ROBO-TECH

Faculty of Engineering

Alexandria university

2019 Technical Report

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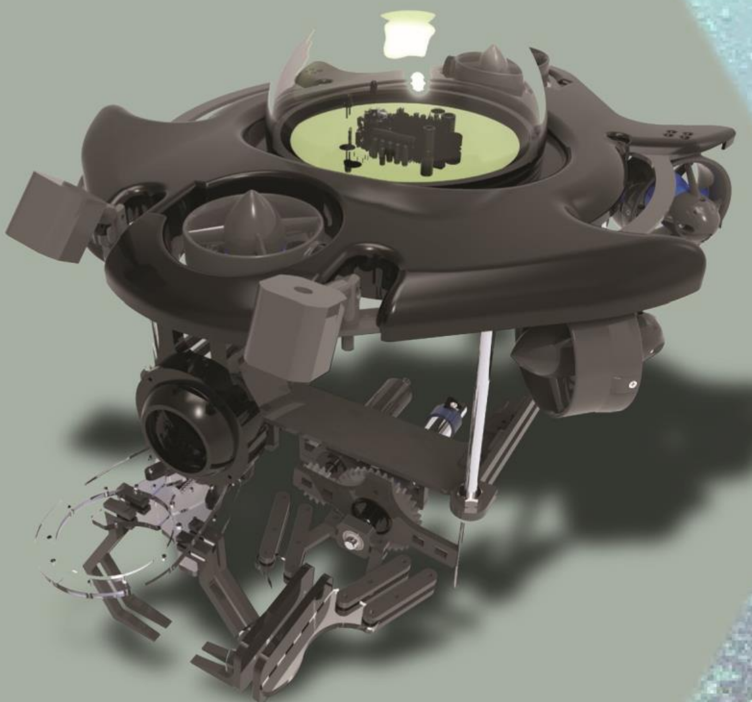

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I. Abstract

The number of secrets below the water surface had been increasing since the creation of the first ocean until reaching the Earth surface of today. This encouraged numerous explorers to go deeper into the ocean in search of answers. For the past four years at Robo-Tech, we believed in our role to join and continue the progress of ocean exploration.

This year, in response to The Applied Physics Laboratory at the University of Washington request for a Remotely Operated Underwater Vehicle (ROV), Robo-Tech engineers designed a new ROV inspired by one of the extinct sharks which the lights of the ocean have not seen before or then, **The Megalodon**. Named after the shark lived 25 million years ago, **The Megalodon** is designed to be of high strength, low weight, streamlined motion, and low cost. These goals were achieved by using Aluminum as the main material, depending on six motors to reach 5 degrees of freedom, designing two flexible cameras for modifiable field of vision, and using an HD camera to reach optimum clarity of vision.

Through this technical documentation, you will be introduced to the two methodologies used for testing the efficiency of The Megalodon, how this project changed the lives of more than twenty engineers, and how the challenges faced during work on The Megalodon were overcome.

Figure (1): ROBOTECH company members

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II. Design Rationale

1. Design Evolution

Since the company started in 2014, Robo-tech built six ROVs, each with its unique features. The company mainly designs its vehicles according to what is requested in the product demonstration missions. Each year has new challenges, and therefore, modifications must be made.

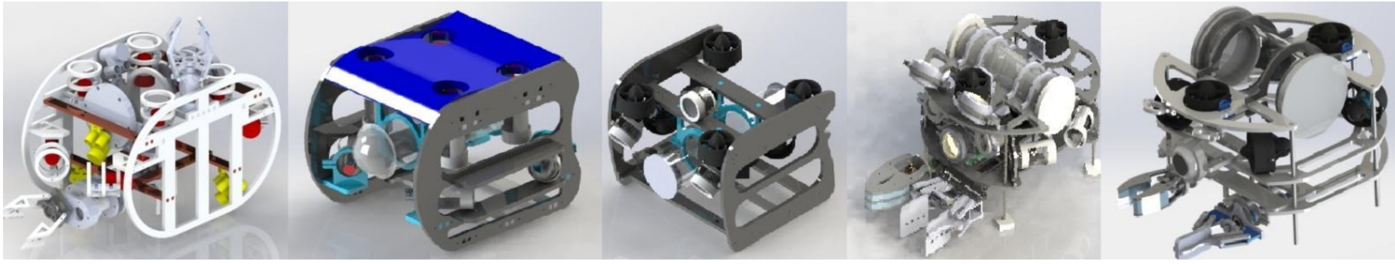


Figure (2): Design evolution of ROVs built by Robo-Tech

2. Design Process

During the design process, our goal was to design an easy-to-assemble, lightweight, and maneuverable ROV capable of finishing missions efficiently and in minimum time. This goal was achieved after three phases of the design process.

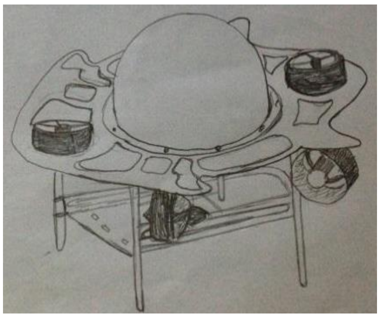


Figure (3): Free hand sketch

1. **Brainstorming Phase:**
   During the brainstorming phase, several free-hand sketches -Figure(3)- were drawn, edited, and discussed by our engineers to reach a suitable design for The Megalodon.
2. **Decision-Making Phase:**
   After reaching The Megalodon design, the free-hand sketch was sent to the electrical engineering department to discuss their notes, requirements, and precautions.
3. **Design Phase:**
   After taking all mechanical and electrical requirements on consideration, the electrical department started working on The Megalodon control system, and the mechanical department started working on the mechanical design. Several **C**omputer-**A**ided **D**esign **(CAD)** programs were used to finish the design process such as:
   - **A. SolidWorks®**
     Used for creating the solid model and assembly of The Megalodon.
   - **B. ANSYS® and COMSOL®**
     Used for the stress analysis and the calculation of several physical quantities such as drag and lift coefficients of The Megalodon.
   - **C. Autocad®**
     Used for preparing the final files of The Megalodon for printing and fabrication.

By the end of the 3 phases, a meeting was held to discuss the material based on the calculations and costs of the suggested materials for the Megalodon main upper and lower plates.

3. The Megalodon Mechanical Structure

Setting the ease of assembly and the lightness of weight as priorities, The Megalodon, shown in Figure (4), is designed to consist of as few parts as possible.

Figure (4): The Megalodon

1. Upper plate:

The Aluminum upper plate, shown in Figure (5), is designed for fixation of The Megalodon main parts such as the motors, cameras, and electronics house. The material of the plate is chosen based on the cost, density, strength, and manufacturability of the available materials which are shown in table (1).

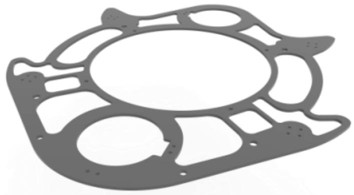


Figure (5): Upper-Plate

Point of Comparison	Stainless Steel	Aluminum	Polyamide
Price	304 →150.54$ 316 →202.65$	Al 1060 →69.48$	Type1 →34.74$ Type 2 →98.43$
Sheet Size	1*2 m^2	1*2 m^2	1*1 m^2
Fabrication	Laser/Router Cutting - Difficult	Laser/Router Cutting - Less difficult	Laser/Router Cutting - Easy
Stress Analysis	Safe F.o.S= 5	Safe F.o.S= 2.1	Safe F.o.S= 1.5
Weight	1700 gram	800 grams	900 grams
Appearance	Good	Good	Worse than others

Table (1): Material Comparison

1.1. Thrusters:

The propulsion system, shown in Figure (6), consists of six thrusters, four T200 Blue Robotics motors, and two T100 Blue Robotics motors. The two T100 Blue Robotics motors are mounted in the holes of the upper plate of the body allowing The Megalodon to heave and pitch. The four T200 Blue Robotics motors are fixed with 45 degrees angle to allow The Megalodon to move horizontally and to yaw.
The variation of the motors model used for vertical and horizontal movement is due to the advanced power of T200 Blue Robotics motors.

Figure (6): Thrusters Fixation

1.2. Electronics Housing:

The electronics housing, shown in Figure (7), is a half-spherical half-cylindrical shape made of 10mm Acrylic. The geometric shape is chosen due to its high stability, low weight, low drag force, ease of assembly, and well-sealed housing for the electrical components of The Megalodon.
The house is fabricated using a lathe machine to reach the accurate dimensions and good surface finish need for this critical part.

Figure (7): Electronics Housing

1.3. Camera:

To provide a vision of large area for the pilot, The Megalodon uses two types of cameras.

A. Fixed Camera

The fixed camera, Figure (9) noted by (2), is fixed in the front hole of The Megalodon to be used as the main camera.

Figure (8): Flexible Cameras

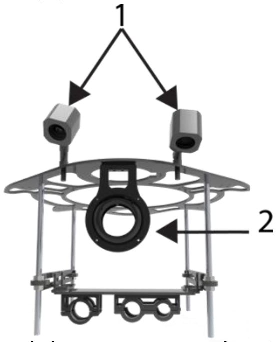


Figure (9): Camera mechanism

B. Flexible Camera

The flexible camera mechanism, Figure (9) noted by (1), is designed to increase the area of vision for the pilot. The Megalodon uses two flexible cameras, each one of them fixed at one side.

- **Mechanism Design**

The mechanism, shown in Figure (8), consists of a joint connected to a link which can rotate around it. The link is then connected to the camera sealing parts. This allows the camera position to be adjusted to provide better vision.

