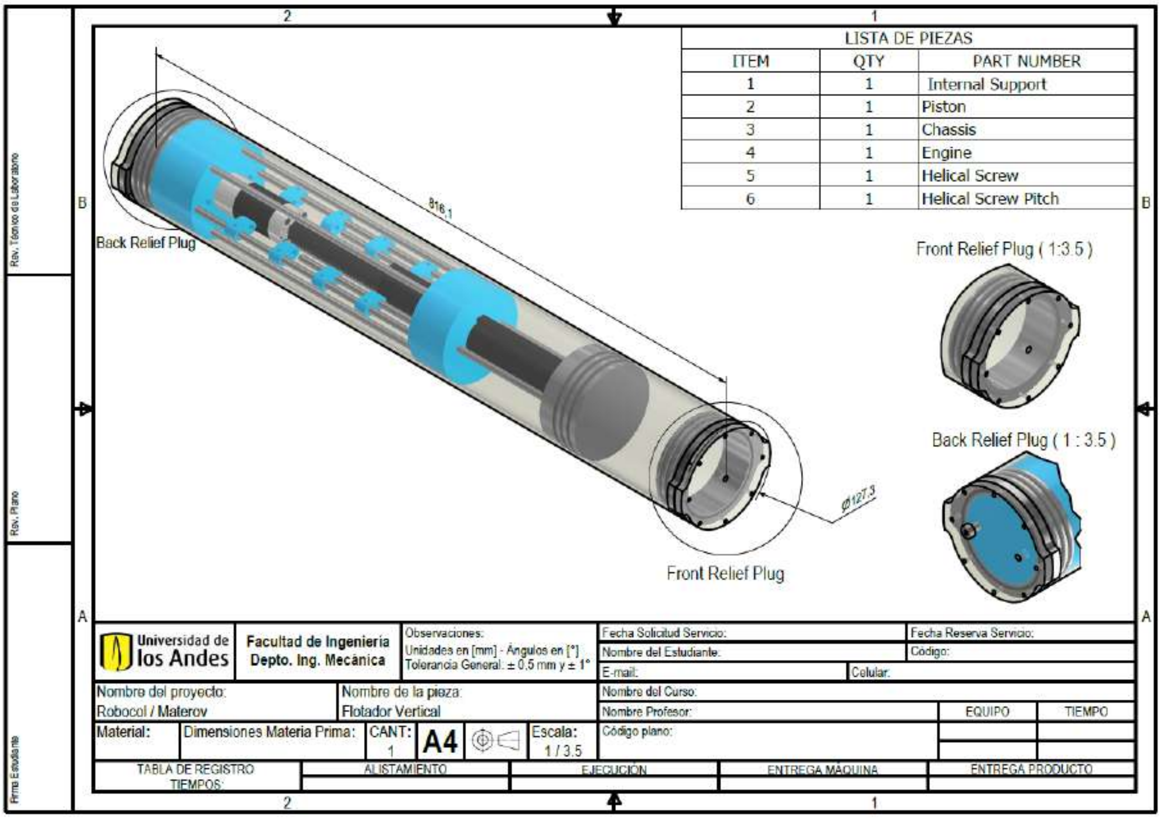


Figure 1: Float final design

After careful consideration, we decided on a mechanism based on a giant syringe driven by a servomotor and an endless screw connected to a piston. This design provided precise control over the float's density, allowing us to adjust the amount of water intake and release according to calculations based on specific equations. By applying these equations, we determined the necessary volume and weight of the float to achieve the desired density variation.

Without water:

$$Volumefloat : 8227.98cm^3 - > 8.228 * 10^{-3}m^{-3} \tag{1}$$

$$Weightfloat : 5.871Kg \tag{2}$$

$$Density : 713.54\frac{Kg}{m^3} \tag{3}$$

With water:

$$Volumefloat : 8.228 * 10^-3m^-3 \tag{4}$$

$$Volumepistonzone : 8.228 * 10^-3m^-3 \tag{5}$$

$$Weightfloat : 5.871Kg \tag{6}$$

$$Weightwater : 2.278Kg \tag{7}$$

$$Density = \frac{floatWeight + waterweight}{floatvolume} = 990.39\frac{Kg}{m^3} \tag{8}$$

Based on this, the float can alter its density with an aproximate value of 276.85 $\frac{Kg}{m^3}$. If we didn't add more weight, based in this calculations the float would float before and after the change in density. In order to fix this, we planned to add a counterweight at the bottom of the float. To maintain stability and prevent rotation during operation, we conducted weight distribution calculations. These calculations led us to introduce a counterweight at the bottom of the float, carefully determined based on the weight distribution analysis. The counterweight served to maintain the float's balance and stability, ensuring its upright position and preventing any unwanted rotation during operation.

