MATE ROV 2021
TECHNICAL DOCUMENTATION

mia robotics

Neptune

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1. ABSTRACT

M.I.A. Robotics is a 23-person company of interdisciplinary students from Alexandria University. This being its seventh year at the MATE ROV Competition, the company has accumulated expertise in the field of underwater robotics over the years. With a steady pace towards improving the performance of each ROV, the company devised innovative solutions to accomplish this year's tasks.

In response to the MATE Organization and Eastman Foundation's request for proposals, M.I.A designed Neptune with the Mariana Trench in mind. By designing a stable ROV with more powerful thrusters, a better imaging system, and the implementation of modern technologies such as Machine Learning, the company is focusing on tackling real-life environmental problems.

Our mission is driven towards solving plastic clogging and climate change's impact on coral reefs. Neptune comes with a compact peripheral, the Micro-ROV, that enables it to explore parts where navigation is limited. Offering an HD video feed that is displayed in the Topside Control Unit (TCU) next to the main ROV's feed. In addition, it has been manufactured from high-quality components and machined using modern manufacturing techniques like Computer Numerical Control (CNC) milling and 3D Printing.

The following technical documentation records the process of designing Neptune from the blueprint to finishing along with the challenges, lessons learned, and reflections from the company's seniors and mentors.

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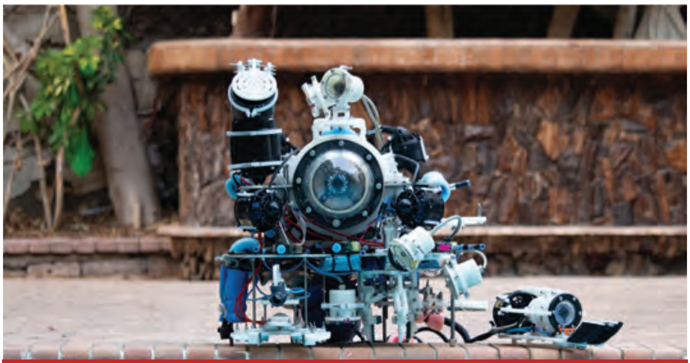
2.DESIGN RATIONALE

A. Design Evolution

We started the year by studying previous designs to draw from our long experience participating in the MATE ROV Competition. Extrapolating their advantages and limitations allowed us to create the best version of Neptune to offer high performance. Our main goal was to manufacture a multifunctional ROV with advanced features.

One of our main targets was to reuse operable parts -since they are in a good state- such as the T2OO thrusters that we own from last year.



Figure(2): Neptune

The mechanical design is modular as it consists of:
- The main base: It is a fixation plate with multi-slot fixation points to install mechanisms, waterproof camera casings, electro-mechanical solenoids, and an electronics enclosure.
- Two-wings: We considered expanding the operating area in front of each thruster's throttle to overcome the drag force on Neptune by avoiding adding peripherals within the perimeter of the thruster's operation to get maximum allowable thrust force without mechanical losses.
- Mechanisms: Multi-purpose mechanisms were mounted on Neptune to facilitate all missions for the pilot to shorten their time.

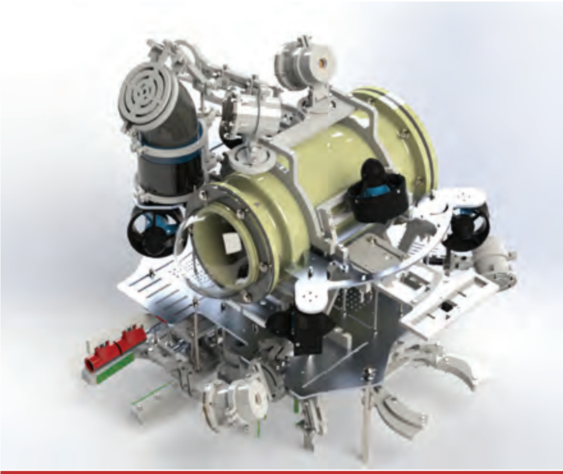
As for the electronic system, smaller printed circuit boards (PCBs) were designed to accommodate less space inside the electronics enclosure and facilitate troubleshooting.

A Validation Board was also added to allow real-time monitoring of power consumption which serves as an efficient and accurate debugging tool.

To give the thrusters the capability to operate at any required speed without disturbing the system, each one is connected to a separate DC-DC buck converter. This connection allows Neptune to operate at higher speeds without issues.

On the software side, we took a huge leap. It was determined that image processing alone was not enough, so we started implementing Machine Learning models for most of the missions side by side with image processing. Being more reliable and efficient, guaranteed better results in the required tasks.
Neptune's software utilizes semantic segmentation neural network (U-net Architecture), YOLOv4 architecture, OpenCV libraries to perform more intensive computer vision and image processing algorithms.