2. Lower plate:

The lower-Aluminum-plate is designed for fixation of The Megalodon manipulators and Micro-ROV. It consists of two sliders and a low-area plate which facilitates the forward and backward movement of the two manipulators.

3- Connecting Rods

To link between the two main plates, four Aluminum rods were used to connect the plates and to provide the needed support for The Megalodon to stand. The Aluminum rods were chosen due to the Aluminum advances in low weight, corrosion resistance, and non-toxicity which prevent water pollution.

4. Buoyancy:

The Megalodon is designed to be neutrally buoyant in order to minimize any loads on the thrusters during missions and to make it more stable. To do this, the weight of the ROV must be equal to buoyant Force. *(“according to Archimedes’ principal”)* The Megalodon weighs =10 kg without tether, and the buoyant force=7.285 kg. So, the difference is about “300 gram”, which is calculated using SolidWorks software.

Floating material or Rigid Polyurethane foam with density of 36 Kg/m3 “is used to increase buoyant force shown in Figure (10). By calculating the needed volume of foam to make the ROV at neutral mode, hollowed circular foam is used under the upper plate and around the circular control box.

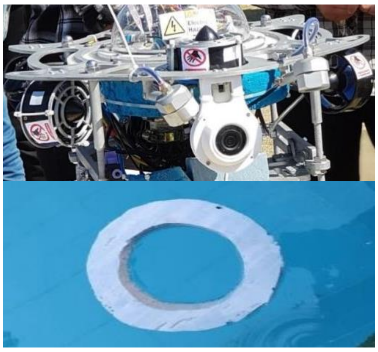


Figure (10): The Foam of The Megalodon

5. Pneumatic Manipulator:

1. Structure:

The Megalodon arm, shown in Figure (11), is a parallel-jaw manipulator which is pneumatically powered. The end effectors are linked to the pneumatic piston through an Aluminum base attached to a 50*20 mm^2 pneumatic cylinder. Also, the end effectors are flattened to increase the contact area with objects gripped. The pneumatic manipulator is designed to move smoothly which is achieved by using two mechanical bearings to reduce friction.

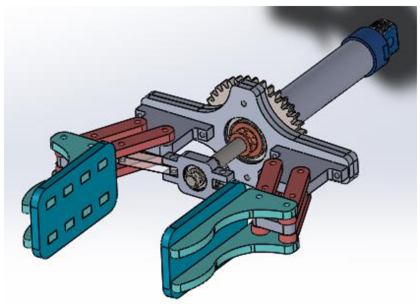


Figure (11): Pneumatic Arm

Arm Specifications:
Weight= 200 gram
Degrees of Freedom= 2

2. Fabrication:

The manipulator is fabricated using 8mm polyamide sheet, 5mm Aluminum sheet, and 6mm Acrylic sheet to provide good vision for the Pilot. The Aluminum is chosen for its high strength which causes no deflection due to bending stress, and for its manufacturability which allowed making a grove on it to set the bearing. During the fabrication process, several **C**omputer **N**umerical **C**ontrol **(CNC)** machines were used as shown in table (2).

Name	Process	Name	Process
Cylinder Mechanism Connection	Lathe Machine	**Gears**	Laser Cutting
Base	CNC Router	**DC Motor Casing**	Lathe Machine
Piston Gland	Lathe Machine	**Joints**	Lathe Machine

Table (2): Fabrication processes for some parts of the pneumatic manipulator

3. Usage:

Due to its rotational feature, high strength and multi-functional end effector shape, the pneumatic arm is used for:

A. Hocking the tire to the lift bag which is going to lift it to the water surface.
B. Holding the markers and the PH sensor.
C. Moving the screen.

6. Fiberglass Shell

Design:

The fully-curved-Shell, shown in Figure (12), is a 3mm fiberglass part designed to reduce the drag force on The Megalodon and to give it a better appearance. The shell uses the NACA 0012 foil as the profile, which led to a coefficient of drag= 0.0117.

Figure (12): Fiberglass shell

Fabrication:

The fabrication of the fiberglass shell is done as follows:

1. A solid wood mold is made using a CNC Router.
2. The solid mold is then covered with paste to provide it with surface smoothness.
3. A layer of wax is then added to the wood mold to cover it.
4. A solid model is made by spraying layers of heat-resistant-material to cover the solid mold.
5. The model is then removed from the mold by heating it to melt the wax layer to ensure smoothness of the surface.
6. The fiberglass is poured to the model gradually.

7. Mechanical Sealing:

1. Camera House:

While designing the main camera sealing, the main goal was to reach a small and easy to assemble design. This led to a design of 4 parts: The Acrylic lens, the back and front covers, and the O-ring. The O-ring is set between the two back and front covers to prevent water leakage as shown in Figure (13). Also, the back cover is connected to a hose which is linked to a valve. The more the mechanical link is fastened, the more efficient the water leakage prevention.

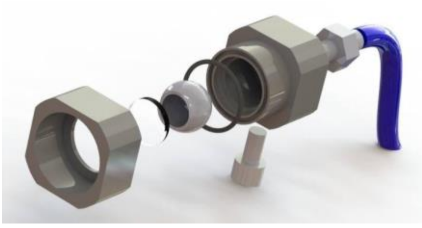


Figure (13): Camera Sealing Parts

2. Electronics Housing:

The sealing of the electronics starts with the Acrylic housing which is set on the Polyamide base. Then, an Aluminum ring is set above the Acrylic housing to increase its strength and eliminate deflection. Furthermore, three O-rings are used between the Acrylic and Polyamide to prevent water leakage. The Aluminum cup, shown in Figure (14), is set on the Polyamide base and is fastened by a nut that pushes on the O-ring. The hose is then set on the Aluminum cup so that the tether takes its way through a gland to the electric components safely. Finally, the hose is fastened by jubilee clips.

No chemicals are used for sealing to maintain safety and to avoid water pollution.

Figure (14): Electronics Housing Sealing Parts

8. Simulation:

As an assurance for the stability and strength of the Megalodon, **C**omputational **F**luid **D**ynamics **(CFD)** and **F**inite **E**lement **A**nalysis **(FEA)** simulation programs were used to conduct several case studies on our ROV for the purpose of:

1- Choosing the suitable material for the plates
2- Testing the strength of the mechanical parts
3- Measuring the coefficients of drag and lift forces

A. The Megalodon CFD Analysis:

Using Ansys Fluent, the physical conditions of the environment surrounding the ROV were simulated after finishing the solid model of The Megalodon.

<u>**Analysis Results:**</u>

Coefficient of drag = 0.0837
Coefficient of Lift = 0.0255
Maximum Pressure = 154.89 Pa

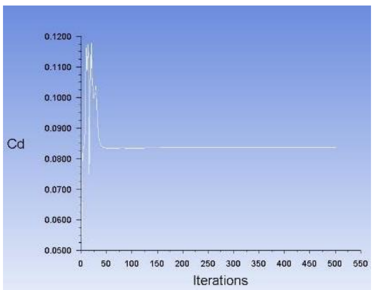


Figure (15): Cd Diagram

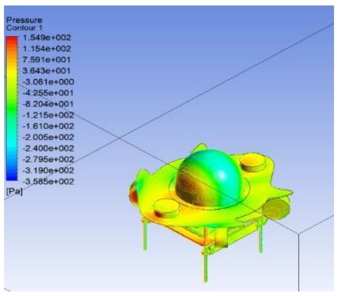


Figure (16): Visual Results of ROV Analysis

B. The Fiber Shell CFD Analysis:

As an assurance for the low drag force effect of the fiber shell, a CFD analysis was conducted to test the shell efficiency.

Analysis Results:

Coefficient of drag = 0.0117

Coefficient of Lift = 0.0338

Maximum Pressure = 122.177 Pa

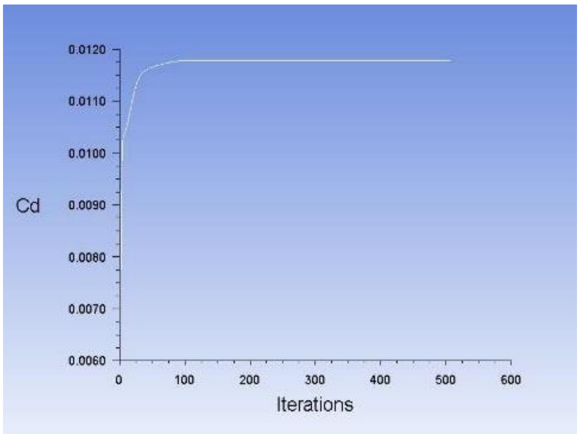


Figure (17): Cd Diagram

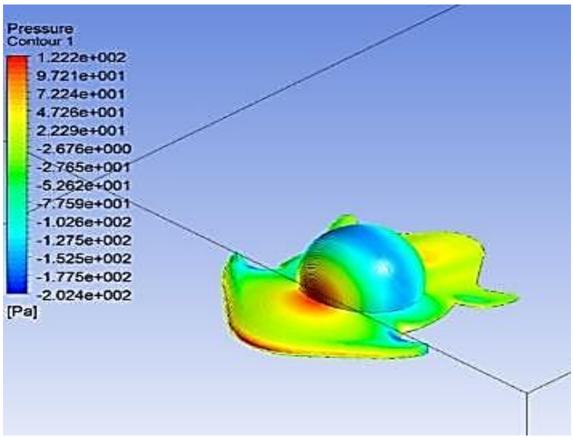


Figure (18): Visual Results of ROV Analysis

C. Upper Plate Stress Analysis:

Taking the weight and strength factors into consideration, a stress analysis was conducted to determine:

A. Best positions to make holes to reduce the total weight of The Megalodon

B. The maximum pressure that the upper plate can withstand

C. The weight effect of the mechanical parts fixed to the upper plate

Analysis Results:

Maximum Stress= 1.83e+07 N/m^2

Minimum Stress= 4.37e+04 N/m^2

Maximum Strain= 0.199 mm

Minimum Strain= 0 m

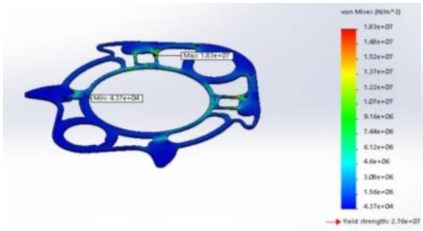


Figure (19): Visual Representation of Stresses

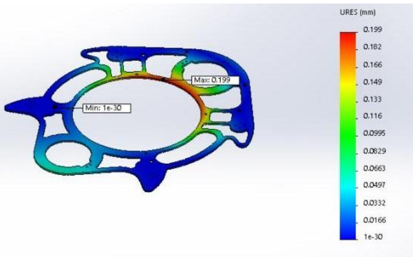


Figure (20): Visual Representation of Strain

D. Lower Plate Stress Analysis:

As the manipulators of The Megalodon are fixed to the lower plate, a stress analysis was conducted to determine if the Aluminum plate will withstand the weight forces acting on it.

Analysis Results:

Maximum Stress= 2.170e+01 N/mm^2

Minimum Stress= 7.634e-05 N/mm^2

Maximum Strain= 5.156e+00 mm

Minimum Strain= 0 mm

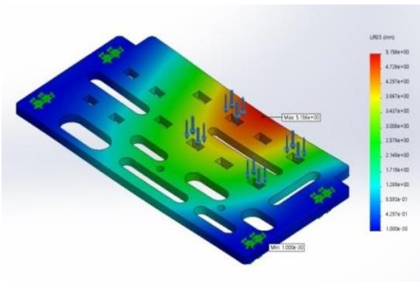


Figure (21): Visual Representation of Stresses

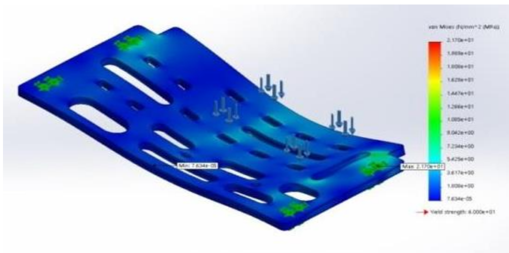


Figure (22): Visual Representation of Stresses

9. Hardware System

1. Control Unit

Following the concepts of ergonomics, safety, and ease of usage, The Megalodon is designed to include the following features:

1. **Usability of Control Unit** which is guaranteed by using high-strength-low-weight polymer
2. **Safety from Collisions** by adding rubber to the internal frame of the Control Unit
3. **Ease of Assembly** by adding connectors to provide less operational time

The Control Unit contains several components as shown in Figure (23)

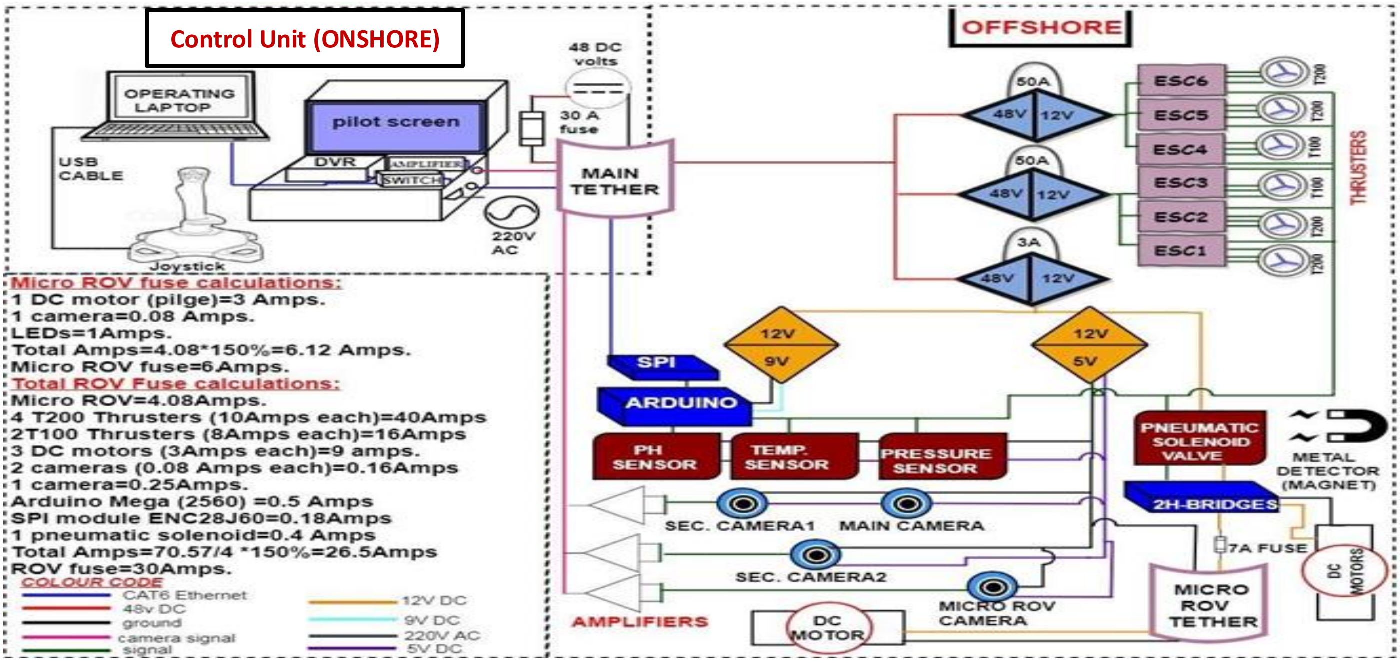


Figure (23): SID and Fuse Calculations

1.1. Laptop:

The laptop is used to provide the Co-Pilot with all the specific software tools needed in missions during the product demonstration.

Figure (24): joystick

1.2. Joystick:

The Megalodon uses an extreme 3D Pro Joystick, shown in Figure (24), to communicate with a C# graphical user interface (GUI) on the laptop, then to the Ethernet module via the Ethernet cable in the tether.

1.3. Network Switch:

It was used due to be a multiport network bridge, the Network switch is used to process data between the laptop, the DVR, and the ROV.

1.4. Indication LED:

They are used to ensure the proper connections of the laptop, ROV, and DVR by checking the corresponding LEDs are on.

1.5. Digital Video Recorder:

The DVR is used to record the cameras' video in a digital format. It also supports the HD camera display. The cameras signals are collected from the tether through the Control Unit amplifiers then enter the DVR which displays this video to the Monitor and the laptop.

1.6. Screen:

It is used to display the cameras stream for the Pilot from the main camera, the two on-side-cameras, and the micro ROV camera.

2. Tether:

The tether, shown in Figure (25), is the gathering of all the cables used to connect between The Megalodon and the 48v power supply. It is also considered as one of the main parts of the ROV as it has several functions such as:

- Allowing the single communication between the Control Unit and The Megalodon by sending and receiving data.
- Transmitting captured images by the camera
- Including the pneumatic hose that controls the pneumatic manipulator.

To enhance the tether efficiency, the cables are attached together by a heat shrink, and tubes are added to reduce the drag force acting on the ROV.

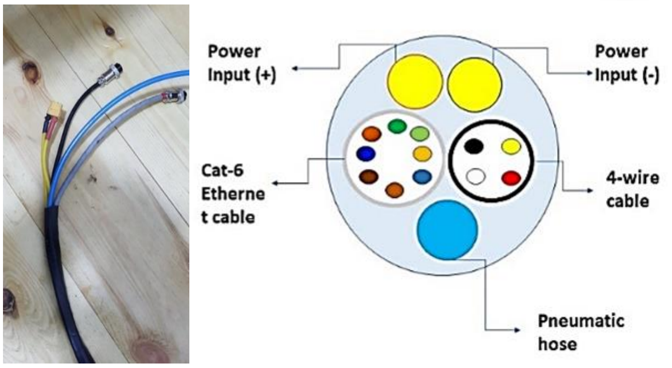


Figure (25): Tether and its Cross-sectional Area

Tether Specifications:
Length= 20m
Weight= 4Kg
Diameter= 2cm

2.1. Power Connection:

The power delivery is done using a 6 **A**merican **W**ire **G**auge **(AWG)** power cable (according to the AWG sizing table) as we used a cable of a diameter of 3mm. It is used to meet the voltage drop allowed which is calculated as follows:

(2: Constant; k: Copper resistivity; I: Current in wire; L: Length; cmil: Circular mil area of wire)

$$\text{Voltage drop allowed } \% = \frac{2.k.I.L(ft)}{cmil} * 100 = \frac{2*12.9*27*65.6}{(3*0.039*1000)^{\wedge}2} * 100 = 3.3\%$$

$$\text{Voltage drop } index = \frac{I.L(ft)}{voltage\ drop.volt} = \frac{27*65.6}{3.3*48} = 11.2$$

$$11.2\ (\text{VDI}) \xrightarrow{\text{from AWG table}} 6\ \text{AWG}$$

2.2. Signals Communication:

The connection between the ROV and the control unit is done by a 4-wire cable, in addition to a Cat6 Ethernet cable which improves the system with high noise immunity (cross talks) and high data rate that handles up to 16 Gb. The Ethernet cable is divided into 2 subgroups each of 4 wires.

