Mate 2018 International Competition

Technical Report

Alexandria, Egypt

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I-Abstract

In order to satisfy The Applied Physics Laboratory at the University of Washington request for a Remotely Operated underwater Vehicle (ROV) which can carry out many tasks in different conditions, Vortex Titans has designed and built the ROV, Sturgeon, to retrieve the vintage airplane's engine after determining its wreckage, in addition to recovering a seismometer and installing a tidal turbine to monitor the environment. Sturgeon was tested to make sure of maximum mission success.

Vortex Titans was founded this year, by the mentoring of Vortex Company, aiming to come out with the best quality ROV. The team consists of 15 mechanical, electrical and software engineers who spent months of learning, planning, developing, testing and troubleshooting that eventually resulted in our ROV, Sturgeon, as a marketable product and an engineering masterpiece.

Sturgeon 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. Sturgeon is equipped with four BlueRobotics T100 Thrusters which are sufficient for the necessary degrees of freedom, a pneumatic system for actuating the main manipulator and the lift bag inflation tool, three cameras for vision and image processing, custom-made printed circuit boards and sensors including a pressure sensor and a water detection sensor to detect leakage. The team is confident that Sturgeon is the most suitable ROV to fulfill the laboratory's request.

The following technical documentation shows how Sturgeon was designed and built to perform the required tasks efficiently.

Figure (1) ***Vortex Titans team photo with Sturgeon after the local competition***
Top row (left to right): Ahmed Medhat, AbdallahElmaradny, Omar Elshanawany , Fareda Hossam , Mai Hesham , Lina Nassar, Ziad AbdelKarim , Mahmoud Saeed, Marwan Taha
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II-Design Rationale

A- Design Process

While designing Sturgeon, we tried to maintain the balance between an efficient high performing ROV and an exquisite design. Our aim was to have a stable, lightweight, compact, easily-assembled, maneuverable, cost effective ROV. Several steps were taken until the final design of Sturgeon was reached. Team members were asked to draw a freehand sketch of their suggested design of the ROV, and then team members discussed and modified these designs. After establishing the outlines of the design, electrical team members estimated the space needed for the electrical components in their enclosure. Upon receiving the dimensions of the electronic components, solid modeling Computer Aided Design (CAD) and Computer Aided Engineering (CAE) programs-as SolidWorks - were used to design and simulate our ROV. The CAD design was modified several times to fit our goals until the optimum design was achieved before starting the manufacturing processes.

Figure (2) Fully assembled Sturgeon

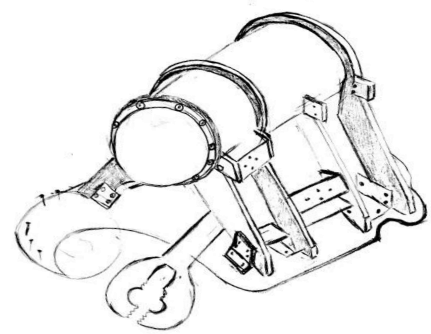


Figure (3) freehand sketch of Sturgeon

B- Design constraints

A set of strict constraints had to be followed while designing Sturgeon. These constraints included weight and size limits; the vehicle and its tether altogether are to fit in a 64 cm diameter ring and weigh no more than 17Kg in air. The design team made sure that Sturgeon met these requirements. Sturgeon and its tether combined weigh 16.83Kg, and fit in a 53 cm diameter ring-**fig(4)**, which is way smaller than the size limit. The vehicle's maximum current is also limited to 30 amperes, where Sturgeon only draws 12.3 amperes.

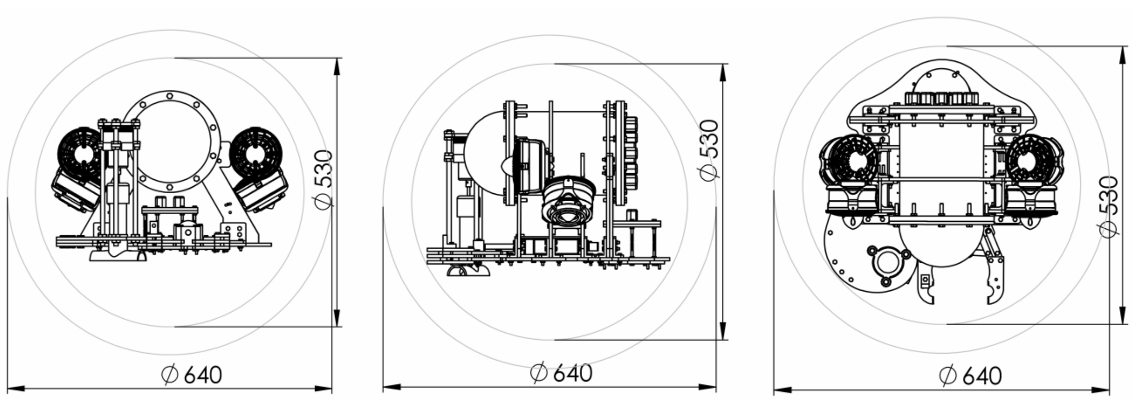


Figure (4) Sturgeon fitting in a 53cm diameter ring

C- Mechanical Design

1- Frame:

When designing the frame of Sturgeon, our priority was to build a lightweight, high strength frame with plenty of space for the payloads and necessary tools. 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 relatively high density (1180 Kg/m^3) to shift the center of gravity downwards, to achieve more stability. It has a dynamic shape to optimize the area usage of it with the smallest dimensions. The slots in the base are used to correctly mount all the components in their supposed places.

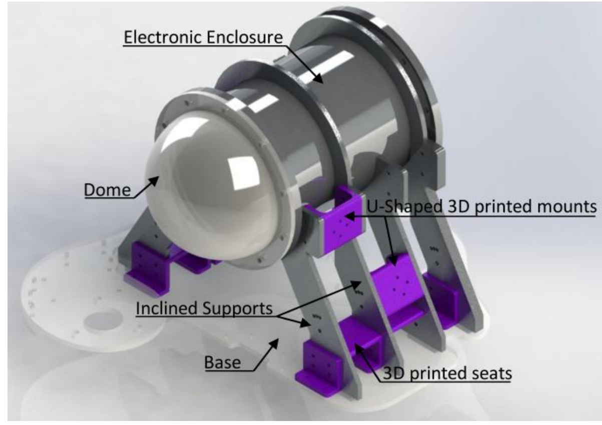


Figure (5) Sturgeon's frame


Figure (6) Assembling Sturgeon's frame

The inclined supports carry the weight of the electronics enclosure and connect it to the base. They are made of 6mm-thick high-density polyethylene (HDPE) as it has high impact strength and high fatigue resistance compared to other polymers. There are 5 supports; 3 from the bottom of the electronics enclosure so that the enclosure sits on top of them, and 2 from the top to lock it 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 seats and U-shaped parts made of Polylactic acid (PLA) are used to maintain the distance between the supports and prevent them from bending. The seats are used to attach the supports to the base; where the supports fit into slots in the seats and then fixed to the base using M4 bolts. The thrusters are attached to the U-shaped parts then mounted on the supports. The 3D printed parts have a filling of 100% to be able withstand the stresses applied to them-**fig(7)**.

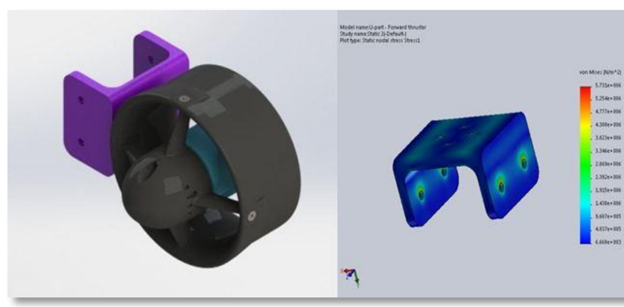


Figure (7) Stress analysis performed on the U-shaped part holding the thruster

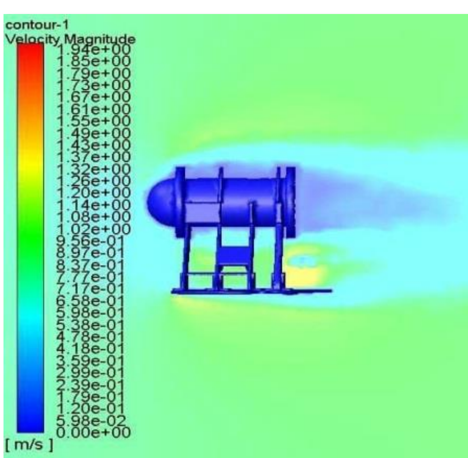


Figure (8) Velocity distribution over Sturgeon

The front face of Sturgeon has a 6mm-thick transparent PMMA dome which was manufactured using vacuum forming, which is a simplified version of thermoforming. The dome was custom made to fit our design requirements as we needed a certain flange diameter and dome depth. The dome served 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-**fig(8).**

2- Buoyancy and stability

Sturgeon occupies a displaced volume of 11710 cm^3. By applying Archimedes' Principle and taking into consideration that the density of water is 1 gm/cm^3 , the weight of the vehicle should be 11.71 Kg to achieve neutral buoyancy. Sturgeon weighed 11.21 Kg, so about 0.5 Kg of weights was needed and no Styrofoam was used.

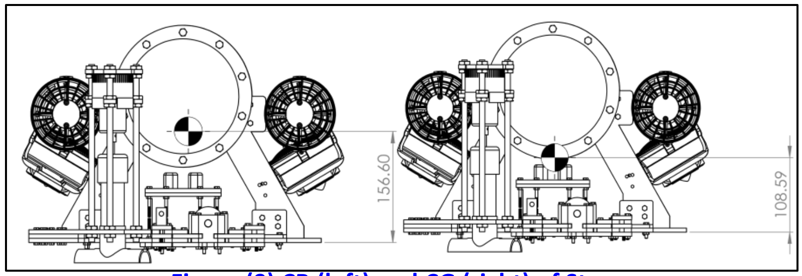


Figure (9) CB (left) and CG (right) of Sturgeon

The largest displacement component is the electronics enclosure, occupying a displaced volume of 6276cm^3 ; hence, why it's placed at the top; shifting the center of buoyancy upwards. The weights and the heavy payloads are placed at the bottom shifting the center of weight downwards to achieve stability **fig(9)**.

