TERRA Technical Design Report - RoboSub 2021

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Abstract – **In 2021, the TERRA Team performs its first participation in RoboSub representing the Federal University of Santa Catarina - Campus Joinville. AUVille is the AUV developed by the team for this edition of the competition, which has a resistant and light structure, in addition to having a cooling system specially developed to soften the internal temperature of the electronic watertight enclosure. In addition, this AUV has excellent battery life to perform competition tasks such as identifying and passing through the gate. For vehicle automation, codes were developed in ROS and with regard to image recognition, OpenCV libraries were used. Another important point of this project is the improvement of the mission through the analysis of data collected from the sensors. As a result of the COVID-19 pandemic, the physical distance was respected, for these reasons all experimental results were obtained through simulations.**

Index Terms – **autonomous, underwater, vehicle, cooling system, computer vision, simulation**

I. Competition Strategy

As it is a new team, TERRA developed the project from a remotely operated vehicle (ROV), performing the automation in such a way that the vehicle could fully autonomously recognize and pass through the gate, which is the main task proposed by RoboSub, in a quick and efficient way.

Considering the structural part of the vehicle, it was decided to keep part of the ROV design, and furthermore, an expansion of the vehicle structure was carried out to allow it to be possible to allocate new components. In addition, the vehicle structure is resistant and light due to the characteristics of the materials used. A whole energy system approach was studied so modern solutions could be implemented that would allow a great autonomy of the vehicle without compromising the vehicle's total weight. In order to obtain better performance from the vehicle, it was equipped with angled thrusters that provide the four degrees of freedom: surge, heave, pitch and yaw. Another important point was the development of an internal cooling system in the watertight enclosure that hosts the electronic components to maintain the proper temperature for the best operation of the vehicle.

For the electronics part, the main challenge was vehicle automation so that the AUV was able to carry out the projected mission and to take decisions in a completely autonomous way in a short period of time. Besides that, an image processing system was designed to guide the vehicle during the mission and an analysis and improvement system, which through the evaluation of data collected by the sensors, enables new improvements to be implemented in the vehicle in the future.

II. Design Creativity

A. Structure

For the design of the AUVille, two possibilities were initially analyzed, one of which would be to continue with the design of the BlueROV2 by the American company BlueRobotics, which is the equipment that the team physically has in its laboratory (Naval Simulation Laboratory - LaSiN). The other possibility, this year being a concept edition of the RoboSub competition, would be to create a completely new design. After several discussions and surveys of positive and negative points, the team concluded that following the design of the equipment already owned by the team would be the most appropriate path, because new solutions developed during the project may in the future be tested experimentally and actually implemented.

In this way, the team improved the initial design of the ROV, incorporating another frame and watertight enclosure, to allow the allocation of more batteries, thrusters and new components should the need arise in the future. It is noteworthy that the frame and additional watertight enclosure are made of the same material as the original ROV components, which are high density polyethylene (HDPE) and cast acrylic, respectively. These materials were selected because they have good physical properties, HDPE has resistance to high stresses and low density when compared to other materials, while cast acrylic has excellent resistance to mechanical stress and good thermal stability.

Therefore, the structural part of the vehicle with all its electronic components and thrusters is about 15 kg and the total weight of the batteries proposed for this project is 2.11 kg thus resulting in a final weight of 17.11 kg for the complete AUVille set. The modeling of the complete structure carried out in the ANSYS software can be seen in the figure below:

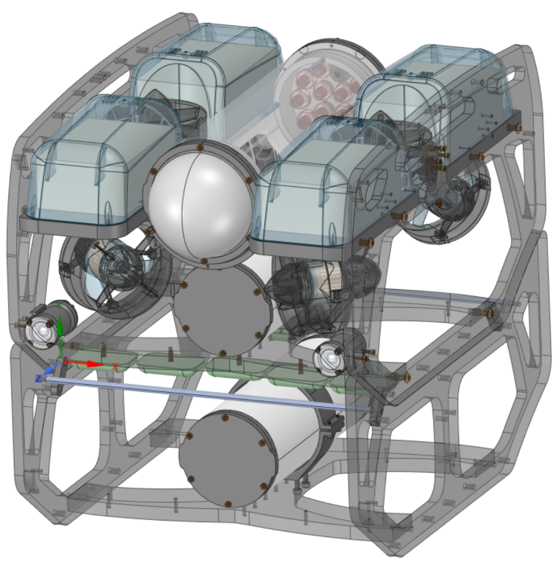

Figure 1: Modeling the AUVille in Ansys.

Due to the impossibility of carrying out experimental tests, the TERRA team chose to use a simplified model of the vehicle's geometry, maintaining the dimensions in order to guarantee the obtainment of results with a high level of reliability in a shorter period of time. For this, the team based itself on the discussions proposed in the article written by Li et al.[1], which presents a model for carrying out simulations for a BlueROV2. Therefore, in order to certify that the simulation results would be reliable values, the team initially simulated a structure similar to the one used in the article and adopted the same parameters. The results obtained were compared and necessary adjustments were made until the error between the result shown in the article and the one found by the team was very small.

With the safe results provided by simulations, the simplified structure of the AUVille was in fact modeled also through the ANSYS software, as can be seen in Figure 2 which shows that all structural components of the vehicle were modeled using simple geometries and the appendices were disregarded. Then, the structural and hydrodynamic simulations were accomplished, and with the analysis of the results it was possible to select the best solutions to be implemented in this project.