$$WaterDensity : 997\frac{Kg}{m^3} \tag{9}$$

$$\delta FloatDensity : 227.86\frac{Kg}{m^3} \tag{10}$$

$$Expecteddensity : 997 - 138.43 = 858.57\frac{Kg}{m^3} \tag{11}$$

$$Expecteddensity = \frac{floatWeight + weightneeded}{floatvolume} \tag{12}$$

$$828.57\frac{Kg}{m^3} = \frac{5.871Kg + weightneeded}{8.228 * 10^{-}3m^3} \tag{13}$$

$$WeightNeeded = 1.19Kg \tag{14}$$

Considering the availability of materials and budget constraints, we initially intended to use acrylic for the float's carcass. However, due to the unavailability of cylindrical acrylic in Colombia and limitations in time and funds, we decided to utilize PVC as an alternative material. For the rods and caps, we chose aluminum due to its light weight and favorable mechanical properties. Similarly, the piston was also made of aluminum to minimize damage caused by friction and ensure smooth vertical movement.

In summary, our design process involved careful consideration of various factors to meet the requirements of the MATE ROV competition. The chosen mechanism, based on a giant syringe driven by a servomotor and an endless screw, enabled precise control over the float's density. The weight distribution calculations and the addition of a counterweight ensured stability and prevented rotation during operation. The material choices, such as PVC for the carcass and aluminum for the rods, caps, and piston, were made based on their availability and properties, allowing us to optimize the float's performance within our constraints.

Overall, our project's success hinged on the thoughtful design of the submarine's tank and chassis, the integration of advanced electronic components, and the use of cutting-edge technologies like ROS 2. The claw's design addressed the challenges of waterproofing and modularity, while the float's design focused on achieving precise control over density variation and maintaining stability. Through meticulous planning and decision-making, our team was able to create a well-rounded and functional submarine system, equipped with the necessary components to explore underwater environments with efficiency and reliability.

3 Innovation

At Robocol, we constantly strive to improve and achieve increasingly optimal results. An example of this approach is the replacement of old components with new ones that have superior design and technical features, whether it's in the chassis, hardware, or software.

In our continuous iteration process, we carefully evaluate every aspect of our product to identify areas for improvement. This includes reviewing existing components and searching for alternatives that offer enhanced performance and greater efficiency.

For example, we have made significant changes to the chassis design to improve the durability and maneuverability of our robot. Additionally, we have updated the hardware to take advantage of the latest available technologies, enabling us to achieve better performance and increased precision in operations.

We have also invested in the development of more advanced software, incorporating sophisticated algorithms and optimizations to increase processing capacity and improve the intelligence and responsiveness of our robot.

The examples mentioned before not only allow us to achieve better results in terms of design and technical features, but they also contribute to cost savings at Robocol. The following are some aspects that demonstrate how these changes help us optimize economic resources:

Energy efficiency: By replacing old components with ones that have better technical features, such as more efficient hardware or optimized software algorithms, we can reduce the energy consumption of our robot. This translates into significant cost savings in long-term operational costs since less energy is required to power and maintain the robot.

Increased durability: The incorporation of components with improved designs, such as a sturdier chassis, helps increase the durability of our robot. This implies a decrease in costs associated with frequent repairs and replacements of damaged parts, as the new components can withstand adverse conditions and daily wear and tear better.

Reduced maintenance: Upgraded and higher-quality components often require less maintenance compared to older ones. This is because they are designed to be more robust, reliable, and less prone to failures. By reducing the need for frequent and expensive maintenance tasks, we can optimize the human and financial resources allocated to those activities.

Improved performance: By enhancing the design and technical features of our robot, we achieve superior performance in terms of speed, precision, and effectiveness in assigned tasks. This results in increased productivity and reduced execution times, which can lead to significant cost savings in automated operations and processes.

3.1 Problem Solving

When a technical problem emerges in the submarine, the first step is to assess its importance considering both its potential harm and level of necessity. Once the relevance of the problem is determined, it is reported to the corresponding subsystem, initiating a resolution process that involves collaboration and analysis from the entire team.

A subsystem of the submarine consists of subgroups that handle specific technical aspects of the robot. There are three subgroups: mechanics, which deals with mechanical components such as the chassis, the robot arm and the buoyancy; electronics, which handles all electronic components of the submarine; and systems, which takes care of the robot's software and vision analysis. Each subsystem works together and has specific responsibilities to address the technical problems that emerges.

In this regard, the team of each subsystem gathers to discuss and provide input on various options to address the problem. During these meetings, ideas are exchanged, possible approaches are evaluated, and different factors that could influence the solution are considered. It is essential to foster a collaborative and participatory environment, as each team member contributes their expertise and specialized knowledge.

Once all options have been analyzed, and possible solutions have been debated, the most suitable alternative is chosen. At this stage, one or several team members are assigned as responsible for completing the task. These individuals carry out further investigation, design prototypes, and assess their feasibility before reaching the final optimal solution.

This collaborative and meticulous approach ensures that well-informed decisions are made and effective solutions are implemented in the ROV.

Used rational process (data, trade study) to evaluate alternatives.