3- Propulsion:

Our aim was to use the least number of thrusters possible in Sturgeon while providing the essential degrees of freedom needed for maneuvering. A four thruster configuration was chosen to reduce power consumption and the overall cost of the ROV. Four T-100 Blue Robotics thrusters were used to drive Sturgeon. The two horizontal thrusters are responsible for the forward, backward and rotational motions of the ROV while the two inclined thrusters are responsible for the upward, downward and lateral motions-**fig(10)**.

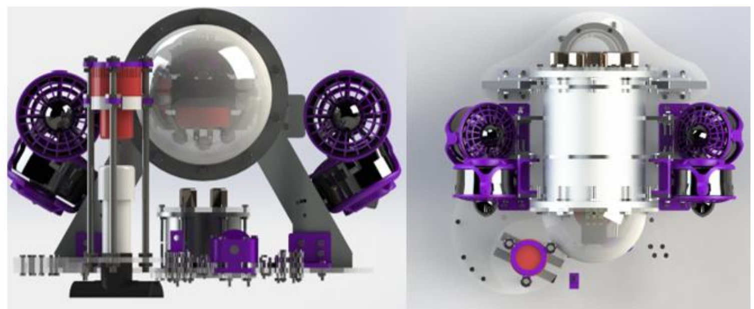


Figure (10) Sturgeon's four thruster configuration

The angles of inclination of the inclined thrusters are mechanically adjustable (60^o-75^o-90^o)-**fig(11)**to control the magnitudes of the forces in each direction to achieve the optimum stability during maneuvering. We are currently using the 60^o angle which gives us sufficient proportions of thrust to fulfill upward and downward motion with the possibility of a stable lateral motion.

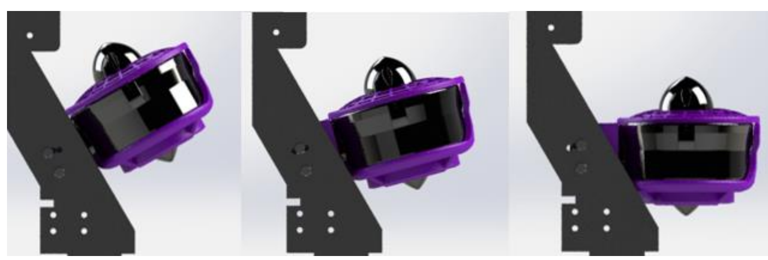


Figure (11) Mechanically adjustable angles of inclination (60^o-75^o-90^o)

We faced a problem with the lateral motion of the ROV. The ROV Sturgeon is to spin around the axis of the cylinder due to the presence of a moment resulting from the inclination of the thrusters.

We solved this problem by ensuring that the restoring torque resulting from the distance between the center of gravity and center of buoyancy was sufficient to provide the stability needed for the lateral motion. We also reduced the speed of the thrusters during lateral motion to minimize the turning torque.

The maximum forward velocity of the vehicle can be calculated by equating the maximum forward thrust force to the drag force.

$$F_{drag} = F_{thrust}$$

$$\frac{1}{2} \times \rho \times V_{max}{}^2 \times C_D \times A_{frontal} = 46.3$$

Taking into consideration that: $\rho = 1000\ Kg/m^3$, $A_{frontal} = 72439.8\ mm^2$, $C_D = 0.877$

Therefore, $V_{max} = 1.207$ m/s

Figure (12) Calculations of Sturgeon's maximum velocity

Direction	Maximum Thrust
Forward	$2 \times 23.15 = 46.3$ N
Backward	$2 \times 17.85 = 35.7$ N
Upward	$2 \times 23.15 \times \sin(60) = 40$ N
Downward	$2 \times 17.85 \times \sin(60) = 31$ N
Lateral	$(23.15 \times \cos(60)) + (17.85 \times \cos(60)) = 20.5$ N

Table (1) Thrust force calculations [Max. forward thrust force of one T100 thruster is 23.15 N, and max. reverse thrust is 17.85 N]

4- Electronics enclosure and sealing:

Sturgeon's electronics enclosure-**fig(13)** is a 21.5cm long flanged cylinder with an inner diameter of 15cm and a wall thickness of 5mm. The cylinder is made of Polyamide (PA type 6) as it is a non-porous, high strength, shock-resistant material.

A laser-cut PMMA face is fixed to the flange on one side of the cylinder, while the PMMA dome is fixed to the flange on the other side. Transparent PMMA was selected to check the compression of the O-ring used.

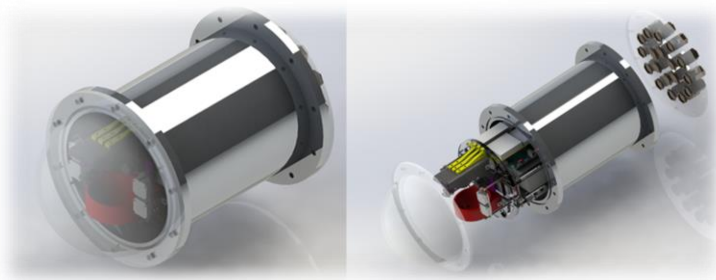


Figure (13) Sturgeon's electronics enclosure

A face seal O-ring was used for sealing ; as it can withstand a pressure difference up to 5 bars ($5x10^5$Pa). According to the Parker sealing Handbook, the O-ring used should have dimensions of 158mm x 2.5mm. Lubricating oil is used with the O-rings to protect it from wear; extending its lifetime. No chemicals -as Silicon and epoxy- were used for sealing; to avoid polluting the underwater environment.

Similar enclosures were used for sealing the image processing camera and the inductive coupling connector (Shown at: **a- Inductive coupling connector** & Image processing camera)

The electronics enclosure internal structure consists of PMMA shelves to mount the electronic components and pneumatic system on them, while the main and secondary cameras are held on 3D printed holders inside the dome. LEDs are fixed to PMMA parts rather than 3D printed because PMMA has a higher temperature threshold. The entire structure is easily pulled out of the cylinder whenever modifications are needed to be done. Heavy components -as the DCVs- are placed on the lower shelves, while light components are place on the upper shelves to increase stability- **fig(14)**

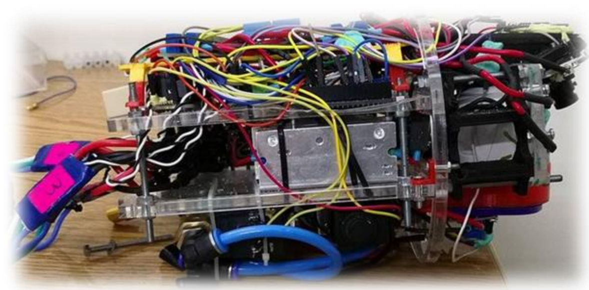


Figure (14) ***Internal structure of electronics enclosure with the components*** **inside**

Nickel-plated Brass cable glands having an IP-68 are used to seal between the cables and the cable holes through the enclosure. The cables enter the body of the gland through a Neoprene gasket which tightly seals the cable when the gland is fastened. The nut of the gland has a Nitrile O-ring to prevent water from entering through the cable holes-**fig(15)**. The glands can withstand a pressure difference up to 5 bars ($5x10^5$Pa) and also provide stress-relief for the cables. Spacing between the glands was optimized to give us the maximum number of glands-**fig(16).**

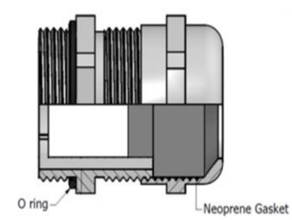


Figure (15) Internal structure of Nickel-plated Brass cable glands

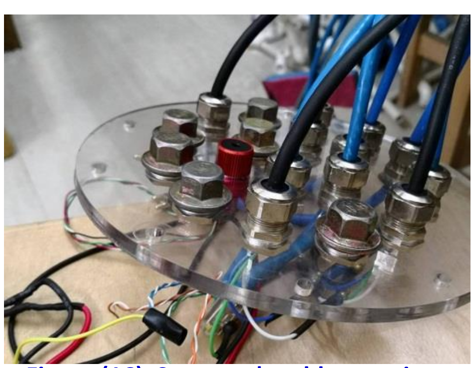


Figure (16) Sturgeon's cables passing through the glands

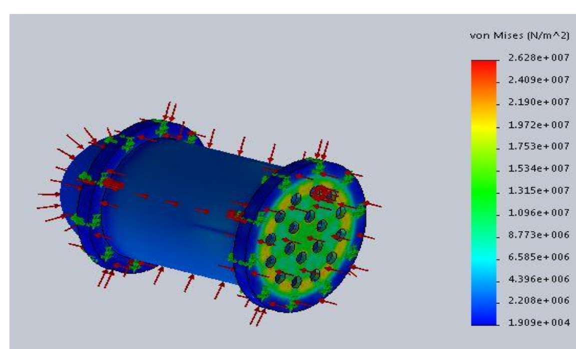


Figure (17) ***Stress analysis performed on the electronics enclosure at 0.12 MPa (12 meters underwater)***

D- Electrical Design

Sturgeon's electrical system is designed in order to provide power and communication through all the sensors, actuators and cameras with minimal power consumption and with simple circuitry. Our vehicle is surface-powered by a 48 volt external power supply then converted onboard to 12 volts, 5 volts and 3.3 volts to power the thrusters, relays, grippers, cameras, sensors and lighting systems **[Connections shown in1- Electrical SID of ROV]**.The vehicle is controlled by a joystick from a station above water through a communication system, and the video captured by its cameras is displayed on an LCD screen.

1- Power Distribution

The current supplied from the 48 volt power supply passes through a 20Amp fuse, then reaches the main electronics enclosure where it's distributed among three DC to DC buck converters (48V to 12V, 200watts)-**fig(18)**.

Figure (18) DC-DC buck converter

The first two converters are used to supply the four thrusters while the third one is used to supply the Arduino Mega, the LEDS, the cameras, the bilge pump, the solenoids of the DCVs and the buzzer used for the acoustic release. A 7805 voltage regulator is used to regulate the voltage from 12 volts to 5 volts to supply the RS485, the Wi-Fi module, and the depth sensor, while a LD1117V33 voltage regulator is used to regulate the voltage from 5 volts to 3.3 volts for the Bluetooth module and the leakage sensor.

