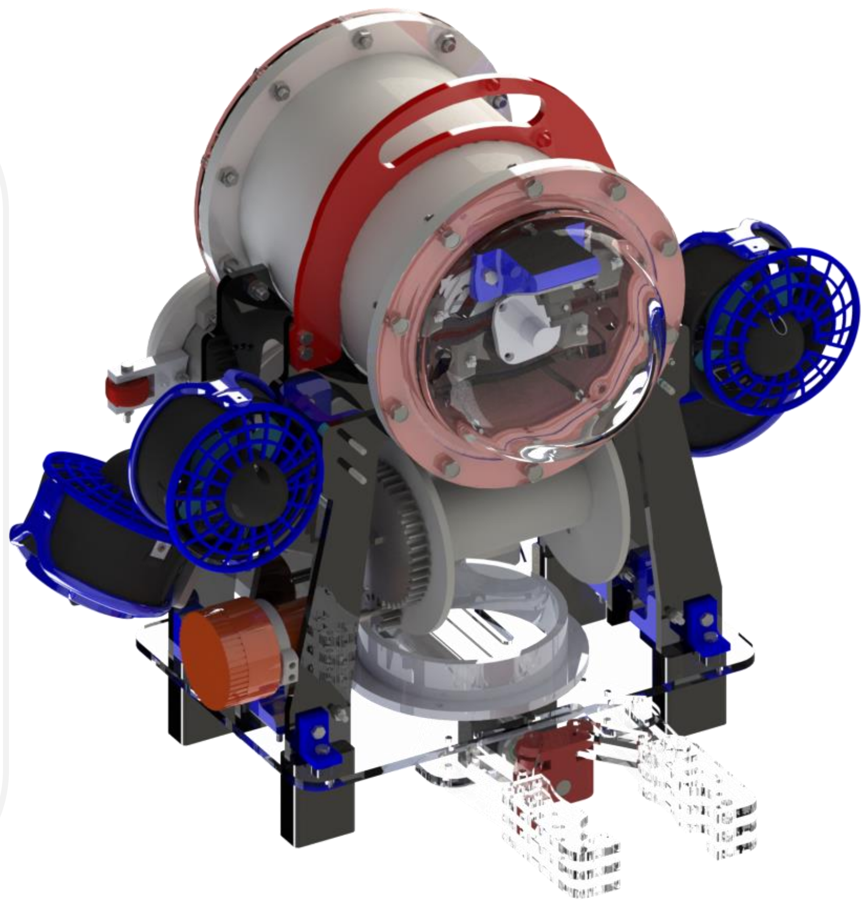
Vortex Brainnovates Technical Report 2019

Alexandria, Egypt



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I- Abstract

In response to the Eastman's request for a Remotely Operated underwater Vehicle (ROV) which can carry out many tasks in different conditions, Vortex Brainnovates has designed and built the ROV, Octopus, to ensure the public safety, maintaining healthy water ways and preserving history. Octopus was tested to make sure of maximum mission success.

Vortex Brainnovates was founded this year, by the mentoring of Vortex Company, aiming to come out with the best quality ROV. The team consists of 10 enthusiastic and determined middle and high school students who spent months of learning, planning, developing, testing and troubleshooting that eventually resulted in our ROV, Octopus, as a marketable product.

Octopus is characterized by its light weight, small size, stability, easy assembly and low cost. It was manufactured using various techniques such as laser-cutting, CNC routing and 3D printing. Octopus is equipped with four BlueRobotics T100 Thrusters for the necessary movements, a pneumatic system for the main gripper, cameras for vision, custom-made printed circuit boards and sensors including a temperature sensor and a leakage detection sensor. The ROV is also equipped with a micro-ROV for inspecting pipes. The team is confident that Octopus is the most suitable ROV to fulfill the laboratory's request.The following information show how Octopus was built to perform the required missions.

Figure 1: Vortex Brainnovates Team in Regional Competition

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II- Design Rationale

A- Design Process

The design of Octopus is a result of a lot of hard work of our team. We tried to make a superb design with the least cost possible. We changed the design several times till we reached this design. The team members discussed the designs they had in their minds first. Then after choosing one, the members of the electric team started exploring what electrical components are needed in the enclosure. After that, we used SolidWorks for the design of Octopus so we can manufacture it easily afterwards.

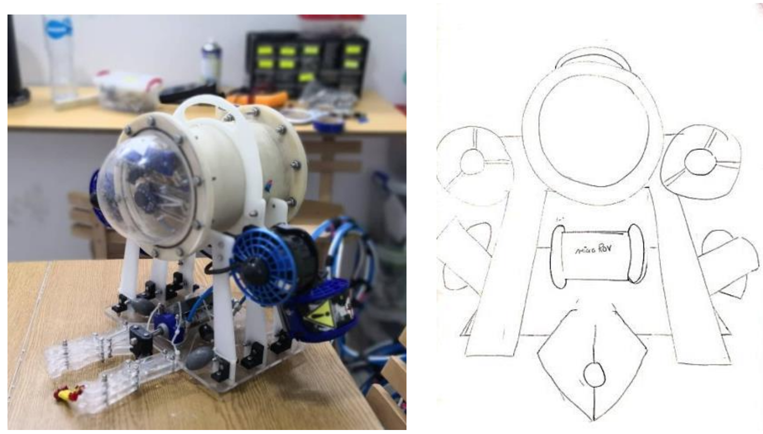
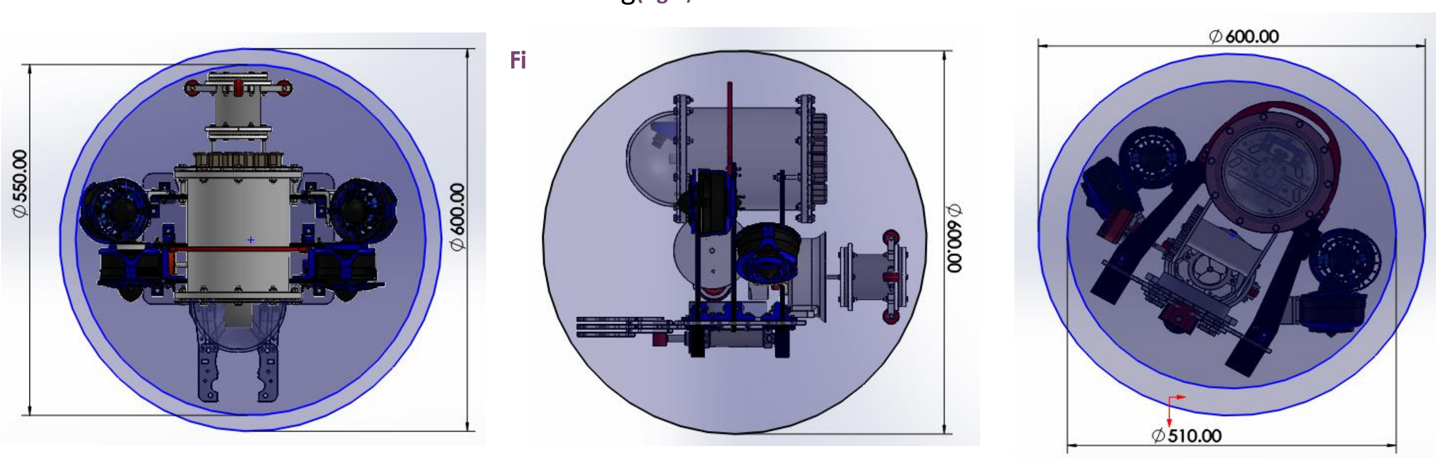


Figure 2: Octopus the ROV and its fee hand Sketch

B- Design constraints

A set of strict constraints had to be followed while designing Octopus. These constraints included weight and size limits; the vehicle and its tether combined are to fit in a 60 cm diameter ring and weigh no more than 15 Kg in air. The design team made sure that Octopus met these requirements. Octopus and its tether weigh 11 Kg combined, and fits into no more than a 600 mm diameter ring(fig 3).



C- Mechanical Design

1- Frame:

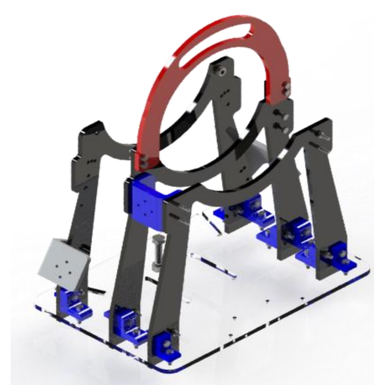


Figure 4: Octopus's Frame

The base of the ROV is made of a 6mm-thick laser-cut transparent poly methyl methacrylate (PMMA) sheet to provide a clear view beneath the ROV for the pilot. PMMA was also selected due to its high density (1180 Kg/m^3) to shift the center of gravity downwards, to achieve more stability. The slots in the base are used to correctly mount all the components in their supposed places. The webs carry the weight of the electrical enclosure, connect all the parts and hold the thrusters in place. They are made of 6mm-thick high density polyethylene as it has high impact strength and high fatigue resistance compared to other polymers. There are 4 supports; 3 for the electrical enclosure to be seated on them and 1 from the top to lock the electrical enclosure into place. They also have guides to prevent the enclosure from rotating or sliding. They were manufactured using a CNC (computerized numerical control) router.

3D printed L and U-shaped parts made of Polylactic acid (PLA) are used for fixation; to attach the webs to the base (fig 5), where the webs fit into slots in the base and then fixed to the base using M4 bolts. The thrusters are attached to the U-shaped parts (fig 6) then mounted on the webs. The 3D printed parts have a filling of 100% to be able withstand the stresses applied to them.