As for the ROV control, we achieved a high degree of maneuverability this year by implementing vectored motion, making Neptune able to move in any direction by calculating the required PWM on every thruster to achieve a specific motion vector in 3D space. Additionally, Neptune has five PIDs implemented on its five degrees of freedom to ensure clean and stable motion and stillness.
For communication, we implemented a packet-based communication system over UART and wrapped it up with a cyclic redundancy check (CRC) algorithm to ensure the validity of every bit.



Figure(3): Neptune

B. Mechanical Design

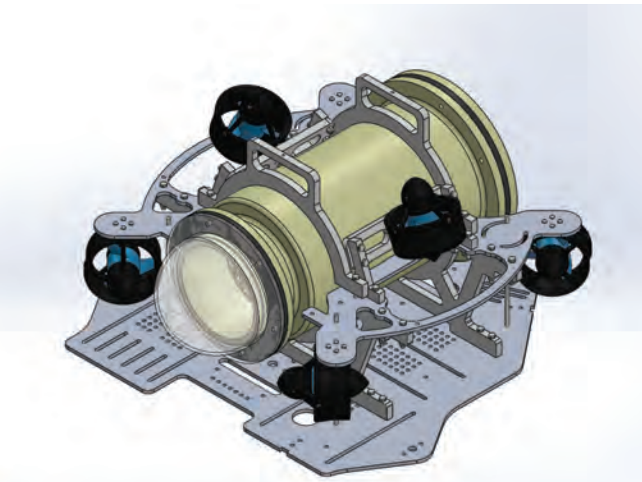
Frame

The frame includes the baseplate, two wings, an electronics enclosure, and caps of the enclosure.
The baseplate was considered the main chassis of Neptune's frame as it had multi-position fixation points, designed in a circular shape about 60cm diameter. It had multi-array vacuum points to allow water to penetrate easily.
The two wings are responsible for mounting the six T-200 thrusters to eliminate their vibration and noise. Also, the material rigidity of the wings improves their overall mechanical characteristics.

The electronics enclosure is the core unit of Neptune. It is fabricated out of high-quality HDPE material and its firm sealing depends on a 4mm thickness gasket, and double O-ring. Also, the electronics enclosure is terminated with an acrylic dome on the front end with a drag coefficient of 0.42 which reduces the drag force and provides a relatively laminar and stable flow with a lower back pressure value. In addition, it gives the main camera a clear and wide viewing angle.

Moreover, the existence of base and wings creates more available spaces to install mechanisms and cameras on Neptune.

This is the first time the M.I.A. company has produced a frame fabricated out of a mix of 5083 aluminium alloy with High-Density Polyethylene (HDPE).



Figure(4): Frame

The 5083-Aluminum alloy was selected to build the baseplate and the two wings. It is characterized by its high strength, good weldability, and corrosion resistance in marine environments; hence, it's known as marine-grade aluminium. Magnesium is the major alloying element (1% of aluminium alloy), also known as the lightest structural metal in the industry due to its low weight and its capability of forming mechanically resistant alloys.

The caps of the frame and the connecting links between the base and wings were fabricated out of HDPE due to their high density and cost-effectiveness. An M5 stainless-steel hex bolt type was used to assemble Neptune's frame.

Mechanisms

All mechanisms are made of HDPE (High-Density Polyethylene) with 8mm thickness. This material was specifically chosen for its cost-effectiveness, high machinability, non-corrosiveness, and high strength compared to other polymers. It is also distinguished by its density (970 kg/m3) which yields better stability and buoyancy effects.

Neptune is equipped with multi-functional mechanisms (Manipulator, Double layers mechanism, Tee mechanism, Three-Jaws mechanism, Hook mechanism). Each mechanism is designed to accomplish a specific mission in the competition.

Furthermore, each mechanism acts as a backup solution to be able to handle any unexpected cases.

Stress Analysis

The process of stress analysis is an essential phase in material selection to check its ability to withstand the loads applied on it to overcome the unexpected bending deformation or material failure. The stress analysis process occurs using the software program ANSYS by simulating real loads, fixations, and material specifications.

The suitable materials to be selected for Neptune's base are HDPE (10mm thickness) and 5083-Aluminum alloy (5mm thickness).

We simulate our ROV's design with all applied loads using two materials to show the stress analysis results.