Table (2) Maximum power consumption calculations:

Component	Voltage (Volts)	Max current (Amperes)	Max power (Watts)	Quantity	Total max power (Watts)
T100	12	10	120	4	480
Bilge pump	12	2	24	1	24
Camera	12	0.2	2.4	3	7.2
DCV	12	0.42	5	2	10
LED	12	0.84	10	6	60
RS485	5	1	5	1	5

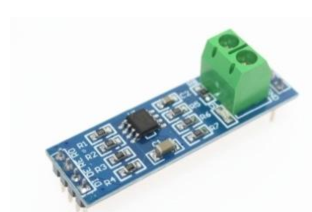
Maximum power consumed = 586.2 watts **Maximum current = 12.3 Amp**

Maximum power is never reached because of our software interlocking system which limits the speed of each thruster individually. The interlocking system also prevents the four thrusters from operating at their full speed at the same time.

Therefore, the actual maximum power is **442.2 Watts**, and the maximum current is **9.2 Amperes**.

2-Communication modules onboard:

Sturgeon uses the RS485 communication module-f**ig(19)**. The RS-485 protocol is a half-duplex UART communication based system. The control panel is equipped with an Arduino UNO microcontroller (master board) on the surface which is responsible for the communication link with the underwater microcontroller (slave board). We decided to use the RS485 due to its availability in our local stores, its signal noise immunity and its long distance limit (up to 1220 meters) which meets our vehicle needs.



Figure(19) RS485 module

3-Control system:

a- Microcontroller:

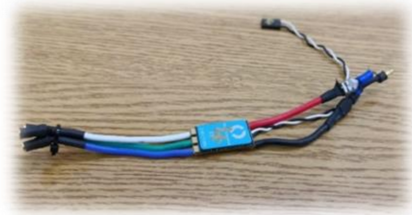
Figure (20) Arduino Mega microcontroller

Arduino boards were used because of their affordable prices as well as their open source AVR microcontroller-based development which can be programmed easily. Specifically, Arduino MEGA (2560) 32-bit-f**ig(20)** was used because it is relatively fast and has several serial communication (UART) ports to be able to communicate with several devices at once. These devices include Wi-Fi, the RS485 communication board and Bluetooth.
Another advantage is that it 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:

T100 thrusters:

Using 4 ESCs (electronic speed control)-**fig(21)**, Sturgeon's main microcontroller is able to control the 4 thrusters using PWM (Pulse width modulation).



Figure(21) Bluerobotics ESC

Directional Control Valves (pneumatic):

For low current loads as DCVs, N-channel MOSFETs were used rather than relays, as they have a smaller size and have faster switching capabilities. These Valves control the main manipulator and lift bag inflation tool.

IRF640 MOSFET temperature calculations:

$$I_D = 0.28\ A$$
$$R_{DS(on)} = 0.18\ \Omega$$
$$P_{dissipated} = R_{DS(on)} \times I_D{}^2 = 0.014 watt$$
$$R_{th\ j-a} = 62\ ℃/watt$$
$$\Delta T = R_{th\ j-a} \times P_{dissipated} = 0.87℃$$

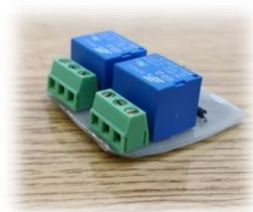
Figure(22) Temperature rise calculations for IRF640 MOSFET when operating the DCVs

DC Motor (bilge pump):

For accurate control on the rotary manipulator, we decided to use the "Monster motor driver" providing full speed and directional control.

Lightening control:

Sturgeon is equipped with 6 LEDs controlled by relay modules-**fig(23)**. Relays were used for high current loads as they're much more reliable than MOSFETs which are subjected to overheating.



Figure(23) Relay module

4- Tether:

a- ROV tether:

Communication:

The signal is transmitted from the station to the ROV through two Category6 Ethernet cables which have 8 cores each. So, the signal is transmitted through 16 cores; 6 cores used for the RS-485 communication protocol and 10 cores for the camera signal. CAT6 was used as it can provide serial communication at a rate of 250 Kbps.

Power transmission:

Based on the AWG wire sizing chart, we decided to use a 10 AWG (2.59 mm diameter) power cable in order to minimize the voltage-drop (4.2%) across the tether's terminals and subsequently providing the DC-DC converters with a stable voltage-**fig(24)**.

$$VDI = \frac{Current\ (Amperes) \times Length\ of\ wire\ (feet)}{\%Voltage\ drop \times Voltage\ (volts)}$$
$$= \frac{12.3 \times (25 \times 3.28)}{4.2 \times 48} = 5$$

$$\text{VDI (5)} \xrightarrow{\text{AWG wire sizing chart}} \text{AWG (10)}$$

Figure (24) Voltage drop index (VDI) and American wire gauge (AWG) calculations

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 25 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- Tether of Non-ROV devices:

The tethers of the release mechanism and the inductive coupling connector are 20 meters long and have a thickness of 12 AWG, considering a voltage drop of about 3-5%.

5- Vision system

a- Main Camera:

Initially, the main camera used was an analogue CCTV camera with focal length of 2.8mm and an angle view of 89.9° horizontally and 79.8° vertically. The camera was horizontally oriented such that it gives the pilot a perfect view ahead of the ROV. Later on, it was replaced with a low light analogue Bluerobotics camera with a 2.1mm focal length; because it has a wider angle of view (128 ^{o} horizontally and 96 ^{o} vertically) to improve the view of the pilot and perform the required image recognition in mission one more accurately.

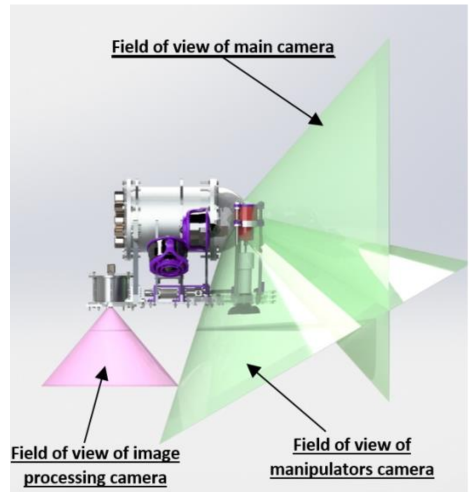


Figure (25) Field views of the 3 cameras

b- Secondary cameras:

Manipulators camera

Another low light analogue Bluerobotics camera is used and tilted at an angle of 30 degrees to have a clear vision of the two manipulators.

Image processing camera

We added an analogue CCTV camera, with a focal length of 2.8mm, which is vertically oriented to have the view of the bottom of the pool to perform the image processing needed in mission three as well as making sure that the ROV doesn't land on any sharp edges. The camera has sufficient light intensity range so it is able to capture videos with very small quantities of light. It is placed inside a separate enclosure at the back of the ROV.

6- Station:

a- Main laptop:

Displays the readings needed by the pilot while controlling Sturgeon through a graphical user interface.

b- Secondary laptop:

Provides the co-pilot with all the mission specified software needed during the product demonstration.

c- Manipulators control laptop:

Displays the video captured by the manipulators camera.

1- Open lift bag inflation tool
2- Close lift bag inflation tool
3- Buzzer on (acoustic)
4- Buzzer off(acoustic)
5- Open Main manipulator
6- Close Main manipulator
7- Rotary gripper speed control
8- Main LEDs on
9- Main LEDs off
10- Reserved
11- Reserved
12- Reserved

- 8-way rubber hat switch : Rotary gripper direction control
- **Y-axis:** forward / backward vehicle control
- **X-axis:** lateral left/right vehicle control
- **Yaw:** rotation clock-wise/anti-clockwise control
- **Cursor:** vertical position control

Figure (26) ROV controls using Logitech 3D pro joystick

d- Control panel:

Our control panel **fig(30)** is built in a neat and workman like manner, without loose components or unsecured wires. The panel consists of a DVR, an LCD BenQ screen, an Ardunio Uno, and an RS485 module which are all covered by a black PMMA sheet. A Logitech 3D Pro Joystick is used for controlling the ROV-**fig(26)**. The DVR is used to display all the videos on the LCD BenQ screen to facilitate controlling the ROV for the pilot.

Figure (27) Control panel

E- Software design

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. **[Shown in Appendix B: Flowcharts:]**

2- Top-Side software:

Our Software Engineers implemented a GUI using "Processing" which is java based programming software. The GUI receives data from the 3D Pro Joystick which was calibrated to ensure the easiest and best control for the pilot as well as providing different vehicle speeds to achieve the mission in the least time possible. The GUI also receives and displays data from the sensors of the ROV.

[Shown in Appendix B: Flowcharts:]

3- Mission specified software:

a- Using flight data to determine the search zone for the wreckage

A GUI software was developed using MATLAB-**fig(28)** to help the co-pilot utilize the flight data to determine the search zone for the wreckage during product demonstration in the least time possible.

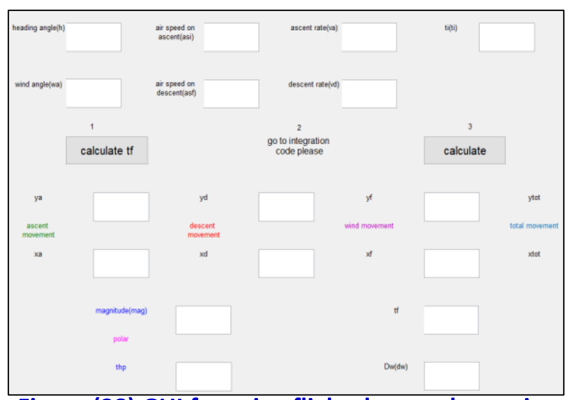


Figure (28) GUI for using flight data to determine the search zone for the wreckage

b- Identifying the aircraft using the tail section

The main camera is used to detect the tail of the aircraft, where the live stream video is imported to the image recognition software which applies the color detection and corner detection on each frame of the video. Once the shape and color are detected, it is displayed on a different screen-**fig(29).** The image recognition software was written using Open CV libraries**.**

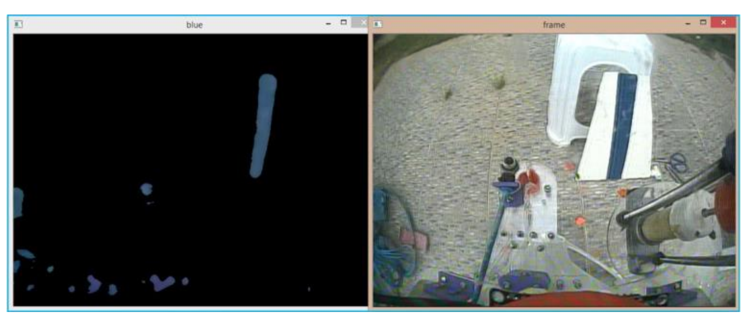


Figure (29) Image recognition software detecting the color blue

c- Displaying the seismograph data transmitted by the OBS

The seismographic data received by the Wi-Fi module is sent to the Arduino Uno on the top side. PLX-DAQ GUI is used to send the data from the Arduino to Excel where the seismographic data is plotted-**fig(30)**