When facing a technical issue in the submarine, a rigorous process is followed to search for different solutions, and the feasibility of each one is carefully evaluated. The following are examples of how this evaluation is conducted:

Technical feasibility assessment: Proposed solutions are analyzed from a technical perspective to determine if they are feasible to implement. For example, if the option of installing a new communication system is considered, compatibility with the existing infrastructure and integration with other onboard systems will be evaluated.

Cost analysis: The costs associated with each proposed solution are examined. This involves considering the initial implementation cost as well as long-term maintenance costs. For example, if replacing a faulty component is being considered, acquisition costs, potential operating and maintenance expenses will be evaluated.

Resource evaluation: The availability of resources necessary to implement each solution is assessed. This includes human working time, material, and financial resources. For example, if a software upgrade is proposed, the availability of trained personnel and the necessary funds to carry out the process will be evaluated.

Risk analysis: Potential risks associated with each proposed solution are identified and evaluated. This involves considering potential impacts on the ROV´s safety, performance, and operability. For example, if the installation of new equipment is suggested, potential risks of incompatibility or affecting the stability of the ROV will be analyzed.

Timeline evaluation: The time required to implement each solution is considered, and its feasibility within the required timelines is evaluated. For example, if repairs to a critical system are proposed, it will be assessed if they can be carried out within the available time without affecting other ROV operations.

These are just examples of how the feasibility of different solutions is evaluated. In each case, a detailed analysis is conducted, and informed decisions are made to select the most suitable option that efficiently resolves the technical issue in the submarine.

3.2 Systems Approach

The submarine was designed so that the sensors, chassis and arm could perform different tasks with different approaches. The sensors were chosen primarily to send constant information about the safety and status of the submarine in the aquatic environment by sending information about the internal and external pressure of the submarine, as well as if a leak is found when underwater. This combined with the tank structure that protects all the sensors and cameras of the submarine gives it a dynamic body with the efficiency to transport itself effectively in the aquatic environment. These two systems are constantly interacting as the submarine is a necessary completion for the efficient and accurate operation of the vehicle.

3.3 Vehicle Structure

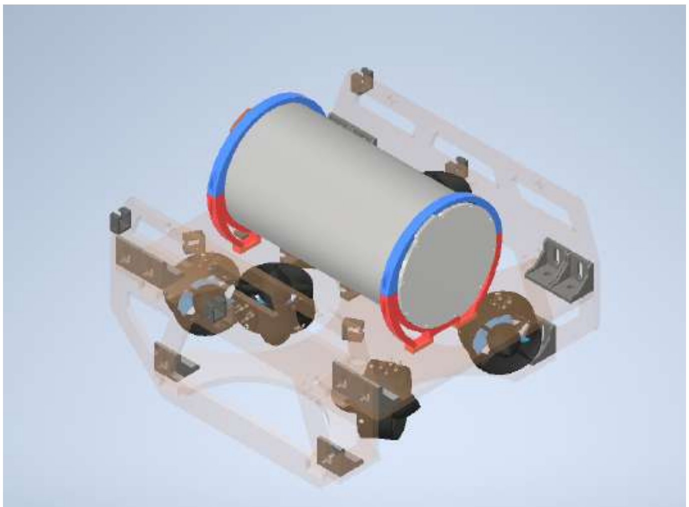


Figure 2: Isometric ROV view

In the design process of our submarine, we encountered various trade-offs and carefully considered the rationale behind the vehicle's cost, size, and weight. These factors played a crucial role in shaping our decisions and ultimately determining the overall efficiency and performance of the submarine system.

When it came to cost, we were mindful of balancing our budget constraints with the need for quality components and materials. While there were alternative options available, we opted for acrylic for the construction of the tank due to its favorable mechanical properties. However, we faced challenges with the availability of cylindrical acrylic in Colombia, which led us to choose PVC as a suitable alternative for the float's carcass. By carefully evaluating the cost implications and considering the availability of materials, we were able to strike a balance between affordability and functionality.

In terms of size, we recognized the importance of finding the right dimensions for our submarine to ensure maneuverability and ease of operation. The decision to eliminate one degree of movement for the tank, prioritizing stability and gravity center balance, was a trade-off we made to achieve a stable and maneuverable submarine. By carefully considering the size of the chassis and its impact on the overall balance and performance, we were able to strike a balance between size and functionality, resulting in an optimized design.

Weight was another critical consideration in our design process. We aimed to minimize the added weight of the components without compromising performance and structural integrity. For the claw, we chose a four-finger design instead of incorporating a servomotor for rotational capability, primarily to reduce weight and complexity. Similarly, the material choices for the float, such as using lightweight aluminum for the rods, caps, and piston, were made to minimize the overall weight while maintaining durability and functionality.

Each decision regarding cost, size, and weight was based on a thoughtful evaluation of trade-offs and a careful consideration of the project's objectives. We took into account factors such as functionality, performance, budget constraints, and available resources. By finding the right balance between these aspects, we ensured that our submarine system was not only efficient and capable but also cost-effective and practical.

