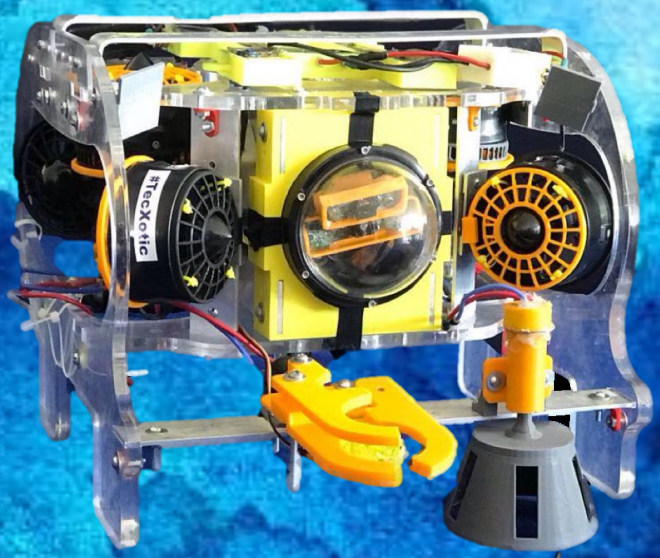
TECXOTIC

Tecnológico de Monterrey

Axolotl

2018 Technical Report



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Eduardo Nava Morales Company Operative Officer Year 2
Paola Yunes Sordo Safety Captain Year 2
José Abraham Torres Juárez Software Leader Year 3
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I.ABSTRACT

This year, Tecxotic company has developed a Remotely Operated underwater Vehicle (ROV) to satisfy the request of Lake Washington to perform a series of tasks under the circumstances of jet city, earthquakes and energy. The exhausting work of 18-person company has successfully resulted on ROV *Axolotl,* which means Monster of Water. For Tecxotic, the circumstances to be working with were a key to keep up motivation due to the past events of September 19, 2017.

Tecxotic is divided into specific fields: mechanics, electronics, software and administration departments, all united by the passion for underwater exploration and technology. An important aspect of this year was the exhaustive communication between all departments for a better development of the ROV.

Axolotl was customized to fulfil missions requirements, improving most of the aspects of previous ROV's. In particular, this time 3D printing technology was used to materialize the prototypes and the final version of the ROV. It let major advances in the mechanics field. On the other hand, the software team decided to use the Raspberry Pi as on-board computer due that its popularity among the makers and roboticists and all the documentation that is available about it. This resulted in a better functionality than the last year ROV.

This technical report describes the process of the Tecxotic team in order to obtain a highly improved ROV, ready to fulfil this year's missions requirements.

Figure 1 *Top row (left to right) Luis Gómez, Jael López, Alvaro Serrano, David García, Jesús Guerrero, Arturo Rusell, Javier López.*
Middle row (left to right) Eduardo Nava, Katia Morales, Brenda Zárate, Paola Yunes, Antonio Abarca.
Bottom row (left to right) Eduardo Ahumada, Jesus Zaragoza, Alexis Mata, Diego Hernández

II.DESIGN RATIONALE

A. Mechanical design

Taking in consideration the previous year, Tecxotic had major design issues. Nevertheless, precautions were taken for this year's competition, doing prior designs and scale prototypes since September, in order to get a better glance of the future ROV functionality. The whole team was subdivided into three design teams, each developed a different approach. At the end, our Mentor and past Tecxotic CEOs helped on the decision of the best design.

Once the final design was settle, the mechanical department worked on an adequate assemble of all modeled parts of the ROV on SOLIDWORKS CAD Software in order to avoid future dimensional and functional problems. After finishing all pieces with their corresponding measurements, sub-assemblies of core parts were made. When the sub-assemblies were finish, it was easier to make corrections. Finally, sub-assemblies were assembled making easier to detect parts that affected or benefited the ROV design. Even though this process took more time than expected, the dedication of the mechanical department was a major key to *Axolotl*'s functionality.

Figure 2 (a) Prototype 1

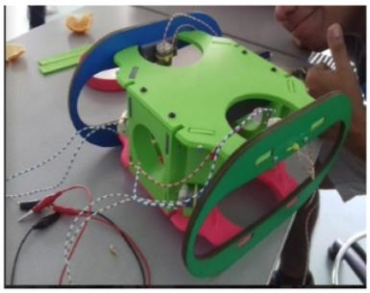


Figure 2 (b) Prototype 2

Figure 2 (c) Finished ROV with Prototype 1

B. Frame

ROV *Axolotl*'s frame consist of four acrylic laser-cut plates, two lateral and two horizontal plates, supporting the acrylic cylindrical water enclosure. Each plate is supported by four aluminum bars, connected by tabs previously designed on the acrylic plates, this for better

Figure 3 (a) ROV CAD

Figure 3 (b) Disassemble ROV

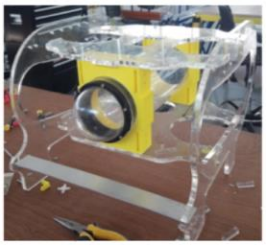


Figure 3 (c) Axolotl's Frame

stability.

For the acrylic cylindrical water enclosure, hosting all the electronics, 3D printed holders were made for its support, connecting the front to the bottom part with four horizontal aluminum bars. Using this structure, the water enclosure has less movement and vibration giving stability to the ROV. Aluminum bars are strong and rigid enough without sacrificing our ROVs lightness. In contrast to last year, the design of the frame is thought to the capacity of extracting the cylinder from the ROV if needed, with no further complications to the assembly, allowing the electronics department more accessibility to the components.

One of the main priorities of Tecxotic, is to be efficient and spend the least amount of resources obtaining the highest quality results.

	Machined Nylamid	**Aluminium**	**Acrylic >9 mm thick**	**3D Printed**	**Wood**	**Steel**
Mechanical Strength	High	Medium-High	Medium	Low	Medium	High
Manufacturing Process	CNC Milling	Hand-cut and drill	Laser cutting machine	3D Printing	CNC Routering	Hand-cut and drill
Weight	High	Low	Medium	Low	Medium	High
Aesthetics	Sensitive to dirt	Finishing process needed	Clean and transparent	aesthetically pleasing	Surface treatment needed	Rust risk
Assembly difficulty	Medium	Medium	Low	Low	High	Medium
Waterproofing	Yes	Yes	Yes	Yes, but it absorbs water	varnish needed	Rust risk
Cost	High	Medium	Medium	Medium	Low	Low
Aviability for team	Low	Medium	High	Medium	High	High

Table 1 Comparison of manufacturing process vs. possible materials

The candidate materials for the frame and electronic protection were the combination of aluminum, acrylic and PLA (polylactic acid). Once again, acrylic was chosen to be the main building material for the frame. The reasons why the company opted to use acrylic for the frame are the following: low cost, easy manufacturing and manipulation, weight, impact resistance and transparency.