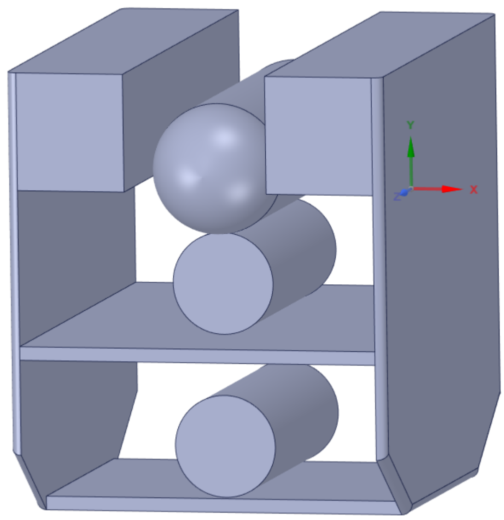

Figure 2: Simplified modeling of AUVille on Ansys.

B. Propulsive System

Regarding the AUVille propulsion system, the team chose to maintain the commercial configuration of the BlueROV2 equipment, due to the impossibility of performing tests in water to validate the new configuration. Hence, four horizontal thrusters angled at 45º and two vertical thrusters were maintained, with this vehicle having the ability to move in surge, heave, pitch and yaw directions. The maximum and operating speed of the vehicle, as well as the voltage required to supply the thrusters, were defined after studying the values found in the hydrodynamic simulation.

C. Energy of the system

The main challenge system was to propose a solution that would allow the vehicle to have a good autonomy without compromising the performance of the electrical components and in order to add as little weight as possible to the structure. To assist in choosing the solution, members of this sector carried out a survey of the vehicle components that consume the most energy in the system, namely the thrusters and electronic components: Raspberry, Pixhawk and ESCs.

Next, the specifics of each of them were analyzed and it was noted that the electronic components in general work at a lower voltage than the thrusters, so it was decided to divide the power system into two circuits, one to power the thrusters and the other to power the watertight enclosure that houses the electronic components, because that way it would be possible to find an ideal battery solution for each of these circuits and it would not be necessary to use a component to reduce the voltage that feeds the electronic components. Herewith, it was also established that the batteries would be placed in the vehicle in different enclosures, with the upper one for powering the electronic components and the lower one for the thrusters.

From this, it was possible to study the best battery configuration to be implemented for each of these circuits. Extensive research was carried out regarding modern battery solutions, and according to the analysis presented by Warner [2] in his book, lithium-ion batteries composed of nickel, cobalt and aluminum (NCA) are the ones with better energy density results than batteries composed of other chemical components.

Thus, with the results of the hydrodynamic simulation and based on technical information from the manufacturer Samsung, it was possible to define an efficient battery configuration that abides all the requirements of this project.

D. Cooling System

Currently, a major challenge faced in electronic systems is the heating of their components due to the increase in the intensity of electrical current resulting from the implementation of new functions and the simultaneous operation of subsystems.

Applying this context to the BlueROV2 operated by the team, converting it to an AUV required the development of a new cooling device for the installed Raspberry processing unit, as its overheating at temperatures above 65°C implied a critical reduction in the autonomy of the vehicle, preventing the performance of the designated activities, as well as reducing the useful life of the component due to the thermal work cycle to which it was submitted.

In face of such problems, an analysis of the initial watertight enclosure dissipation capacity and the survey of the unfavorable cooling characteristics of the system were carried out. In which it was observed that the thermal exchange was performed via free convection with the air inside the watertight enclosure. The low thermal conductivity of the air and the polymeric walls of the watertight enclosure, together with the inefficiency of free convection in heat exchange, imply a high thermal resistance between the electronic components and the external environment. Thus, it was essential for the effectiveness of the project that this resistance be reduced.

Based on this, some constraints and selection criteria were listed, as follows:

1. Difficulty in repositioning components and spatial restriction, so the designed device would need to be spatially efficient, allowing localized cooling, with minimal change from the original position of the hot source(s).

2. Alteration the transport mechanism and preservation of structural integrity and tightness of the watertight enclosure, as the low thermal conductivity of the polymer structure and the air in the immediate vicinity of the electronic components was verified, the team chose to develop a device that prioritized the transfer by conduction of the heat generated in the processor to water in the external environment. This solution invariably involves replacing the watertight enclosure wall material in some region. Structurally, this variation in composition and geometry im-

plies stress concentrations at its borders, affecting the mechanical integrity of the watertight enclosure. Inserting a discontinuity in the wall also imposes mounting method analysis in order to avoid water entering. Thus, the proposed solution should be designed in such a way that its installation requires minimal alteration to the original structure and ensuring its watertightness.

3. Restriction of energy recruitment, which preference was given to the use of solutions that worked independently of the battery, so as not to compromise the autonomy of the AUV. Thus, solutions involving the use of compressors, fans or other electrically active thermal control devices should be avoided.

4. Reduction of electromagnetic noise, avoiding the use of components that generate or propagate magnetic fields, due to their interference in the calibration of AUV sensors.

Having identified all these restrictions and knowing the importance of implementing an efficient cooling system, it was possible to propose several solutions. Among them, there is the forced convection cooling system (type A/C), which would consist of removing heat from the components affected by overheating through the forced circulation of cooled air inside the AUV watertight enclosure. However, this solution was discarded due to inadequacy of constraints 1, 2 and 3.

Another solution proposed with this previous solution was the implementation of a water cooler that would have a similar operation. Here, however, the heat would be removed from the processors by conduction via conduits containing water. This, when heated, would be pumped out of the watertight enclosure and come into contact with the external flow for cooling. The liquid would then return to the interior of the watertight enclosure, where the process would be repeated. However, this solution was discarded due to inadequacy of restrictions 1 and 2.