In summary, our design process involved analyzing the trade-offs and rationale for the vehicle's cost, size, and weight. We made informed decisions to strike a balance between affordability and quality, optimize size for maneuverability, and minimize weight without compromising performance. By considering these factors and making well-justified choices, we achieved a submarine system that successfully met our objectives while effectively managing the trade-offs inherent in any design endeavor.

3.4 Vehicle Systems

In the pursuit of a cost-effective solution for our student project, the selection of components and materials was driven by logical and clear considerations of their performance in fulfilling specific tasks. Our budget constraints prompted us to explore innovative approaches, but we also recognized the importance of meeting mission specifications and ensuring reliable performance.

To achieve impermeability for the tank while minimizing costs, we initially attempted to 3D-print O-rings. However, this approach proved unsuccessful during the pressure test, emphasizing the need for impermeability to meet the mission requirements. In response, we made a logical decision to outsource and purchase O-rings from a supplier, prioritizing reliable performance over a smaller budget. This choice demonstrated our commitment to meeting the mission specifications effectively.

Conversely, when it came to the manufacturing of the claw, we found it more cost-effective to produce a significant portion of it in-house. The intricate design of the fingers necessitated the use of 3D printing, which offered a cost-efficient solution. We custom-designed these intricate pieces using Inventor, taking into account the mission requirements of a strong grip to securely catch and hold objects. This approach not only fulfilled the mission requirements but also considered our limited budget, showcasing a logical and cost-effective design choice.

In certain cases, we acknowledged that outsourcing was the most suitable option due to the inherent complexity of certain products and processes. For example, while we designed our own printed circuit board (PCB), we recognized that we lacked the capability to produce it ourselves. Therefore, we engaged one of our suppliers to handle the printing process, ensuring high-quality production while maintaining cost-effectiveness.

Reflecting on our decision-making process, we realized that the mission requirements played a pivotal role in guiding our selection of manufacturing methods. The failed attempt to 3D print the O-rings highlighted the importance of reliability, prompting us to prioritize performance over budget constraints. On the other hand, the decision to 3D-print the claw's fingers and incorporate a corrugated surface exemplified the effectiveness of leveraging advanced manufacturing techniques to meet the mission requirements while optimizing costs.

As a team focused on innovation and continuous improvement, we evolved our designs to meet the mission specifications effectively. We introduced new iterations of essential components such as the PCB, vertical float, and claw, aiming to enhance their performance and functionality. However, we also embraced a reuse strategy by incorporating previously used components for the vertical float and claw. This approach not only reduced material waste but also aligned with our commitment to sustainability while efficiently meeting the mission requirements.

In summary, the selection of components and materials in our design process was driven by a logical and clear understanding of their performance in fulfilling specific tasks in a cost-effective way. We made informed decisions, considering the mission requirements, reliability, budget constraints, and available resources. Our commitment to meeting the mission specifications effectively drove the evolution of our designs, while our focus on sustainability led us to incorporate reuse strategies, reducing material waste.

3.5 Control/Electrical System

The two cables that go directly to the ROV are the power and data (LAN) cables. The power cable goes directly to all motors ESC´s, the actuators controller H-bridge and a buck that regulates the voltage to 5 volts for the microcontroller and main computer. This step down regulator gives power to a raspberry pi 4B (the main brain of the ROV) which connects the cameras and the ROV´s microcontroller which connects to all the sensors. The data cable, a LAN cable, connects to the raspberry too for the main communication with the router outside the pool which connects everything for control and sensor information.

3.6 Described the control system design (to include code, if applicable)

The model of control that was used is the next

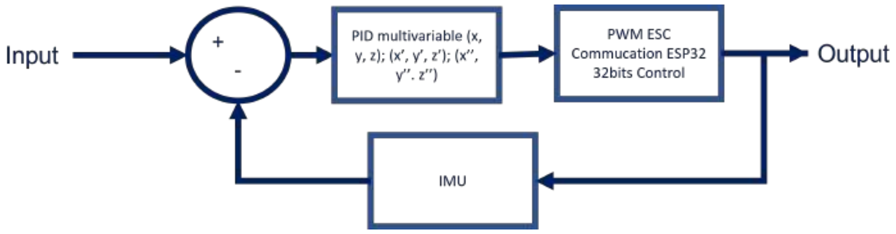


Figure 3: System of control and retroalimentation of the ROV

The official codes of the ROV system are housed in the next link: `https://github.com/DuneV/glowing-enigma.git`

3.6.1 Demonstrated understanding of tether design and requirements

The mechanical properties of the tether lets it have a neutral weight in water which cause almost no effect on the ROV. This is very important for ROV's control algoritms and movement freedom. The main protocol used for communication is UDP, the standard ethernet (LAN) protocol controlled and directed by the router. The other main cable is the power cable. This cable has no neutral weight because of it´s density. In a future it is desired to have floats attached to this cable so it does not effect the ROV´s movement,

3.6.2 Developed and described a tether management protocol

For tether management the tether was rolled in an industrial roller for easy transportation and easy use when needed. Every time the tether is unrolled from the roller it is checked and both cables are separated enough so they do not get twisted with each other while mantaining a safe and organized work zone around them.