So easy: The 3D printing process let us obtain complex and customized parts at a low cost. For example, the gripper and spinner tools were designed to be made with 3D printing. These choice allow us to accomplish a design cycle from the stage of a proof of concept to a functional part. In the same way, the parts that fix the main cylinder to the frame of ROV, were made through 3D printing. On the other hand, the aluminum was the choice for the main bars because its combination of mechanical strength at low weight, fundamental aspects for a ROV. Finally, the acrylic was chosen because the union of physical properties as low weight and a waterproofing material. The combination of 3D printed, aluminum and acrylic parts result in a mechanical platform optimized for accomplishing the tasks that will be asked to do in the challenge

C. Buoyancy

To compensate the weight of the acrylic frame, electronic components and tools, a buoyancy system was developed using foam, located on the side-top part of *Axolotl*. This was a difference from last year's ROV, because the design itself had a buoyancy system.

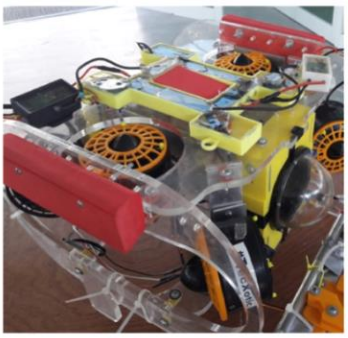


Figure 4 Buoyancy system

Several tests and calculations were taken once all tools and electronic components were fitted in the ROV. As the ROV weight is 10.35kg, the main target was to obtain neutral buoyancy, gaining as minimum weight as possible. Thus, our main floater is the Water Enclosure, weight was distributed symmetrically, only minimum foam floaters were used to achieve better stability.

D. Water Enclosure for ROV (WER)

From 2017 ROV, the only reused design aspect was the Blue Robotics acrylic - cylindrical 4" water enclosure. This WER have proved to be efficient to prevent water leaking. A four inches acrylic cylinder is an adequate size to fit *Axolotl* electronics and controls. Nevertheless, Tecxotic had several issues with water leaking at the beginning of the underwater tests. We solved this problem executing a vacuum tight test, in order to find pressure leaks and damaged O-rings and sealing.

An exhaustive examination was made before putting *Axolotl* back to the water, resulting the wear of the O-rings to be the cause of this problem. Tecxotic solved it by sealing the external part of the O-rings.

Inside the cylinder, a plate is found with all the electronics. This plate is a 3D printed part allowing each electronic component to have a place and also giving the cables its own way through the cylinder, not interfering with each other, preventing a possible shortcut. This place was also designed for separating the frontal camera, providing better stability avoiding any possible movement of its own.

The cylinder is attached to the ROV by the 3D printed pieces that connects each other with four aluminum bars. No screws were used, allowing an easier manipulation when needed. There are two caps on the cylinder, front and bottom, in order to give the electronic component an easier access, whenever it is the frontal camera on the dome or the Raspberry Pi at the front part or rather accessing from the bottom part where all connections and the

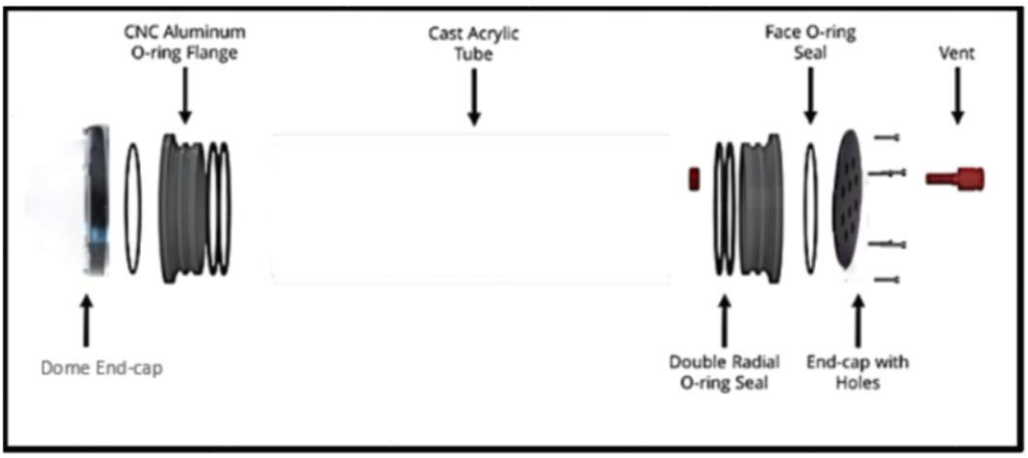


Figure 5 WER SID

power distribution module take place.

E. Propulsion

Axolotl is once again powered by four T200 and two T100 brushless thrusters from Blue Robotics with 3.55 kgf and 2.36 kgf, respectively. The reason Tecxotic decided to use these models again because of the outstanding functionality from last year.

The T100 thrusters are located on the top part of the ROV for vertical motion, the T200 are located on the lateral acrylic plates with a 30 degrees angle, resulting greater speed and better malleability for *Axolotl* to go into any direction except diagonal due to software issues and 6 degrees of freedom.

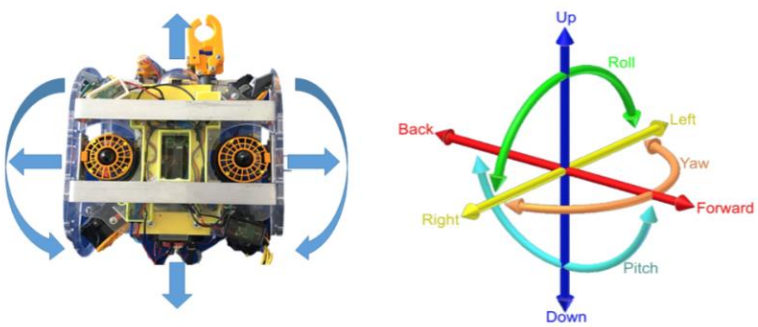


Figure 6 Schematic propulsion vectors and directions

F. Tools

Gripper

The grip mechanism was designed so the pilot could maneuver easy and quickly. This tool design consist of claw that holds tubes with different diameters. To open or close the claw we use a 5V HS 311 servo motor. And to spin the entire gripper 90°, we a 12V DC Hennkwell motor.

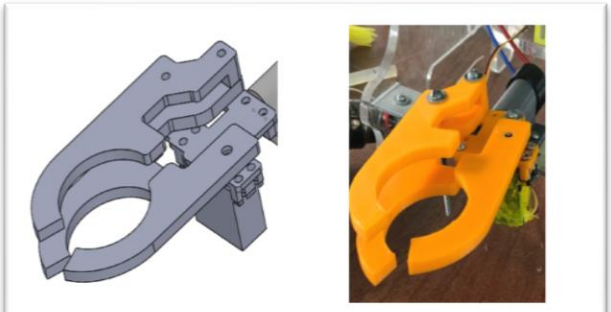


Figure 7 (a) Gripper CAD *Figure 7 (b) 3D printed Gripper*

The claw opens up to 90º from its original position, and it closes until it is indicated. Thanks to our actuators versatility, there is a vast possibility of replacement in case of failure. The servo is all covered with epoxy resin for long life span and full function underwater.

Another advantage of this design is its lightweight because it was 3D printed. Being that light does not affects the ROV buoyancy, and it is also easy to transport. The claw CAD can be seen on Figure 7.

Spinner

The spinner has a conic form, located on the front of the ROV next to the gripper. Its objective is to spin the PVC pipes that stabilize OBS . The way this tool operates is introducing the object inside the cone.