The use of a circular flange was also considered, in which critical electronic components would be relocated to the periphery of the watertight enclosure, where via contact with a conductive flange, they would transfer by conduction the heat generated in operation to the water flowing around the AUV. But this solution was disregarded due to restrictions 1 and 4.

According to the information mentioned, the team defined the final characteristics of the thermal control device to be implemented in the AUV, which is described in detail in the results section.

E. Software

The electronics sector is responsible for all the AUV's electronics related parts, which goes from the codes that were created and adapted up to the selection of the electronic components such as circuit boards and PCB (printed circuit board) development. In order to build the code for the AUVille, the team decided to split the sector into two fronts: one working with Python and C++, using ArduSub packages and software from the ArduPilot project open sources, while the second would be working with ROS (Robot Operating System) using GitHub's repository as a base. The decision to follow these two approaches was due to the proximity and familiarity with the systems, in addition to providing a "backup" for any difficulties that could come up later during the project. Then started the vehicle automation through Python by establishing an initial connection using ArduSub's pymavlink protocol with the QGroundControl simulator, in order to develop a simple initial code to establish a connection between the software and the Pixhawk and test all the degrees of freedom that the AUV has. Once all these initial steps were successfully concluded, it was possible to start testing with more complex and used simulators. Therefore, the attempts to set a connection between ArduSub's software and Gazebo Robotics Simulator began, however, since the preexisting documentation is quite diversified, it was difficult to connect the two softwares. As a way around this problem, the team decided to turn to ROS.

For ROS, the team used a GitHub's repository preexisting code with some modifications to suit the team needs. The first modification was to make it autonomous since the original code was for ROVs. The communication was established through a connection emulator code using the MAVROS protocols and pymavlink once more, making the execution commands come from the image recognition and no longer from an external connection. This avoided having to create a specialized code (or an AI) for the decision-making during the mission, providing a time-saver to refine the control code.

In the following flowchart, the code is presented illustratively, listing all its divisions and modules:

1. Check if all components are operational for the mission.

2. Responsible for recognizing the shapes obtained by the camera.

3. Performs simplified processing, recognizing and double checking the results.

4. Main control code where data is processed.

5. Analyzes the collected data so that the system makes the best decision.

6. Perform the action decided on in the previous step and the movement of the vehicle begins.

7. Execute the command using mostly basic control codes present in the standard package.

8. At the same time, in a separate module, called the T.A.R.D.I.S. module, all critical information from the sensors and components is collected, saving on a micro SD card in '.txt' format for eventual case studies and graphic analysis.

9. Finally, there is the S.O.S. Button, responsible for interrupting the mission at any time by anyone who presses the button.

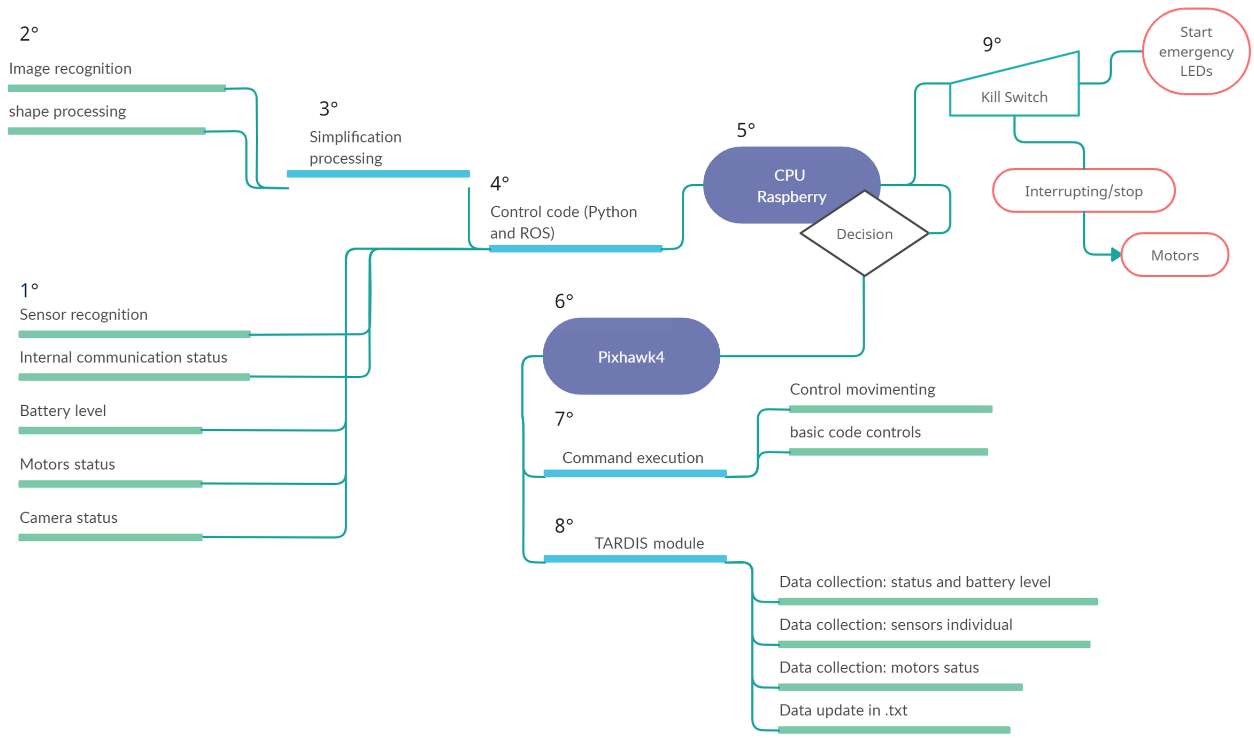

Figure 3: Electronic system flowchart.