3.7 Propulsion

3.7.1 Explained rationale for number, type, and placement of thrusters.

The number of thrusters arranged in the submarine is a total of 6, considering the movements associated with 6 degrees of freedom, for the calculation and movement of these the following states of forces were assumed for the ROV with the next reference of axes. (The approximate mass is close to the 15kg).The thrusters used are the t200 by blue robotics, that give us a waterproof option that consumes a low power in comparison with other brands, with a precision of PWM that could adjust through the microcontroller.

The thrusters that are in the base are placement at $\pi/4$ respect the opposite of the main axe.

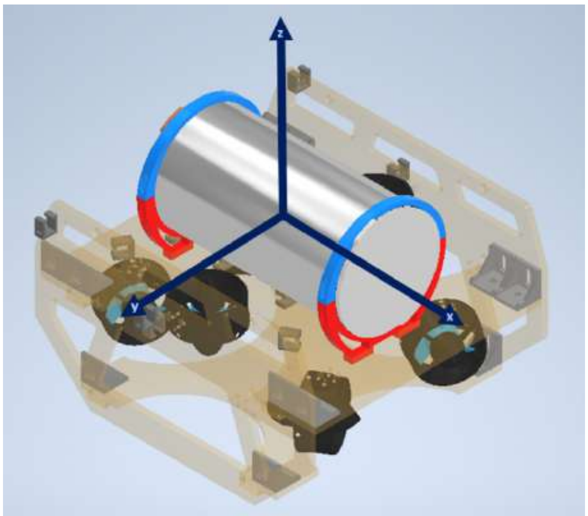


Figure 4: Disposition of the main axes on the ROV chassis

So, doing the force balance, we obtained the expressions.

$$\sum F_x = 4 * Fm * sin(\pi/4) = 15kg * a \tag{15}$$

Where the F_m is a regular to a 12v and 1300 microsecond assuming symmetry in the graph is 1.02 kgf converting this to newton we have, 10N of force.

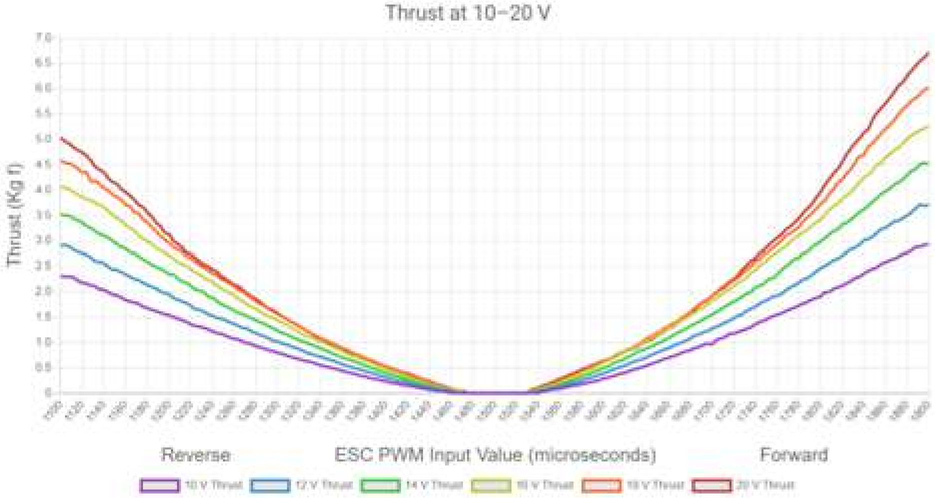


Figure 5: Blue Robotics T200 Thrust force vs ESC PWM

Obtaining the next force in this axe.

$$\sum Fx = 4 * Fm * sin(\pi/4) * 10N = 15kg * a \tag{16}$$

$$a = \frac{40N}{15kg} = \frac{2.6m}{s^2} \tag{17}$$

So, the force is adjusted to take advantage of 4 times the force on an angle of $\frac{\pi}{2}$ in the axe with an average acceleration of $2.6m/s^2$, configurating the direction of the thrusters of the movement. Taking into account this, it fulfills with the next relation.

$$\sum F_x = \sum F_y \tag{18}$$

To optimize this, we must consider that the center of mass is equidistant to all the thrusters, implicating that we are not considering the z axe.

In this case the ROV is prepared to have neutral buoyancy, therefore this is disposed in the middle of the x axe of the ROV, avoiding generating some change in the center of mass. So, in the z axe we have the next expression of force in the ROV.

$$\sum F_x = 2 * F_m = 15kg * a \tag{19}$$

$$a = \frac{20N}{15kg} = 1.3\frac{m}{s^2} \tag{20}$$

Saving energy on the movement of this axe. The complementary movement is rotatory that adds maneuverability to the ROV, taking the inertia of the z axe. Calculating this by Inventor software we obtain $0.867kgm^2$, in terms of an approximate. Thanks to that we can use the equivalent in terms of the rotation plane of the newton equation. Obtaining this expression. (Note: the distance between the thruster and the center of gyro is 0.18m)

$$\sum_{z}^{w} \Gamma_z = I * \alpha = 4 * 0.18m * 10N \tag{21}$$

$$0.867kg * m^2 * \alpha = 7.2N * m \tag{22}$$

$$\alpha = 7.7\frac{rad}{s^2} \tag{23}$$

Having the 4 thrusters in the direction of the gyro making the most of them.