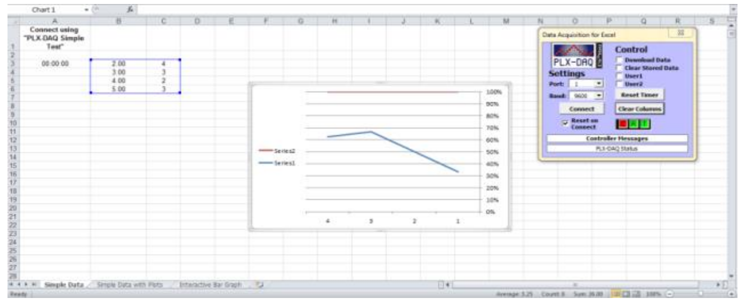


Figure (30) GUI displaying the seismograph data transmitted by the OBS

d- Measuring distances to place the mooring

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 calculate the required distance accurately while placing the mooring. -**fig(31)**

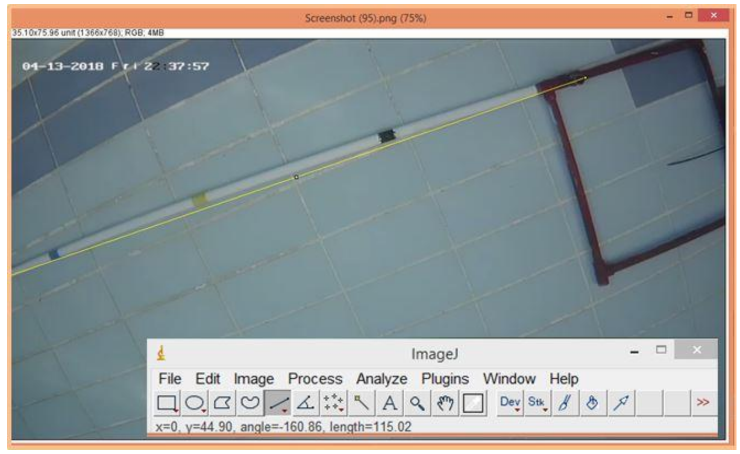


Figure (31) Image captured by Sturgeon to identify the place of the mooring

F- Mission specified tools and payloads:

1- Electrical

a- Inductive coupling connector

The inductive coupling connector-**fig(32)** is used to wirelessly charge the power receiver module placed inside the OBS. The connector is surface powered by a 12 volt DC supply, and supplies about 1.5 Amperes to the receiver module. The DC supply is presumably fed through a chopper circuit at the transmitter to achieve mutual induction between the two coils and the induced current is rectified at the receiver. The inductive coupling connector is placed in a sealed enclosure **–fig(33).**

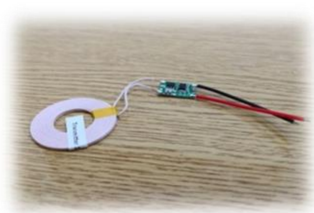


Figure (32) Inductive coupling connector

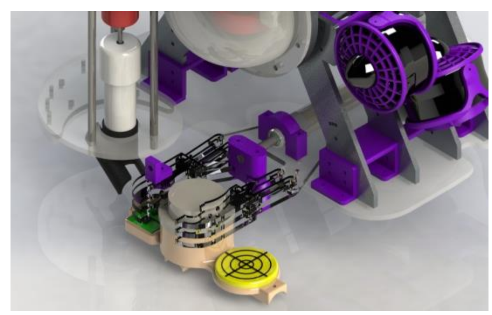


Figure (33) Sturgeon instaling the sealed inductive coupling connector

b- Depth sensor:

Bar30 Depth/Pressure Sensor MS5837-30BA is used to measure the vertical distance needed for suspending an Acoustic Doppler Velocimeter (ADV) at a given height on the mooring line. The sensor reads the pressure difference between two vertical levels and sends the data to be displayed to the pilot.

The depth is calculated from the following equation: $h = \frac{P_1 - P_2}{\rho g}$

c- WI-FI NodeMCU module:

ESP8266 NodeMCU Wi-Fi module is used to receive the data transmitted while leveling the OBS. The module is connected to a separate RS485 which sends data to the control panel to display the seismographic data.

2- Mechanical

a- Main manipulator

Sturgeon is equipped with a multifunctional, pneumatically actuated, parallel jaw manipulator. The manipulator is designed to reduce the number of tools needed for the missions and subsequently reducing the overall size and mass of the ROV. The manipulator is used for holding objects throughout the missions as well as inflating the lift bag and pushing the I-AMP locking mechanism.

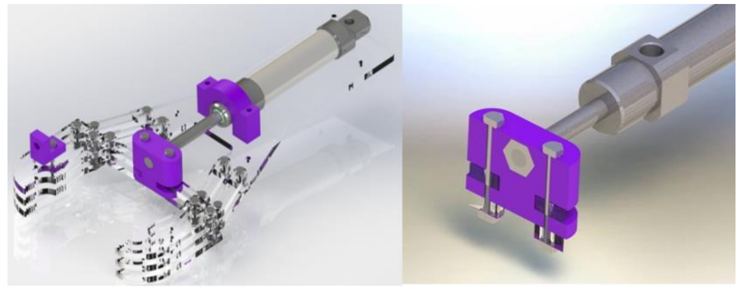


Figure (34) Sturgeon's main manipulator (left) having a 3D printed part with a nut embedded inside (right)

The manipulator is made of laser-cut transparent PMMA to provide clear vision of what the manipulator is holding. The end effector is linked to the pneumatic piston through a nut embedded in a 3D printed part-**fig(34)** attached to the piston's rod. The end effector has multiple curves-**fig(36)** to be able to handle round objects and PVC pipes with ease. The large curve is used to pick up large objects - like the base of the turbine-**fig(37)**- while the smaller curve is used to pick up smaller objects –like the turbine itself- .The end effector is also coated with rubber to increase friction between it and the objects to be held, resulting in a stronger grip.

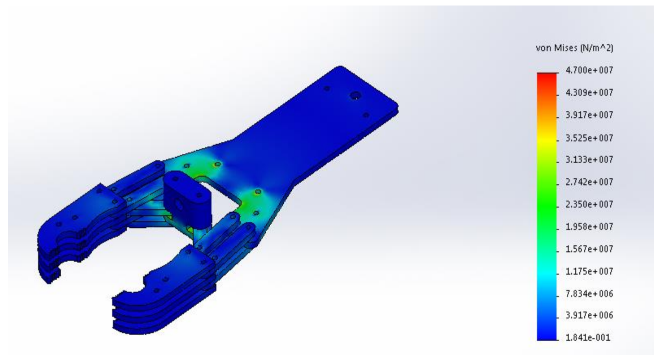


Figure (35) Stress Analysis on Main manipualtor when applying a load of 6 kg(60 N).

The pneumatic piston has a bore diameter of 25 mm and a stroke length of 50mm and operates at a pressure of 2.5 bars (25×10^4 Pa). The maximum force exerted by the piston can be calculated from the relation:

$$F = P\,A = 25 \times\ 10^4 \times \frac{\pi}{4} \times (25\ \times\ 10^{-3})^2 =\ 122.7\ \mathrm{N}$$

As the largest mission object was the base of the turbine (outer diameter of 6.5cm/2inch PVC). The manipulator opens up to 10cm wide to provide enough space for the pilot to be able to pick up the mission objects easily. The pneumatic cylinder is controlled via a 5/2 DCV which was chosen as there would be no neutral position needed.

Figure (36) End effector of the main manipulator

Figure (37) Sturgeon holding the base of the tidal turbine

A 3D printed L-shaped part is used to hold the pneumatic fitting used for inflating the lift bag. The pneumatic hose used is attached to the fitting at one end, while the other end is attached to a 2/2 DCV to control when to inflate the lift bag. A non-return valve is used to prevent water from entering through the hose to the electronics enclosure

b- Rotary manipulator:

The manipulator consists of a bilge pump coupled with a 1-inch PVC tee. The bilge pump is controlled via a motor driver to be able to rotate in both directions. This mechanism is used to level the OBS where the 1-inch PVC tee fits over the ½-inch PVC tees handles of the mission and rotates them.

Figure (38) Sturgeon leveling the OBS

c- Lift bag:

Initially we used a nylon liftbag, but due to its large size, it blocked vision and caused a lot of difficulties for the maneuvering of the ROV. Rather than using an opaque object, we decided to use a transparent plastic bottle to provide clear vision for the pilot. Due to its rigidity, it didn't disturb the motion of the ROV as much as the nylon bag.

Since the debris weighs 40 Newtons underwater and the engine weighs 60 Newtons underwater, then by applying Archimedes' principle the lift bag must have a volume greater than 6 liters to be able to lift them.

d- Debris release mechanism:

The release mechanism is based on a power screw mechanism. It consists of a PA type 6 cylinder that contains an electronic enclosure and a bilge pump coupled with the power screw. The enclosure contains a motor driver, an Arduino Uno and a sound detector which is sealed axially using an O-ring. A female-female mechanical connector is attached to the power screw at one of its ends, while its other end is attached to a hook used for holding the debris-**fig(39)**.

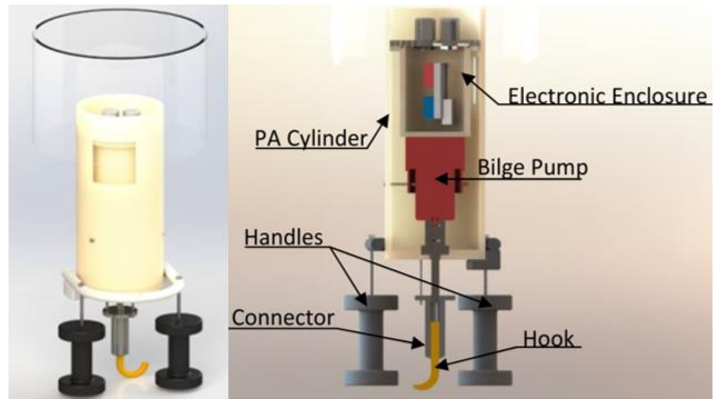


Figure (39) Structure of the release mechanism

The Arduino transforms the signals received by the sound detector from time domain functions to frequency domain functions using the FFT algorithm (Fast Fourier Transform) then loops on the selected frequency band for a certain time to make sure that this signal isn't a glitch (noise). Once the sound detector receives a 2.6 KHz acoustic signal from a water resistant buzzer placed on the ROV, the bilge pump rotates the power screw. The female-female connector has a flange through which 2 guides pass, such that when the screw rotates, the connector moves linearly until it falls and releases the debris.