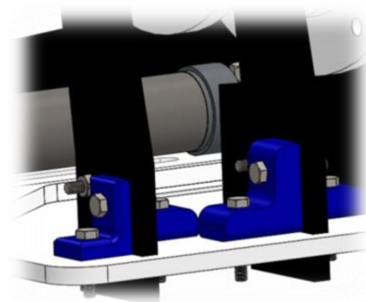


Figure 5: L-Shaped3D printed parts

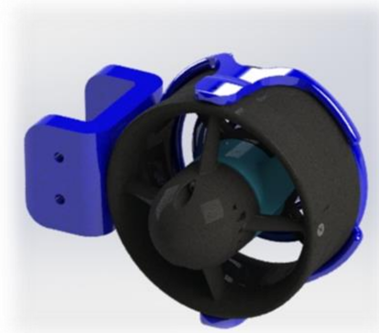


Figure 6: U-Shaped3D printed parts

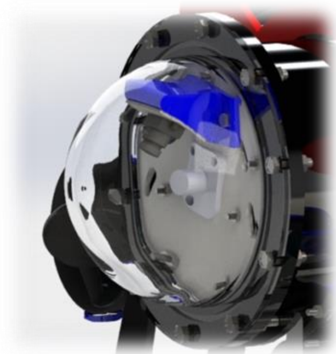


Figure 7: Octopus's Front Face

The front face of the ROV Octopus has a 6mm thick transparent poly methyl methacrylate (PMMA) dome(fig 7). The dome serves multiple purposes as providing the cameras with a clear vision of the surrounding, adding more space to afford two cameras at different view angles and reducing the overall drag force on the ROV which gives more efficient thrust power usage. The flow over the ROV was simulated to determine its coefficient of drag.

2- Buoyancy and stability

The largest displacement component is the electronics enclosure, occupying a displaced volume of 5663.76 cubic centimeters; hence, why it's placed at the top; shifting the center of buoyancy upwards. The weights and the heavy payloads are placed at bottom shifting the center of weight downwards to achieve stability. The restoring moment provides the stability needed during maneuvering

Figure 8: Centers of Buoyancy and Gravity

3- Propulsion:

Our aim was to use the least number of thrusters possible in Octopus without losing any of the degrees of freedom needed for maneuvering. A four thruster configuration(fig 9) was chosen to reduce power consumption and the overall cost of the ROV. Four T-100 Blue Robotics thrusters were used to drive ROV Octopus.

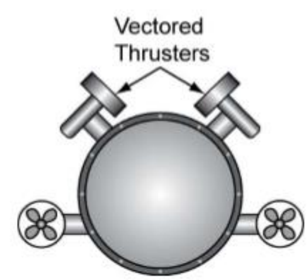


Figure 9: Octopus's four thruster configuration

This four-thruster arrangement allows the vehicle to move straight sideways, a motion called "Crabwalk" in addition to many other movements ,but does so without requiring any thrusters to occupy a central position in the vehicle. It relies on thrust vector addition to produce vertical and crabwalk motions.

The vectored thrusters interact to produce a wide range of vehicle motions. When both of the vectored thrusters are generating a force diagonally upward and towards the midline, represented by the blue arrows, these thrust vectors are equivalent to the combination of a vertical force, red arrows, and a horizontal force, black arrows.

The resultant force is directed upwards and propels the vehicle towards the surface. And if both of these thrusters now reverse their direction, the vehicle will dive. Thus, this arrangement allows straight up and straight down motion(fig 10).

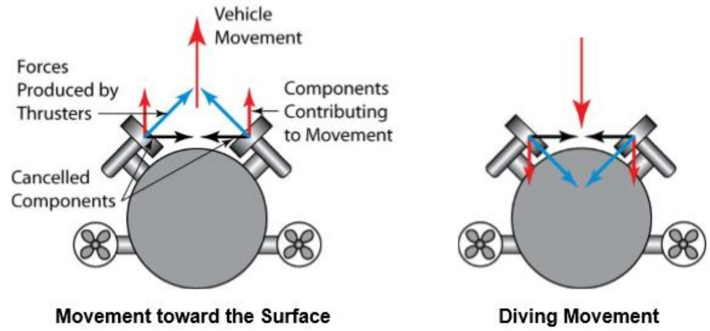


Figure 10: Octopus's Vertical Movement

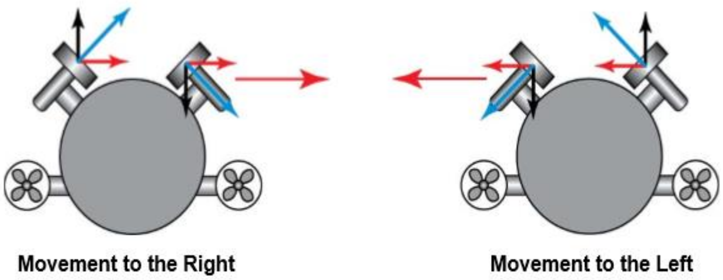


Figure 11: Octopus's Lateral Motion

The port thruster is creating a propulsive force downward and to the left, while the starboard thruster is creating a force directed upward and to the left. In this case, the horizontal, red, components cooperate, so the vehicle is pushed sideways in a crabwalk motion to the left. And if both of these thrusters reverse their directions, the horizontal, red arrows, will cooperate in the opposite direction and the vehicle will crabwalk to the right(fig 11).

4- Electrical enclosure and sealing:

At the heart of our vehicle, is an inclusive lathed machined pressure housing that is made of polyamide (PA nylon 6) with an integrated flange(fig 12). This housing contains the electronics structure and its endings are closely sealed by transparent PMMA faces: one of them has one 3.5 mm radial groove and 1.9 mm depth that houses O-rings of Buna-N/NBR rubber which are responsible for the sealing between the housing itself and the acrylic face

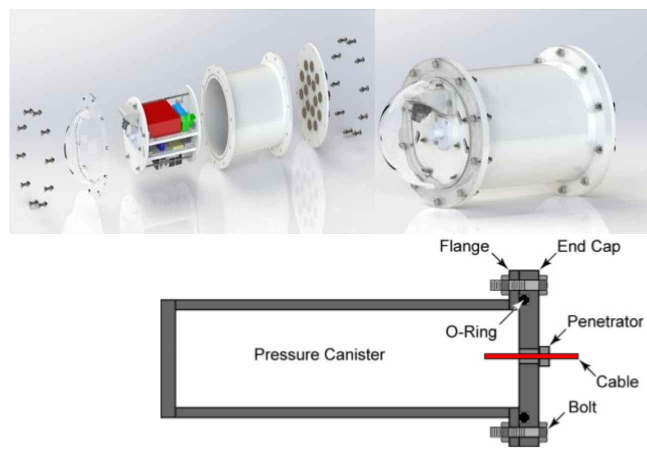


Figure 12: Electrical Enclosure

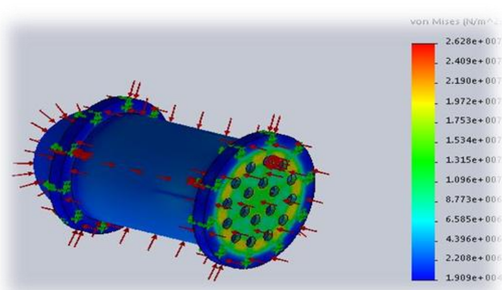


Figure 13: Stress analysis of the Electronic Enclosure

Moreover, we chose the housing cylinder structure to be made of (PA nylon 6) because of its excellent surface finish, stiffness, strength, manufacturability and lightweight.

The electrical enclosure internal structure(fig 14) consists of PMMA shelves holding the electronic components and pneumatic system, while the main and secondary cameras are held on 3D printed holders inside the dome. LEDs are fixed on PMMA parts rather than 3D printed parts because PMMA has a higher melting point. The entire structure is pulled out of the cylinder whenever modifications need to be done.

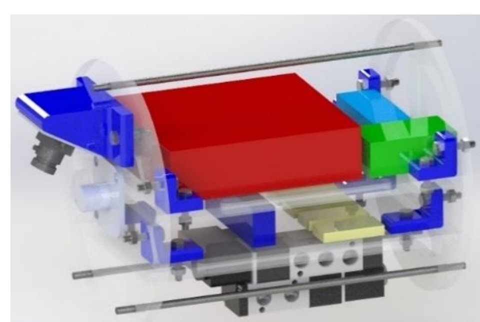


Figure 14: Internal Structure for the electrical and electronic components

Moreover, for complete sealing of the electrical enclosure, Agro cable glands (Nickel-plated brass) (fig 15) were used to seal between the cables and the cable holes . Some modifications were made on the gland; custom made rubber fittings were made in order to match the diameter of the cables going into and out of the electrical enclosure. For high modularity, the rear cover which contains the grooves for the cables is designed specifically for simple fastening of the glands. We made sure that a wrench was to easily reach easily each gland so we can fasten or unfasten any independently.

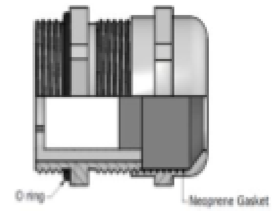


Figure 15: Nickel-Plated Brass Cable Glands

D- Electrical Design

The ROV's electrical system was designed to be as compact as possible for easy maintenance and troubleshooting. The vehicle has a system onboard using customized double layer PCB on which the microcontroller is mounted. Our joystick -through serial communication- sends signals to the microcontroller which controls the actuators, while the C# based GUI displays the readings of sensors, direction of maneuvering and speed level. The vehicle is surface-powered by a 12-volts external power supply which is fed through a series RC (Resistor-Capacitor) circuit to avoid sudden changes in voltage levels and subsequently prevent noise and signal fluctuations. 5-volts regulators are used to supply the sensors

1- Power Distribution

The current supplied from the 12 volt power supply passes through a 25Amp fuse, then reaches the main electronics enclosure where it is fed to the onboard system through a series RC circuit. When a large load current is drawn, a sudden voltage drop occurs across the tether; hence, electromagnetic interference (EMI) and noise cause the cameras to flicker due to the high rate of voltage change (dv/dt). For that reason, a capacitor of 4700 µF and a resistor of 110 Ω are connected in series to filter out the noise. As per the rules, the ROV system that is disconnected from the surface supply must stop functioning in less than 5 seconds. Our system meets those requirements as shown by the calculations in figure 17.