Described trade-offs to balance power consumption, cost, performance, and mission requirements.

The consume by each thruster at the usual speed of use is 3.1 A with a voltage of 12v, with this we can multiply obtaining 223.2w of power consumption with all the motor enable, nevertheless in the restriction of 12v 25A, we manage the power of the z axes thrusters with a lower PWM when the motor of movement on the x and y axes are enable to control the power consumption, and taking into account the consume of the raspberry, 2 linear actuators and the cameras, are close to 60 w.

In normal conditions, the consumption of the ROV is controlled below 250w with all connected and enabled. The cost of the product can be control thanks to the access that currently we have to the laboratories of manufacturers in the University the penetrator and the arm, the encloser of different cameras are manufactured by us, also we have many pieces that are 3D printed, assuming that the electricity cost and a 3D printer is a cost assuming by the University.

The case of the design of the PCB was made by us. The case of the manufacturer is an enterprise called “Microcircuitos” that finances the development of this. We use the cheapest microcontroller that supports microros that is the newer version of rosserial for ROS2, to communicate with the raspberry thought topics.

In the case of performance, the calibration and characterization of the thrusters help to improve the minimum cost of the movement in the water. Optimization the energy that must be distributed to them. Moreover, the use of a pocket pc as a raspberry based on the ARM architecture allows us to spend less current on this to use in the 3D cameras and the ML processing.

To improve the mission requirements, we use Robot Operative System (ROS) in the version 2 and the distribution humble this is a middleware that helps to connect different languages in c++, python and Java, all connecting through the topics of ROS, using an interface of packages, on the operating system GNU Linux with the distribution Ubuntu 22.04 Jelly. Making it easier to connect all the software parts from different high-level languages.

4 Buoyancy and Ballast

4.1 Description of buoyancy system that demonstrated application of buoyancy principles.

Neutral buoyancy is a state in which the density of the submarine's chassis is equal to that of the surrounding water. This balance is sought to avoid unnecessary energy expenditure. When the submarine has neutral buoyancy, minimal effort is required to maintain its position in the water and make depth changes.

By achieving neutral buoyancy, the submarine does not tend to sink or rise naturally, allowing for better control and maneuverability. This prevents wasted energy in constantly correcting the submarine's depth and contributes to a more efficient use of resources.

To attain neutral buoyancy, we have conducted various calculations and tests. This involves adjusting the volume and weight of the submarine by incorporating additional flotation devices when introducing new elements and components. These evaluations ensure that the modified weight is properly balanced, preventing the submarine from becoming too heavy or light in relation to the surrounding water.

The objective of seeking neutral buoyancy is to maximize the submarine's energy efficiency and optimize its performance in terms of maneuverability and control. By maintaining a proper balance, we can reduce the efforts required to maintain the submarine's position and minimize expenses associated with energy consumption, thereby contributing to a more cost-effective and sustainable operation.

5 Payload and Tools

5.1 Explained rationale for number, type, and placement of cameras

To fulfill the submarine's missions, two cameras are installed: a standard Nexigo 1080 web and an Intel Realsense D-435 located at the front of the submarine inside a tank compartment, so movement in all axes is critical. to guarantee its operation and the fulfillment of the assigned tasks.

The selection of these cameras is done by dividing the two main functions of the submarine, among which is the vision of the space through which it is navigating and the tasks that the submarine must fulfill.

Due to its low complexity when transmitting, the nexigo camera was chosen to be our eyes while the submarine is underwater, fulfilling the navigation requirements. For the fulfillment of the tasks, the realsense camera is used due to its characteristic of providing depth to the image it transmits, helping to implement the algorithms designed for each mission.

5.2 Payload tools were designed to meet mission requirements

For the programming part of the submarine there are two stages, one of the stages is the control and management of the submarine which is supported using algorithms generated in the language of python and ROS from ubuntu. Tools such as github, platformio and visual studio code are used to load these codes.

The other stage consists of carrying out the tasks that the submarine must fulfill, which are mainly programmed in python language and loaded in visual studio code. The only exception is the underwater rope damage detection task which uses notepad and assembler to run the algorithm.

Sensors were designed or selected to meet mission requirements

To have a security control and a good management of the submarine in general, the decision was made to use different measurement sensors such as: DHT11 temperature and humidity sensor, Internal pressure sensor, External pressure sensor, IMU and Leak sensor to be able to guarantee navigation and operation for the time required to accomplish all the missions.

The tasks that the submarine must fulfill will be carried out through the cameras installed in it, through the images that they capture, the different evaluations are carried out in each test environment.