F. Computer Vision

For the image processing part, the team chose to use conventional vision tools to perform these tasks to detect the objects involving the competition activities, rather than using machine or deep learning. The computer vision tool chosen to be used in the project was the OpenCV library with the code implementation being done in Python. This choice was made for two main reasons, the first being the computing limitations regarding the deep learning tools that the team currently has, since the team only dispose of a Raspberry Pi 3B+ for this task. The second reason is related to the lack of a substantial dataset for the training process of a neural network for the image processing part, that would lead to unsatisfactory results and would require reworking on this topic.

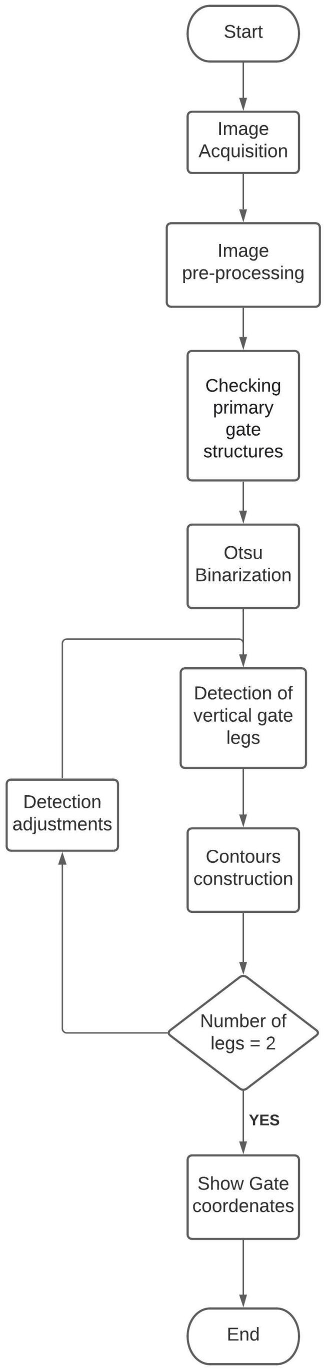

Figure 4: Computer vision flowchart.

The code implemented through OpenCV uses the library standard methods to detect the competition's portal, a qualifying task in this competition. It operates by tracking down the vertical bars found on the portal and determining their coordinates. This detection is done using OpenCV's morphological operations [3], which spot the vertical and horizontal lines in images. So, after the identification of the central coordinate of the gate, the system also identifies the center coordinates of the chosen character, that in this case was a police officer. Figure 4 shows a flowchart demonstrating these steps programmed into the team's image processing code. After providing the coordinates of the portal and of the police officer in the image, this data can be sent to the AUV's control code that will activate the thrusters according to the direction the vehicle should follow to pass through the gate by the previously selected side.

G. T.A.R.D.I.S module

The AUVille's project also included a module to collect all the data from the AUV's sensors individually (barometer, gyroscope, velocity, compass, energy consumption, motors and camera status) and separate them into txt files. This will allow the team to plot graphs using the extracted data to study and evaluate the system's performance. Lastly, from the analysis of the collected information, new solutions and improvements could be suggested in the future to further optimize the vehicle's performance.

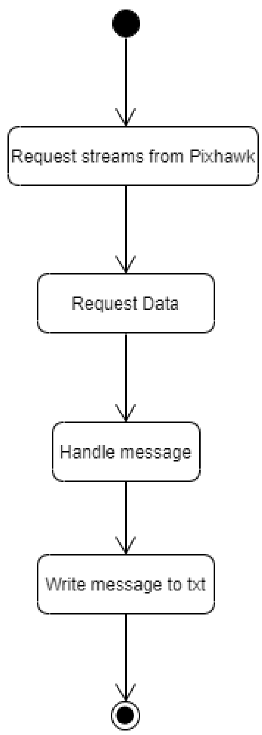

Figure 5: Flowchart of the T.A.R.D.I.S module

In this sense, it was established that the data should be updated between 1 and 2 seconds apart. The files will be saved in a micro SD attached to a microcontroller that will collect the data. Since it is extremely important for this module to be independent from the rest of the electronics, mainly so as not to impair the performance of the system and to reduce the number of update cycles, this module will be powered directly by the same power supply as the electronic components and will consist of an Arduino nano and a memory card, taking as little space as possible.

H. Security System

Because the AUV is a vehicle that during the mission must do its tasks autonomously, it is necessary to implement a safety system in case of some unanticipated, that was not considered in the pre-programing stage, occurs. Therefore, the team created a code and modeled a shutdown button that once pressed will turn off the thrusters, so that the vehicle enters a safe mode for its retrieval and does not put at risk the diver who approaches to perform the rescue.

The modeling of the button was done using SolidWorks software. A simple and easy design was sought, but with sturdy and reliable components in order to ensure that the button actioning can be done in a fast and safe way. Meanwhile the code was developed in order to deactivate the thrusters by cutting the power to these components as soon as the button is pressed. In this way, the propulsive system should remain deactivated until the vehicle is rescued and the diver is allowed to press the button again to continue the mission.

Detailing the operation of the shutdown button, initially, as soon as it is pressed, the system is put into safe mode. In this way, AUVille suspends the execution of the mission and turns off the thrusters. At this point, the AUV was also programmed to flash its four LEDs, equipped according to the standard S.O.S. signaling, to indicate to the rescuer that it is safe to approach and handle the equipment. Lastly, if the button is pressed again while in suspended mode, the system will resume normal operation and will signal this by fully lighting the LEDs.