The 12 volts are used to supply the cameras, DCVs, thrusters, LEDs, Arduino and bilge pumps, while a 7805 voltage regulator supplies 5 volts to the sensors.

Table 1: Maximum Power Consumption Calculation

Component	Voltage (Volts)	Max current (Amperes)	Max power (Watts)	Quantity	Total max power (Watts)	Total max current (Amperes)
T100	12	10	120	4	480	40
Bilge pump	12	2	24	2	48	4
Camera	12	0.2	2.4	3	7.2	0.6
DCV	12	0.28	3.36	2	6.72	0.56
LED	12	0.84	10	4	40	3.36

Maximum power consumed = 581.92 watts **Maximum current = 48.52 Amperes**

Maximum power is never reached because of our software interlocking system which limits the speed of the thrusters. (1720 µs PWM input to the ESC fig 16) , two thrusters at a time)

Therefore, the actual maximum power is **200 Watts**, and the maximum current is **16.6 Amperes**.

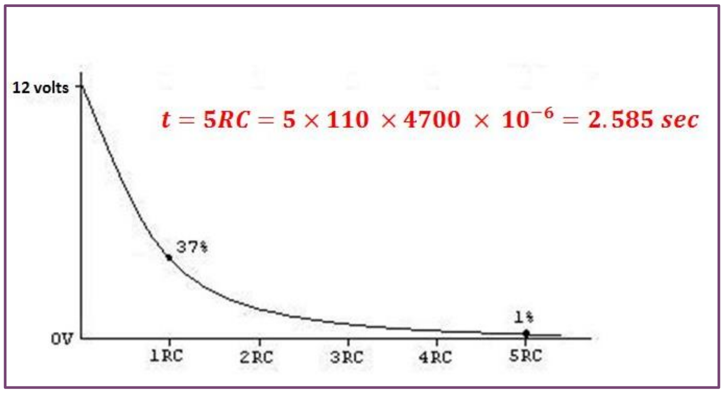


Figure 17: Discharge rate of capacitor

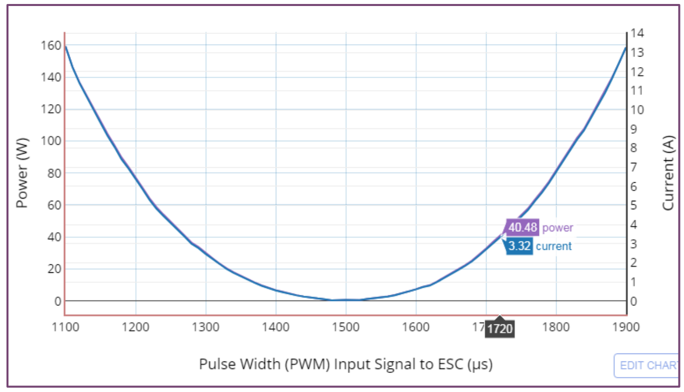


Figure 16: PWM Signal to the T100 thrusters

2-Communication:

USB to RJ45 (Ethernet) adapter (fig 18) is used, where the D+ and D- data lines of the USB cable are directly connected to the TX and RX terminals of the Ethernet cable. The Ethernet protocol is a full-duplex differential communication based system. The USB extension enables us to control the ROV from a considerable distance up to 50 meters away from the station. The adapter offers an easy access to the Arduino directly to upload codes without the need to open the electronics enclosure. Additionally, its cheap price and availability in local stores encouraged us to use it.

Figure 18: RJ to USB converter

3-Control system:

Figure 19: Arduino Mega

a- Microcontroller:

Arduino boards were used because of their affordable prices and because they're open source AVR microcontroller-based development boards which can be programmed easily. Specifically, Arduino MEGA (2560) 32-bit (fig 19) was used because it is relatively fast and has 54 digital input/output pins to be able to control all the ROV's actuators, and 12 analog input pins to be able to receive multiple sensor readings.

b- Actuators control:

ESCs (Electronic Speed Controllers)

Using 4 ESCs (fig 20), the microcontroller is able to control the 4 thrusters using PWM (Pulse width modulation).

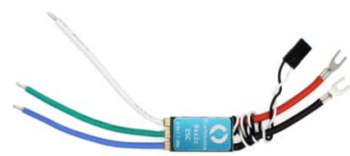


Figure 20: ESC

Figure 21: Motor Driver

"Monster" Motor Driver

The motor driver (fig 21) provides full speed and directional control to the DC motors/bilge pumps used in the docking mechanism and the micro-ROV.

IRF640 MOSFETs

IRF640 MOSFETs are used for controlling the DCVs of the pneumatic circuits and the LEDs. Conduction losses in the MOSFET were calculated to ensure that its temperature rises to an accepted level (fig 22).

IRF640 MOSFET temperature calculations:

$$I_D = 0.28\ A$$

$$R_{DS(on)} = 0.18\ \Omega$$

$$P_{dissipated} = R_{DS(on)} \times {I_D}^2 = 0.014 watt$$

$$R_{th\ j-a} = 62\ ^{\circ}C/watt$$

$$\Delta T = R_{th\ j-a} \times P_{dissipated} = 0.87^{\circ}C$$

Figure 22: MOSFET Calculation

c- System onboard

During the design of our customized double layer printed circuit board (PCB) -which acts as a motherboard (fig 23).- , we were keen on making our board capable of accepting additions and flexible in use as possible; hence, it has places to mount our commonly used components e.g. regulators, ESCs, Arduino Mega, MOSFETs, water sensor...etc , while in terms of the capability of accepting additions, we pinned out the unused pins (like unused digital pins and communication pins) to be used whenever needed. We also made our analog pins ready to accept new sensors at any time just by mounting it directly in place.

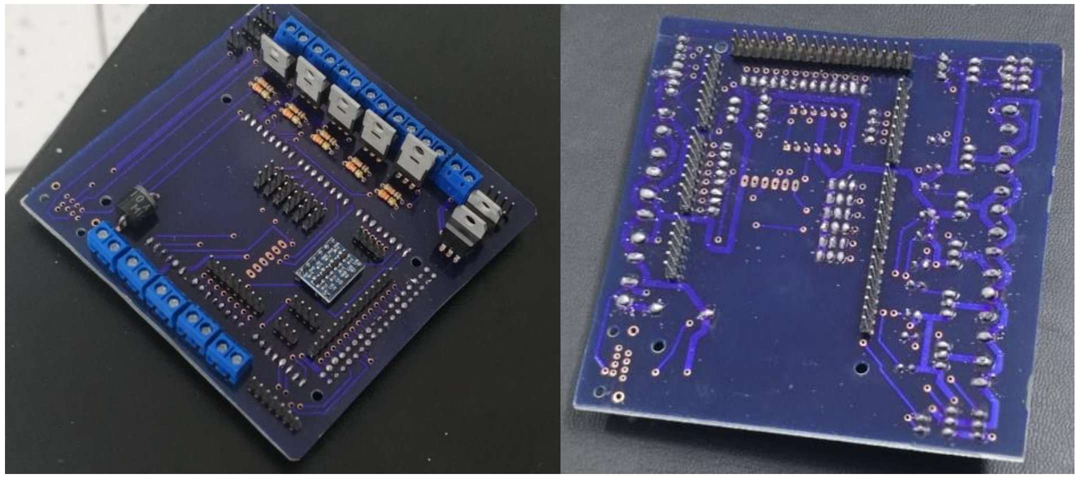


Figure 23: Mother Board

A diode rated at 6 amperes is placed to protect the system from reverse voltage.

The widths of the traces were calculated based on the relation: $I = K\Delta T^{0.44} A^{0.725}$

Where I is the current, k is a constant, ΔT is Temperature Rise, and A is the cross-sectional area of the trace. The trace width can then be calculated by rearranging this formula to determine the cross-sectional area that our desired current can safely pass through. Then, the width is calculated from the cross-sectional area for a chosen thickness:

$$\text{Width(mils)} = \frac{\text{Area}}{\text{Thickness (oz.)}} \times 1.3$$

Based on the formulas: PCB trace width for signals equals to 0.8 mm and for high current loads is equal to 2.5mm.

4- Tether(fig 24).

a- ROV tether:

Communication:

The signal is transmitted from the station to the ROV through two Category6 Ethernet cables which have 8 cores each. One cable is for the USB –RJ45 adapter, while the other is for the camera. CAT6 was used as it can provide serial communication at a rate of 250 Kbps.

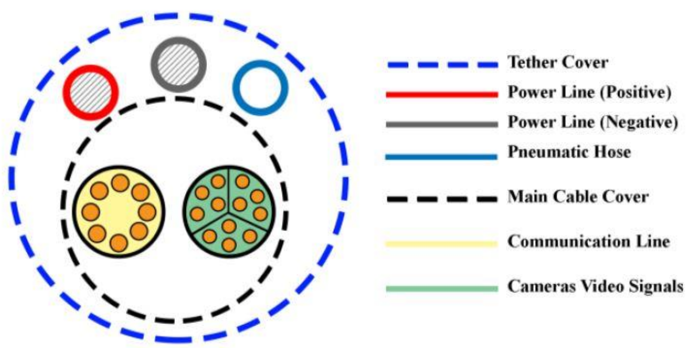


Figure 24: Tether Diagram

$$VDI = \frac{Current\ (Amperes) \times Length\ of\ wire\ (feet)}{\%voltage\ drop\ \times voltage\ (volts)}$$

$$= \frac{16.6 \times 65.6}{7.5\ \times 12} = 12$$

VDI (12) → AWG (6)

Figure 25: Voltage drop index (VDI) and American wire gauge (AWG) calculations

Power transmission:

Based on the AWG wire sizing chart, we decided to use a 6 AWG (4 mm diameter) power cable in order to minimize the voltage-drop (7.5%) across the tether's terminals and subsequently providing the system with a more stable voltage (fig 25).