6 Build vs. Buy, New vs. Used

When working on a student project with limited funds, budget becomes a crucial factor in material selection. In our endeavor to save money and explore innovative solutions, we decided to 3D-print O-rings for the tank to achieve impermeability. Unfortunately, this approach failed the pressure test, highlighting the importance of ensuring impermeability to meet the mission requirements above having a smaller budget. As a result, we opted to outsource and purchase O-rings from a supplier to ensure reliable performance.

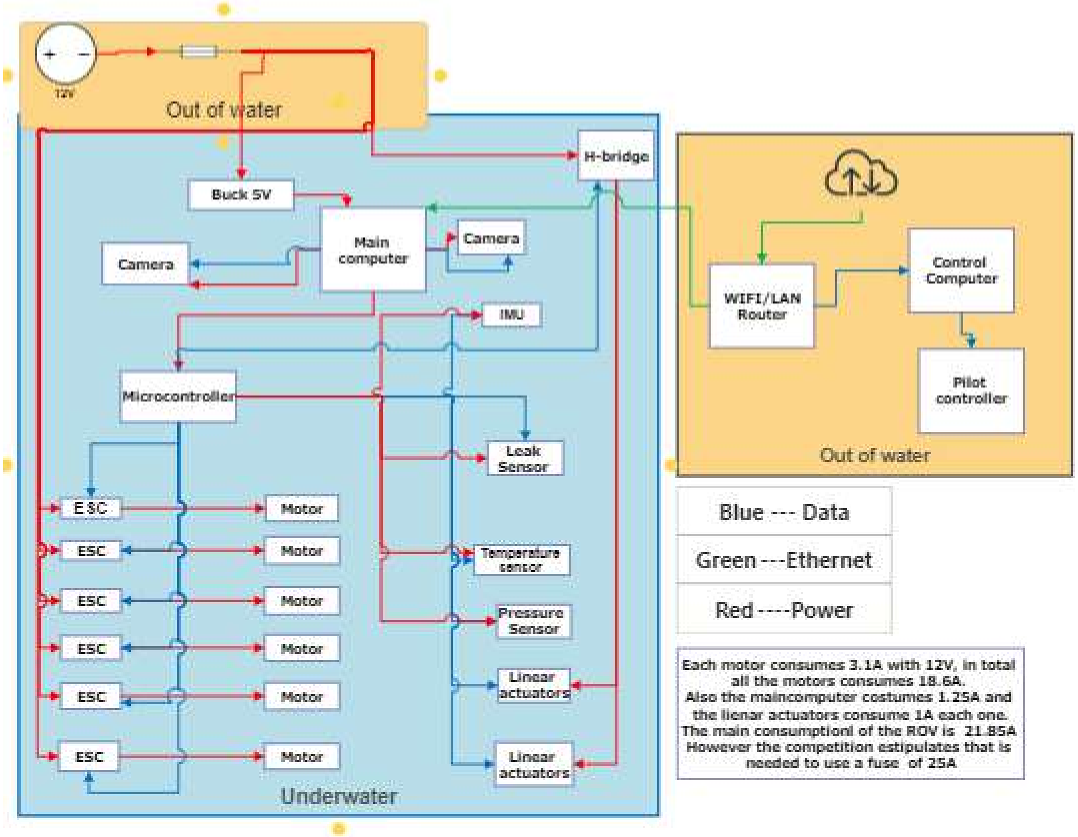
Conversely, for the manufacturing of the claw, it was better to build a significant part of it in-house. The intricate design of the fingers required the use of 3D printing. This decision also extended to other intricate pieces, which we custom-designed using Inventor. Specifically, in the case of the claw's fingers, adhering to the mission requirements involved designing them with a strong grip in mind, ensuring the ability to securely catch and hold objects. This approach not only met the mission requirements but also considered the limited budget.

Additionally, certain products and processes are inherently complex, requiring outsourcing. For instance, even though we designed our PCB, we could not produce it ourselves. Therefore, we engaged one of our suppliers for the printing process.

Reflecting on our decisions, we recognized that the mission requirements played a crucial role in determining the appropriate manufacturing methods. While the attempt to 3D print the O-rings did not meet the impermeability standards, it reinforced the importance of reliability. On the other hand, the decision to 3D-print the claw's fingers and incorporate a corrugated surface exemplified the effectiveness of leveraging advanced manufacturing techniques while keeping a limited budget in mind.

Innovation drives us to constantly improve our designs and strive for the best iteration of our product. In comparison to the previous year, we have introduced new iterations of our PCB, vertical float, and claw. However, we also implemented a reuse strategy by incorporating previously used components for the vertical float and claw, effectively reducing material waste. This decision aligns with our commitment to sustainability and meets the mission requirements efficiently.

7 System Integration Diagrams



Each motor consumes 3.1A with 12V, in total
all the motors consumes 18.6A.
Also the maincomputer costumes 1.25A and
the lienar actuators consume 1A each one.
The main consumptionl of the ROV is 21.85A
However the competition estipulates that is
needed to use a fuse of 25A

Figure 6: SID

The diagrams consist in a superficial review of the cont

8 Safety

8.1 Safety Procedures

Regarding security protocols The submarine handles enough power to cause harm to the user or to surrounding aquatic life. Among other dangers there is also the risk of entrapment with the motors. For this reason, different security protocols were designed and are carried out when using the submarine.