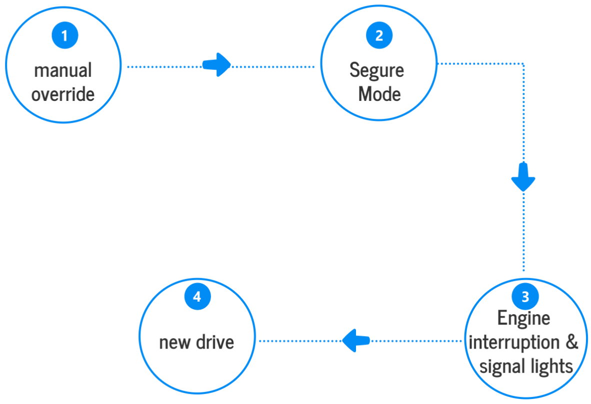

Figure 6: Mechanism to switching off the AUVille.

III. Experimental Results

A. Structural Simulation

The structural simulation were performed using ANSYS software to determine internal and external forces and the corresponding stresses, as well as the determination of displacements and corresponding deformations of the designed structure, so that with the obtained results, it was possible to understand if the structure would resist to all tensions that would act throughout the mission.

It was determined as input parameters the mass of the structural part of the AUV (15 kg), disregarding the batteries that were still in the selection process. HDPE material was applied to the frames and cast acrylic for the watertight housings. In addition, the team considered a pressure of 4 MPa, which is considering the AUV acting in the deepest part of the pool available at the venue. Finally, the supports were evaluated on the sides of the structure.

With the structural simulations performed, it was possible to analyze the deformation results, as well as Von Mises Stress and Equivalent Elastic Stress. The region of greatest stress in the structure is the main watertight housing that will house the electronic system, the results indicate that this component will suffer the greatest deformation and structural stress, however all values found are within the limits allowed by the materials, taking into account also an appropriate safety factor. Figure 7 depicts the values obtained from the analysis of the Von Mises stress, which in the most critical region reaches 48.58 N.

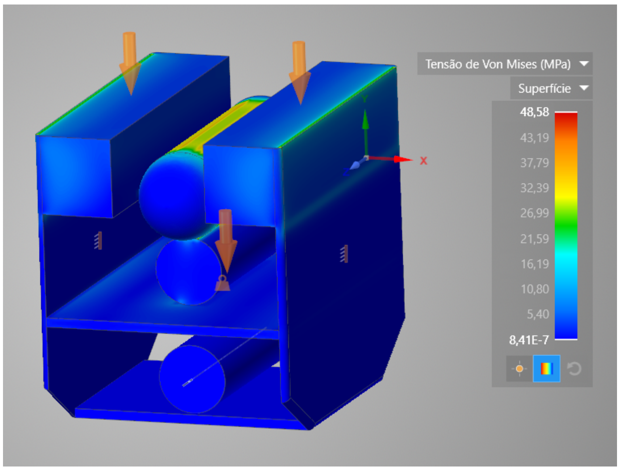

Figure 7: Von Mises stress analysis.

B. Hydrodynamic simulation

The behavior of fluids is not very intuitive, making it very difficult to predict its impact on projects. It is very common to conduct tests in water to understand the behavior of the vehicle in operation. However, due to the impossibility of conducting experimental tests, the team also used ANSYS software to simulate the flow behavior and analyze the obtained results.

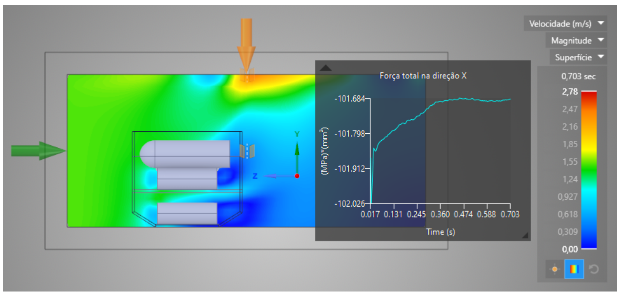

Figure 8: Analysis of total force and velocity on the x-axis.

For this simulation, water at a temperature of 20 ºC was considered, with a flow velocity of 1.5 m/s (equivalent to 3 knots) and a pressure of 4 MPa. As a result of the conducted simulations, it was possible to understand the speed, pressure and drag force on the AUV hull. Figure 8 shows the maximum drag force (101 N) applied on the AUV in the x axis direction. From this result, the selection of the correct power supply voltage of the thrusters were possible and thus selected the battery configuration most suitable for the project.

C. Battery selection

From the results found in the hydrodynamic simulation, it was possible to identify the voltage required to power the thrusters so that the drag force was overcome and the AUVille could navigate with an appropriate speed during the mission. Thus, for each speed simulated in the previous item, the vehicle's autonomy was determined. From the analysis it was possible to observe that the maximum speed of the vehicle would be 3 knots and that the ideal operational speed would be 2 knots.

In order for the team available to carry out the mission until the battery was fully discharged, the team configured two lithium-ion batteries with the aim of meeting all the project's requirements. For this reason, information on the performance of lithium-ion batteries chemically composed by NCA produced by the manufacturer Samsung was collected, the main information is available in the table adapted below:

TABLE
Battery Performance

Current (A)	Time (min)	Temperature (ºC)
3	59.1	33.7
5	35.4	41
10	17.7	60.9
15	11.7	81.2
20	8.6	99.4

Through the information collected it's possible to observe that the longer battery life and the lowest heating system is reached when the current has a value of 3 A. From this, it has been established that the battery that will supply energy to the six thrusters must be composed of five cells in series and six in parallel (5S6P) and will be able to supply 18V to the thrusters for approximately 59.1 minutes. The battery that will power the electronics watertight enclosure will be composed of two cells in series and seven in parallel (2S7P) enabling the supply of 7.2 V to the electronic components with the same autonomy as the other battery. Additional technical information about each of these batteries is available in the component specification tables in Appendix A.