- The 1st subgroup is used for receiving data from the controller to the laptop through the Control Unit and sending instructions from the joystick consequently.
- The 2nd group, with the aid of the 4-wire cable, serves as the feeding of the cameras with the signal and the ground for 4 cameras (2 wires per camera).

3. Power Conversion:

The Megalodon power board is designed with maximized compactness and effectiveness as the input 48v is converted to 12v by 2 parallel DC-DC converters 50A, shown in Figure (26-a), to obtain the high current necessary to drive:

1) The 4 horizontal T200 (15A each) and 2 vertical T100 motors (12.5A each) via the ESC drivers.

2) The DC arm motors via the Cytron motor driver (3A for each channel), shown in Figure (26-a), which is placed above the signal board to conserve the power board space.

Figure (26-a): From top to bottom, Cytron Motor Driver, DC Converter

Moreover, the 48v is also converted to 12v by the DC-DC converter 3A, shown in Figure (26-b), which is used in feeding the pneumatic valve and the light system, and is then converted to:

1. 9v for driving the Arduino microcontroller by the 7809-voltage regulator.
2. 3.3v for driving the Ethernet module.
3. 5v by the buck converter, shown in Figure (26-b), to supply the cameras and the IMU module

The 12,9,5,3.3 volts are then gathered by data cable and sent to drive the signal board components.

Figure (26-b): From top to bottom, Buck Convertor, DC-DC Converter 3A

4. Control System:

The signal manipulator is represented by the board, shown in Figure (27), which is responsible for controlling The Megalodon. The main control unit in the ROV is the Arduino Mega mini (2560). An ENC28J60 Ethernet module is used to convert The **U**ser **D**atagram **P**rotocol **(UDP)** to The **S**erial **P**eripheral **I**nterface **(SPI)** protocol to establish a stable communication channel between the control unit and the Arduino. The UDP is chosen as it provides high data rate, in addition to its simplicity to be synchronized with Arduino. Moreover, the UDP uses a simple transmission model but does not employ handshaking dialogs thus avoiding processing at the network interface level for better performance.

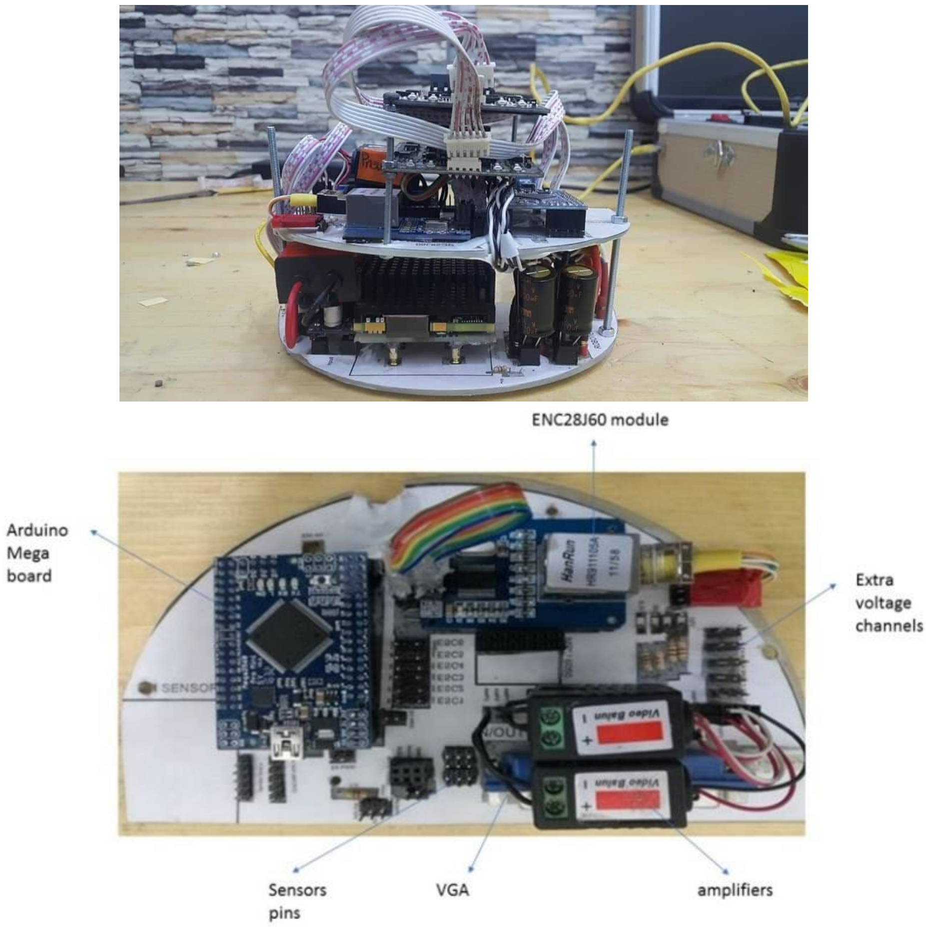


Figure (27): Control System Board

The Arduino mega mini, shown in Figure (28), is used for multiple functions which are:

- Controlling the six thrusters according to the data received from the joystick.
- Receiving the PH, pressure, and temperature sensors data. Then, processing the data and sending it to the Co-Pilot on the Control Unit laptop.
- Sending the signal for triggering the solenoid responsible for the pneumatic arm function.
- Sending the **P**ulse **W**idth **M**odulation **(PWM)** signal and the directional signal for the two Cryton 10A 5-30v dual channel DC motor drivers that drive 4 DC motors. These 4 dc motors are divided according to their functions as follows:
- One is used for the main ROV DC arm.
- Other two are used for the micro ROV and its tether roller.
- The last one serves as turning gear for the pneumatic arm.

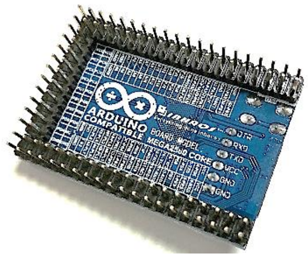


Figure (28): Arduino Mega mini

Both the Cytron motor drivers are compacted vertically to allow more spacing in the boards housing.

The three cameras captured images are first processed by amplifiers before being sent through the tether in order to provide higher quality images without noise and interference between the signals that was experienced last year.
At last, all the signals meant to be sent to the tether are gathered in a **V**ideo **G**raphics **A**rray **(VGA)** connector, shown in Figure (29), which has been chosen for its high efficiency in data transmission and its easiness in soldering wires to it.

Figure (29): VGA Connector

5. Vision System:

5.1. Cameras:

In order to reach the widest field of view for the manipulators and the ROV's surroundings, The Megalodon uses three **A**nalog **V**ideo **(AV)** cameras that are classified to:

A. Main Navigational Camera

The HD resolution camera, shown in Figure (30), is used as the main camera due to its wide angle of view which is up to 160 degrees and for its clear and high-resolution images. It is positioned at the center front of The Megalodon and directly attached to the middle of the main plate.

Figure (30): Main Camera

B. Manipulator Cameras:

To achieve the maximum vision and profitability, two secondary cameras, shown in Figure (31), are positioned a top of the upper plate at its front sides. Both cameras are tilted downwards with a slight angle to cover the corresponding manipulator and vision on hand.

<u>**Secondary camera specifications:**</u>

- CMOS sensor for true color & HD video
- Field of View: 127° diagonal 160° horizontal
- Lens: 2.6mm IR coated
- Horizontal Resolution: 700TVL
- 30 frame/sec

Figure (31): secondary Camera

5.2. Amplifier:

The video baluns, shown in Figure (32), convert the camera signal into a differential pair that is sent up by the tether and converted back into a single wire on the surface by another video balun. This reduces the effects of interference and noise to obtain a clearer and undistorted image.

Figure (32): amplifier

5.3. Light System

Integration between 10 high-power **LED**s (**L**ight **E**mitting **D**iodes), shown in Figure (33), is done to achieve a clear vision for the micro ROV camera. This system is designed by Robo-tech engineers to reduce the power consumption to 10 watts, to be small and to be easily fit in the micro ROV.

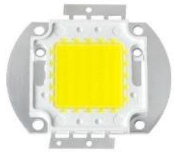


Figure (33): High Power LED

10. Software System

Here we start to present our Software System, shown in Figure (34).