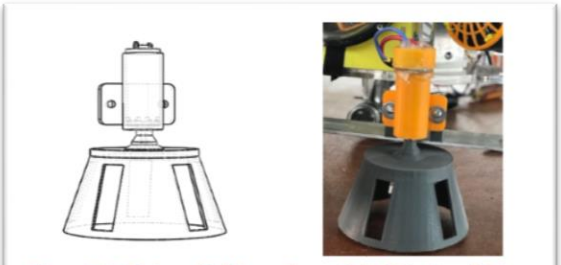


Figure 8 (a) Spinner CAD *Figure 8 (b) 3D printed Spinner*

This tool was designed for an easy utility for the pilot. Thanks to its design, this tool applies pressure to the object and avoids the object from escaping the cone. It is not necessary for the pilot to locate the pipes on the center of the spinner radius, as the surface of the tool will place the object on its center once the turning starts. We used sandpaper inside the cone to increase its friction.

The spinner is also 3D printed, thus it is light and it is easy to manipulate, it does not interferes with the ROV´s stability. This tool also works with a 12V DC Hennkwell motor.

The pilot only has to pressure one button on the joystick to activate the rotation and releases the button for stopping it.

III.ELECTRONIC DESIGN RATIONALE

A. Electronics Overview

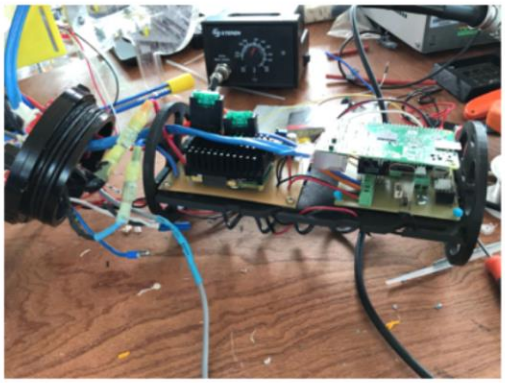


Figure 9 Electronic Overview

Axolotl's electronics also variate from last year, although few aspects were preserved, like the Power Distribution Module. The electronics are subdivided into three different systems for a better manipulation of each component: Power Distribution Module, Signal Board and the Raspberry Pi Shield Board.

The electronics cylinder, as mentioned before, contains a 3D printed plate were all components are distributed according to Tecxotic needs. On the dome the frontal camera is located, on the tube the Raspberry Pi takes place having on top it's Shield Board, finally the Power Distribution Module can be found.

Axolotl power supply is provided by a 48 Volts and a 30 Amps source given by MATE. The conversion begins inside the electronics cylinder on the Power Distribution Module (which is divided on two main plates). The first sector is the 48/12 volts conversion distributed to the six thrusters via the signal board, and the tool bar. The second section is the 12/5 volts conversion for the cameras.

The Shield Board being placed on top of the Raspberry Pi connected by header pins to provide better processing capabilities to the ROV and allows us more works space inside the cylinder.

B. Raspberry Pi

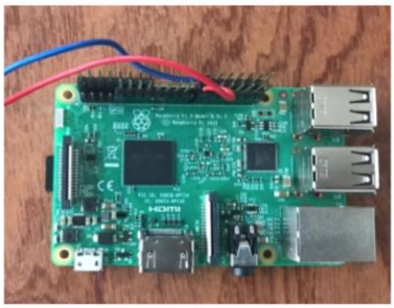


Figure 10 Raspberry Pi 3

Raspberry Pi 3 is used for the first time in Tecxotic competition history as the main controller of the ROV instead of the Intel Galileo. Tecxotic had a discussion about this year main controller, where the decision was cut down to two: the BeagleBone Black or the Raspberry Pi 3.

The team had a severe discussion, listing all the pros and cons of each controller, at the end, the BeagleBone Black was not a viable solution because the Software division had issues on the camera control.

The Raspberry Pi 3 is a suitable solution due to its fast and effective processing module and the integrated Wi Fi and Bluetooth modules that fits in this year's missions requirements. Also the four USB ports, Ethernet and HDMI ports, Micro SD, a CSI camera and 1GB of RAM.

Thanks to its speed and the compatibility with the our operating system, we avoided most software errors and achieved a more efficient job. In addition to this, programming in Python with an interface in Unity allowed us to have a wide control of the actions that the ROV can perform and a better stability for the pilot to use with the joystick.

C. Raspberry Pi Shield Board

This Shield was designed on Proteus, with the purpose of making voltage and ground lines of the external part of the ROV with the Raspberry Pi for a better data processing of *Axolotl*'s movements and all of what's happening inside the electronics cylinder. Due to water leaking problems inside the electronics cylinder, the temperature sensor (DHT11) played an important key during *Axolotl* underwater testing, because on the interface the company was able to observe the humidity levels inside the cylinder, having an emergency shutdown and rapid extraction of the ROV if the level increased.

A big difference from last year's shield is the header pins that connects the shield with the Raspberry Pi, minimizing all possibility of data loss, in behalf of eliminating all wires that could be connected to the Raspberry Pi. The Raspberry Pi is powered by 5 volts provided by the Power Distribution Module.

An L298n was used in the interest of its manage of amperage the thrusters require for their proper functionality. The thrusters are moved by the signals of an I2C port, nevertheless a PWM port was printed in case of any I2C failure due to last years' experience were an ESC failed, Tecxotic wanted to be prepared for any possible failure. The IMU is an important factor this time, because Tecxotic paid close attention on the ROV stability.

There is also the 12 Volt power to the two DC motors of the tools and Aqua Vu camera. The SID are shown in figure 11.

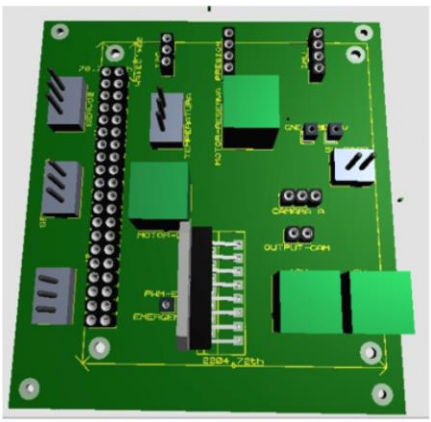


Figure 11 (a) Proteus PCB

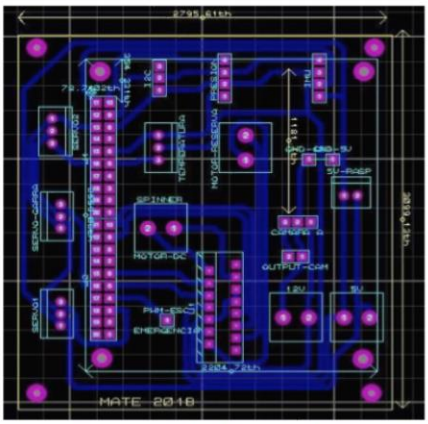


Figure 11 (b) Proteus PCB

D. Power Distribution Module

For the Power Distribution module, the only electronic component Tecxotic re-used from last year, the electric current flow is controlled with a circuit breaker connected to a power supply of 48 volts or more. Tecxotic designed this control to be automatic and manual in case of emergency. The manual shutdown is once again controlled with a switch and the automatic shutdown is controlled by a 30 amperes fuse.