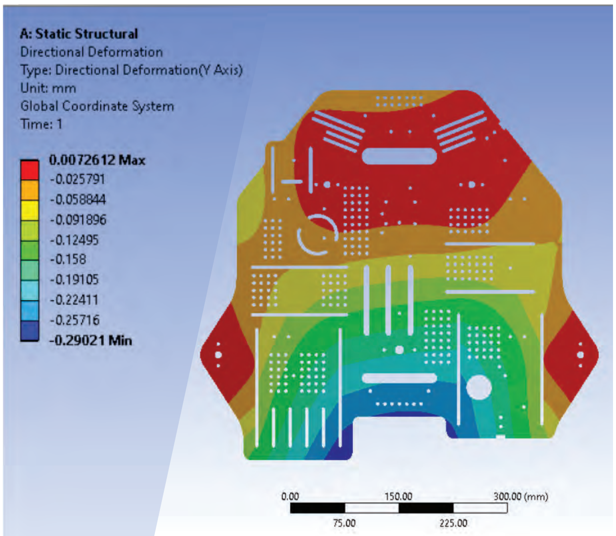
- 5083-Aluminum alloy simulation loads:

The maximum negative deformation was 0.29 mm as shown in Figure(5.1), and the maximum stress 21.3Mpa at fixation points as shown in Figure(5.2). The aluminium alloy has tensile strength 350Mpa and Hardness Brinell 75HB for a 5mm sheet. Using the results shown in the previously mentioned figures, the aluminium alloy was suitable for all applied loads. Also, the alloy has a melting point of 570ºC and is a machinable material that can be easily shaped using CNC machines.

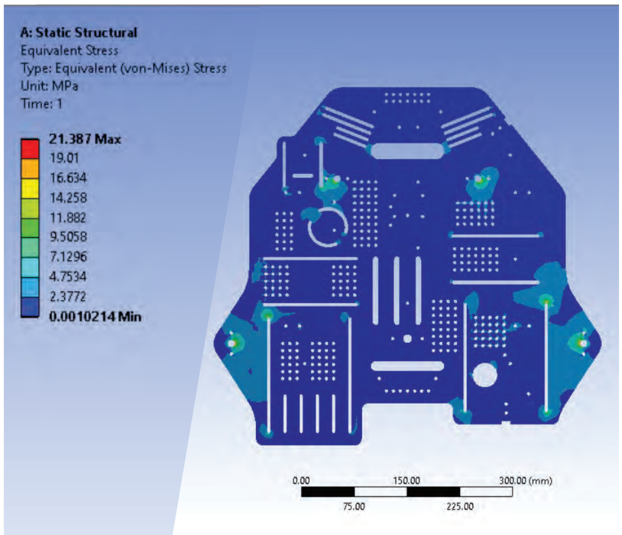
- HDPE simulation loads:

There was a negative deformation range between (1-50mm) as shown in Figure(5.3), and the maximum stress was about 13.77Mpa as shown in Figure(5.4). HDPE has a tensile strength that equals 0.4Mpa and the yield strength equals 25Mpa. Its maximum melting point is 140ºC, which is why it was not possible to be shaped by all types of CNC machines.

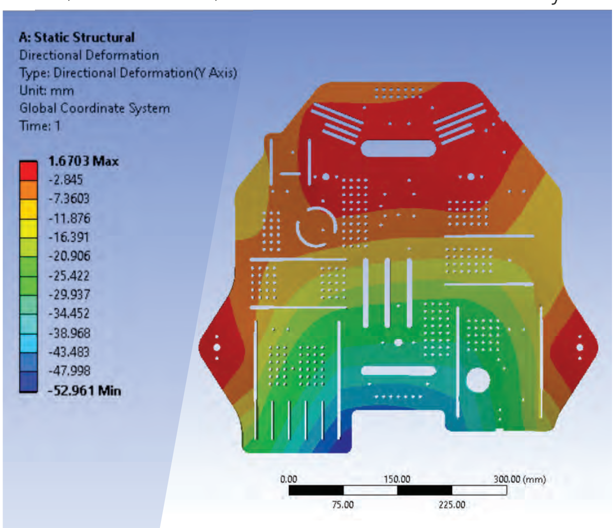
To conclude, based on the explanation above, the company selected the 5083-Aluminum alloy 5mm sheet thickness since it provides high strength and hardness, and is suitable for all applied loads without bending or failures in the design.



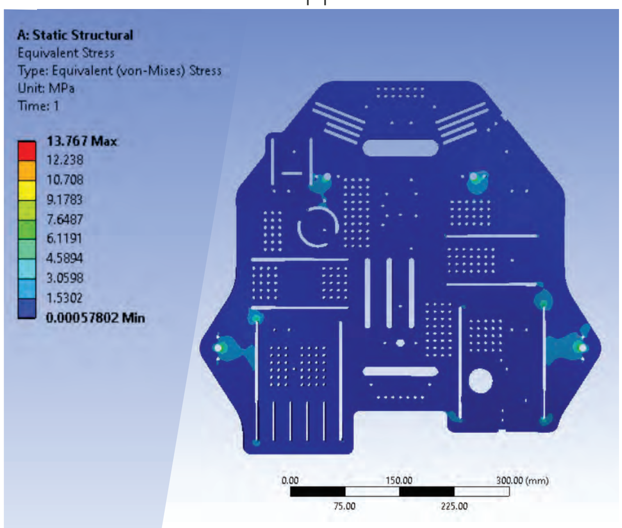
Figure(5.1): Directional deformation (true scale) of 5083-Aluminum alloy