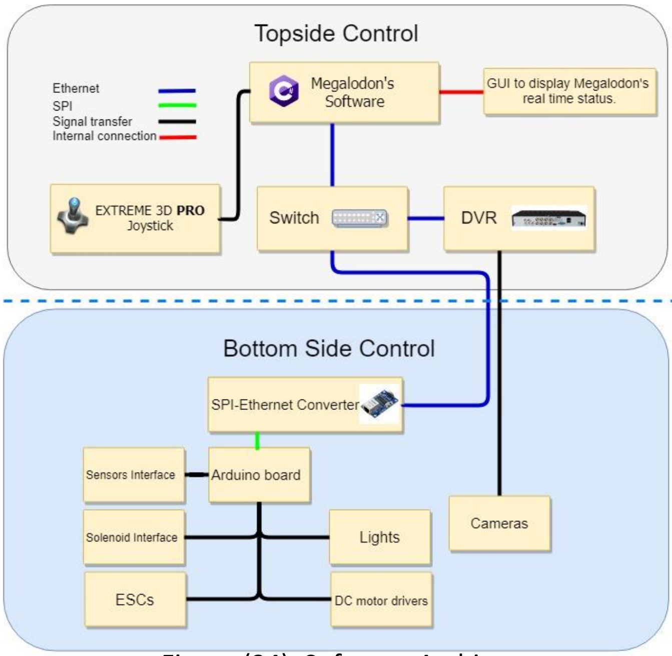
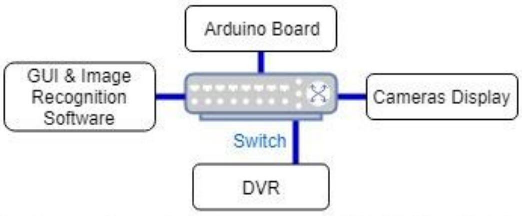


Figure (34): Software Architecture

1. Top Side

1.1. Network

The **L**ocal **A**rea **N**etwork **(LAN)**, shown in Figure (35), is used to connect the major control unit components, which are **D**igital **V**ideo **R**ecorder **(DVR)**, Microcontroller, and Computer, through a Network switch.



Network connecting each major component of the ROV control system

Figure (35): Network Diagram

The reasons beyond establishing this Network are:

- Giving an internal connection between all devices through the switch.
- Allowing multiple devices to send and receive data at the same time with a high-speed rate.
- Allowing the control unit data to be sent through any computer.
- Allowing all devices to monitor the data exchange operation, view camera stream.

1.2. Graphical User Interface (GUI)

The Megalodon software has several important functions which help in handling multiple tasks. It consists of 5 tabs, each one of them has its own functions as follows:

1. A tab to display the coordinates of the joystick and its buttons status
2. A tab to start communication with The Megalodon
3. A tab for the co-pilot to display the values of motors and sensor values
4. A specially made tab to perform the third task in which the radiuses and length of the cannon are determined, and the size, weight, and force of the canon are calculated
5. A tab shows the live broadcast of the cameras of The Megalodon

Figure(36): enc28j60

1.3. Communication

Communication between the control unit and the Arduino board inside The Megalodon is achieved by using an Ethernet-SPI module enc28j60, shown in Figure (36), to convert the data coming from the Ethernet into **S**erial **P**eripheral **I**nterface **(SPI)** protocol to be readable by the Arduino board.

The UDP is used for its suitability at transmitting and receiving lengthy data, and for its eligibility as a connection link for sending data faster than **(TCP).**

2. Bottom Side

Sensors, manipulators, thrusters and micro-ROV motors are all controlled using the atmega2560-based Arduino Mega-Mini board using data received from the control unit,
The Arduino board is also responsible for sending sensors readings continuously to be shown on the GUI. The reason beyond the selection of this board is its small size and the large number of pins (54 digital and 16 analog pins).

IV. Mission Specification

1. Micro-ROV

1.1. Usage:

The Megalodon Micro-ROV, shown in Figure (37), is designed especially for pipe inspection purposes to navigate through the 6-inch corex pipe and to provide a clear image of the muddy water inside the pipe.

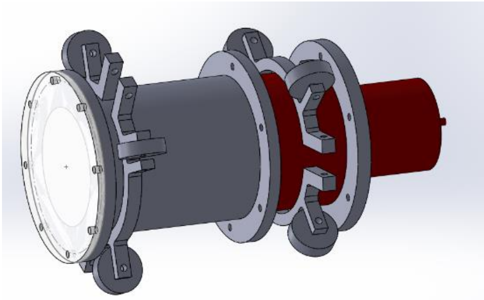


Figure (37): Micro ROV Electronics Housing

1.2. Mechanical Structure:

The Micro-ROV consists of four main parts which are:

A. Main Body:
The Cylindrical body is made from machined polyamide to hold the electrical components including the H-bridge, camera, and flashlights. The radius of the cylinder is 11cm to minimize its size.

B. Sealing:
The Micro-ROV consists of a rubber gasket and a clear Acrylic disc. Both parts are fixed to the main body.

C. Bilge Motor:
The Micro-ROV uses only one motor for moving through the pipe which saves space and minimizes the size of the Micro-ROV as much as possible.

D. Guide Rollers
The rollers are placed on two frames which are fixed to the main body. This facilitates the Micro-ROV movement inside the pipe.

1.3. Electric Control System:

The Micro-ROV is controlled by the joystick in the same way as in The Megalodon. The control program, used by the pilot, has a special mode that is activated when we want to use the Micro-ROV instead of the main ROV, and its tether is also pulled using the joystick. To be sure that the Micro-ROV docked with The Megalodon after finishing inspection inside the pipe.

2. Lift Bag

2.1. Usage:

The lift bag, shown in Figure (38), is designed to lift heavy objects to the surface of the water. As for The Megalodon mission, the lift bag is used to lift the cannon from the bottom of the pool.

2.2. Mechanism:

The mechanism is designed to be as simple, quick to open, and easy to assemble as possible. The mechanism consists of two hocks which are designed to hold the cannon, then lift it with the lift bag.
The lift bag is simply inflated via the pneumatic system and a non-return valve. Once the valve is opened, air can occupy the balloon by pneumatic-pipe which is controlled by a solenoid.

Figure (38): lift bag mechanism

3. Image Processing

The image processing feature is used to calculate the amount of force needed to lift the cannon done by using Image processing as follows:

1. The actual length of the reference is fixed on The Megalodon before it goes down under water.
2. A picture is taken containing the reference and the part to determine (R1, R2, R3, Length).
3. The photo is uploaded on a C# tab, shown in Figure (39), to be processed.
4. As the reference's actual and virtual (in-image) length value of the parts are known, the true length of the part can be calculated.
5. The radiuses, lengths and the specific gravity are used to calculate the volume and the force of the cannon.

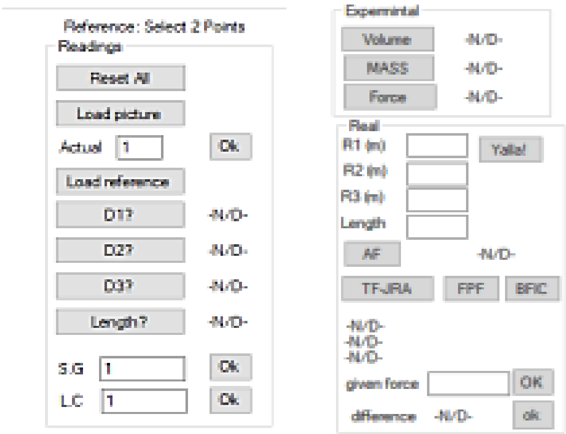


Figure (39): C# Tab

6. After the difference between force and lift capability is determined, the lift bag is used to help The Megalodon go up and overcome this difference.

4. Image Recognition Software

In order to autonomously follow the red line, measure the length of the crack and locate it. In addition to shape detection task, image recognition software is designed using the open-source library "OpenCV" to fulfill all required tasks.

4.1. Line Follower

The "Line Follower" software program relies basically on color filtering due to the diversity of colors engaged. A flowchart of the algorithm, shown in Figure (40).

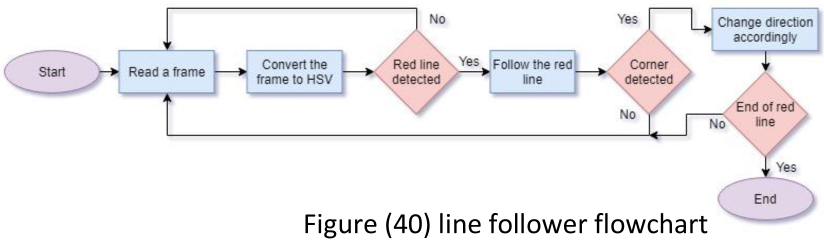


Figure (40) line follower flowchart

Before processing a frame, the frame is converted to HSV (hue, saturation, value) instead of BGR as HSV is more efficient when detecting colors in various lighting conditions. Then, three masks are applied for each color (red, blue and black). A mask is a binary image that is only black and white. Each mask has a function. The red mask is for line following as shown in Figure (41), the blue mask is for crack detection and measurement while the black mask is for detecting grid lines. The algorithm of the program is shown in figures (42). With the help of this program, the ROV follow the line simultaneously and measure crack length when it is detected. To map the crack, the program counts the grid lines continuously and calculates the position of the ROV and the crack accordingly in real time.

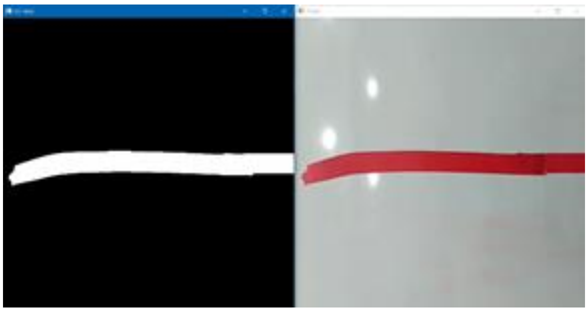


Figure (41) red line detection

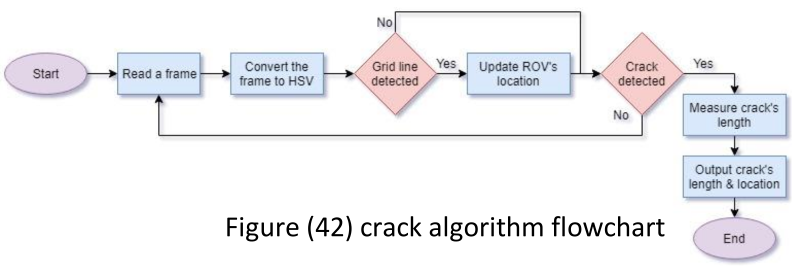


Figure (42) crack algorithm flowchart

4.2. Benthic Species Detection

The algorithm, shown in Figure (43), is basically finding contours of each shape and highlighting them. Then, the shape can be easily determined by counting the vertices of each contour. Contours are lines representing the boundaries of an object. For example, if a shape has three vertices then it must be a triangle and so on.