A bearing was used to minimize the friction between the coupling and the base of the cylinder.
Initially the gripper of the ROV held the mechanism by the hook, but due to its smooth surface, it kept slipping. 3D printed handles were used which made holding the mechanism much easier for the gripper.

Acoustic release was chosen because several issues arise when using WiFi and/or Bluetooth communication as their range is significantly small due to the high carrier frequency and large attenuation underwater. Also, they are prone to noise.

e- Acoustic Doppler Velocimeter:

The aim of the ADV is to simulate a device that measures the velocity of water at a certain height. We used a 3D printed double hooked gadget fastened into a PVC pipe. The end of the hook is threaded where it screws into a nut embedded in the PVC pipe.

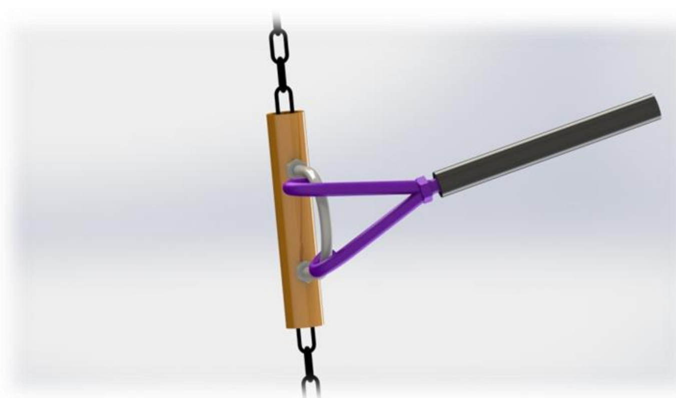


Figure (40) ADV suspended on the line of the mooring

III-Safety

Figure (41) Safety precautions taken when manufacturing or dealing with pneumatic components

A- Safety philosophy

There is always the possibility of accidents or fatal injuries due to manually handling heavy loads, dangerous machinery, toxic substances or electric hazards. Vortex Titans takes into consideration all the safety aspects; the company provides team members with a safe work environment and believes that all accidents are preventable by following safety protocols and regulations**[Shown in Appendix D: Safety checklist].** The safety instructions are printed and hanged at 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 welding iron after soldering.
- A First aid kit, as well as a fire extinguisher, is provided in case of emergencies.

Figure (42) Safety instructions are printed and hanged at our workshop

C- ROV safety features:

Mechanical Safety Features:

The ROV has smooth curved edges and no sharp corners, and exposed bolt threads are secured with cap nuts in order not to cause any injuries. Thruster guards completely cover any openings on the thrusters and have a mesh size that meets IP-20 standards to prevent entry of foreign objects and/or subjection of human hands to the thruster blades.

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 at 2.5 bars($2.5x10^5$Pa). Pneumatic fittings either have O-rings, or Teflon tape is wrapped to prevent leakage.

Electrical Safety Features:

Short circuit and over current protections on all DC-DC converters and 20A fuse with an isolated casing are provided. Color coded cables are used for power and signal transmission across the electronics enclosure. Software interlocking system is designed to prevent all the thrusters from reaching full power at the same time. Also, a water detection sensor is used to detect any leakage inside the electronics enclosure.

Warning Labels:

Warning labels are placed on thrusters and moving parts, high-pressure parts, PMMA parts that are 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 Titans consists of two main technical departments; an electrical department and a mechanical one, and each department is subdivided into several project groups. The team first started as an engineering training program by our mentors such that each member was able to determine which department and which project group he preferred. Once the training had ended, the CEO, the CTOs of each department and the CFO were selected based on their performance in the training program and their personal skills.

The CTOs held frequent meetings and constantly gave tasks with deadlines to the team members to make sure that we followed our timeline. The CEO held general meetings such that the two departments communicated regularly and followed the progress of one another. The CFO calculated the estimated budget and made a financial plan to be followed until the desired product had been achieved.

Tasks were assigned such that each member had a specific role to play. For the mechanical department, 3 members were responsible for designing the frame and propulsion system, 3 for the manipulators and payloads and 2 for the electronics enclosure and sealing. For the electrical department, 2 members were responsible for designing the GUI and image recognition software, 3 for the communication and control system, 1 for the power distribution and vision system and 1 for PCB manufacturing. The team also included several non-technical departments such as human resources, public relations, marketing, media and IT.

B- Project management

Our team was established after joining an engineering program that lasted for about 3 months and included all the needed information for building a well-functioning ROV. After finishing the program, a detailed schedule was prepared and deadlines were set to finish the entire ROV in two months, followed by pilot training until the regional competition.

After the regional competition, we prepared another schedule for the Visa and travelling procedures in addition to pilot training and some modifications to the ROV.

Pre-regional:

Post-regional:

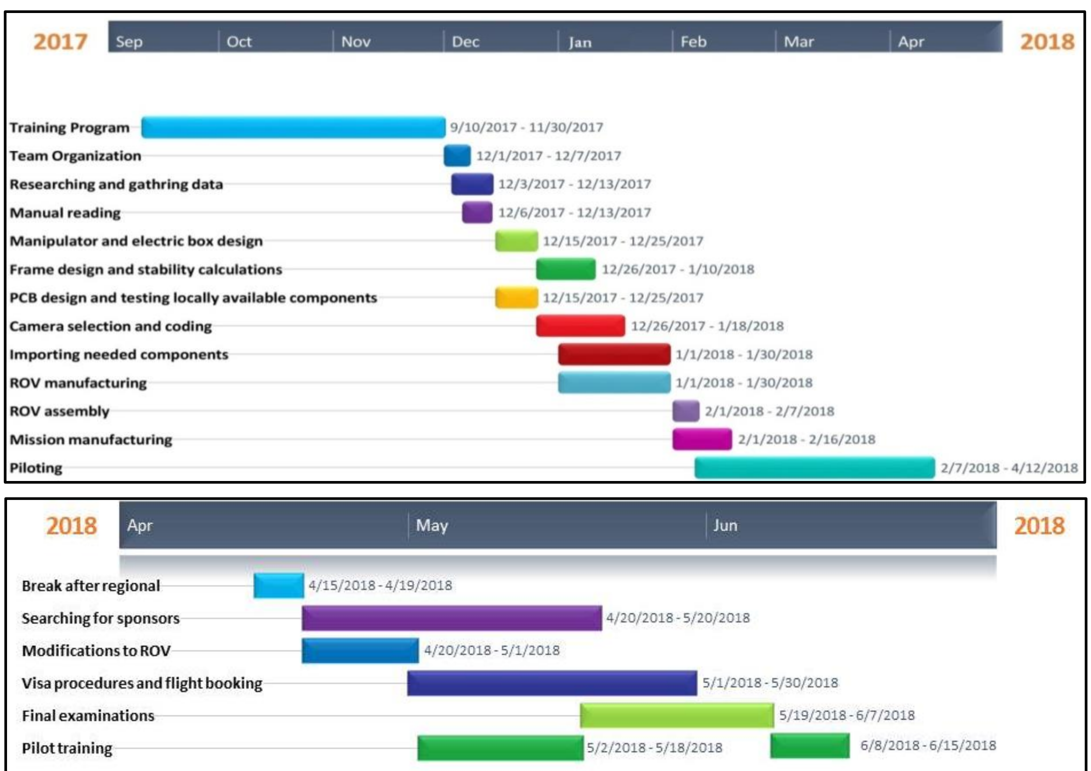


Figure (43) Project timeline (Gantt chart)

C- Estimated budget

After finishing the mechanical and electrical designs, the price of the ROV was estimated so that the team members would start gathering the money needed for the manufacturing processes.

Category	Item	Estimated price	Reason for estimation
Materials	PMMA sheet	$120	PMMA is a relatively expensive polymer and the majority of the frame is made of it, so a large sheet was needed.
	PMMA Dome	$35	Taking into consideration that the dome was custom made, the manufacturer would have to build a mold for the dome with the required dimensions followed by casting PMMA which is a very costly process.
	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 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 3 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	$140	We took into account the costs of the DCVs, the pneumatic cylinder ,the fittings, the compressor and the pressure regulator
Nuts and bolts	M6 and M4 bolts and nuts	$25	We needed about 140 M4 bolts and nuts, and 20 M6 bolts and nuts , as well as cap nuts for safety.
Sealing	O-rings and glands	$50	We had 3 PA cylinders each needed two O-rings. We estimated that we needed about 24 glands and 6 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, 48V power supply, Bilge pump , motor drivers, PCBs, wires and fuses .
	Imported components	$900	Imported components that we needed included T100 thrusters, ESCs, Bluerobotics camera , DC-DC converters , pressure sensor, Anderson connectors, joystick and a wireless charger. We estimated a 50% increase in the prices of the components due to shipping and customs
Tether	Communication cables , Power cables and pneumatic hose	$60	We needed a 25 meter long pneumatic hose , 25 meter long power cable , and three 25 meter long Cat-6 cables.
Media	Poster , brochures ,flyers and banner	$50	We needed to print about 50 flyers and brochures, as well as a 120 cm x 90 cm poster and a 2 m x 80 cm.
Total ROV budget = $1950			
Travel expenses	Flight tickets	$13300	By checking the prices online and calling travel agencies. The flight ticket was estimated to cost about $950 per person, transportation about $20 per day (for 5 days) and accommodation about $45 per night per person
	Accommodations	$2450	
	Transportation	$100	
	Shipping	$700	
Total Travel budget = $16500			
Overall budget = $18500			

Table (3) Budget estimation

[The detailed actual project cost can be Shown in Appendix C: Total project cost]

V- Conclusion

A- Challenges

1- Technical challenges

While we were making Sturgeon, both our mechanical and electrical teams faced a few technical issues. Our electrical team was constrained by the miniature size of Sturgeon's electronics enclosure, so we found some difficulties fitting the components inside it. We also had some unexpected failures with the MOSFET circuits initially, as we were using IRF720 MOSFETS which have a relatively high drain-source resistance (R_{DS}) and subsequently dissipate a large amount of power. They also have large junction-to-ambient thermal resistance (R_{thJA}) which caused them to overheat, so IRF640 MOSFETS were used instead as they dissipate much less power and don't overheat as much. Our mechanical team faced some problems too, since a pneumatic leakage caused fractures in the PMMA face covering the cylinder of the electronics enclosure, so we had to replace the fractured face and wrapped Teflon tape on the fittings to prevent leakage.