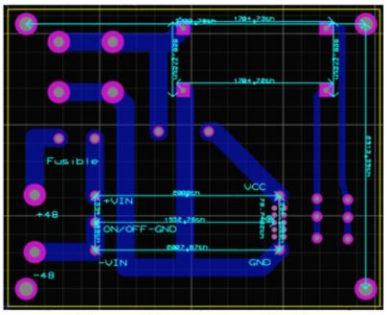


Figure 12 Proteus PCB

The circuit breaker output is connected to a Murata Solutions DC/DC converter reducing the original 48 volts to 12 volts without any amperage change, having an efficiency of 92%. Security measures were taken by connecting the 30 amperes fuse before supplying all of our six thrusters and cameras. On the second unit of conversion, we have a LM2596 converter reducing 12 volts to 5 volts with short-circuit protection and maximum output of 3 amperes supplying all tools and the Raspberry Pi. The SID is shown in figure 12.

E. Signal Board

The Signal Board was a theme for this year's ROV. Plenty ideas were given, being faced back and forth between designing a PCB for all ESC's voltage, ground and I2C, or rather connecting all of them directly. The decision of using once again ESC is because of the facility of manipulation outside the WER and also the results they provided last year.

A main problem last year, was the extensive amount of wire surrounding the upper part of the ROV, this was the reason to use only one system of connection for all wires coming from the ESC. After examining the cons and pros of each solution, it was decided to connect the wires without a PCB, this to prevent a possible short-circuit. Once this decision was declared and done, the electronics team made an exhaustive continuity test in case any wire was poorly welded. When the Electronics team gave the results of complete continuity on the board, epoxy resin was pour on all the board, causing no water leaking but also no further manipulation of the wires, that is why, for sake of the ROV, the continuity test was made several times before announcing the results.

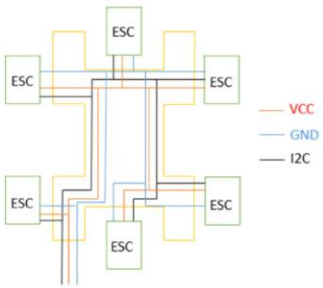


Figure 13 Signal Board SID

F. Joystick controller

To control the ROV from the surface we use a Thrustmaster T-Flight Stick, it has 12 programmable buttons and 5 axles, which we use to control the thrusters and the tools. The controller is connected to the computer which is connected with the ethernet wire directly to the ROV. We are able to visualize the movements of the stick in our Unity interface even though the ROV is not powered.

IV.SOFTWARE DESIGN RATIONALE

A. Overview

The software for controlling the ROV *Axolotl* is focused on the quality and reliability of the communication. Its architecture is based on the client-server model. The connection is established using TCP (Transmission Control Protocol) between the client (Base station) and the server (ROV), this protocol offer us reliability in our communication, preventing the loss of data. All the data transmitted by the socket is packaged into a JSON (JavaScript Object Notation) string, .

We used a Flask-Socket.IO app for the server, which allow us to stream the video, and sensor data from the ROV with ease. Then for the client we developed a desktop application using Unity3D, in which the video feed is displayed, as well as the relevant data acquired by the sensors inside the ROV. These technologies allow the pilot to received feedback from the ROV in almost real time. Look for the Appendix B for the software´s flowchart diagram.

B. Base Station

This is the Tecxotic official software for manipulate the ROV *Axolotl*. It allows the pilot to control the ROV with a flight simulation joystick (T-Flight Hotas x), which give the pilot a complete access to all the functions of the ROV with simple and intuitive movements. These movements get processed by the software and generate the control data, which is send to the ROV at an approximate rate of 75 times per second. Thanks to the usage of Unity3D the software is device independent, hence is capable of running on a Windows, Mac OS X or Linux computer.

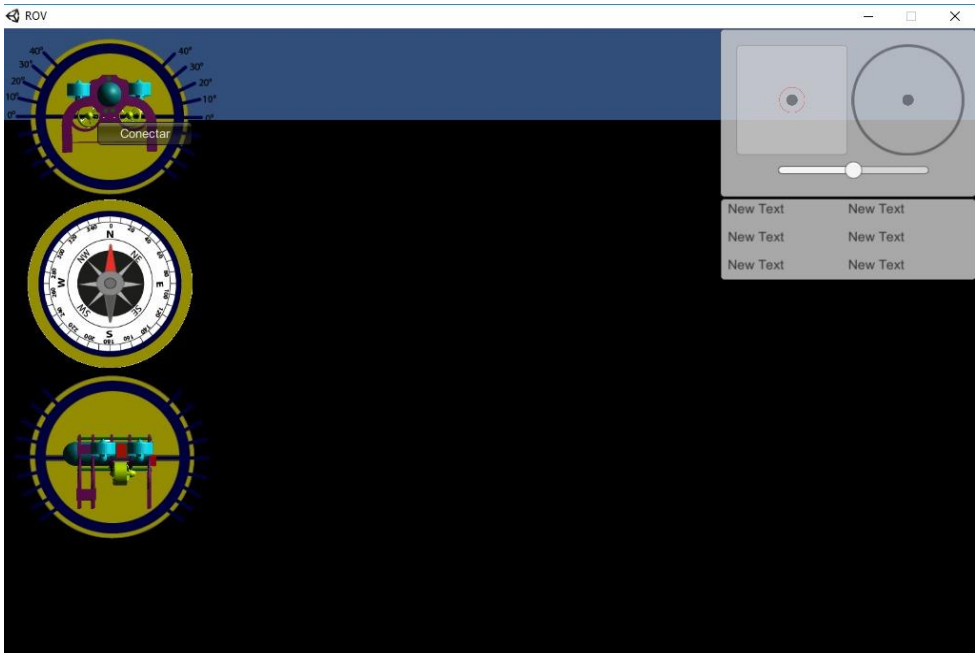


Figure 14 Base Station

The image above is the Base Station graphical interface, it contains in the top left corner, the joystick input, and below it the raw sensors data. In the left side we find the pitch, roll and heading from the ROV so the pilot can understand the orientation of the ROV.

C. ROV

The ROV uses a Raspberry Pi is directly connected to the cameras and a custom Printed Circuit Board (PCB) shield, which is connected to all the peripherals of the ROV. The software mainly use I^2C to communicate with them. Because all the Electronic Speed Controllers (ESC) in the ROV communicate via I^2C, as well as the IMU and pressure sensor. For the manipulator and the spinner tools we used two DC motors and one Servo motor, so we also used digital and PWM signals from the Raspberry Pi.

For the video feed, we used Logitech C920 and C525 cameras. Obtain the image using OpenCV and then it is streamed in the socket connection. Using OpenCV to process the images from the cameras, allow us to analyze the image and search for colors or patterns in the field of view of the ROV.

V.SAFETY

A. Safety Philosophy

For Tecxotic, safety is a core value and it is an intrinsic belief that dictates our actions in any circumstance. Our focus is not only to prevent accidents, but to improve the process under which we operate. We believe that an active and effective accident prevention and safety

program is an integral part of the construction process providing not only a safe work environment for the staff, but a safe environment to flora and fauna surrounding the ROV.

B. Safety Standards

As company we know that staff safety is first, that is why we applied the series of safety rules posted in the workplaces where the ROV was built, including the use of appropriate equipment and clothing, such as gloves, safety glasses, robe and closed shoes. Also the right use of the tools in the corresponding work area. Another important safety consideration was the proper use of ventilation and lighting, these two are essential for the quality of perception, mood and performance of the personnel.