Pneumatic:
The pneumatic hose has an inner diameter of 4 mm and an outer diameter of 6 mm. It's able to withstand pressure up to 10 bars (10^6 Pa).

The tether of the ROV is 20 meters long and foam rods are attached to it with a constant spacing between them to make the tether neutrally buoyant to minimize the drag on the vehicle and to keep it balanced.

b-Micro-ROV tether:
The micro-ROV tether is a 12 pair telephone cable. 6 pairs for power transmission, 3 pairs for signal transmission for the motor driver, 2 pairs for signal transmission for the camera and 1 pair signal transmission for the relay.

5- Vision system
a - Main camera:
An analogue CCTV camera having a focal length of 2.8mm, an angle view of 89.9° horizontally and 79.8° vertically is used. The camera was horizontally oriented such that it gives the pilot a perfect view ahead of the ROV.

b- Secondary camera:
Another low light analogue Blue robotics camera with focal length of 2.1 mm and an angle of view 128° horizontally and 96° vertically is tilted at angle of 50° to have of the manipulator. It's also used for image processing during the identification of the benthic species beneath the rock.

Figure 26: Vision Cameras

6- Station
a- Main laptop:
Displays the readings needed by the pilot while controlling the ROV through a graphical user interface.

b- Secondary laptop:
Provides the co-pilot with all the mission specified software needed during the product demonstration such as length measurement and image processing.

c- Manipulators control laptop:
Displays the video captured by the manipulators camera.

Figure 27: ROV controls using Logitech 3D pro joystick

Figure 28: Control Panel

d- Control panel:
Our control panel fig(28) is built in a neat and workman like manner, without loose components or unsecured wires. A Logitech 3D Pro Joystick is used for controlling the ROV (fig 27). The DVR is used to display all the videos on the LCD BenQ screen to facilitate controlling the ROV for the pilot.

E- Software

1- Onboard Software

Our software engineers designed the onboard software using the most flexible architecture: the Round-Robin architecture which is considered to be one of the simplest techniques; because there are no interrupts, no shared data and no latency concerns. Our main loop checks each I/O devices in order, services any device requests and returns data from the sensors to the top-side Arduino if needed. Therefore, our onboard software is characterized by its ease of modification & debugging.

2- Top-Side software

Our Software Engineers implemented a fig(29). which is C# based. The GUI receives data from the 3D Pro Joystick which is then sent to the Arduino onboard in the form of JSON (JavaScript Object Notation) string. For the Arduino to process the received data, it converts the data to JSON objects. Similarly, the readings of the sensors received by the Arduino are sent to the GUI by converting the data into JSON strings.

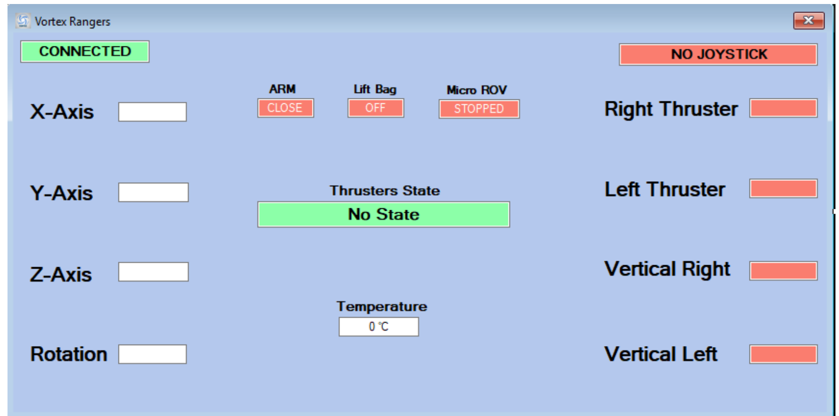


Figure 29: Graphical User Interface

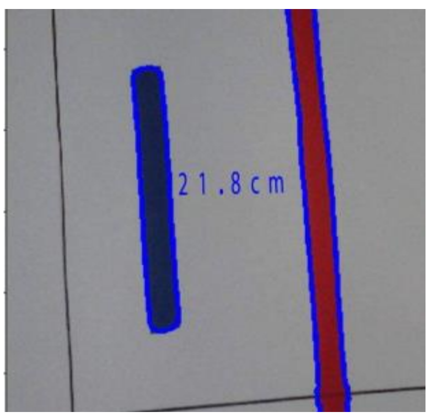


Figure 30: Measuring the cracks

3- Mission specified software:

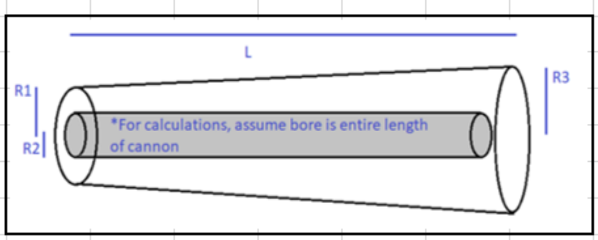
a-Measuring crack length and cannon dimensions

Using the CCTV camera placed on the base of the ROV, a photo is captured and imported to the image processing software. A scale is set to a known distance in the captured photo and using the concept of relative distance measuring based on pixels counting, a relation between the number of pixels and the unit length could be established which is used to determine the length of the crack during dam inspection fig(30), as well as measuring all the dimensions of the canon to calculate its volume.

b-Calculating the canon's volume and weight underwater

An Excel Sheet fig(31)is used to calculate the canon's volume and weight underwater by inputting the canon's dimensions and its density.

Inputs		
R1	6.8	cm
R2	3.3	cm
R3	12.16	cm
L	96.7	cm
canon volume		
24720.93301	cm³	
denisty		
7870	kg/m³	
canon weight		
1666.059864	N	



values of	numbers	unit
D1	13.6	cm
D2	6.6	cm
D3	24.32	cm
water densi	1000	kg/m³

Figure 31: Canon Underwater Weight Calculation

a- Determining the number and the type of the benthic species

The Algorithm used for detection of benthic species fig(32) is as follows: When a frame is captured, it undergoes several operations starting with grey scaling and thresholding, then using the find contours function it detects all closed contours and then check each of them, if the contour has 3 edges then it would be a triangle and specified as species A, if it has 4 edges then it's either a square or a line, thus we check it's aspect ratio in order to determine whether it is a square which is species B or a line which is species C, if the contour has more than 4 edges than it's a circle and specified as species D.

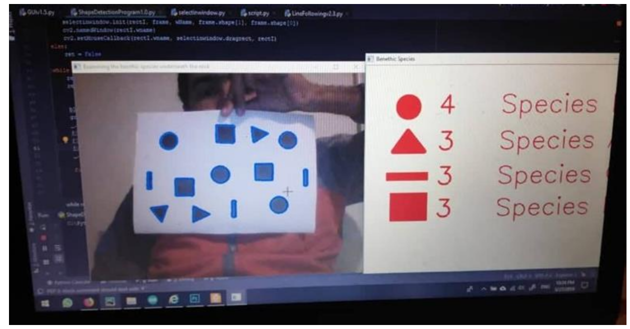


Figure 32: Benthic Species Identification

F- Mission specified tools and payloads

1- Manipulator

Octopus is equipped with a multifunctional, pneumatically actuated, parallel jaw manipulator(fig 33).The manipulator is used for holding objects throughout the missions.

The gripper motion is provided through the linear motion of the pneumatic piston rod (bore 25 mm and stroke 50mm). It uses the parallel link mechanism to convert the rod's motion to the gripping action. The jaws of the gripper are designed according to the missions' requirements, our design team designed each part in the jaws carefully to enable the pilot to hold the mission tools with ease.

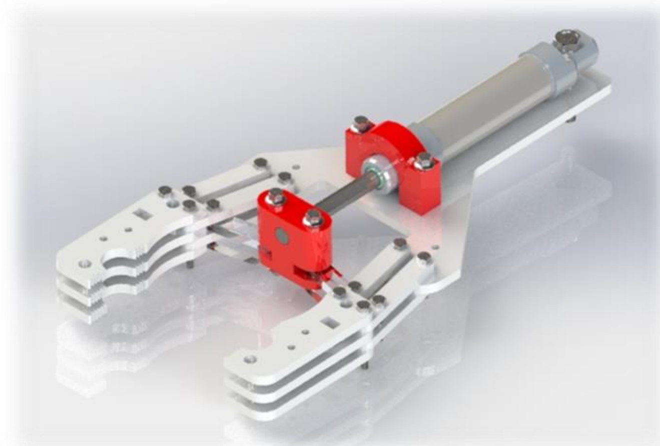


Figure 33: Octopus's Manipulator

Jaws are manufactured from transparent acrylic (PMMA – Poly Meta Methyl Acrylate) so it won't block the view for the items gripped. The connecting links and the base of the piston are made from acrylic (PMMA – Poly Meta Methyl Acrylate) to avoid high bending and 3 layers of jaws

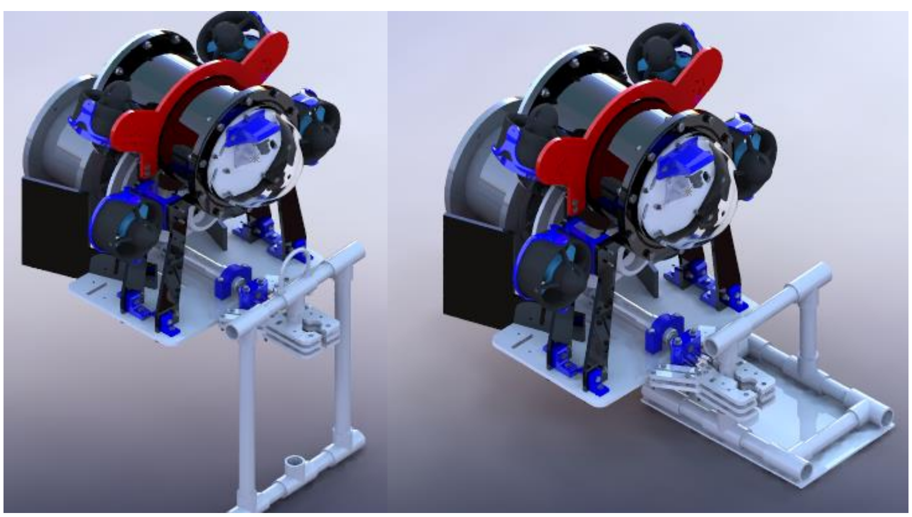


Figure 34: Octopus Simulation of some missions using its Manipulator

b-

The manipulator was designed to open up to 10 cm to provide enough space for the pilot to be able to pick up the objects easily.