2- Non-Technical challenges

Our team struggled to find a sponsor, as it was newly founded this year, so the majority of the expenses were paid by the team members. We also had trouble with the imported components, as the customs were very expensive and some components were confiscated at the airport due to some misunderstandings. In addition to that, there were no available pools near the workshop, so our pilot's training area was relatively far away.

B- Testing and Troubleshooting

Each time we initialize and/or troubleshoot our ROV, we follow the same strategy. Before connecting the tether, we check the compressor and the power supply; the regulator of the compressor must be set to 2.5 bars (2.5×10^5 Pa) and the supply must be supplying 48 volts. After connecting the tether, if the power is not working, we check the fuse and replace it if it failed. We initialize the joystick followed by a dry test which includes testing thrusters, manipulators, payloads and cameras. For any malfunctions we check the communication board and the printed circuit boards inside the enclosure using an AVOmeter.
Whenever a component is producing an error or not operating properly, we isolate the component by removing it from the ROV, and conducting tests to determine the error.**[shown in Appendix B: Flowcharts:]**

C- Lessons learned and skills gained

1- Technical skills

Before starting the project, team members participated in a three-month engineering program which included informative courses about CAD design, sealing techniques , propulsion systems, manufacturing methods , materials and their properties, pneumatic circuits , PCBs , vision systems , image processing, power distribution, communication protocols and electronic control. This program has been life-changing for all team members in their engineering career, as it included not only skills related to ROVs but also skills needed in all engineering projects.
New members helped improve the organization and implement new ideas. This year was the first year that our used MOSFETs rather than relays, as MOSFETs occupy a smaller space, so the size of the PCBs were much smaller and subsequently a smaller electronics enclosure was used.

2- Non-technical skills

We've built our ROV not just to compete in the competition but also to be a marketable product. We've gained a lot of non-technical experience related to marketing, media outreach, poster design, video editing and different methods to advertise our product.
Considering that we are a new organization and that we had to build everything from scratch with no sponsors before the regional competition, we learned how to make a proper financial plan and how to optimize between building our own components and buying commercial components, taking into consideration the quality of the product in both cases.

D-Future improvements

Double layer, surface mount PCBs

The PCBs used in Sturgeon are all single layer PCBs. We've faced a lot of difficulties in fitting the PCBs and electronic components inside the electronics enclosure due to its small size. Using double layer, surface mount PCBs-**fig(44)** would save a lot of space inside the enclosure due to component miniaturization and the denser packing of boards, making it easier to organize the components within the enclosure and easier to troubleshoot.

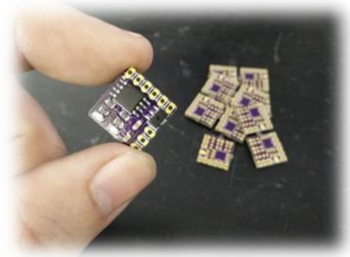


Figure (44) SMD PCBs

Software and Control Systems Upgrades

We aim to upgrade our software system by adding interrupts architecture to the system which will give us the chance to add more complicated moves to enhance the maneuverability of the ROV without decreasing the response time of the control. Also adding a feedback system to the ESCs of the thrusters to be able to know the consumed current by the thrusters simultaneously will enhance the reliability of our control system.

Heat dissipation system

Our electronic enclosure and components heat up when the ROV operates for long time periods. We plan to add a fan-cooled aluminum heat sink that dissipates the heat away from the components, thereby allowing regulation of the components' temperatures at optimal levels increasing their efficiency and lifetime.

Figure (45) Fan-cooled heat sink

Time management

We started the design of the ROV from scratch once the manual had been released, rather than having an initial ROV design earlier. Having an initial design would've helped as save a lot of time, as modifying a design is much easier than starting it from scratch. In the future, better planning and scheduling would be essential

E- Reflections

Marwan Taha (Mechanical Chief Technical Officer)

"After several months of designing and manufacturing the ROV and spending days without sleep, the feeling of success after assembling the ROV and seeing how our hard work paid-off made it all worth it for me. This experience has been truly life-changing and taught me how to be patient and not to stress over simple issues. Most importantly it taught me how to properly assign tasks, organize the team and bring out the full potential of each member. I couldn't be more proud of our team and how far we've come."

Ziad AbdelKarim (Electrical Chief Technical Officer)

"Although this wasn't my first time competing in a robotics competition, I've learned a lot from Vortex Titans. As a second year communication engineer, it has been a wonderful experience dealing with the different communication protocols. Implementing what we study at college in practical life applications has been thrilling.

Mahmoud Saeed (Chief Financial Officer)

"Estimating the budget of the team and coming up with a financial plan has been a very challenging task for me. This experience has taught me how to be a well-organized, responsible person in life in general, not just during the competition."

Fareda Hossam (Our youngest team member)

"When I first joined Vortex Titans, I thought that I won't be able to acclimate with the team, but this wasn't true at all. I was able to complete my tasks and I enjoyed working with such an amazing team. The amount of support I've gotten from my team was truly overwhelming."

VI- Acknowledgments

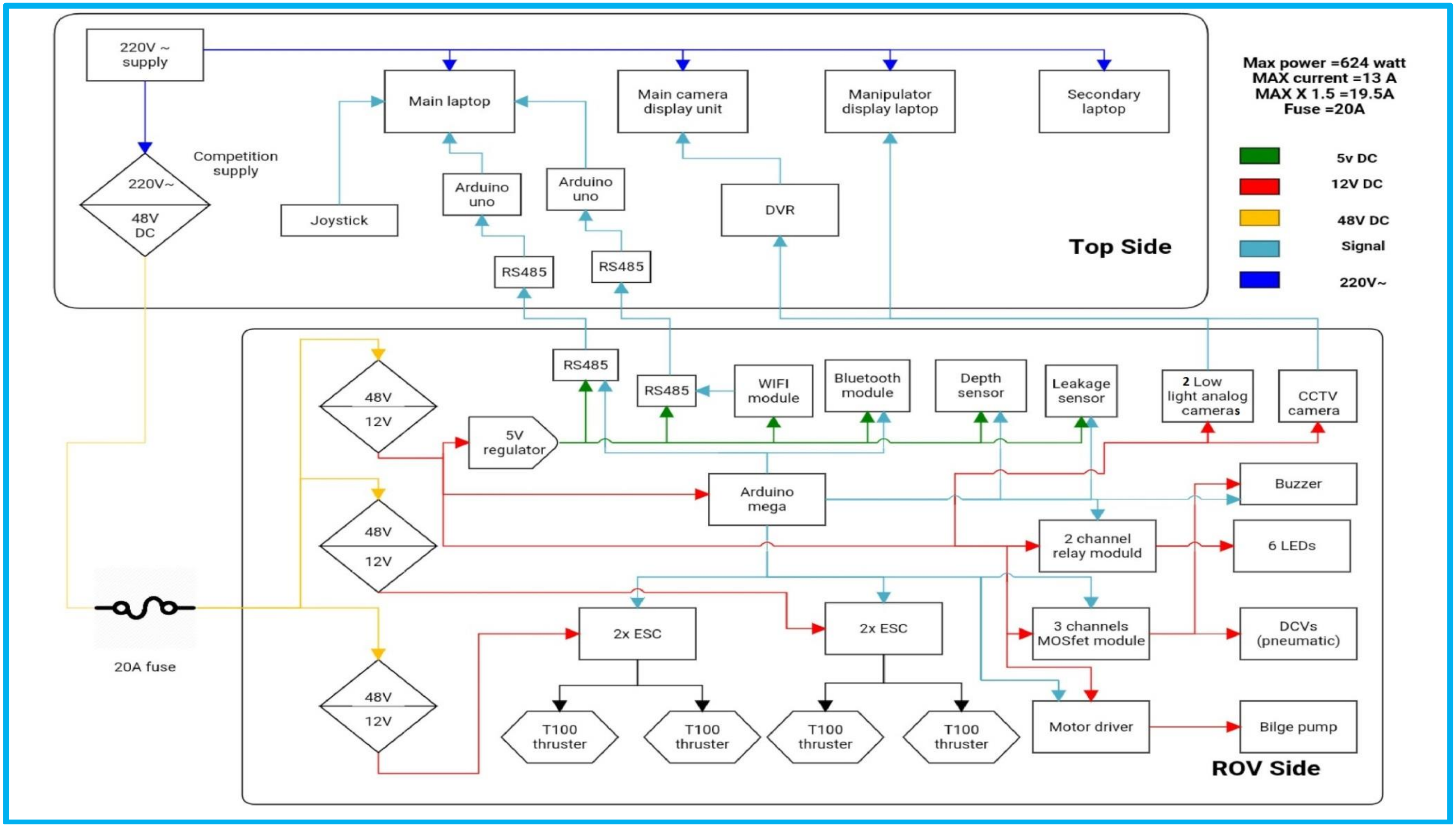
We would like to thank those who supported us and helped us overcome the challenges we faced throughout the competition.

- **MATE "Marine Advanced Technology Education"** – for creating such a professional competition where engineers from all over the world explore their passion for marine education and develop technical and non-technical skills.
- **Hadath company** – for organizing the regional competition.
- **AASTMT Arab Academy for Science Technology & Maritime Transport**– for Organizing the regional competition.
- **Telecom Egypt** – for sponsoring the regional competition and sponsoring us in the international competition by giving us 5 travel tickets and 10 hotel reservations during the competition.
- **Alexandria University faculty of engineering** – for providing technical support and labs for the team.
- **Oxy-dive training center** – for providing us with a workshop having all the necessary tools.
- **Vortex Co. and our mentors** –for providing technical support throughout the competition as well as moral support and encouraging us to bring out our full potential.
- **Vortex JR** –for support and help throughout the competition.
- **Aquaphoton Academy** – for providing technical support.
- **Air Technology Company** – for providing us with discounted pneumatic components.
- **SolidWorks™ and ANSYS** – for providing us with student licenses.
- **Eng. Mahmoud Hamdy** –for helping us simulate the flow over the ROV, and explaining the obtained results.
- **Eng. Ahmed Shaheen**– for helping us manufacture the PMMA dome.
- **Eng. Mohamed Salamah**– for helping us with the cover design.
- **Our beloved families and friends** for support.