C. Safety Features

The ROV was built with several safety features such as a 30 Amperes fuse connected between the ROV and the power supply. Also, thrusters are shrouded and ROV edges are rounded. An improvement from last year was the watertight enclosure drawer, this allows a better wire organization and as a result a safer electronic space.

A checklist is followed before launching the ROV into the water (appendix A1) to maintain a low risk environment. The company launch it safely or not at all.

Also a diagnosis is made when the ROV is powered and it is displayed on the pilot's screen, it is given the temperature and humidity inside the WER to detect any leak.

VI.LOGISTICS

A. Company Organization

As any complex project, it is integrated by several areas of development which attend an specific subject and their performance. It is very important that each area has an effective communication between them, because it is true that everyone has their focus on a task, but they have a common objective; to complete the missions as a whole team.

To accomplish an efficient communication, we had different groups dedicated to specific parts of the development of the ROV. Design, Manufacturing, Electronics, Software Design and Programming. Each of them has a lead, which whom reported to a "Project Manager" who was in charge to attend and ensure the correct relation and comprehension between areas and their works. Everyone on the team has their own skills and strengths, to ensure to take advantage of them at maximum profitability, each person was located on the area in witch has more experience. As the projects grown, the proximity of the different groups grew closer and closer and finally, join all the parts together to give birth to the *Axolotl* ROV. The final stage of the development was the most critical one, because the technical issues and the complications involved different areas at the same time, and was necessary an efficient logistic and plan to work together between areas, attending all the ideas and getting to

general conclusions to get the problems solved. The Project Manager has the specific task to get all this work done and to show and documented all the evidence and information about the conception of the ROV.

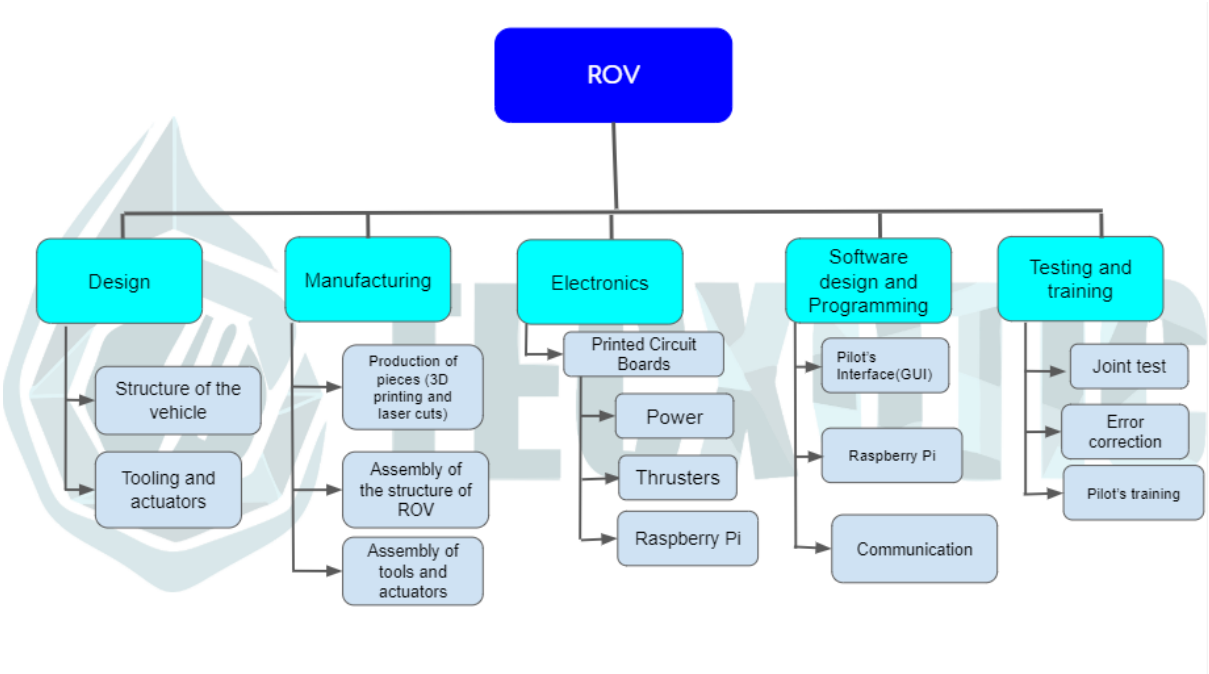
B. Project Management

Tecxotic went through 5 stages in order to accomplish the built of *Axolotl*: initializing, planning, executing, monitoring and closing.

In the first stage we identified the business model and started the process of recruiting people on the different areas of the company according to experience.

For the second stage, a work breakdown structure was made (figure 15) (WBS), this hierarchical decomposition of the total scope of work is to be carried out by the project team to accomplish the project objectives and create the required deliverables. Each descending level of the WBS represents an increasingly detailed definition of the project work.

Figure 15 WBS



It was used the Microsoft software: Project 2013, where all the stages, activities with deadlines and human resources were assigned in a Gantt Chart based on the WBS.

Due to a terrible earthquake near our campus, the past September 19th of 2017, the start date of the project was postponed to November 24th of the same year and the end date was considered only for the international qualification video.

Resources Names showed in figure 16 are the team leaders.