8.1.1 Electronic review protocol

Before submerging the robot, the power connections and the joints of the cables must be checked away from the water. Once this system is completely checked and in good condition, the main power is connected and the voltage level in the interior of the tank is checked. While there is no electronic component overheating or acting different from how it should, the ROV can continue it´s way to the water.

8.1.2 Sealing and pressure protocol

After review and approval by the electronics, the process of sealing and verification begins. The submarine must be subjected to a depressurization of up to 15 inHg and must maintain this pressure for a minimum of 20 minutes. Once this is accomplished, the tank can be re-pressurized, the valve hole sealed, and proceed with submerging the robot.

8.1.3 Immersion protocol

The robot must be energized out of the water and when power is confirmed, it is left in the water and waits for confirmation from the control interface. The control interface is a device or several to which the robot will be connected and from where it will be controlled remotely. When there is confirmation from the control interface, the movement tests can be carried out. There will only be interface confirmation when the information from the cameras and sensors is correctly received. To start the movement of the robot, all the basic movements must be tested to verify their correct operation and it must be verified that each movement is in accordance with the order given and the information from the cameras and sensors.

9 Critical Analysis

Throughout all tests made with the ROV there was always something to learn and improve. That's why this troubleshooting analysis is important for all future tests. When there is a problem while running a test with the ROV there should be always a fast reaction from the team depending on the problem. There are three types of main problems that have been found with the ROV: electronical problems, sofware problems and mechanical problems. Mechanical problems usually are solved or verified before the ROV enters the water, there should not be any contact with water before the ROV passes all mechanical tests. Electronical problems and software problems may be identified usually in the water. There are multiple electronical components with LED´s which provide visual confirmation for the ROV functioning while for software confirmation there are multiple internal communication confirmation tests for the ROV.

10 Accounting

10.0.1 ROV general Cost and Travel budget

Total cost			
Item	Cost per unit	Qty	Total
Chassis and tank			
Acrylic	264 USD	1	264 USD
Aluminum	110 USD	1	110 USD
Penetrators	85.80 USD	1	85.80 USD
3D printed pieces	33 USD	1	33 USD
DATA wire 100m	400 USD	1	400 USD
Power cord 50m	184.80 USD	1	184.80 USD
screws	22 USD	1	22 USD
O-rings	22 USD	1	22 USD
Floater			
aluminum rods	3.96 USD	6	23.76 USD
aluminum-cylinder Ø150mm*250mm	146.08 USD	1	146.08 USD
Filament PLA	17.60 USD	3	52.80 USD
ESP-32	9.46 USD	1	9.46 USD
PVC 4”*1m	3.94 USD	1	3.94 USD
Hardware			
ESC	36 USD	6	216 USD
Engines	200 USD	6	1200 USD
Anderson conector	5 USD	15	75 USD
PCB	134.14 USD	2	268.28 USD
Leak Sensor	3 USD	5	15 USD
DHT22	9 USD	3	27 USD
IMU	7.59 USD	1	7.59 USD
Shipping	230 USD	1	230 USD
pressure sensor	1.39 USD	1	1.39 USD
Consumables			
Wires	11 USD	1	11 USD
Screws and nuts	22 USD	1	22 USD
3D printing filament	110 USD	1	110 USD
Conectors	50 USD	1	50 USD
Tin	11.22 USD	1	11.22 USD
Heat shrinkable	0.59 USD	20	11.88 USD
Tie ups	1.10 USD	20	22 USD
Manufacturing			
Manufacturing	1000 USD	1	1000 USD
TOTAL			
-	-	-	4771.19 USD

Since our creation in 2020, we have been supported by our university. The department of Mechanical engineering of the university have given us 3000 USD and access to laboratories and machinery to manufacture and print various pieces of the submarine. Additionally, the department of Electrical and Electronic Engineering have provided us with spaces to work and 1000 USD. The remaining costs have been obtained thanks to our sponsors; we have had the opportunity to work along a printed circuit company (Microcircuitos) and a software company (Ekumen).

Description	Quantity	Unit cost	Total
Flight BOG-MIA-BOG	10	$437	$4370.00
Flight MIA-DEN-MIA	10	$509	$5090.00
Car rental	2	$763.84	$1527.68
Hotel (Comfort Suites Longmont)	10	$201.5	$2015.00
Meals	10	$60	$600
Snacks, drinks, etc.	10	$15	$150
Others		$500	$500
Total price	$14252.68		

For the financing our travel, our university will help with the costs of plane tickets. For the hotel, some members will finance their stay themselves while others will be financed by Ekumen, a robotics company that sponsors our projects. The transportation of the submarine and our members will be financed by the engineering faculty of our university. Costs related with food, drinks and others will be covered by each member of the team individually.