End effecter of the manipulator grooves designed especially to suit all missions like Trash rack, simulated rock and Reef/fish balls.

2- Manipulator Attachments

Grout Tool:(fig 35)

A tool mounted on the main manipulator is designed to carry 300 ml worth of grout- which is simulated by ½-inch to 1-inch Black Mexican Beach Pebbles- and then inserts it into the void fig(37). This tool is also used to carry the trout fry.

Figure 35: The grout tool

Figure 36: Tire Tool

Tire Tool: (fig 36)

This tool This tool is used to carry the degraded tires, which is simulated with 3-inch Corex drain pipe. It is designed in way that encloses the tire by the two halves of the tool fig(39). The tool is also attached to the main manipulator.

Lift bag: (fig 38)

Our lift bag is made from a rubber balloon to which a hook and a pneumatic cable are attached. This tool is used to lift the canon in mission 3. Once the hook is attached to the U-bolt of the cannon, pressurized air pass through a non-return valve on the ROV to inflate the lift bag.

Figure 38: Lift Bag

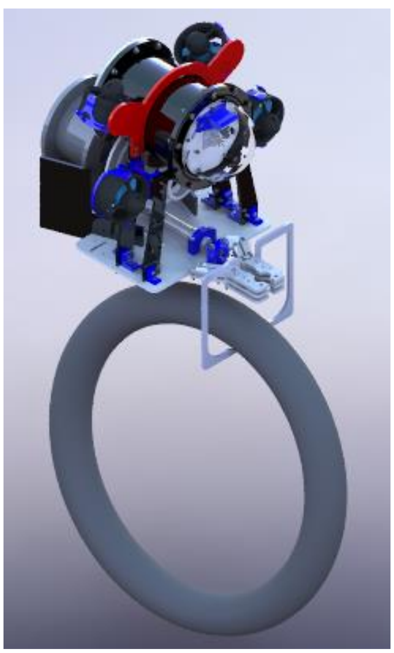


Figure 39: Octopus Lifting the Tire

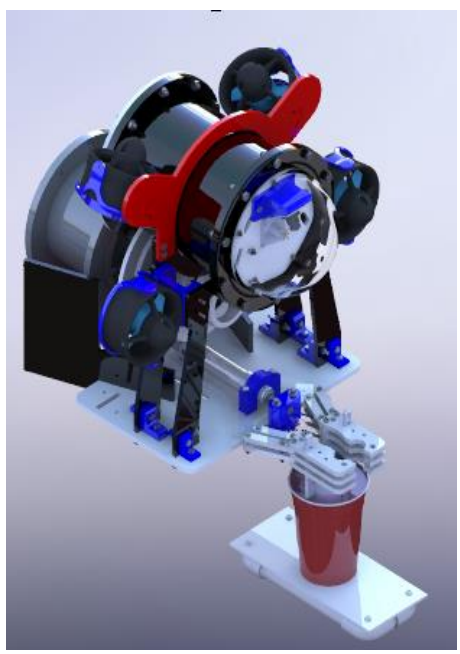


Figure 37: Octopus inserting grout

3- Temperature sensor

For the temperature measurement we decided to use the temperature sensor (DS18B20) for its sealed construction (IP68 0.6 bar), acceptable error reading within 0.5 degree centigrade from the actual values and resolution of 0.04 degree centigrade.

Figure 40: Temperature Sensor

4- Micro ROV and Docking system

The micro ROV (fig 41) is designed to be as compact as possible; it has only one bilge pump / sealed DC motor to provide its thrust, an electrical enclosure made of PA type 6 , one camera and one LED. The bilge pump is coupled with a T100 propeller through a stainless steel coupling. Four plastic rollers are attached externally for a smooth movement inside the Corex pipe.

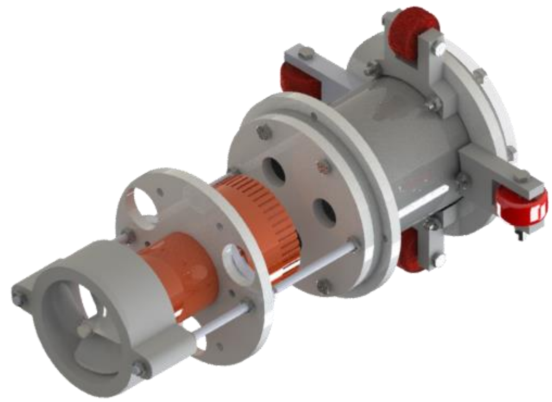


Figure 41: Micro ROV

We designed a specific docking mechanism for micro ROV (fig 42) where it releases a part of its tether while moving forward and wind some while moving backwards. We used an external 2 spur gear mechanism; these 2 gears serve as a speed reduction method with a ratio of 4:1 to optimize the rotation of the propeller with the wire and increase the torque. To maintain the Micro ROV locked in its place, we designed a storage mode where some extrusions in the micro-ROV fit inside slots in the main ROV.

Figure 42: Docking System

The micro-ROV is connected to the primary ROV through a 12 pair telephone cable. The Micro-ROV contains an analogue CCTV camera, a motor driver to control the bilge pump and a relay module to control the LED.

III- Safety

A- Safety philosophy

Throughout the construction and operation of our ROV, safety has been our highest priority. By employing safety protocols for using tools and requiring adult oversight during meetings, we worked efficiently and ensured the safety of our team members. All members were taught the proper operation of each power tool before they began using them with the supervision of one of our mentors. We are required to wear safety goggles, gloves, masks, and close-toed shoes when working with power tools. Also, to prevent accidents during fabrication, we cleaned all floors and organized all surfaces after every meeting. While testing, running on the pool deck was prohibited and all members (except the tether man) worked away from the pool edge. In addition to safety precautions taken during fabrication and testing, we developed many safety features onboard our ROV to ensure the safety of vehicle operators.

Figure 43: Safety Precautions in our workshop

B- Safety instructions

- During testing or manufacturing, at least two safety instructors must be present at the workshop.
- Using safety equipment as goggles, gloves and footwear while machining or using pneumatic circuits is a must.
- Members should make sure that their hands are dry when in contact with the power supply.
- When loading or unloading heavy components, slightly bend your body forward to prevent back injury.
- It's necessary to use a holder for the welding iron while soldering the PCBs.
- Use flux to clean the soldering iron after soldering.
- A First aid kit, as well as a fire extinguisher, is provided in case of any emergency.

Figure 44: Safety instructions in our workshop

C- ROV safety features:

Mechanical Safety Features:

Our company prioritizes safety above all else, and believes that all accidents are preventable by implementing strict safety measures. Therefore, numerous safety practices and protocols are enforced to ensure that all members are working under a suitable and safe environment as Safety instructions are always considered during designing, building, handling and testing of the ROV.

Our mechanical engineers ensured the presence of no sharp edges on the ROV. Also, moving parts, such as thrusters, are covered with 3D-printed meshes designed by our mechanical team to meet IP20 standard. Thus, protecting the thrusters from any foreign objects of 12.5 mm diameter or greater. Cap nuts are used to eliminate any exposed threading.

Pneumatic Safety Features:

A pressure relief valve is added to the compressor and is set to 10 bars (10^6 Pa), which is the maximum allowable pressure for the tank, and the pressure regulator is adjusted to 2 bars ($2x10^5$Pa) at all times. Pneumatic fittings either have O-rings, or Teflon tape is wrapped to prevent leakage. Also, all the pneumatic hoses are rated up to 10 bars (10^6 Pa) of pressure.

Electrical Safety Features:

A fuse-box between the 12V power supply and the tether, which has an inline two fuses of 25 Amp was installed. Polarized connectors and color coded cables are usedto prevent inverted connections for power and signal transmission across the whole system. ROV's static sealing was tested against a pressure up to 2 bars and confirmed its potential for tolerance, and a water detection sensor is placed to detect any leakage . Glands work as strain relief for electrical wires. The micro-ROV has a 6 amp fuse.

Warning Labels:

Warning labels are placed on thrusters and moving parts, high-pressure parts, PMMA parts that maybe subjected to fractures, electrical components and close to the high brightness LEDs to insure that anyone in contact with the ROV is fully aware of the possible hazards.

IV- Logistics

A- Company Organization and Teamwork

Vortex Brainnovates organization is mainly divided into two main divisions; electrical and mechanical, and each division is subdivided into several project groups. Before starting the first stage of designing the ROV, elections were held to select the board members including: a chief executive officer (CEO), electrical and mechanical chief technical officers (CTO) and a chief financial officer (CFO).