GANTT CHART

	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	**ROV**	**110.31 days**	**Fri 24/11/17**	**Mon 07/05/18**		
2	START	0 days	Fri 24/11/17	Fri 24/11/17		
3	**DESIGN**	**30 days**	**Fri 24/11/17**	**Sat 06/01/18**		
4	ROV Structure	30 days	Fri 24/11/17	Sat 06/01/18	2	Jesús G.,Diego H.
5	Tools and actuators	30 days	Fri 24/11/17	Sat 06/01/18	2	Eduardo N.
6	**MANUFACTURING**	**20 days**	**Mon 08/01/18**	**Wed 07/02/18**		
7	Producing pieces	15 days	Mon 08/01/18	Tue 30/01/18	5	Katia M.[50%]
8	Assembly of ROV	5 days	Wed 31/01/18	Wed 07/02/18	7	Jesús G.
9	Assembly of tools and actuators	5 days	Wed 31/01/18	Wed 07/02/18	8SS	Eduardo N.
10	**ELECTRONICS**	**50.25 days**	**Mon 08/01/18**	**Fri 23/03/18**		
11	**Printed circuit boards**	**50.25 days**	**Mon 08/01/18**	**Fri 23/03/18**		
12	Power	5 days	Mon 08/01/18	Mon 15/01/18	3	Arturo R.
13	**Raspberry pi**	**50.25 days**	**Mon 08/01/18**	**Fri 23/03/18**		
14	IMU	5 days	Mon 08/01/18	Fri 23/03/18	12SS	Kim Y.[33%]
15	Temperature	5 days	Mon 08/01/18	Fri 23/03/18	14SS	Kim Y.[33%]
16	Pressure	5 days	Mon 08/01/18	Fri 23/03/18	15SS	Kim Y.[33%]
17	Actuators	5 days	Mon 08/01/18	Mon 15/01/18	16SS	Kim Y.[50%]
18	Lights	5 days	Mon 08/01/18	Mon 15/01/18	17SS	Kim Y.[50%]
19	**Thrusters**	**50.25 days**	**Mon 08/01/18**	**Fri 23/03/18**		
20	ESC	30 days	Mon 08/01/18	Fri 23/03/18	3	Katia M.[50%]
21	**PROGRAMMING**	**50.25 days**	**Mon 08/01/18**	**Fri 23/03/18**		
22	**Pilot's interface**	**50.25 days**	**Mon 08/01/18**	**Fri 23/03/18**		
23	Display of cameras	25 days	Mon 08/01/18	Wed 14/02/18	3	Abraham T.[33%]
24	Display of telemetry (sensors)	10 days	Fri 09/03/18	Fri 23/03/18	27	Abraham T.[50%]
25	ROV control	25 days	Wed 14/02/18	Fri 23/03/18	29	Abraham T.[50%]
26	**Raspberry Pi**	**40.25 days**	**Mon 08/01/18**	**Thu 08/03/18**		
27	**Obtain telemetry information**	**40.25 days**	**Mon 08/01/18**	**Thu 08/03/18**		
28	IMU	1 day	Mon 08/01/18	Tue 09/01/18	3	Kim Y.
29	Thrusters and actuators control	10 days	Mon 08/01/18	Wed 14/02/18	28SS	Abraham T.[33%]
30	Comunication	25 days	Mon 08/01/18	Wed 14/02/18	29SS	Abraham T.[33%]
31	Temperature	1 day	Wed 10/01/18	Thu 08/03/18	28	Kim Y.
32	Pressure	1 day	Fri 12/01/18	Thu 08/03/18	31	Kim Y.
33	**Training and testing**	**30 days**	**Fri 23/03/18**	**Mon 07/05/18**		
34	Joint test	10 days	Fri 23/03/18	Sat 07/04/18	3,6,10,21	Abraham T.,Eduardo N.
35	Error correction	10 days	Sat 07/04/18	Sat 21/04/18	34	Eduardo N.,Jesús G.
36	Pilot's training	10 days	Sat 21/04/18	Mon 07/05/18	35	Jesús G.
37	END	0 days	Mon 07/05/18	Mon 07/05/18	36	

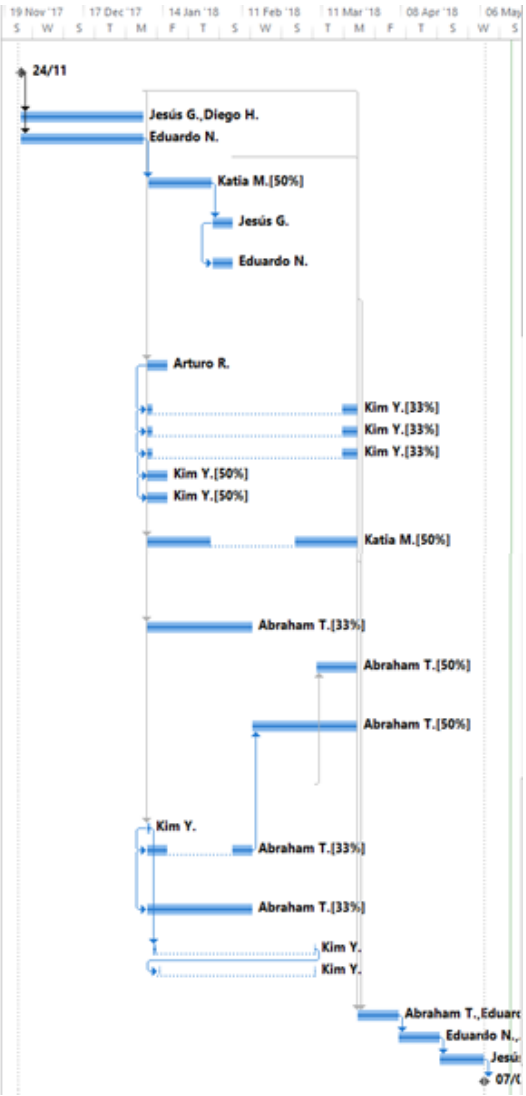


Figure 16 Work Chart

In the execution stage, the different areas of the company worked simultaneously to finally enter the closing stage where testing was made and the lessons learned were discussed.

C. Project Costing and Budget

Tecxotic had a rough time this year talking about expenses, as a consequence of the earthquake the past September 19, 2017, an extensive amount of precautions were taken, some were the careful use of material, like the acrylic. Donations from our school were distributed in order of importance. As mentioned before, many materials were reused, so only the necessary components had to be bought. Travel expenses will be cover by each member of the company.