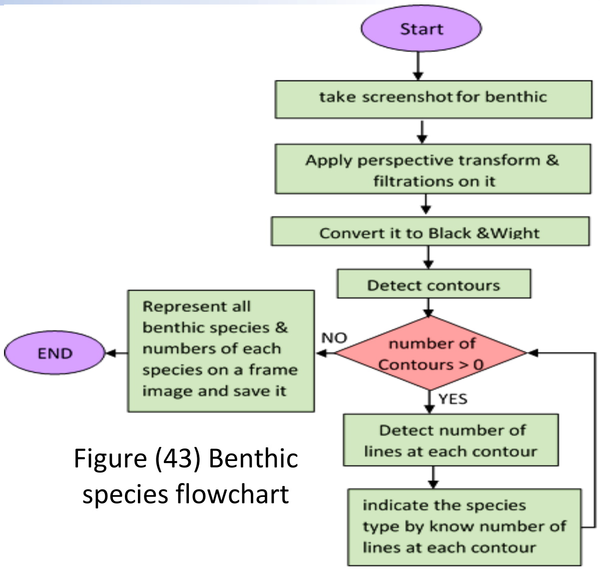


Figure (43) Benthic species flowchart

V. Safety

1. Safety Philosophy

At Robo-tech, we believe our first responsibility is to the safety of our engineers, and environment. For this reason, our company always aims to improve its safety standards and develop the level of safety for its workshop tools as shown in figure (44). The standards are not only followed during the fabrication and operation processes but also during our early design process to ensure that our design decisions will not hurt our engineers or pollute the environment.

2. Safety Standards

1- Tools with sharp edges should be used carefully and properly.
2- When working with high-pressure devices or testing high-pressure components, a barrier should be used.
3- Before using electrical tools, check their insulation.
4- At least two engineers must be present during test or fabrication processes.
5- Engineers should wear gloves, glasses, and footwear during machining, welding, or using pneumatic devices.
6- Welding iron holders should be used while soldering the PCBs.
7- Engineers should make sure that their hands are dry before contacting any power supply.

Figure (44): safety

3. The Megalodon Safety Features:

A. Mechanical Safety Features:

The Megalodon is designed to include smooth and curved edges as shown in Figure (45). The bolts are covered with caps to prevent any injuries or high stresses which can cause deflection as shown in Figure (45). Furthermore, the motors are all covered with safety guards to prevent any accidents as shown in Figure (45). Also, the pressure relief valve is added to the compressor and is set to 1000kpa which is the maximum allowable pressure for the tank. And the pressure regulator is adjusted at 250kpa. Lastly, several O-rings have been used to optimize the efficiency of water leakage prevention.

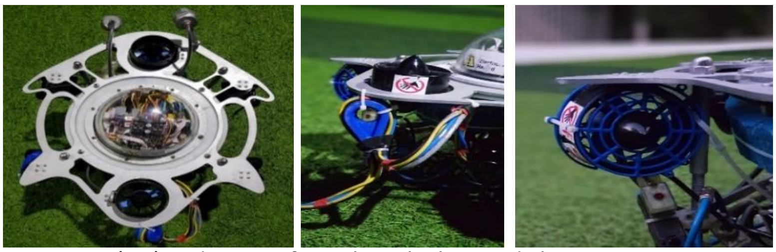


Figure (45): edges, Safe tether, bolts, and thrusters.

B. Electrical Safety Features:

The Megalodon Electrical system is developed to provide safety for its users and the environment surrounding. It uses a 20A fuse with an isolated casing and color-coded cables for power and signal transmission across the electronics housing. Moreover, the software interlocking system is designed to protect thrusters from reaching full power at the same time.

VI. Test and Troubleshooting

After the end of the fabrication process, The Megalodon was mechanically and electrically tested to ensure its safety.

1. Mechanical Testing:

1.1. Camera Sealing Test:

As one of the critical parts of the ROV, the camera sealing parts were tested by the following steps:

a. The camera sealing parts were put inside a container connected to a compressor

b. The pressure was increased gradually up to 700 kpa. After the test, the parts were assembled to the 2 Aluminum parts.

1.2. Electronics Housing Test:

To ensure the safety of electrical components. The holes of the electronics house were all closed, and an air hose was connected to the housing to induct pressure of 50 kpa. After the test, it was decided to use an Aluminum ring to support the acrylic housing to eliminate deflections.

1.3. Free-Electric-Components Test:

To cause no damage to the electrical components, The Megalodon was tied to a rope and left in the water for 10 minutes without containing its electric components. After the 10 minutes, the electric house, the hoses, the cameras, and the tether were all checked for water leakage.

2. Electrical Testing:

Line Follower Test:

Corner detection was tested in all cases many times. The program classifies a corner by its two ends. So, for example, the corner Should be classified as an 'up-right corner' as its two ends are in both right and top directions. Another test was made to test the proportional integrated differentiation (PID) system for maintaining the red line in the middle of the camera frame to prevent The Megalodon from getting out of line.

3. Full Testing of The Megalodon

After the Free-Electric-Components test, The Megalodon was launched into water while containing its electric components. Then, the software system was checked to ensure that the motors respond to the values entered by the pilot and co-pilot, and the cameras were checked for providing the best vision possible as shown in figure (46).

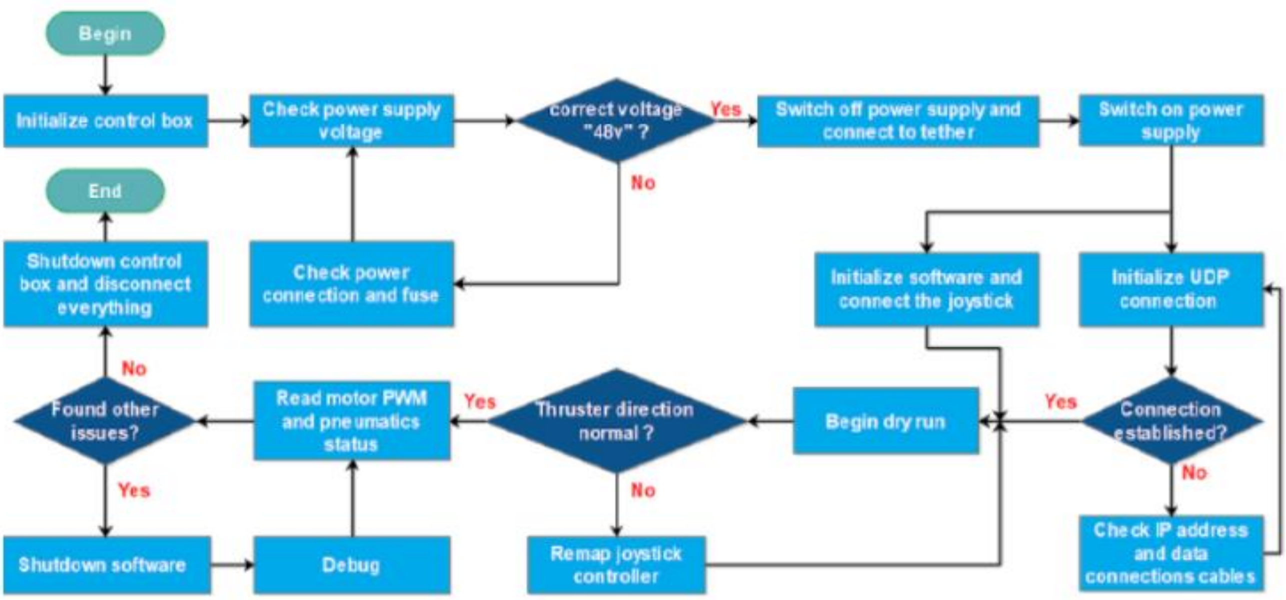


Figure (46): Full Testing of The Megalodon flowchart

VII. Lessons Learned

Working on The Megalodon has changed every one of us and enhanced our technical, managerial, and soft skills. It has also taken our mindset and appreciation for human values to a higher level.

1. Technical Skills:

- Our mechanical engineers started using SolidWorks surfaces in a more professional way which provided a unique fully curved design for the fiber shell.
- The research and development mechanical engineers took a further step in using CAD simulation programs such as Ansys Fluent and COMSOL. This was achieved by joining more CFD courses, running more case studies, and asking more CFD and FEA experts for help and advice.
- After analyzing last year technical report mistake, a new system for technical writing was implemented.

2. Soft skills:

- As one of the most important skills to introduce others to our product and to help the Ranger branch students, our company worked on the development of our engineers' presentation skills by:
- Attending several presentation skills training, participating in fairs and events, and training on presentations on our weekly meetings.
- During the work on our final presentations, each section of the presentation was assigned to two engineers to help each other and to choose the best presenters qualified to present our Megalodon.
- The edit in the hierarchy of our company provided more managerial positions which enhanced our engineers' managerial skills.
- As a result of the changing circumstances around us, our engineers' planning skills were enhanced and became more flexible and efficient in re-planning and handling hard situations to cause no delays to our timeline.