Figure(5.2): Equivalent stress with all applied loads



Figure(5.3): Directional deformation (true scale) with all applied loads



Figure(5.4): Equivalent stress with all applied loads

Figure(5): ANSYS Results

Propulsion

BlueRobotics T200 brushless thrusters are responsible for actuating the motion of Neptune. They have proven their efficiency during the past two years due to their high thrust force with ranges between (0.02-6.7kg.f), high speed, and performance.
However, the T200 thrusters have one deficiency which is their high power consumption, yet this is only considered at high-speed operations as shown in the drag equation:

$$F_D = \frac{1}{2}\rho u^2 C_D A$$

Where: F_D: drag force (N), ρ: density of fluid(kg/m³),
u: speed of the ROV relative to the fluid (m/s²),
C_D: drag coefficient, A: cross sectional area (m²).

The above equation shows that drag force is directly proportional to the square of the velocity; and hence, does not hinder Neptune's operation as the maximum speed required safely considers the drag force resistance.

Achieving better maneuverability and introducing lateral translation, four equally spaced thrusters are placed on a common plane and are vectored at 45° and 135° angles respectively in the corners to provide maximum thrust force at lateral motion and yaw. Two vertical thrusters are placed on two wings to allow vertical motion and roll for the ROV. Thus, the vehicle can achieve five degrees of freedom (DOF): Surge, Sway, Heave, Yaw, and Roll. This configuration allows the thrusters to contribute the power efficiently towards better propulsion and minimizes flow interference, taking into account vehicle and tether drag.

The thrusters are mounted laterally, as shown in Figure(6), and face the drag force of water by the back-end direction to provide the maximum operating force at the optimum speed.
Also, the two thrusters vectored vertically are mounted at 20° in the y-axis to overcome thrust losses caused by the lower plate and mechanisms.
The 20° configuration was selected so that the two thrusters can operate smoothly to overcome the drag below with no efficiency loss.

Figure(6): Thrusters Configuration

Buoyancy and Stability

One of the major challenges that faced the mechanical team was the stability configurations. To solve this, our goals were summarized in the following points: achieving smooth suspension of the vehicle in water for better navigation, obtaining neutral buoyancy underwater, and making the buoyancy force slightly higher than the vehicle weight as it will directly affect safety and maintenance issues. Taking into consideration that the vehicle has to be slightly floating.

In order to accomplish all the required tasks, we put into consideration the design of certain mechanisms. Also, taking into account the frame and electronics housing that occupied a considerable amount of space.

After the assembly operation, the final mass of the ROV was equal to 25,177.91 grams, the mass of the displaced water (which causes the negative buoyancy effect) was 23,847.44 grams. This sort of variation in the vertical forces' components tends to counteract the buoyancy effect; hence, it shall cause the vehicle to sink. Different solutions were devised, the company employed several fixed buoyancy aids and constructed a ballast system. The flotation material should maintain its form and resistance to

Quantity	Type	Displaced Volume (cm3)	Mass Outside Water (gm)	Buoyant Force
6	Thruster	936	2064	-1128
1	Main Base	916.045	2436.68	-1520.635
2	Wing	266.34	708.46	-442.12
4	Frame Caps	702.68	808.08	-105.4
1	Electronics Enclosure	13417.09	6164.45	7252.64
7	Camera Casing	1683.92	1110.06	573.86
1	Manipulator	427.61	616.86	-189.25
1	Double Layers Mechanism	698.6	1166.69	-468.09
1	Tee Mechanism	202.17	293.43	-91.26
1	Three Jaw Mechanism	373.92	575.99	-202.07
1	Suctioning Mechanism	646.77	1057	-410.23
1	Hook Mechanism	188.32	326.21	-137.89
1	Micro-ROV	824.02	1029.41	-361.39
Total		23847.44	25177.91	-1330.47

Figure(7): Buoyancy Effects

water pressure at the anticipated operating depth. The company settled on using lightweight foam as a buoyancy aid. It is a rigid polyurethane foam chosen for its low-density and excellent insulating value. They are made in a high volume-to-mass ratio at a density of 29.96 kg/m^3 and are reasonably inexpensive. Their stiffness, brittle consistency and their propensity to shed dust (friability) when abraded identify its properties.

Static stability is achieved by placing buoyancy aid on top of the ROV to keep the center of buoyancy (CB) above the center of gravity (CG). For ballast configurations, the company chose to use a system of modular lead weights manufactured in-house. Lead was chosen for its high density and low cost.