Part ID	Part name	Description	Supplier	Qty	Units	Unit Cost	Cost
E-E-1	T100 Thruster	The T100 Thruster is a patent-pending underwater thruster designed specifically for marine robotics. It's high performing with over 5 pounds of thrust and durable enough for use in the open ocean at great depths.	Blue Robotics	4	piece	$119.00	$476.00
E-E-2	T200 Thruster	The T200 Thruster is a patent-pending underwater thruster designed specifically for marine robotics. Versus the T100 Thruster, the T200 is better for larger vehicles and especially for human-carrying vehicles. 3.55 Kgf	Blue Robotics	2	piece	$169.00	$338.00
M-WER-1	Acrylic Tube	Cast Acrylic Tube - 11.75", 298mm (4" Series)	Blue Robotics	1		$54.00	$54.00
M-WER-2	O-Ring Flange	This flange has a double O-ring seal that fits the tube for the 4" Series Water Tight Enclosure. Comes with O-rings.	Blue Robotics	2	piece	$29.00	$58.00
M-WER-3	Dome end CAP	Dome end cap for use on Watertight Enclosure for ROV/AUV (4" Series). Rated to 500m (1640 ft) water depth	Blue Robotics	1	piece	$39.00	$39.00
M-WER-4	Aluminum End Cap with 10 Holes (4" Series)	This aluminum end cap with 10 holes is for use on the 4" Series Watertight Enclosure.	Blue Robotics	1	piece	$24.00	$24.00
M-C-5	Enclousure Vent and Plug	This vent allows trapped pressure to escape from an enclosure after it has been closed. Based on the cable penetrator design, it includes a threaded plug with double O-ring seal to open and close the vent.	Blue Robotics	1	piece	$8.00	$8.00
E-W-1	Cable penetrator for 6 mm	This cable penetrator makes a waterproof, high-pressure seal to pass the thruster cable into a water-tight enclosure. Each set includes a bolt, nut, and o-ring. Some assembly required.	Blue Robotics	4	piece	$5.00	$20.00
E-W-2	Cable penetrator for 8 mm	This cable penetrator makes a waterproof, high-pressure seal to pass the thruster cable into a water-tight enclosure. Each set includes a bolt, nut, and o-ring. Some assembly required.	Blue Robotics	3	piece	$4.00	$12.00
E-W-3	Cable Penetrator Blank (No Hole)	This blank cable penetrator is used to seal any unused holes on your watertight enclosure with a high-pressure seal. Each set includes a bolt, nut, and o-ring.	Blue Robotics	2	piece	$4.00	$8.00
E-E-3	Loctite Marine Epoxy	Loctite Epoxy Marine is a two-part system consisting of an epoxy resin and a hardener. It can be applied and cured underwater, and it is sandable, but not paintable.	Blue Robotics	2	piece	$6.00	$12.00
E-I-1	Bar30 High-Resolution 300m Depth/Pressure Sensor	This pressure sensor can measure up to 30 Bar (300m depth) with a depth resolution of 2mm. It is waterproof and ready to install.	Blue Robotics	1	piece	$68.00	$68.00
E-T-1	ESC 30A	afro ESC 30Amp del Electronic Speed Controller (SimonK firmware)	Hobby King	5	piece	$13.00	$65.00
E-T-2	ESC 20A	afro ESC 20Amp del Electronic Speed Controller (SimonK firmware)	Hobby King	1	piece	$11.25	$11.25
E-B-1	Turnigy Pure-Silicone Wire 14AWG 1m (Blue)	Turnigy Pure-Silicone Wire 14AWG 1m (Blue)	Hobby King	4	meter	$4.00	$16.00
E-B-2	Turnigy Pure-Silicone Wire 14AWG 1m (Red)	Turnigy Pure-Silicone Wire 14AWG 1m (Red)	Hobby King	4	meter	$4.00	$16.00
S-1	Thrustmaster T. Flight HOTAS X	The T. Flight HOTAS X from Thrustmaster is a programmable joystick and throttle that is compatible with PCs and PS3 systems for realistic flight simulation.	Fry's Electronics	1	piece	$49.99	$49.99
S-C-1	Aqua-Vu AV 715C	Aqua-Vu AV 715C Underwater Viewing System with Color Video Camera and 7" LCD Monitor	Cabela's	1	piece	$299.99	$299.99
E-PBM-1	DC/DC Converter	Digikey Isolated DC/DC Converter 500W 38-75Vin 12Vout N Log	Digikey	1	piece	$157.00	$157.00
M-F-1	Acrylic Sheet	400 x 800 x 9 mm uncolored acrylic sheet	Grupo Grabado	1	sheet	$480.00	$480.00
S-2	RASPBERRY PI 2 MODEL B	The Raspberry Pi 2 Model B is the second-generation Raspberry Pi.	Raspberry	1	piece	$53.00	$53.00
S-C-2	Logitech C920 Web Cam	Logitech C920 USB Web Cam	Office Depot	1	piece	$81.00	$81.00
S-C-3	Logitech C525 Web Cam	Logitech C525 USB Web Cam	Office Depot	1	piece	$39.00	$39.00
S-2	Esp-01 Serial Wireless Wifi Transceiver Module	Makerfocus 4pcs ESP8266 Esp-01 Serial Wireless Wifi Transceiver Module Compatible with Arduino	Amazon	1	piece	$12.99	$12.99
E-W-4	THWN WIRE (2 x 12 AWG)	THWN WIRE (2 x 12 AWG RUBBER COVER)	Home Depot	18	meter	$1.50	$27.00
E-W-5	UTP CAT6 WIRE	UTP CAT6 ETHERNET WIRE	Steren	18	meter	$0.25	$4.50
M-E-1	1/4" Crystal hoose	1/4" Crystal hoose	Home Depot	18	meter	$0.35	$6.30
E-E-4	Epoxy resin & catalyzer	Epoxy resin & catalyzer can with 500 ml	Home Depot	1	Can	$21.60	$21.60
S-3	Workstation Lenovo ThinkPad W541 Serie	Intel Core 4, Invidia Optimus, Thunderbolt port	Lenovo	1	Computer	$862.00	$862.00
M-T-1	HATCHBOX 3D PLA-1KG1.75-WHT PLA 3D Printer Filament	HATCHBOX 3D PLA-1KG1.75-WHT PLA 3D Printer Filament, Dimensional Accuracy +/- 0.05 mm, 1 kg Spool, 1.75 mm, Yellow	Amazon	2	Roll	$32.00	$64.00
M-T-2	HATCHBOX 3D PLA-1KG1.75-WHT PLA 3D Printer Filament	HATCHBOX 3D PLA-1KG1.75-WHT PLA 3D Printer Filament, Dimensional Accuracy +/- 0.05 mm, 1 kg Spool, 1.75 mm, Orange	Amazon	2	Roll	$32.00	$64.00
M-T-3	HATCHBOX 3D PLA-1KG1.75-WHT PLA 3D Printer Filament	HATCHBOX 3D PLA-1KG1.75-WHT PLA 3D Printer Filament, Dimensional Accuracy +/- 0.05 mm, 1 kg Spool, 1.75 mm, Grey	Amazon	1	Roll	$32.00	$32.00
M-T-4	2 x 1/8 in Squared Aluminium Bar	2 x 1/8 in Squared Aluminium Bar	Aceros vijaf	2	Bar	$15.00	$30.00
M-F-2	1/8" x 1" bolts with nuts	1/8" x 1" bolts with nuts	Home Depot	50	pieces	$0.25	$12.50
E-E-5	8 in. Cable Tie - Natural (100-Pack)	8 in. Cable Tie - Natural (100-Pack)	Home Depot	2	pieces	$7.21	$14.42
E-R-1	Triple-axis Accelerometer+Magnetometer	Triple-axis Accelerometer+Magnetometer (Compass)	Adafruit	2	pieces	$14.95	$29.90
E-PBM-2	3.3V 800mA Linear Voltage Regulator	3.3V 800mA Linear Voltage Regulator - LD1117-3.3 TO-220	Adafruit	1	pieces	$1.25	$1.25
E-E-6	58V 40 A FUSE HOLDER	FUSE HLDR BLADE 58V 40A IN LINE	Digikey	1	pieces	$9.92	$9.92

E-E-7	30A 58V FUSE	FUSE AUTOMOTIVE 30A 58V AUTO LNK	Digikey	1	pieces	$1.94	$1.94
E-W-6	Bullet Polarised Connectors	4mm RCPROPLUS Supra X Gold Bullet Polarised Connectors (6 pairs)	Hobby King	4	pieces	$15.39	$61.56
E-E-8	Advanced Sanding Sheets (6-Pack)	Pro Grade Precision 9 in. x 11 in. 80, 150, 220 Assorted Grits Advanced Sanding Sheets (6-Pack)	Home Depot	1	piece	$6.97	$6.97
E-E-8	Anderson SBS50 Heavy Duty Power Connector	Anderson SBS50 Heavy Duty Power Connector	Seamate	1	piece	$40.00	$40.00
	Servomotor - TowerPro SG-5010	Servomotor - TowerPro SG-5010	Adafruit	2	piece	$12.15	$24.30
	FUTUBA Geared DC Motor	FUTUBA Geared DC Motor	FUTUBA	2	piece	$27.00	$54.00
E-W-7	Thermofit	Thermofit 1/8" - 1/2"	Steren	1	box	$9.20	$9.20
E-E-9	Hot Glue Sticks	10 in. x 7/16 in. Dia Hot Melt Multi Temperature Full Size Glue Sticks (5 lb. Bulk Pack)	Home Depot	1	box	$21.41	$21.41
						Total ROV cost	$3,796.99

VII.CONCLUSIONS

A. Troubleshooting and Testing

Testing began since the ROV was completely finished on the mechanical field, resistance tests were made with each material *Axolotl* contains. Afterwards, a water leaking tests had to be done on the WER, initially there was no water leaking but as the days went by and the ROV was fully completed, the O-rings were worn and water leaking on the WER became our priority. Once the ROV was assembled, tests for the electronics were made outside the water for facility of correction in case of failure. When *Axolotl* was ready for underwater tests, buoyancy was proved. The final step was testing the ROV to complete the tasks with different team members in order to select the final pilot.