This solution founded by the team met all the requirements and restrictions of this current project, providing a good autonomy without impacting the vehicle's performance with respect to its operating speed and structural weight.

D. Cooling Solution

Based on the project constraints and through the discussed discarded solutions, the team defined the final characteristics of the thermal control device to be implemented in the AUV, which it was concluded that a conductive base will be mounted on the Raspberry processor, adhered via thermal paste. From this base, the heat produced will be conducted by a heat pipe to the heatsink, a conductive component installed through the watertight housing wall. The coupling of the heat pipe to the heatsink will also be done through a conductive base. The interface of this assembly will be filled with a thermal epoxy adhesive. Observing the low thermal conductivity of this adhesive in relation to the metallic materials of the set, the dimensional adjustment of the coupling will be such that, while still guaranteeing adhesion, it will minimize the thermal resistance at the interface.

In order to avoid heat transfer via internal natural convection by air in the vicinity of the components, the entire surface of the assembly (bases, heat pipe and heatsink) exposed to the internal air will be enclosed by an insulating film. Recalling the discussion made in restriction 2, the effectiveness and efficiency of the device are linked to the proportion of heat conducted through the set in relation to that transferred to the air inside the watertight enclosure.

Since the heatsink will be mounted through the wall of the structure, there is a concern with stress concentration and tightness after installation. The solution found by the team consists of machining a single circular hole in the wall, avoiding geometries with sharp edges and installing the heatsink by treating the surface of the interface with a primer and applying a polymeric sealant, similar to that used in the automotive industry in the adhesion of glass to metallic components.

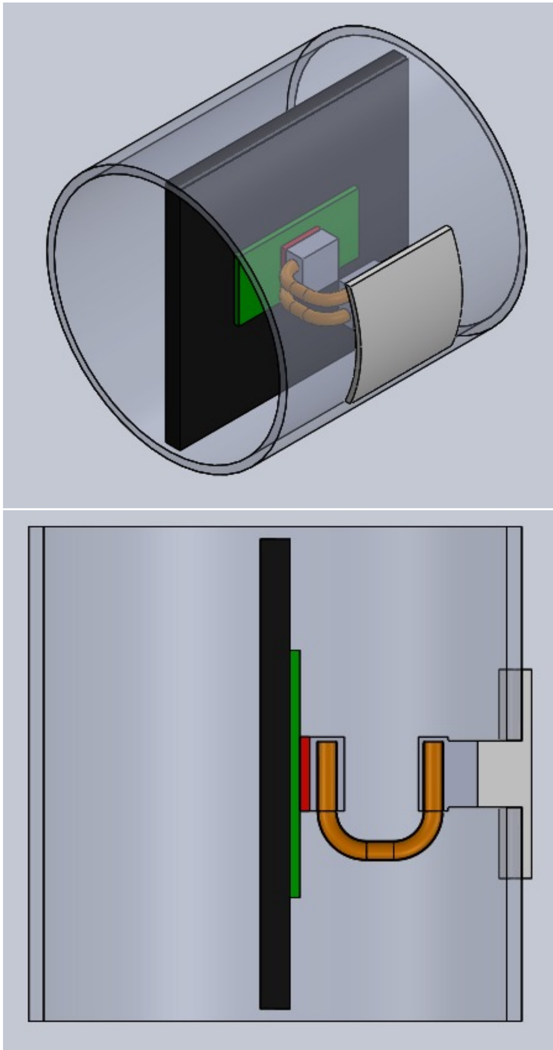

Figure 9: Modeling the thermal control device.

This solution consisted of implementing a conductive path so that the heat transmission could be done more efficiently. From the perspective of thermal control, an interesting possibility to be addressed in an eventual redesign would be the reduction of the distance between the electronic component (hot source) and the external flow (cold source).

E. Gazebo Simulation

The ROS (Robot Operating System) simulations were performed in the Gazebo Robotics Simulator, which has several tools and is the one with the best compatibility with ROS. Communication problems between the code and the simulation were faced, such as not recognizing movement commands and paths traced by the AUV that weren't on the code. These errors were caused by conflicting versions of libraries that were fixed with the duly update. However, the simulation occured as expected after correcting the aforementioned errors, managing to perform maneuvers and measure sensor data.

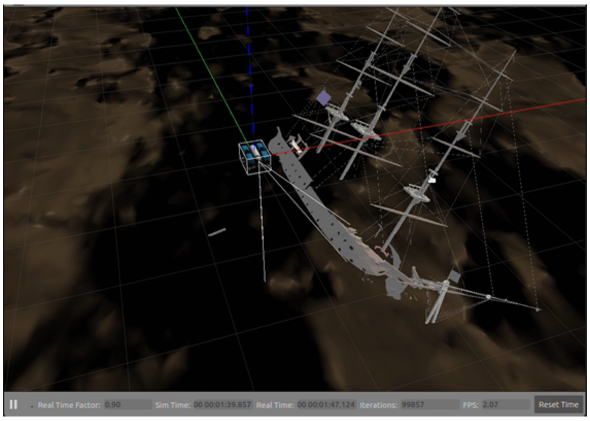

Figure 10: Gazebo simulation.

Improvements have been implemented to the code in order to identify side, top and bottom collisions during the trajectory of AUVille, using data obtained from location sensors such as the compass and accelerometer. In the future, it is intended to increase the complexity of this identifier, integrating the calculation of the distance from obstacles through the camera and an ultrasonic sensor or DVL sensor (Doppler Velocity Log).

F. Computer Vision Simulation

The computer vision of AUVille will identify the structure of the gate.