The CFO set a clear budget and estimated the expenses to be paid within the manufacturing phase. The CEO held general meeting to ensure that each division finishes the assigned tasks before the due date. The CTOs enabled efficient work flow in each division, by setting weekly goals and breaking down the project into several smaller points to be divided among the company members.

The mechanical division has 5 members: 2 responsible for CAD modeling 1 responsible for sealing and propulsion system selection and 2 responsible for manufacturing. The electrical system has 5 members: 3 responsible for the ROV's software –including the GUI, the onboard system and image processing , 1 responsible for power and tether calculations and 1 responsible for PCB design and manufacturing. The team also includes several non-technical departments such as marketing, media and documentation.

B- Project management

A Work Breakdown Structure (WBS) is used to take the large project goal and break it down into a series of more manageable tasks. These tasks are then prioritized; dependencies are linked, and then placed on a timeline. The schedule is divided into five main phases: training, designing, manufacturing, testing and travel preparation. During the training phase, all of members trained on SolidWorks software, Eagle PCB design software, pneumatic systems, manufacturing techniques and communication systems.

After training, the company initiated the design phase, starting with the ROV's core components –as the frame, vision system, power distribution system and communication system- then moving to the mission specified tools. Additionally, software members started in implementing the GUI and the image processing algorithms.

The next step is the building phase, where the company employees simultaneously manufacture the frame, tools, and the PCBs. The testing phase consists of pilot practice and software calibration for the image processing, if an unsatisfactory part is discovered during testing, parts will then be redesigned and manufactured. Finally, company members prepare for travelling by flight booking and Visa preparations.

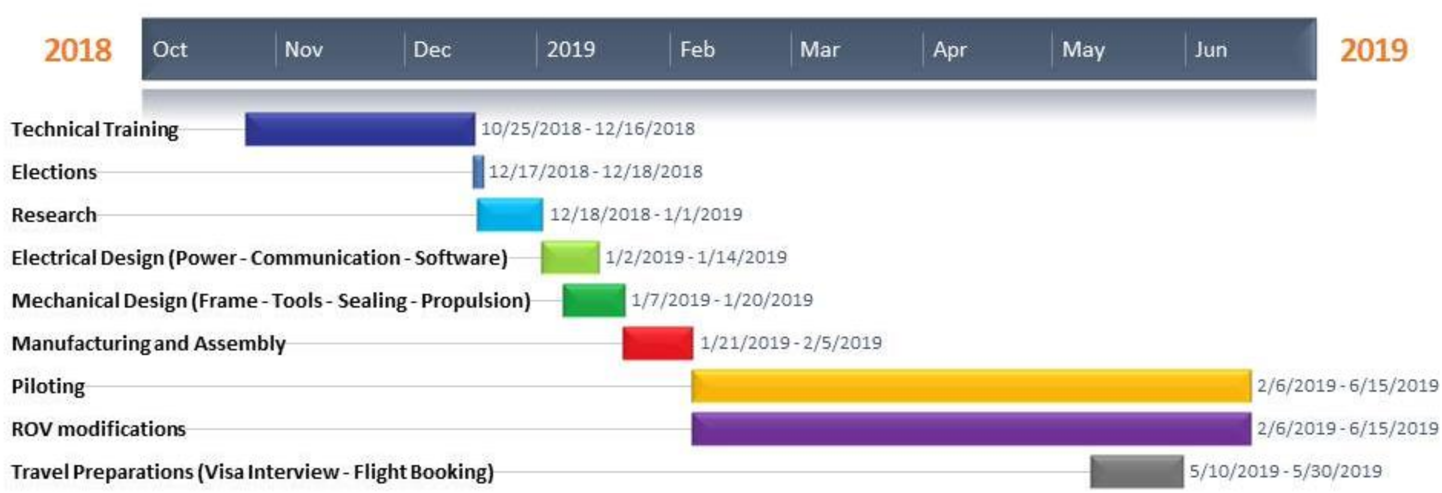


Figure 45: Project Timeline

C-Estimated budget

The following table shows the detailed estimation of the project's budget and the reason for estimation of each component used.

Table 2 : Estimated Budget

Category	Item	Estimated price	Reason for estimation
Materials	PMMA	$120	PMMA is a relatively expensive polymer and the majority of the frame is made of it, so a large sheet was needed.
	HDPE sheets	$10	The use of HDPE in our ROV is limited to certain parts of the frame only, so a small sheet was needed.
	Polyamide type 6 cylinders	$70	All electronic enclosures in our ROV and micro-ROV are made of PA, which is a relatively expensive polymer.
	3D printed parts	$55	Since we have our own 3D printer, we only took into consideration the price of the PLA filament
Machining	Laser-cutting	$27	Laser-cutting was needed for the PMMA sheets, estimating that the work would require 1 hour and that the price of cutting is $0.45 /minute
	CNC router cutting	$8	CNC was needed for the HDPE sheet. The sheet needed was small, so the manufacturing should be inexpensive
	Lathe machine cutting	$50	We had 2 PA cylinders so we knew that lathe machine cutting was going to be the most costly method of manufacturing compared to the previous two.
Pneumatic circuits	Pneumatic circuit components	$70	Considering we had our own compressor, we only took into account the costs of the DCVs, the pneumatic cylinder and the fittings.
Sealing	O-rings and glands	$50	We had 2 PA cylinders each needed two O-rings. We estimated that we needed about 24 glands and 4 O-rings
Electrical components	Locally bought components	$350	The needed electrical components that were available in our country included Arduino Uno, Arduino Mega, Arduino nano, CCTV cameras, DVR, LEDs , 12V power supply, Bilge pump , motor drivers, PCBs, wires and fuses .
	Imported components	$750	Imported components that we needed included T100 thrusters, ESCs, Bluerobotics camera , temperature sensor, Anderson connectors and 3D pro joystick . We estimated a 30% increase in the prices of the components due to shipping and customs
Tether	Communication cables , Power cables and pneumatic hose	$60	We needed a 20 meter long pneumatic hose , 25 meter long power cable , and three 20 meter long Cat-6 cables, as well as a telephone cable for the micro-ROV
Total ROV Cost = $1620			
Travel expenses	Flight Tickets	$9000	This was estimated based on online offers as well as contacting travel agencies
	Accommodations	$1700	
	Shipping and Transportation	$650	
Total Travel budget = $11350			
Overall budget = $12970			

V- Conclusion

A-Challenges

1- Technical challenges

This was the first year that any of the company members implemented double layer PCB design. All members had previous experience related to single layer PCB design, but when designing the mother board the tracks of the PCB had to be traced on the upper and lower layers which was a real challenge

2- Non-Technical challenges

We don’t all live in the same city so managing our time was very difficult especially when we started manufacturing and bringing the ROV all together. But we were able to assign tasks effectively and we divided ourselves to teams that can meet easily in different parts of the country.

B- Testing and Troubleshooting

Each time we start our ROV, we follow the same steps every time. Before connecting the tether, we check if the compressor’s regulator is at 2.5 bars. We check if the power supply is supplying 12 volts. After connecting the tether, if the power is not working, we check the fuse and replace it if it failed. Then we start running the thrusters and the gripper and make sure they are working correctly. If anything is wrong we check that all the connections are in place correctly.
If a component is not working properly, we remove the component from the ROV, and test it to know the error.

C- Lessons learned and skills gained

1- Technical skills

Before building the ROV, our company members participated in a three-month training program which had all the information we need to know to build the ROV. The courses taught us CAD design, sealing techniques , propulsion systems, manufacturing methods , materials and their properties, pneumatic circuits , PCBs , vision systems, power distribution, communication and electronic control. We gained a lot of skills not only related to ROVs but also skills needed in many other projects.

2- Non-technical skills

We gained a lot of non-technical experience related to marketing, since we attended various events were we had to display our ROV. The competition taught us to think of ourselves as entrepreneurs , presenting an exquisite engineering product.

D-Future improvements

ROV Simulation using Unity

Using Unity software, we were able to design an ROV simulation software fig(46), where the missions are inserted and the user can control the simulated ROV by joystick or train with the VR with the highest degree of simulation reality and water conditions.
Unity gives users the ability to create games in both 2D and 3D, and the engine offers a primary scripting API in C#, for both the Unity editor in the form of plugins, and games themselves, as well as drag and drop functionality. Our objective is to help teams to compete training, without the need to rent a swimming pool.

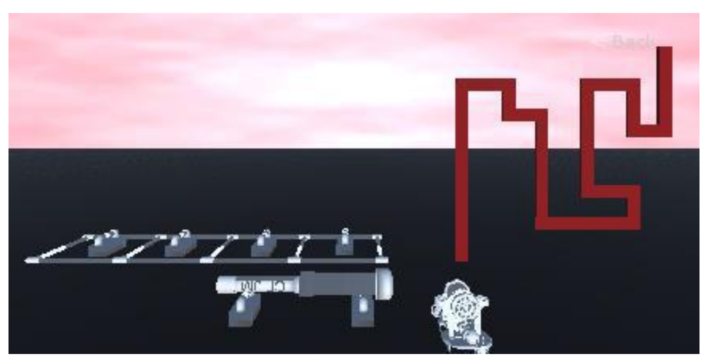


Figure 46ROV Simulation on Unity

In the future, we aim to develop our game and make it available to students free of charge to market our ROV and the possibilities that makes it stand out.

E- Refections

Youssef Taha (Mechanical Chief Technical Officer)

This has been an incredible journey and it's one where I grew as a person and was able to gain a lot of skills while also making new friends along the way and I am grateful to Vortex Brainnovates for this great opportunity

Fareda Hossam

Undoubtedly, the road was full of Obstacles. I had a lot of passion to learn how to build an ROV. I am happy to be a member of this team, they were helpful and supportive.