C. Electrical Systems

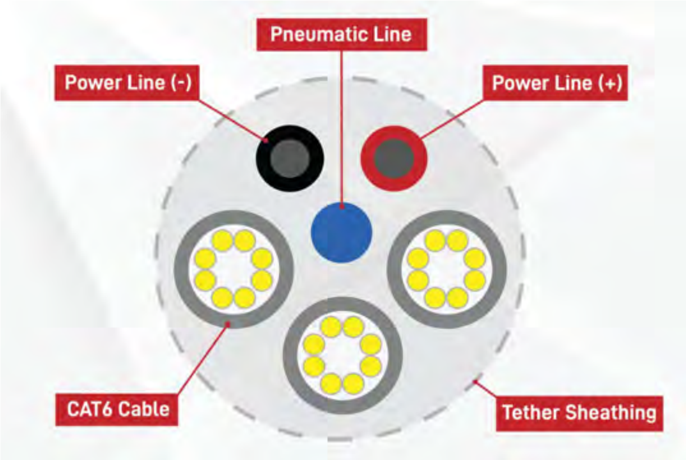
▪ Tether

Neptune's reliable, manageable, and lightweight (2.8 kg) tether is designed to carry necessary signals, power, and pneumatics between the TCU and ROV. The tether is wrapped in a durable, flexible sheathing that protects the lines housed within. The tether contains three Cat6e ethernet cables, two 12-American Wire Gauge (AWG-12) DC power cables, and one 4mm pneumatic cable.

Two Cat6e cables are used to carry the video signals of the eight cameras to the TCU, and the third (main ethernet) is responsible for transmitting the signals between the Top-Side Control Unit (TCU) and the control centre (Communication Board) to communicate with the systems of the ROV in addition to carrying the ninth camera signal. Cat6e was chosen over alternatives such as coaxial, Cat5e, or Cat4 cables based on its lower crosstalk and higher signal-to-noise ratio (SNR), which altogether minimizes the distortion of the video signals during transmission over the 22m tether.

AWG-12 was chosen for its low resistance/unit length, minimizing voltage drop over the tether's length, and carrying the ROV's current efficiently.

The power cable is sized for the maximum current draw of over 32A and has a tested resistance of 0.208Ω. With the full load current drawn, the maximum voltage drop on the power cables equals 6.25V, giving the ROV a minimum operating voltage of approximately 41.75V.



Figure(8): Tether

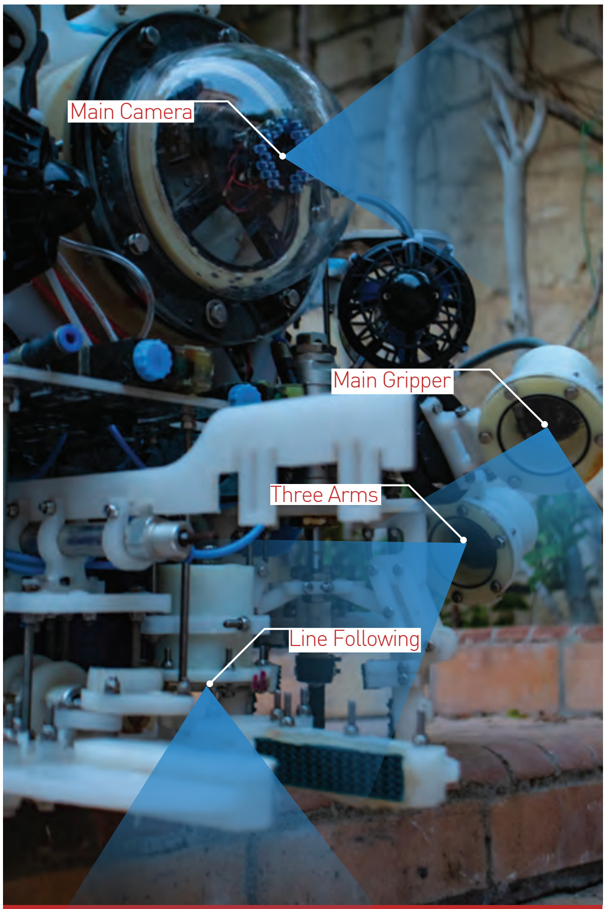
Imaging System

Unlike the designs of the last two ROVs produced by MIA, where the ROV relied on a single gripper to perform the tasks and a single camera (besides the main view camera); several mechanisms have been installed on the ROV, and thus each mechanism requires a dedicated camera, which is why nine cameras were installed:

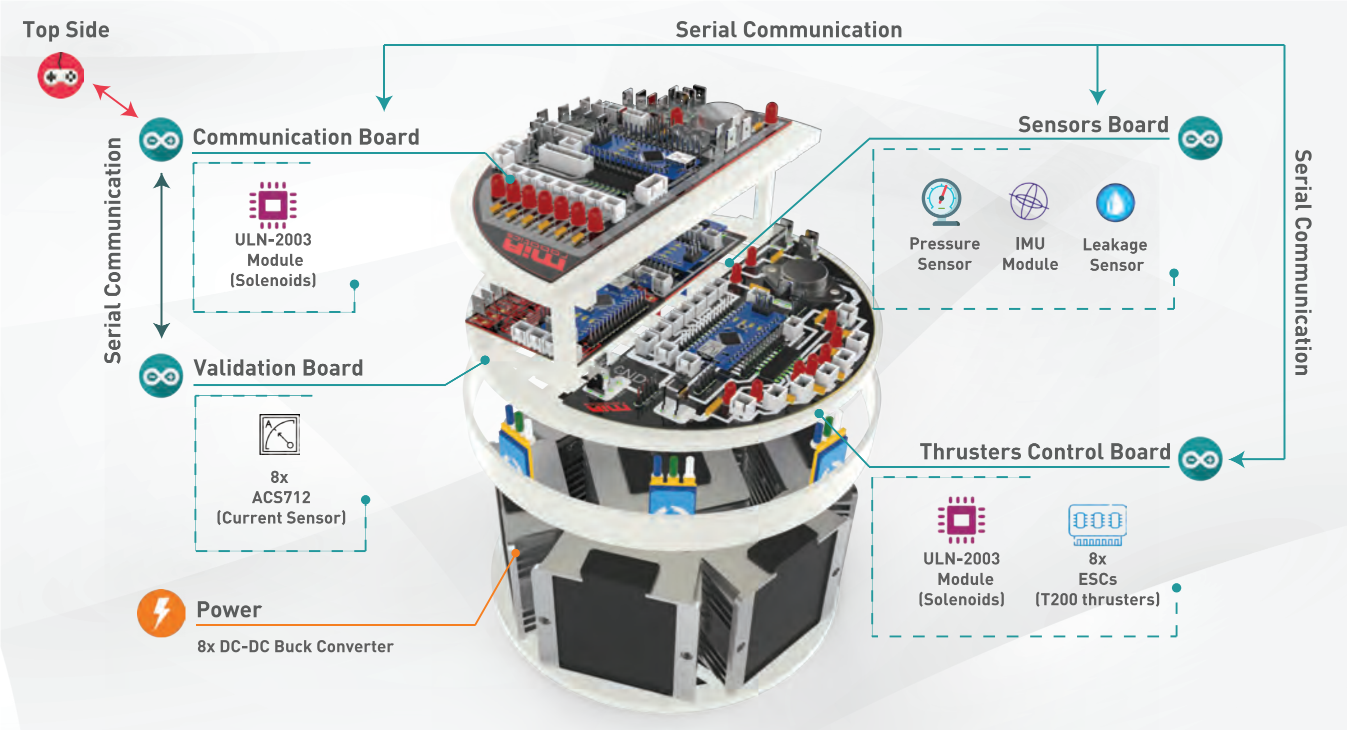
1. One camera is used as the primary vision for the ROV (Main camera).
2. A camera used to achieve a clear view of the 1st gripper (Main gripper).
3. A camera used to achieve a clear view of the 2nd gripper (Sea bin gripper).
4. A camera used to view the three-jaw mechanism.
5. A camera used for the micro-ROV's view.
6. A camera for the Micro-ROV fixation mechanism.
7. A camera for line following and object detection.
8. A camera for the suctioning mechanism.
9. Another camera for the hook mechanism.

Five of those nine cameras are of higher quality due to the importance of their function on Neptune. For example, the main camera, manipulator and tee's camera, double layers camera, object detection camera, and the Micro-ROV's camera.

All cameras have night vision active for clearer and better vision in low-light conditions. They have a focal length of 2.8 mm, 103° angle view, and provide a max resolution of 1080p. The four remaining cameras are used for micro-fixation, the suctioning and hook mechanisms, as well as the three-jaws mechanism. Those plastic cameras have a similar focal length of 2.8 mm but provide a max resolution of 720p.
All cameras are connected to an eight-channel Analog High Definition Digital Video Recorder (AHD DVR) which supports camera resolutions of up to 1080p. The cameras' signals are transmitted to the TCU through a Cat6e ethernet cable terminated by video baluns connected to the DVR for noise reduction and signal amplification. The three ethernet cables (Cat6e) transfer the signal to the station board to be then viewed by the DVR. The top-side laptop can receive the cameras' feed from the DVR and perform the needed image processing on them by connecting them to the DVR wirelessly using routers that are connected to the DVR through an ethernet cable, so the two station laptops can receive the feed over WIFI.