VIII. Future Improvement

The knowledge we gained this year opened the gates for us to set a list of suggestions for next year mechanical and electrical improvements.

1. Electrical Improvements:

a. Building a new web application using Django rather than a desktop application. Django is a high-level Python framework that has advances of better pragmatic design, security, open source, scalability, and taking care of the hassle of web development.
b. Implementing Robot Operating System (ROS) on our next ROV. ROS is an open source framework which offers many tools such as Gazebo and offers libraries and services that will cut off lots of hard work and complexity. ROS will also optimize our next ROV software system by:
    - Achieving maximum reusability as ROS is developed in units of nodes which is the minimum unit of executable program that has been broken down.
    - Allowing it to run on several computers.
    - Make our system easier to understand and develop.

2. Mechanical Improvements:

a. Develop our company tools by buying a small 3d printer and a lathe machine. This will not only reduce the cost of fabrication but will also save time and effort.
b. Conduct a dynamic analysis for our next ROV which will provide more accurate values and more advanced simulation.
c. Expand our knowledge about finite element analysis to reach a mechanical optimized design to reduce the weight of our next ROV.

IX. Project Management

1. Company Structure

Along the years, the management system of Robo-tech company has developed to maintain the stability of Robo-tech, the quality of our service, and the developing level of experience and knowledge of our engineers. This year, Robo-tech management system follows a new philosophy which aims at developing professional engineers in certain fields. Not only this but also qualified educators to pass their knowledge to the next generation of engineers and students of The Rangers Branch.

To achieve the previous goals, our company is divided into two sections: The non-technical section and the technical section as shown in figure (47). The technical section is divided into two departments, and each department consists of several units.

The non-technical sections are usually joined by our engineers as a secondary job which helps them increase their soft skills furthermore.

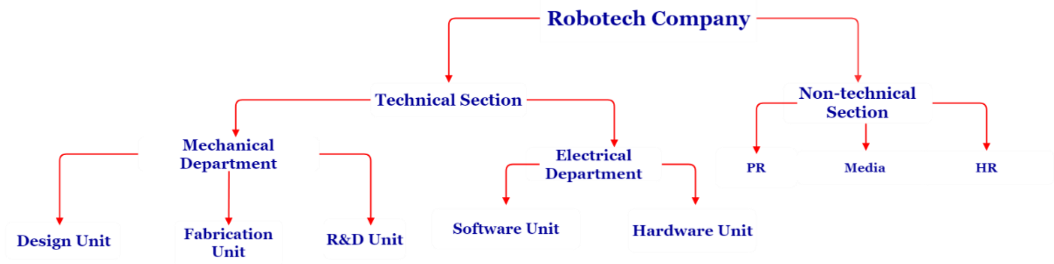


Figure (47): Company Structure flow chart

2. Timeline

Our timeline started by the recruitment process for new engineers to join us the hard work, and to pass our knowledge to them. Then, the training duration started. Its goals were to develop our new engineers technical, searching, problem-solving, and time management skills. The training duration was followed by the work on The Megalodon. Starting from the previous phase, our engineers started taking their position in department units.

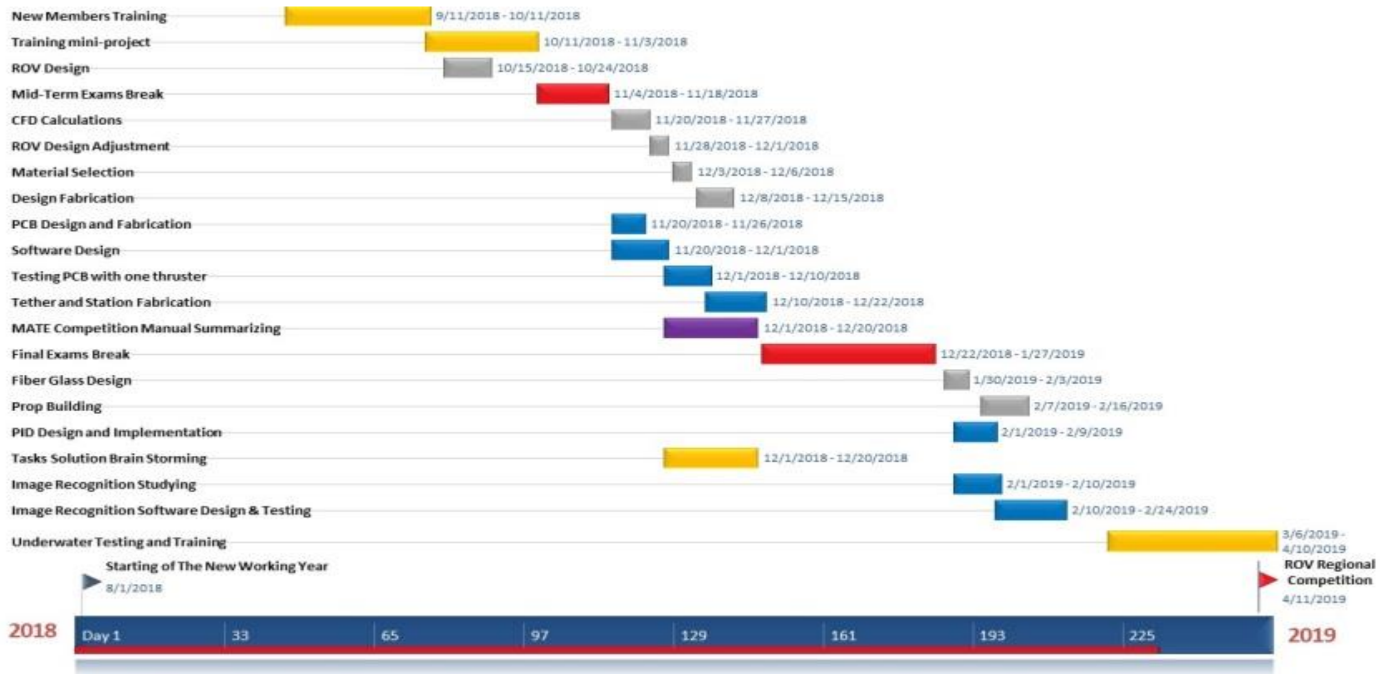


Figure (48): our company timeline

3. Task Distribution

Since the start of our training duration, the human resources members, the mentors, and the department heads have all been working on discovering the points of strength and weakness of each new engineer. Not only this, but also on discovering their interests, aspirations, and characteristics. By the end of the training duration, a meeting took place so that each member decides what unit they want to join.

4. Work Management

During our work on The Megalodon, we maintained the flow of communication between our engineers by:

- Holding two meeting per week so that our engineers meet and discuss their work, problems, and results.
- Holding one general meeting every 2 weeks to inform our engineers of the latest updates and what we have achieved recently.

5. Problem Handling

In case of problems, Robo-tech has a clear system and flow of communication process to handle problems.

5.1 Internal Problems:

As internal problems are of high importance to maintain the stability of our company, the department of human resources has created a strategy to solve them.

5.2 External Problems:

In the case of external problems such as timeline delays, financial issues, or failure of decisions, the board members are responsible for solving all types of external problems. This rule works for all problems except for public relation problems which are only solved by the CEO and vice CEO to maintain confidentiality.

X. Budget Analysis:

1. Budget

Megalodon Development (USD)		Income (USD)	
Mechanical Components	$900.00	Electronics course produced by Robo-tech Company	$500.00
Electrical Components	$2000.00	Mechanics course produced by Robo-tech Company	$500.00
Workspace Expenses	$1100.00	Academy of Scientific Research and Technology Sponsorship	$3730.00
Pool Expenses	$580.00		
Operations sub-total	**$4580.00**	**TOTAL INCOME**	**$4730**
BALANCE			**$150.00**

2. Cost Projection

Type	Item name	Quantity	Price (USD)	
Electrical Components/Devices				
Re-used	T-200 Thrusters, (from RT04 2018)	4	$676.00	**Electronics Sub-Total**
Re-used	T-100 Thrusters, (from RT04 2018)	2	$238.00	
Purchased	DC Motors	4	$57.50	
Re-used	48 to 12 V Regulator, (from RT04 2018)	1	$9.00	
Re-used	48 to 12 DC Converter, (from RT04 2018)	2	$248.00	
Re-used	12 to 5 V Regulators, (from RT04 2018)	2	$00.20	
Re-used	12 to 3.3 V Regulator, (from RT04 2018)	1	$00.60	
Re-used	Mega Mini Arduino, (from RT04 2018)	1	$14.00	