VI- Acknowledgments

We would like to express our deepest appreciation and gratitude to all those who provided us with the possibility to complete this product and those who helped us overcome all the obstacles we encountered along the way.

- **MATE Center** – for organizing the international competition, providing a platform for the growth of the community, and promoting STEM education around the world.
- **AASTMT [Arab Academy for Science Technology & Maritime Transport]**– for organizing the local and regional competitions in Egypt.
- **Hadath Company** – for organizing the regional competition.
- **ADES [Advanced Energy Systems]** – for sponsoring us by providing us with accommodation during the competition.
- **Vortex Co. and Brainnovate Academy** – for providing technical courses and training as well as their continuous guidance and mentorship.
- **Vortex Raiders and Vortex Troopers**- for their technical support.
- **SolidWorks™** – for providing us with student licenses.
- Our beloved family and friends- for their continuous support and encouragement in all of our pursuits.

VII- References

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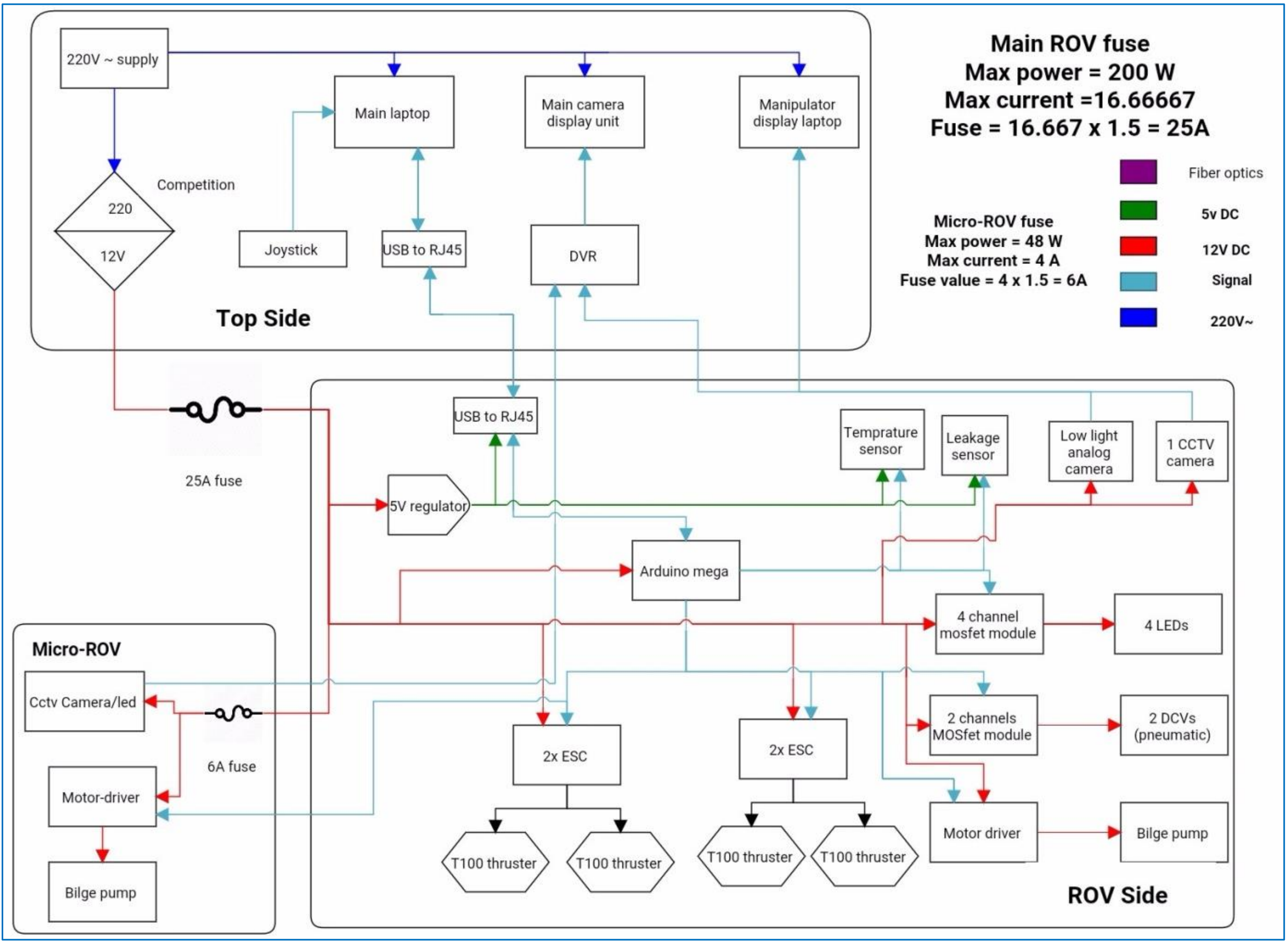
  19%20RANGER%20Manual_11_withCover_updated.pdf>
- AWG wire sizing chart <https://homequicks.com/electrical-wire-sizing-chart>