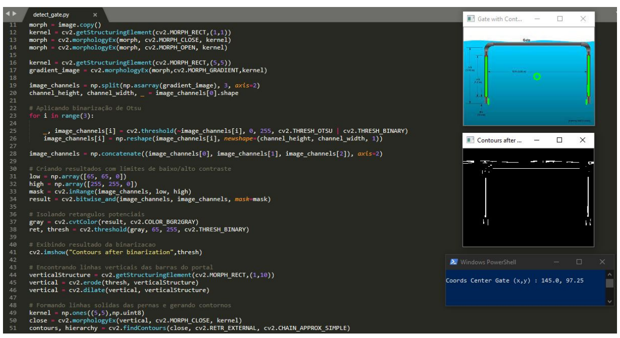

Figure 11: Identifying the central coordinates of the gate.

The implemented code allows the AUV to be able to identify the coordinates of the center of the gate and then, the center of the image of the police character. From that, AUVille will be able to activate the thrusters and move in the identified direction to cross the gate through the side of the predetermined character.

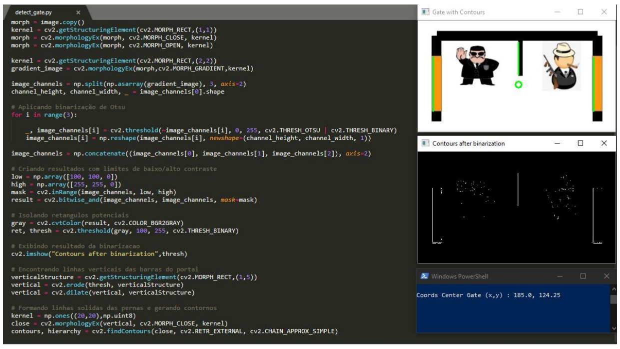

Figure 12: Identifying the central coordinates of the police character.

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APPENDIX A

TABLE I
Component Specifications

Component	Vendor	Model/Type	Technical Specifications	Cost	Status
Buoyancy Control	Blue Robotics	BlueROV2 Machined Buoyancy Foam	**Quantity:** 4 **Material:** LAST-A-FOAM® R-3318	$ 53.00	Installed
		Ballast Weight	**Quantity:** 5 **Material:** Stainless Steel	$ 9.00	Installed
Frame	Blue Robotics	BlueROV2 Frame	**Material:** High-density polyethylene	$ 339.00	Installed
		Payload Skid	**Material:** High-density polyethylene	$ 279.00	Purchased
Waterproof Housing	Blue Robotics	Watertight Enclosure	**Diameter eletronic enclousure:** 4 in	$ 224.00	Installed
			Diameter battery enclousure: 3 in **Quantity:** 2	$ 123.00	One installed and one purchased
Waterproof Connectors	Blue Robotics	M10 Cable Penetrator	**Quantity:** 8 **Diameter Cable:** 6 mm	$ 4.00	Installed
			Quantity: 2 **Diameter Cable:** 8 mm	$ 5.00	Installed
Thrusters	Blue Robotics	T200 Thruster	**Quantity:** 6 **Operating Voltage:** 7-20 V **Thrust Maximum (20 V):** 5.25 kgf	$ 179.00	Installed
Electronic Speed Controller	Blue Robotics	Basic ESC	**Quantity:** 6 **Maximum Current:** 30 amps **Firmware:** BLHeli_S **Operating Voltage:** 7-26 V	$ 27.00	Installed
Camera	Blue Robotics	Low-Light HD USB Camera	**Maximum Resolution:** 1080 p **Field of View :** 80º (Horizontal) and 64º (Vertical) **Compression format:** H.264/MJPEG	$ 99.00	Installed
Pressure Sensor	Blue Robotics	MS5837-30BA	**Measurement:** 30 bar (300m / 1000 feet deep)	$ 72.00	Installed

Component	Vendor	Model/Type	Technical Specifications	Cost	Status
Light	Blue Robotics	Lumen Subsea Light	**Quantity:** 4 **Operating Voltage:** 10-48 V	$ 115.00	Installed
Microcontroller	Arduino store	ATmega328 (Arduino Nano 3.x)	**Microcontroller:** ATmega328 **Flash memory:** 32 KB, of which 2 KB is used by the bootloader	$20.70	Installed
CPU	Submarino	Raspberry Pi 3B+	**Processor:** BCM2837B0, Cortex-A53 (ARMv8) 64-bit SoC at 1.4 GHz **RAM memory:** 1 GB LPDDR2 SDRAM **Internal memory:** Micro SD 16 GB **Power input:** 5 V / 2.5 A DC	$ 115.00	Installed
Flight controller	Banggood	pixhawk px4 pix 2.4.6	**Processor:** 32 bits STM32F427 Cortex M4 core with FPU - 168 MHz 256 KB RAM 2 MB Flash **Security coprocessor:** STM32F103 **ST Micro Gyroscope:** L3GD20 **ST Micro Accelerometer/Magnetometer:** LSM303D **Barometer:** MEAS MS5611	$ 128.00	Installed
Stepper motor	Blue Robotics	HS-5055MG	**Velocity:** 0.2 s for 4.8 V 0.17 s for 6 V **Output torque:** 1.3 kg-cm for 4.8 V 1.6 kg-cm for 6 V	$ 39.00	Installed
Battery	Samsung adaptation	Lithium-ion battery: 5S6P	**Number of cells:** 30 **Power:** 18 V, 18 Ah **Weight:** 1.44 kg	-	Selected
		Lithium-ion battery: 2S7P	**Number of cells:** 14 **Power:** 7.2 V, 21 Ah **Weight:** 0.67 kg	-	Selected