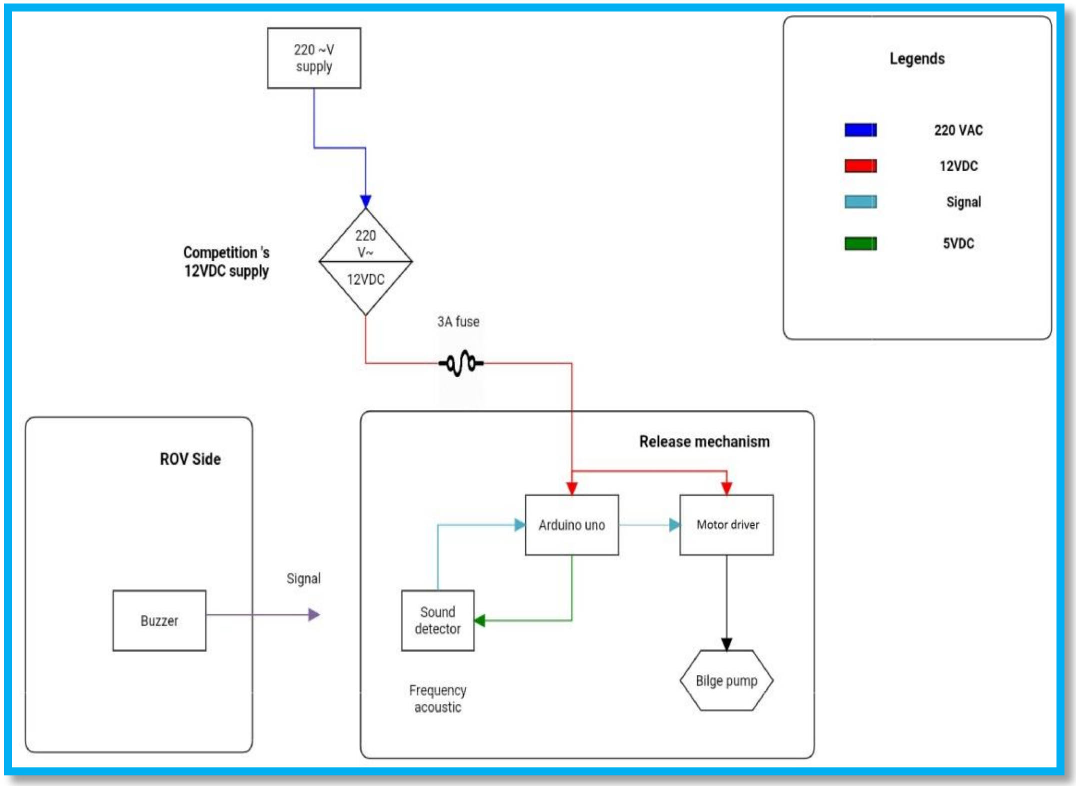
VII- Appendices

Appendix A: System interconnection diagrams

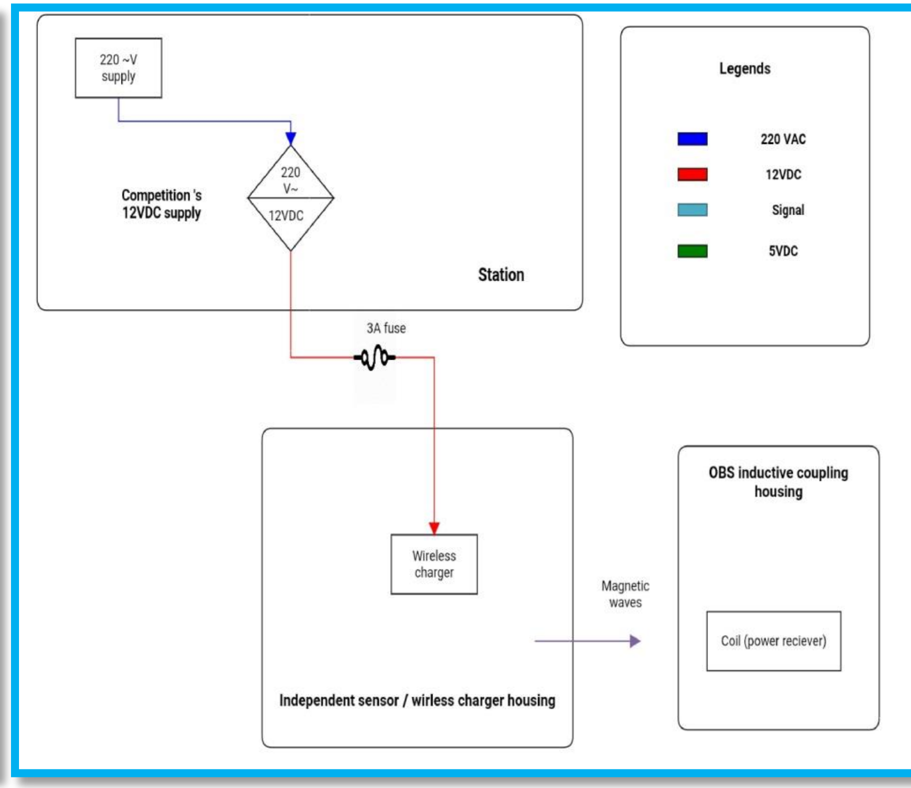
1- Electrical SID of ROV



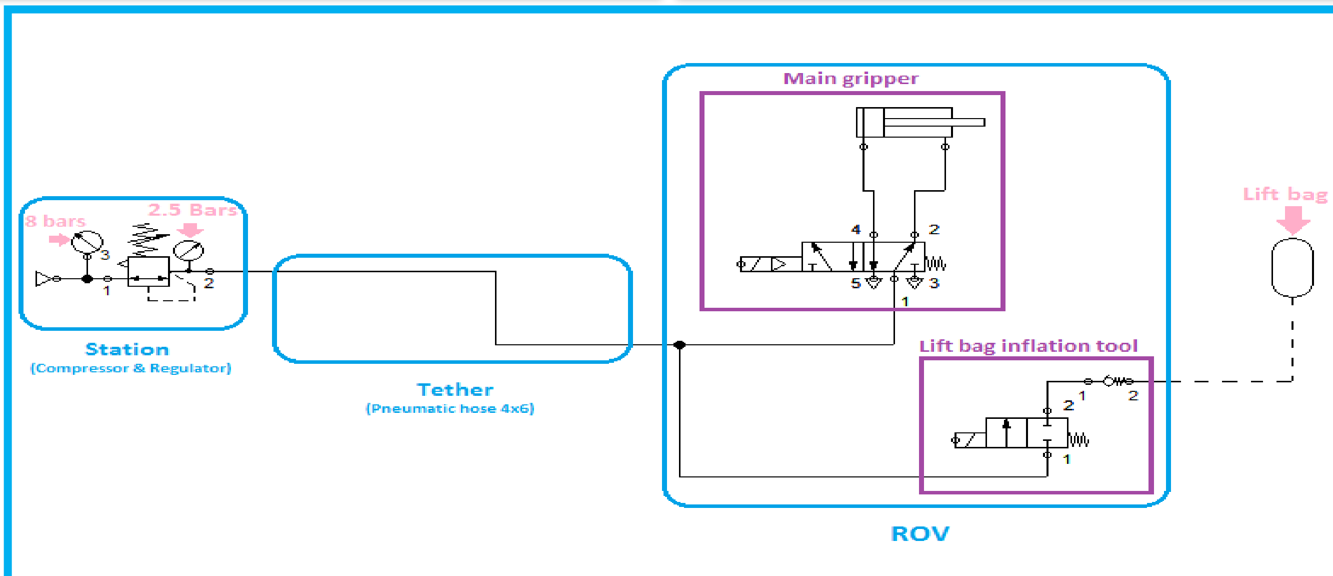
2- Electrical SID of release mechanism



3- Electrical SID of Inductive coupling connector

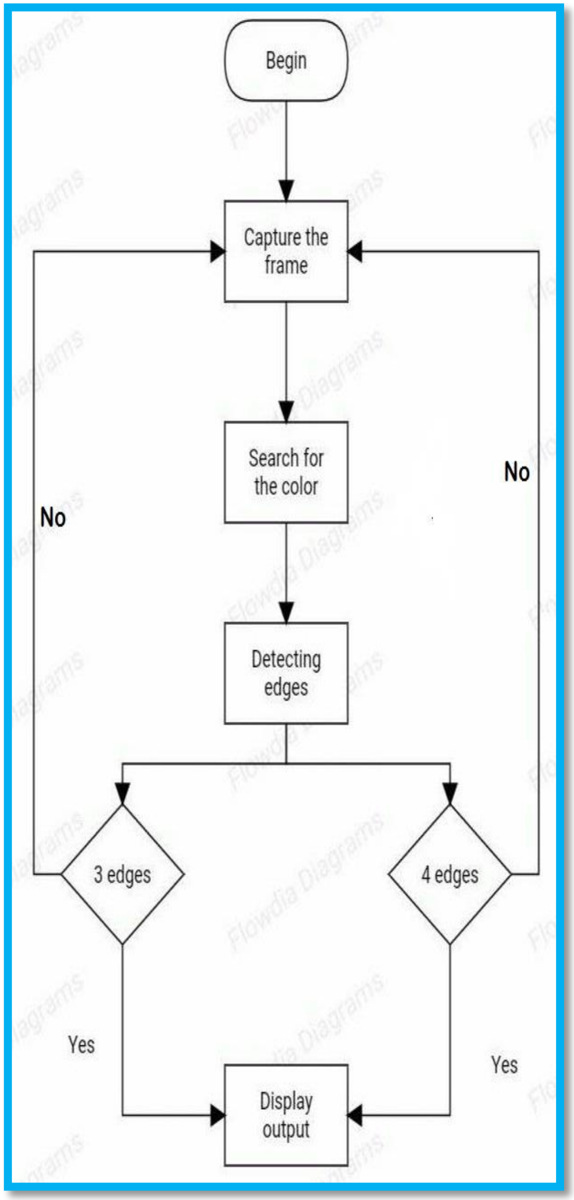


4- Pneumatic SID of ROV

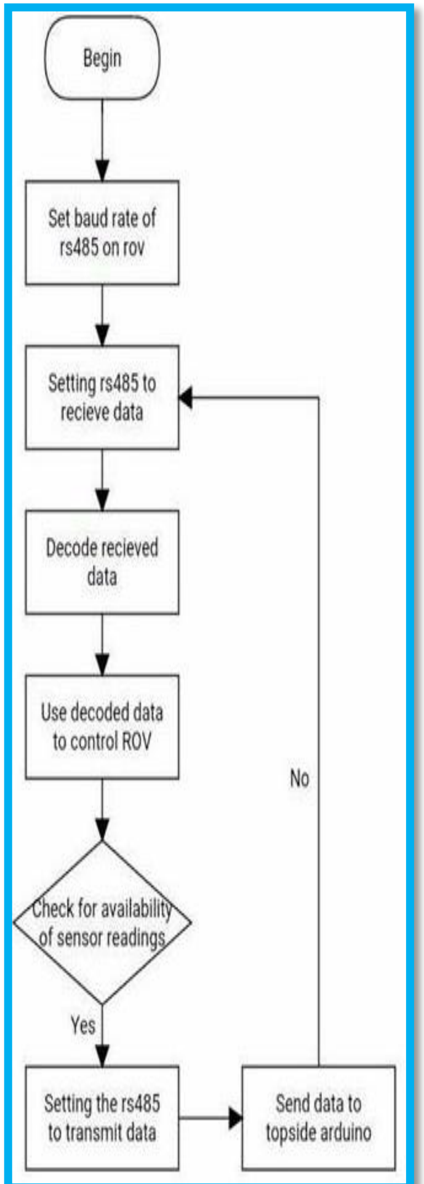


Appendix B: Flowcharts:

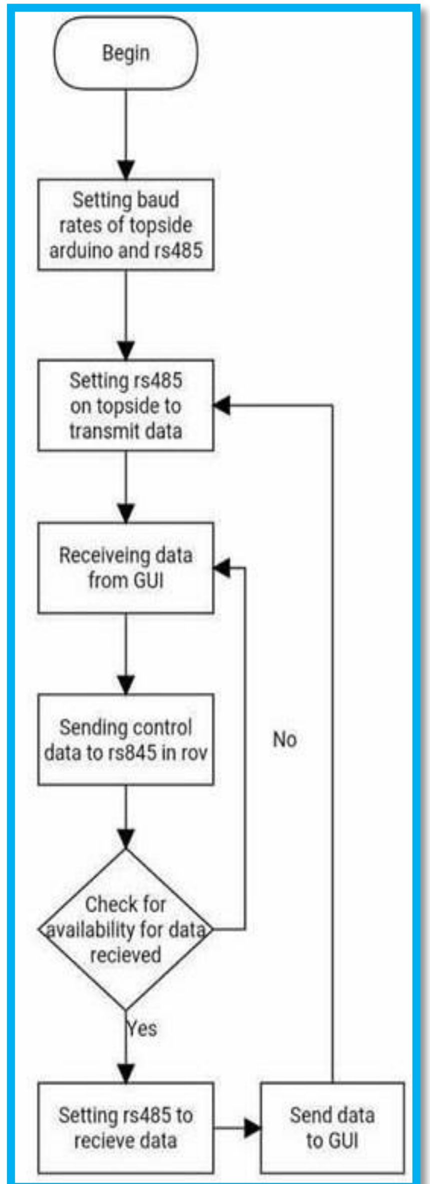
1- Image recognition



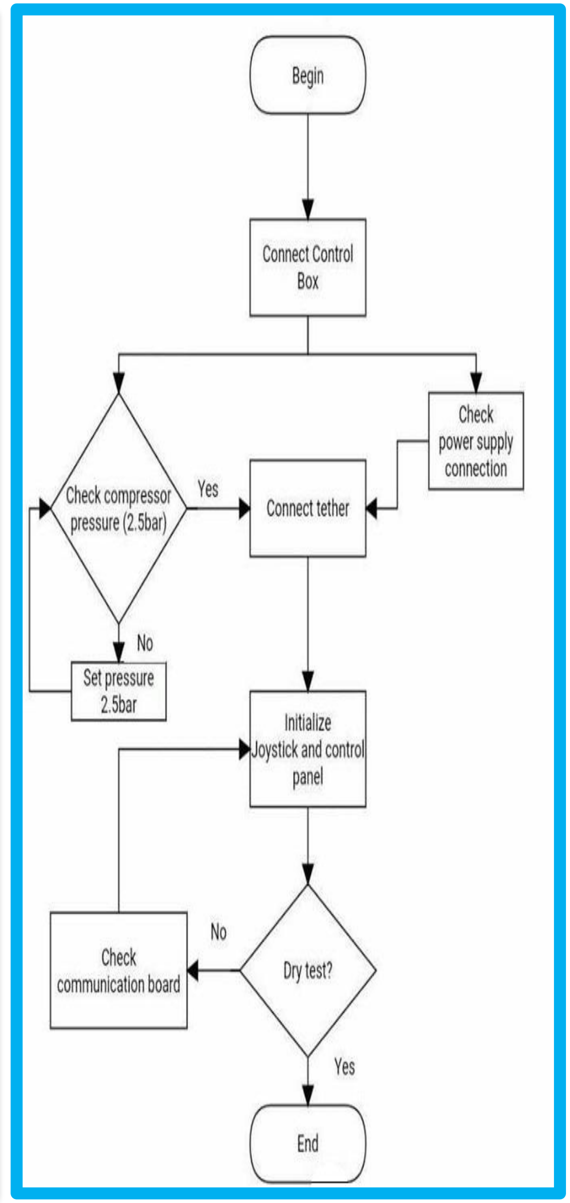
2- Onboard software



3- Top-side software



4- Initialization& Troubleshooting



Appendix C: 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 1m x 1.3m x 6mm thickness	Purchased	$66.7	1	$66.7
	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	Purchased	$111.1	1	$111.1
	Fittings	Purchased	$13	-	$13
Thrusters	Bluerobotics T100	Purchased	$520	4	$520
	Thruster mesh	Purchased	$2.2	1	$2.2
Sealing	Glands & Rubber	Purchased	$2.38	24	$57.3
	Electronic box O-ring	Purchased	$0.85	2	$1.7
	Camera box & release mechanism O-ring	Purchased	$0.4	4	$1.6
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 release mechanism & OBS	Purchased	$0.444/m	50 m	$22.2
	Ethernet cable (Cat-6) for ROV	Purchased	$0.556/m	50 m	$27.8
	Ethernet cable (Cat-5) for OBS	Purhcased	$0.28/m	25 m	$7
Electrical components	Arduino Mega	Purchased	$15.3	1	$15.3
	Arduino Uno	Purchased	$7.67	3	$23.3
	Arduino Nano	Purchased	$4.7	1	$4.7
	Relay module	Purchased	$2.2	1	$2.2
	Buzzer & Sound detector	Purchased	$9.7	1	$9.7
	Wifi module (Node MCU)	Purchased	$7	1	$7
	48V Power supply	Purchased	$41.65	2	$83.3
	DC-DC converter	Purchased	$20	3	$60
	ESC	Purchased	$27.3	4	$109.1
	CCTV camera	Purchased	$18.35	2	$36.7
	Bluerobotics camera	Purchased	$73.9	1	$73.9
	Pressure sensor	Purchased	$78.6	1	$78.6
	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
	RS422	Purchased	$8.9	4	$35.6
	PCBs	Purchased	$13.3	-	$13.3
	Connectors, fuses, wires	Purchased	$25.5	-	$25.5
	Wireless charger	Purchased	$12.8	1	$12.8
	Anderson connector for release mechanism and OBS	Purchased	$16.7	2	$33.4
	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					**$2257.07**
Travel expenses	Flight tickets	Purchased	$800	9	$7200
	Accommodations	Purchased	$800	5 nights / 5 members	$800
Total travel cost					**$8000**
Overall cost					**$10257.07**
Funds (Sponsored by Telecom Egypt)	Flight tickets	Sponsored	$1100	5	$5500