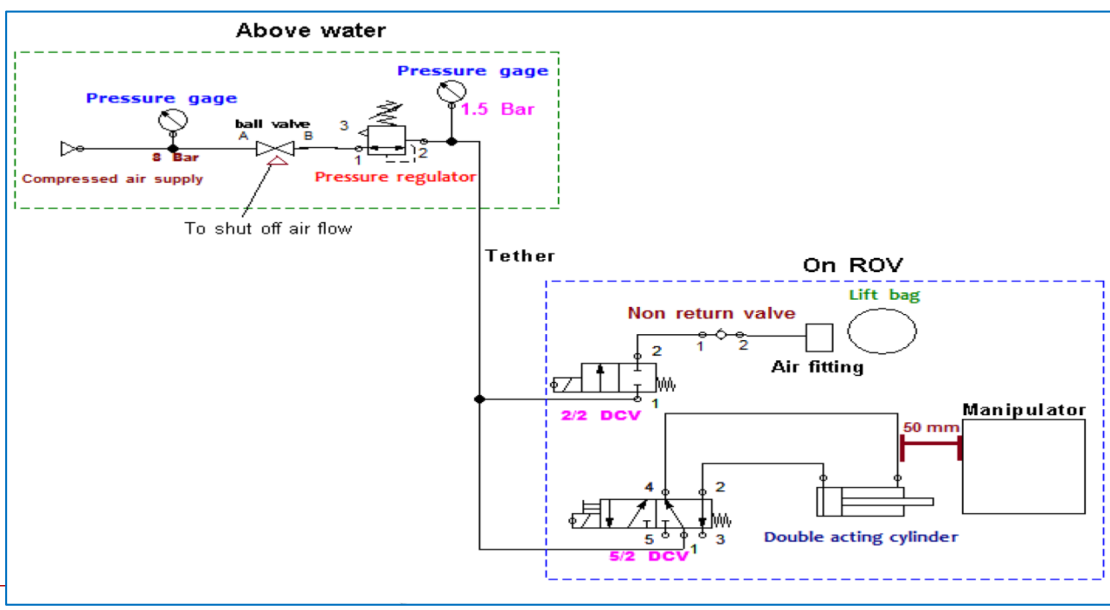
VIII- Appendices

Appendix A: System interconnection diagrams

1- Electrical SID of ROV and Micro-ROV

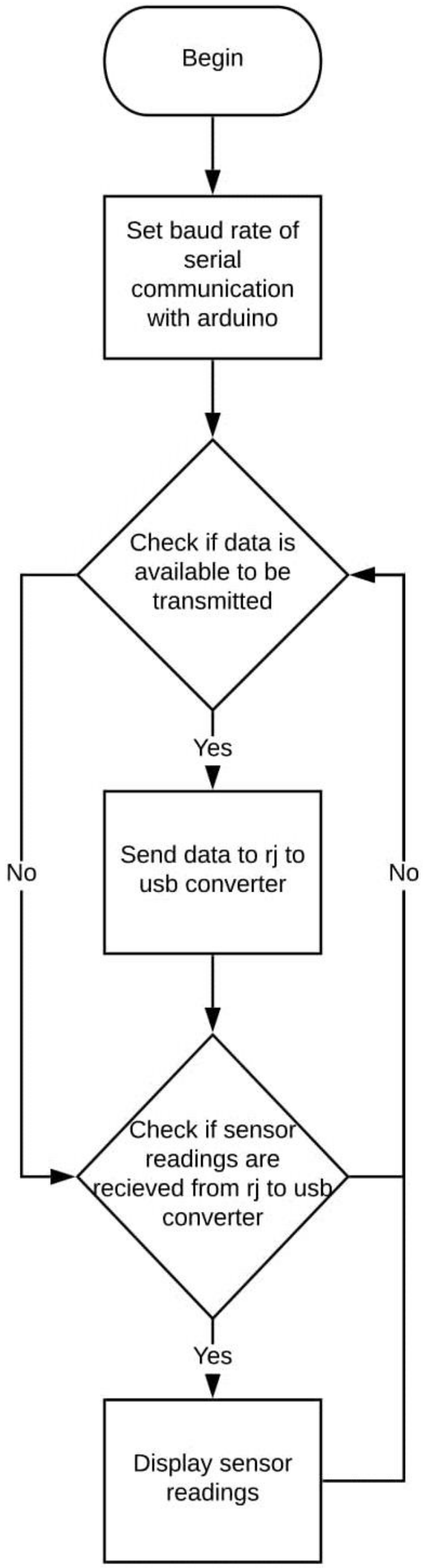


2- Pneumatic SID of ROV

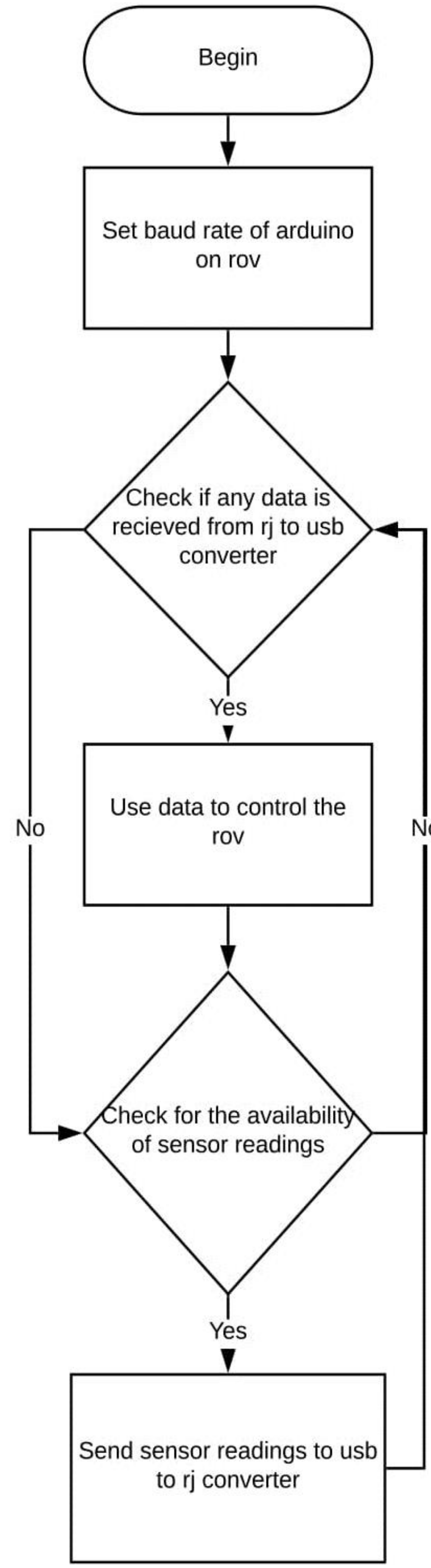


Appendix B: Flowcharts

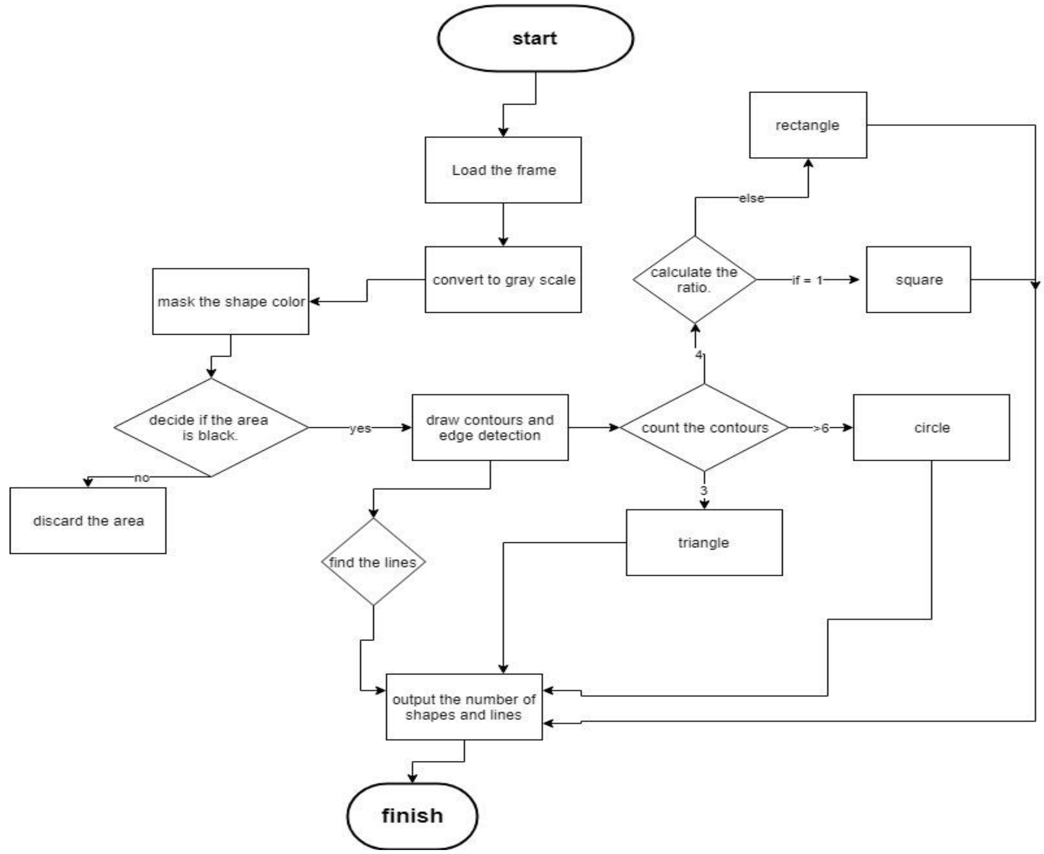
1- Top-side software



2- Onboard software



3- Image Processing (Benthic Species)



Appendix C: Safety Checklist

Phase	Topic to check	✓
Pre-launch	The power supply is placed on a dry location	
	Anderson connectors of tether are connected to power supply	
	Micro-ROV is completely docked	
	Fuse of main ROV and micro-ROV are not blown	
	All bolts are well tight	
	All of the thruster shrouds are well installed	
	Dry test for the thrusters to check on the control	
	Check cameras and vision system	
	Dry testing the micro-ROV system (DC motor, LED and Camera)	
	Checking on the compressor's regulator (less than 2.75 bars)	
	No one is touching any moving parts	
	Safety labels are all placed properly	
	All seals are installed correctly	
	Members are wearing safety gears	
In-water checks	Check for bubbles	
	Constantly check on the readings of the water-detection sensor	
Retrieval	Switching the power off	
	Compressor is discharged	
	ROV is retrieved by at least two members	
	Ensure that the micro-ROV is docked	
	Quick visual inspection for any cracks or damages	
	Tether is neatly rearranged	

Appendix D: Total Project Cost

Category	Item	Type	Amount	Qty.	Total (Dollars)
Materials	Polyethylene sheet 150cm x70cm x6mm thickness	Purchased	$17.85	1	$17.85
	PMMA sheet 46.5cm x 34.5cm x 2.5mm thickness	Purchased	$16	1	$16
	PMMA dome	Purchased	$11	1	$11
	PA cylinders	Purchased	$6.9 /Kg	12 Kg	$83.33
	Foam Sheet	Purchased	$5.6	1	$5.6
	3D printed parts	Purchased	$0.08/gm	813 gm	$67.8
Machining	Laser cutting	Purchased	$21.67	-	$21.67
	CNC router cutting	Purchased	$8.3	-	$8.3
	Lathe machine cutting	Purchased	$38.9	-	$38.9
Pneumatic circuit	5/2 DCV	Purchased	$37.2	1	$37.2
	2/2 DCV	Purchased	$13.8	1	$13.8
	Check-valve	Purchased	$5	1	$5
	Pneumatic cylinder 20x50	Purchased	$12.2	1	$12.2
	Compressor	Re-used	$111.1	1	$111.1
	Fittings	Purchased	$13	-	$13
Thrusters	Bluerobotics T100	Purchased	$520	4	$520
Sealing	Glands & Rubber	Purchased	$2.38	24	$57.3
	O-rings	Purchased	$0.85	4	$3.4
Mechanical components	Nuts, Bolts & Guides	Purchased	$33.8	-	$33.8
	Bearing	Purchased	$0.85	2	$1.7
Tether	Pneumatic hose "4x6'	Purchased	$0.153 /m	25 m	$3.82
	Power cable for ROV	Purchased	$0.668/m	25 m	$16.7
	Power cables for Micro-ROV	Purchased	$0.444/m	50 m	$22.2
	Ethernet cable (Cat-6) for ROV	Purchased	$0.556/m	50 m	$27.8
Electrical components	Arduino Mega	Purchased	$15.3	1	$15.3
	Relay module	Purchased	$2.2	1	$2.2
	12V Power supply	Purchased	$20.65	1	$20.65
	ESC	Purchased	$27.3	4	$109.1
	CCTV camera	Purchased	$18.35	2	$36.7
	Bluerobotics camera	Purchased	$73.9	1	$73.9
	Temperature sensor	Purchased	$30.6	1	$30.6
	Water detection sensor	Purchased	$2.77	1	$2.77
	Bilge pump	Purchased	$32.2	2	$64.4
	Motor driver	Purchased	$12.2	2	$24.4
	LED	Purchased	$0.83	6	$5
	USB-RJ45	Purchased	$8.9	2	$17.8
	PCBs	Purchased	$13.3	-	$13.3
	Connectors, fuses, wires	Purchased	$25.5	-	$25.5
	Anderson connector for the ROV	Purchased	$27.7	1	$27.7
Station	Joystick	Purchased	$105.5	1	$105.5
	DVR	Purchased	$50	1	$50
	Case	Re-used	$16.7	1	$16.7
	LCD screen	Re-used	$44.4	1	$44.4
	Easy cap	Purchased	$6.7	1	$6.7
Media	Flyers, brochures, poster and banner.	Purchased	$60	-	$60
Total ROV cost					**$1902.09**
Travel expenses	Flight tickets	Purchased	$800	10	$8000
	Accommodations	Purchased	$600	5 nights / 6 members	$600
Total travel cost					**$8600**
Overall cost (Self-Paid)					**$10502.09**
Funds (Sponsored by ADES)	Accommodations	Sponsored	$400	5 nights / 4 members	$400
	Transportations	Sponsored	$500	-	$500
Total funded					**$900**