TABLE II
Software Information

Control Unity	Language(s)	Tools/Libraries
Algorithms: computational vision	Python	OpenCV
Algorithms: simulation	C++	Gazebo
Algorithms: T.A.R.D.I.S module	C	MavLink
Algorithms: state machine	Python	ROS
Algorithms: engine control	C++	ROS

TABLE III
Additional Information

Team Size (number of people)	13
Expertise ratio (hardware vs. software)	7:4 (2 energy system, 2 cooling system, 3 modeling and simulation, 4 software, 1 design, 1 management)
Testing time: simulation	77 hours
Testing time: in-water	0 hours

APPENDIX B
Outreach Activities

One of the missions of the TERRA team is to socially contribute to the dissemination of the extension projects of the Federal University of Santa Catarina. The team were present at various events aimed to the university's internal community, such as the Week of Teaching, Research Extension and Innovation (SEPEX) which takes place every 2 years, at the reception of new students every semester and at the scientific dissemination fairs that constantly take place in our campus. In addition, the team actively participates in meetings of student entities, contributing to the growth of competition teams and to excellence in extension projects.

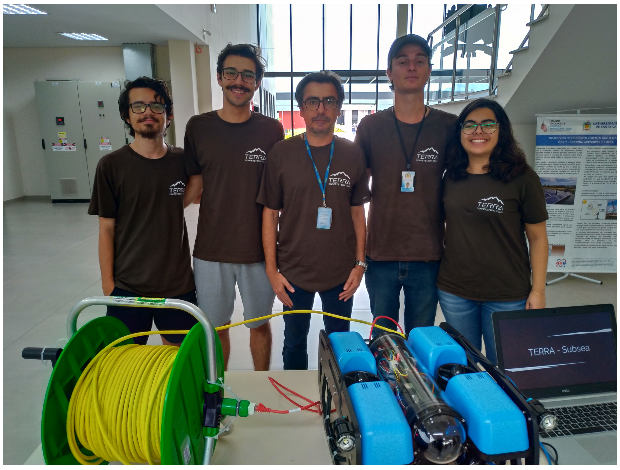

Figure 13: Dissemination of projects to the university's internal community.

Also with regard to the dissemination of projects, the team contributes to the movement of holding project exhibition fairs in public spaces, thus promoting closer contact between society and scientific knowledge. And in particular, participation in UFSCÊNCIA project promoted by Tutorial Education Program of Engineering for Mobility (PET EMB - UFSC) which takes place every six months with the objective of bringing scientific knowledge of the university to young school students, encouraging them to become future scientists.

Respecting physical distancing measures, the TERRA team found other ways to divulge their projects, besides recording videos for various events promoted by our university, the team also participated in the recording of an episode of the LabbryCast podcast. In this episode, the team members talked about the experience of developing a theoretical project of an AUV capable of carrying out explorations in the frozen seas of the moon Europa of the planet Jupiter, for the COBRUF competition, which happened between 2019 and 2020. And also about expectations that existed for the debut in the world's biggest AUV competition, RoboSub 2021.

Figure 14: Dissemination of projects in schools.

Figure 15: LabbryCast podcast recording

Since its beginning, the TERRA team has always wanted to participate in an edition of RoboSub, therefore, has always sought to maintain contact with other teams that already have experience in this competition. The team has already had the opportunity to talk and share knowledge with the Triton team at the University of California, San Diego and the Nautilus team at the Federal University of Rio de Janeiro.

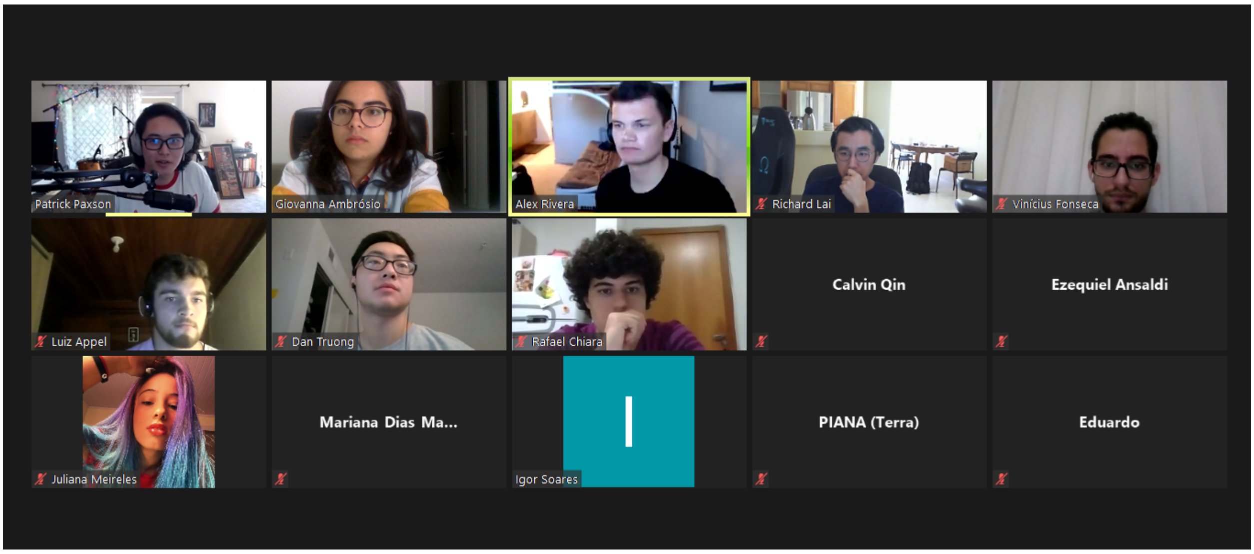

Figure 16: Contact with other teams.