B. Challenges

The problems started since the CAD design and continued during all the manufacture and testing process. Initially, one of the main discussions Tecxotic had was the realization of the Signal board. As mentioned before, last year's ROV had wires interfering with the thrusters, the Signal Board had to cover this problem, but the location of the ESC became another problem. The team worked hard on the design in SolidWorks until the two possible solutions were on the table: a non PCB terminal or one with PCB. For solving the location problem of the ESC, it was decided to make three holes on the acrylic on positions near the thrusters, but not too close, so the ESC's wires could have a shorter path to the Signal Board.

Because in the end it was decided not to use a PCB for unifying the wires to prevent major signal loss, the wires were welded carefully, and subjected to several continuity tests to reassure the signal, which in the end was successful.

Also the camera distribution wasn't the best, besides the fact that the Aqua Vu had a short-circuit and a delay on the software for the other two cameras. The short-circuit problem was solved by welding new wire from the ROV to the Aqua Vu terminals.

But the major problem Tecxotic had, was the water leaking into the WER. The O-rings are now worn due to the usage since the first Tecxotic competition. The problem was the unknown situation of the O-rings, and when the team discovered the leaking problem, there was humidity and drops inside the WER causing one drop to fall directly to the microSD reader of the Raspberry Pi, making impossible to recover the Raspberry Pi. This problem

appeared when the shooting for the video qualification began. The O-rings were replaced, causing no more damage.

C. Future Improvements

Each year, Tecxotic has improved thanks to previous competition experiences. For this year, the biggest improvement was the design, but also electronics and software areas had improvements too.

For next year, the biggest improvement Tecxotic will have evolves around project management and time usage. As a consequence of the Earthquake, we had a late start, causing many decisions to be rushed, working against the clock. The areas of Mechanical and Electronics will work at the same time, not one after the other, for better visualization of the resulting ROV.

D. Reflections

José Guerrero: "This project was a great opportunity to learn what does teamwork means, as we had to work together almost every day for a whole semester, this means that beside being partners, we needed to become comrades in order to build the ROV and send the qualification video in time. I think the most difficult part of this competition is to shape a team spirit, joining together a group of students with the same concern and goal, and we did achieved it."

Brenda Zárate: "Being part of this amazing team has been one of the most important and exciting experiences of my life. This team has taught me how important is to be persistent and resilient despite the drawbacks, because that kind of disadvantages are always an opportunity to grow to and learn.

I think that it was a little bit hard for all of us to find the right balance between the project and our grades, but in spite of the challenges we faced, we were able to achieve our initial goal, which was to design and build our beautiful ROV *Axolotl*."

Eduardo Nava: "This team showed the true meaning of team work, I learned new things being COO, something I will always remember and the biggest lesson I've learnt is everything will turn out right if you do it with passion, trust and companionship.

We worked from months, rough months, incomplete ideas, impatience and excitement for pushing forward this project, but the team worked every time, positive in the worst challenges."

VIII.ACKNOWLEDGEMENTS

This year, Tecxotic ROV Team, *Axolotl*, would like to extend our deepest gratitude to the following benefactors:

- Marine Advanced Technology Education Center
- Tecnológico de Monterrey Campus Cuernavaca and Director Ph. D. Karla Vargas - For being our alma mater, funding the ROV materials, components and all the support given to the team through all these rough months.
- Ing. David Garcaía Suarez - For being our mentor, for all the extra time he dedicated to the project, guiding us on decision making, always leading us with patience.
- Ph.D. Mónica Larre, Director of the School of Engineering and Sciences in Tecnológico de Monterrey in Cuernavaca - For authorizing this project, allocate budget for the ROV costs, and her unconditional support.
- Ph.D. Wilmer Gaona and its NOVUS project: "MakerLab: Microlaboratorio de fabricación digital para el desarrollo de prototipos y a través del prototipado rápido" for showing us the 3D printing desktop technology and its possibilities for a obtain a functional prototype from a digital design
- Ofelia Sosa, Ignacio Merlín, Juan Aguirre, Alfredo Nava, Salvador Fuentes- For their valuable time and teaching us how to use the machinery at their laboratories to manufacture the ROV.
- Miguel Figueroa, for being our adviser, supporting our leaders and guiding them.
- All the Tecnológico de Monterrey masters, teachers, engineers and community that supported our team by helping us in every possible way.

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X.APPENDICES

A. Safety Checklist

Pre-Launch

- ❑ Area clear/safe (no tripping hazards, items in the way)
- ❑ Verify power switches and circuit breakers are off
- ❑ Tether flaked out on deck
- ❑ Tether connected to Anderson connector and secured to ROV
- ❑ **Tether** strain relief connected to ROV
- ❑ Check electronic distribution is correct
- ❑ Electronics WER completely sealed
- ❑ Verify enclosure vent and **plug** for Electronics WER are **completely sealed.**
- ❑ **Call "Plug"**
- ❑ Visual inspection of electronics for damaged wires, loose connection
- ❑ Thrusters and tools free from obstructions
- ❑ Power source connected to the 30 amp. fuse box

Power Up

- ❑ Pilot checks control computers up and running
- ❑ Power supplying 48 Volts nominal. Call **"Power ON"**
- ❑ Verify thrusters are working properly (joystick movements correspond with thruster activity)
- ❑ Verify video feeds
- ❑ Call "ROV ready"

Launch

- ❑ Call **"launch"**
- ❑ Check Tether is in order
- ❑ Launch ROV, maintain hand hold. Call **"ROV IN"**
- ❑ Wait for release order

In Water

- ❑ Release air bubbles from buoyancy materials
- ❑ Visually inspect for water leaks
- ❑ If there are large bubbles, pull to surface immediately
- ❑ Engage thrusters and begin mission

ROV Retrieval

- ❑ Pilot calls "ROV surfacing"
- ❑ Deck crew calls "ROV captured", kill thrusters
- ❑ Operation Technician (OT) powers down power supply. Call **"Power OFF"**
- ❑ OT calls out "safe to remove ROV"
- ❑ After securing the ROV on deck, deck crew calls out **"ROV OUT"**

Leak Detection Protocol

- ❑ Call **"STOP, Abort, Leakings"**
- ❑ Surface immediately
- ❑ Power down fuse box
- ❑ Inspect (may require removal of electronics)

Loss of Communication

- ❑ Call **"Communication Failure"**
- ❑ Cycle power on power supply to reboot ROV
- ❑ If no communication, power down ROV, retrieve via tether
- ❑ If communication restored, confirm there are no leaks, resume mission

Pit Maintenance

- ❑ Verify thrusters are free of foreign objects and spin freely
- ❑ Visual inspection for any damage
- ❑ All cables are neatly secured
- ❑ Visual inspection for leaks
- ❑ Verify camera positions

Safety Key Words

1. PLUG
2. ROV in
3. ROV out
4. Power On
5. Power Off
6. Tether
7. Abort
8. Trapped or stocked
9. Leakings
10. Communication Failure
11. Ready
12. Tools Failure
13. STOP