	Accommodations	Sponsored	$4200	5 nights / 10 members	$4200
	Transportations	Sponsored	$60	-	$60
Total funded					**$9760**
Total expenses (Overall cost + Funds)					**$20017.07**

Appendix D: Safety checklist:

Phase	Topic to check	Check mark
Pre-launch	The power supply is placed on a dry location	
	Anderson connectors of tether are connected to power supply	
	All cables are secured and well fastened to the frame	
	No wires are exposed	
	Fuse is 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	
	No one is touching any moving parts	
	Checking on the compressor's regulator (less than 2.75 bars)	
	Checking on all the fittings and dry testing the manipulator to avoid any leakage	
	Safety labels are all placed properly	
	Tether is not tangled	
	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	
	Control unit shutdown	
	ROV is retrieved by at least two members	
	Quick visual inspection for any cracks or damages	
	Tether is neatly rearranged	

Appendix E: References

- Parker O-ring handbook. 50th Anniversary Edition
- Fluid Mechanics Fundamentals and Applications by YunusCengel and John Cimbala 3rd edition
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- Blue Robotics analog camera Documentation<http://docs.bluerobotics.com/camera/>
- Blue Robotics ESC Documentation <http://docs.bluerobotics.com/bescr3/>
- Blue Robotics Bar30 Pressure Sensor Documentation<http://docs.bluerobotics.com/bar30/>
- Anssion Pneumatic Piston Documentation<http://www.anssion.com/uploads/download/DSNU.pdf>
- ODE 2/2 DCV Documentation<http://www.ode.it/en/catalogue/general-purpose-solenoid-valves/2-way-direct-acting/>
- Shako 5/2 DCV Documentation<http://www.shako.com.tw/pneumatic-solenoid-valve/SM520.htm>
- THB non-return valve Documentation<http://www.thb.com.tw/en/products/?method=detail&aid=1223>
- IRF640 MOSFET Datasheet<http://www.alldatasheet.com/datasheet-pdf/pdf/17801/PHILIPS/IRF640.html>
- PLA Material Properties <https://plastics.ulprospector.com/generics/34/c/t/polylactic-acid-pla-properties-processing>
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- MATE ROV Competition Manual Explorer 2018<https://www.marinetech.org/files/marine/files/ROV%20Competition/2018%20competition/Missions/2018%20Competition_Product_Demo_Spec%20briefing_5_cover.pdf>
- AWG wire sizing chart <https://homequicks.com/electrical-wire-sizing-chart>