Re-used	Ethernet-SPI module, (from RT04 2018)	1	$6.00	
Purchased	Connectors	-	$10.00	
Purchased	SMD LEDs	4	$00.20	
Purchased	MOSFET Transistors	2	$1.50	
Re-used	Electronic Speed Controllers, (from RT04 2018)	6	$150.00	
Re-used	Motor Drivers, (from RT04 2018)	2	$38.50	
Purchased	Pressure Sensor (300m)	1	$68.00	
Purchased	Temperature Sensor	1	$2.50	
Purchased	PH Sensor	1	$63.00	
Purchased	IMU Sensor	1	$4.50	
Purchased	Analog Cameras	2	$28.50	
Purchased	HD Analog Camera	1	$14.50	
Re-used	Anderson plug, (from RT04 2018)	2	$35.00	
Purchased	30A & 10A Fuses	2	$20.00	
Purchased	Printed Circuit Board	2	$16.50	
Control Unit				
Purchased	LCD Display	1	$35.00	
Purchased	DVR	1	$28.50	
Re-used	Network Switch, (from RT04 2018)	1	$30.00	
Purchased	Analog Camera Amplifiers	6	$12.00	
Re-used	Joystick, (from RT04 2018)	1	$45.79	
Re-used	Control Box Case, (from RT04 2018)	-	$40.00	
Re-used	Power Supply, (from RT04 2018)	1	$115.00	**$1947.79**
Mechanical Components				
Purchased	Acrylic tube	1	$11.50	**mechanical Sub-Total**
Purchased	Polyethylene Sheet	1	$57.50	
Purchased	Aluminum Sheet	1	$171.50	
Purchased	CNC Service	-	$100.00	
Purchased	Lathe Cutting Service	-	$300.00	
Purchased	O-Rings	4	$5.00	
Re-used	Solenoid Valve, (from RT04 2018)	2	$17.00	
Purchased	Pneumatic Arm Cylinders	2	$17.00	
Purchased	3D Print Service	-	$100.50	
Purchased	Bolts and Nuts	-	$15.50	
Purchased	Polyethylene Caps	2	$50.00	
Purchased	Sealing Hose	-	$5.00	
Purchased	Tether	-	$42.00	**$892.00**
			Final Cost	**$2839.79**

XI. Challenges

During our work on The Megalodon, our company faced many challenges which added knowledge and experience to our engineers such as:

A. Technical Challenges:

1. **Fabrication of the fiber shell:**

   Due to its fully-curved shape, the fiber shell couldn't be fabricated directly by using usually-available-methods such as 3d printing, lathe machining, or laser cutting. This led us to search for new methods of complex-shapes-fabrication.

   The challenge was overcome by implementing the fiberglass-spraying-method which is mentioned in Fiberglass Shell section.

2. **Size of mother-board:**

   The new spherical electronics house presented a challenge of designing a motherboard which can fit in a sphere of 14cm diameter. This was overcome by decreasing the board dimensions and designing three half-circle areas to reach a motherboard of three layers: power, signals, and motor drivers sequentially bottom up.

3. **Image Recognition**

   The work on the autonomous line follower created a challenge due to the variety of colors engaged, the change in color in water, and speed and direction control.

B. Personal Challenges:

1. As most of the work on The Megalodon was during our semesters' durations, our engineers faced the challenge of managing their time to balance between study and work. Due to this challenge, our timeline was set to include vacations before exams and to include meetings after college time.
2. As part of the development of our units, certain topics and courses were assigned to our engineers to finish them. This created a challenge for us to balance between finishing our on-hand tasks and developing our knowledge.
3. As the electrical department started working on The Megalodon, they found that they need to enter new fields to develop our ROV from the previous one. To solve this challenge, they searched for courses which can help them and started managing their time between finishing the courses and on-hand tasks.

XII. Acknowledgment

Robo-tech engineers can't show enough gratitude to all their sponsors and supporters. So, this is a thank you note to:

- **Prof. Islam Abd El-Maksoud** for his efforts as Robo-tech Supervisor
- **Eng. Mina Adel and Eng. Mina Safwat** for their great efforts and technical support
- **Faculty of Engineering, Alexandria University** for its technical support
- Mate ROV Competition for giving us this chance to develop our skills and expand our knowledge.
- **EzzSteel Company** for its financial support
- **Academy of Scientific Research & Technology** for their financial support

XIII. Appendix

1. Pneumatic Circuit

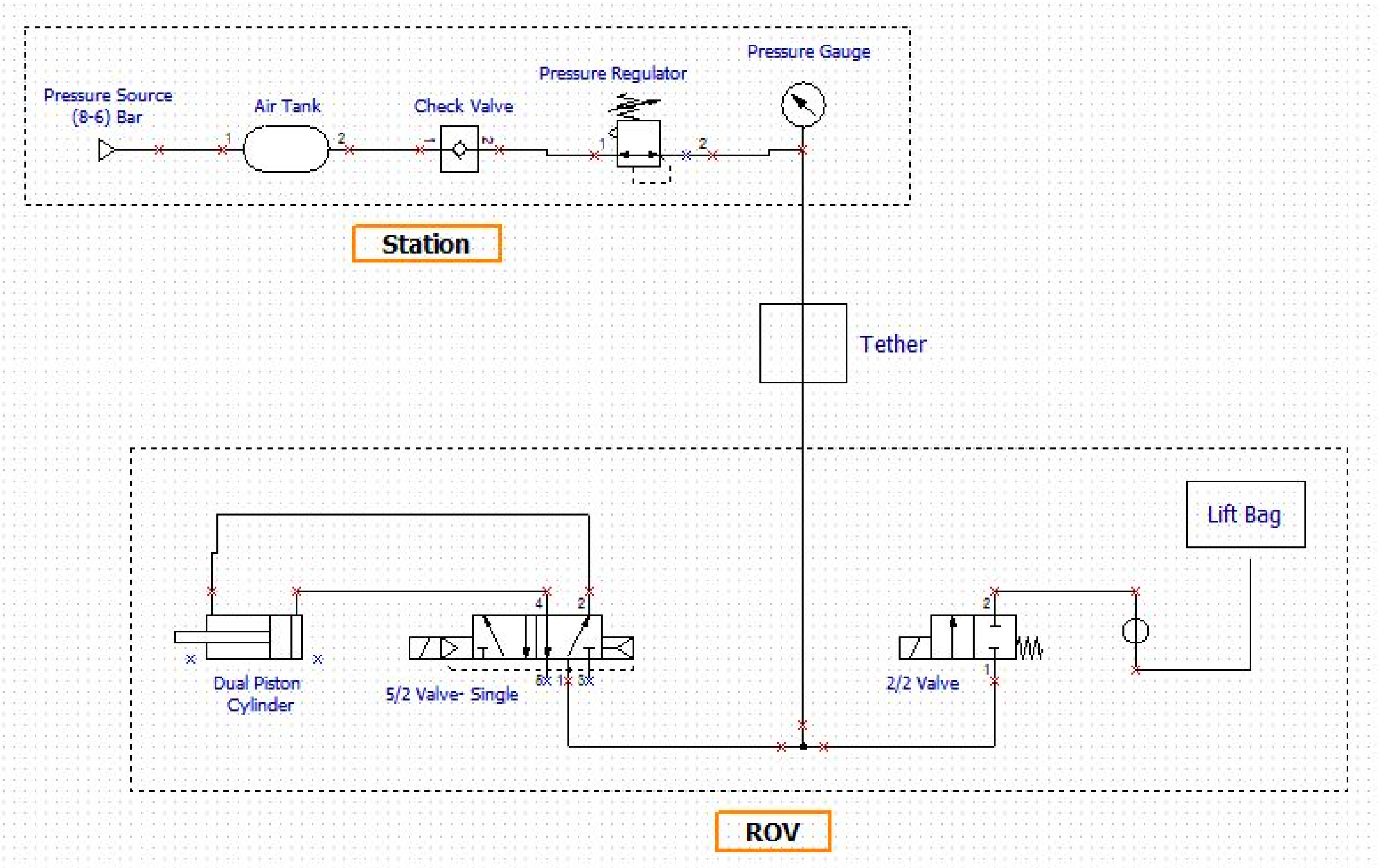


Figure (49): Pneumatic Circuit SID

2. Safety Checklist

1. ROV Physical Checks

All items attached to ROV are secure.	✓
Hazardous items are completely Y shrouded to IP-20 Standards. Mesh size less than 12.5mm.	✓
No sharp edges or elements of ROV design that could cause injury to personnel or damage to pool surface.	✓

2. Pre-Launch Checks

Tether is properly secured at the ROV and No exposed copper, bare wire or motors	✓
All electrical components are properly sealed	✓
Fuses are connected properly, and power supply produces 48v.	✓
Thrusters respond to controls and Camera check.	✓
Anderson power plugs for electrical attachment and All bolts are well tight	✓
Properly sized inline fuse within 30 cm of power supply attachment point	✓
Safety labels are all placed properly	✓
The surface control unit is built in a near and workmanship like manner. No loose components or unsecured wires. All electrical components covered inside an enclosure	✓

2.1 Pneumatic Checks

Passed pneumatic test and Pneumatic diagram present	✓
All pressure lines have minimum pressure rating 100psi stamped on line or verified with specifications ,the Valves meet the minimum pressure of 100 psi ,and Attachment to the pressure source is secure	✓
Pressure is regulated to 40 psi max	✓
Pressure vessels have a stamped pressure rating or verification by a specification, have current inspection sticker, can be secured on pool deck and No hydraulic fluids are leaking	✓
Pneumatic utilize compressed air or inert gas and the pressure release valve is closed tightly and with mounted Protection cap	✓

3. Operating Checks

Buoyancy check and Bubbles check	✓

4. Retrieval Checks

Service, transport or handling of ROV must be performed by at least 2 company members.	✓
Check for cracks or leakages ,Tether is relieved and Thrusters are clean and Power is off	✓

XIV. Reflections

"Working on The Megalodon has not only taught me how to work on a team and to organize my tasks to be capable of finishing several tasks on short time. It has also made me realize that what a person can learn is further than what we can imagine."

- Ahmed Said, Software Engineer.

"As a fabrication engineer, working on The Megalodon changed my mindset about mechanical design as it made me realize the importance of taking fabrication tools and type of process into consideration. Also, working with technicians added to my technical experience and knowledge about machining tools."

- Ali Nabil, Mechanical Engineer

Figure (50): From top to bottom
Ahmed Said – Ali Nabil

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