Figure(9): Imaging System



Figure(10): Exploded-View of the Structure

Electronic Housing

After reviewing the printed circuit boards (PCB) designs from the last two years, the team concluded that better space management is critical. Semi-circular-shaped power boards design were proposed to circumvent the issue. The new PCB arrangement focuses on modularity, serviceability, and cable management.

We have five boards:

- Communication Board:

This semi-circular board is responsible for transmitting the signal between the cameras and the tether. Besides having a ULN2003 module that operates the solenoids of the ROV, it is also connected to the remaining boards to enable all sorts of required communications as well as uploading different programs to different boards without having to intervene with the electronic system's hardware.

- Thrusters Board:

This board is connected to the solenoids and the Electronic Speed Controllers (ESC) which control and regulate the speed of the thrusters and transmit the signal from the Arduino to the ESCs. Moreover, it is equipped with a ULN2003 module to control the actuation of the remaining solenoids.

- Validation Board:

This board is connected to eight DC-DC buck converters to give continuous readings of the drawn current using ACS712 ICs to ensure high protection and quick fault diagnosis.

- TCU Board:

Three Cat6e ethernet cables of the tether are connected to this board which is responsible for transferring the signal of the nine cameras to the TCU through the RJ45 connectors that are connected to video baluns to the DVR to ensure the highest video quality. It is also responsible for transferring signals between the GUI and the control center (Communication Board) in the ROV via the main ethernet cable.

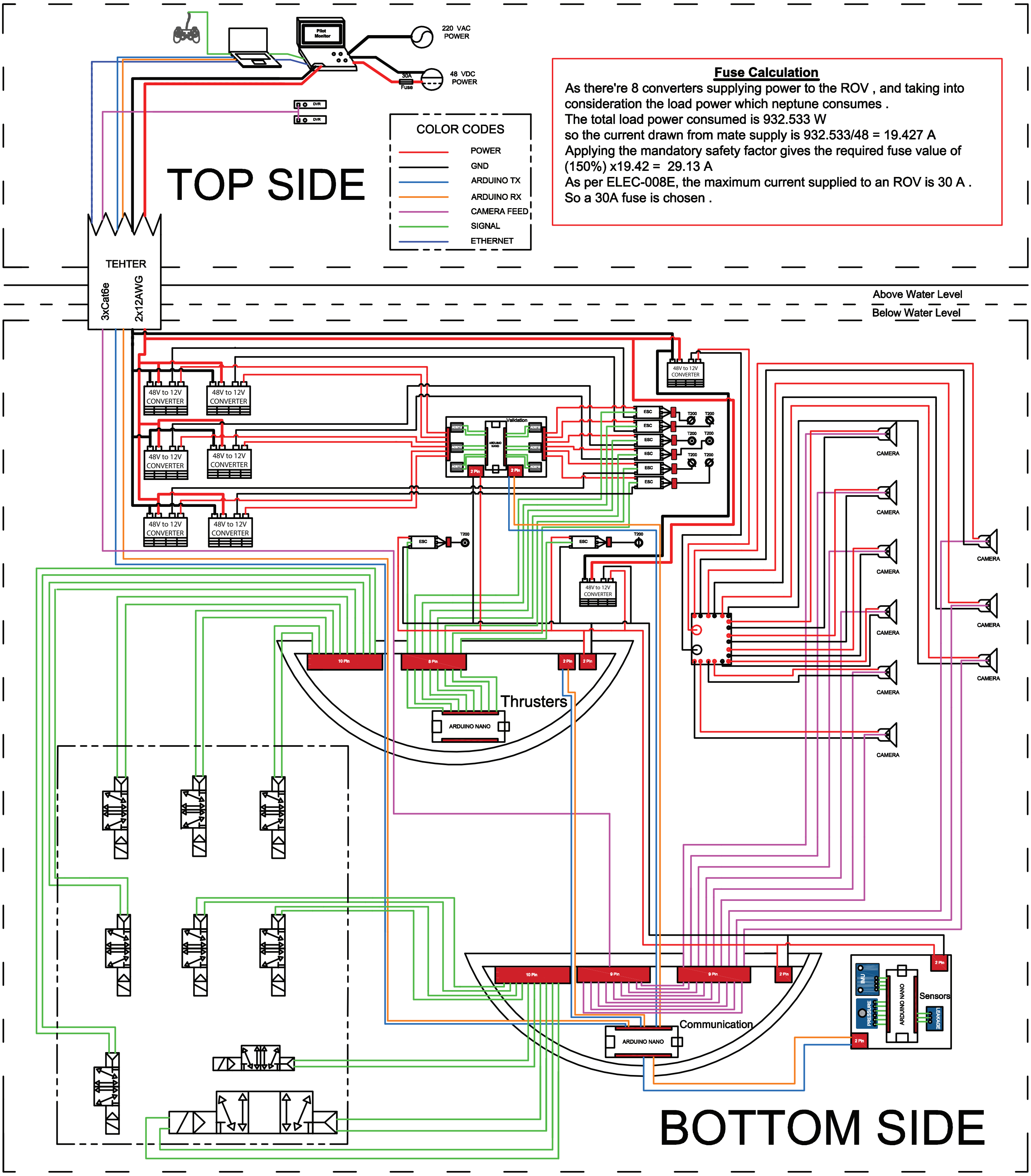
- Sensors Board:

It mainly consists of the pressure and IMU sensors to measure the balance, movement, and rotation of the ROV. Also, a leakage sensor is installed to alert the pilot in case water enters the tube, providing protection against water leaks.

Additional minor board:

- Cameras Board:

This board is used to power the cameras.



Figure(11): SID

Energy Conversion System:
Eight 48-12V built-in DC-DC converters that are fused for safety measures are used for power distribution. Six converters are used to power six thrusters (two vertical and four horizontal thrusters) during their operation. Another converter powers the cameras, and the last one is used to power the boards and the remaining thrusters, one for the micro ROV, and the other one is used for removing plastic pollution "ping-pong balls".

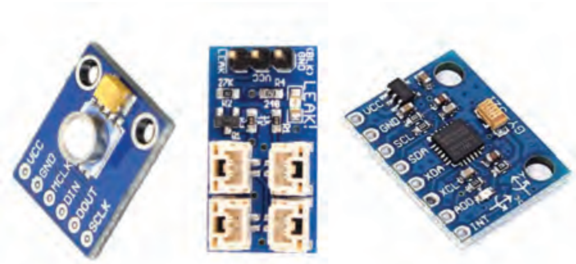
Sensors

A dedicated PCB is added to interface the sensors in the ROV. It is equipped with three different sensors to achieve precise measurements for not only real-time telemetry to implement the PID control but to ensure the safety of the vehicle as well. First, we used an MPU-6050 sensor (IMU sensor) to measure the value of the yaw angle to set the desired angle of rotation around the Z-axis for both high-quality PID control and stability.
Secondly, the MS5540C sensor (pressure sensor) is used for measuring the water depth level. By using the following relation:

$$h = p/\rho g$$

Where: h: height (m), p: pressure (Pa), ρ: density of fluid (kg/m^3), g: gravity (m/s^2).

We can calculate the depth of the ROV to localize its vertical position and use that data to improve the PID model. Third, the SOS Leak Sensor is responsible for the safety of the ROV since whenever a leak occurs in the tube the sensor immediately alerts the pilot through the GUI. The depth telemetry is fed through the Communication Board to be displayed on the GUI, therefore, allowing the pilot to have full control and enabling him to take swift decisions if need be.



Figure(12): Pressure/ Leakage/ IMU

D. SOFTWARE

Top-Side Control Unit (TCU)

One of MIA's major investments this year was Neptune's TCU. It provides a friendly experience with a touchscreen GUI designed specifically to provide intuitive and fast control over ROV crucial functions. The platform also maintains several features such as displaying telemetry from ROV sensors and pilot's joystick actions, a user-friendly command prompt, integrated PID graphing, and constant management. The top-side platform is written entirely in C++ using Qt cross-platform framework to guarantee fast and smooth execution regardless of the operating system.

TCU consists of two GUIs: a Control GUI and a Mission GUI. The Control GUI features a new software architecture that is based on packet communication which allows for asynchronous, event-driven execution, and reduces latency achieving real-time control. The Mission GUI is designed to be a convenient solution for ROV missions (Coral, Mapping, Mosaic, and Calculation); supporting manual and autonomous solutions.

Figure(13): Mission GUI

Serial Managing and Data Handling

Data and commands are transferred between boards as packets starting with an indicator header followed by text information sent over UART. The communication board - which is considered the master board - is responsible for such action as it interprets commands and helps in switching data. It also helps avoid multiple bytes loss as it makes it easier to send, poll, and mirror data losslessly.

Cyclic Redundancy Check (CRC) checksum algorithm is used to make communication more robust and discard or resend faulty-received packets. These functions are translated in software by a "SerialManager" class which enables uploading software on other boards over UART by resetting them to trigger the bootloader and act as a bridge for the data being sent to it from PC. This bridge functionality enables easier debugging on a specific board and the uploading capability saves a lot of time since we can upload and update the code of any specific board without the need to get the ROV out of water or remove a specific board to update its software and reinstalling the board again. Universal Serial Bus (USB) to Universal Asynchronous Receiver and Transmitter module (TTL UART) is used to transfer data back and forth between the TCU and the microcontrollers. It also allows uploading Arduino codes directly without replacing the microcontrollers each time a firmware update is needed.

Figure(14): USB to TTL

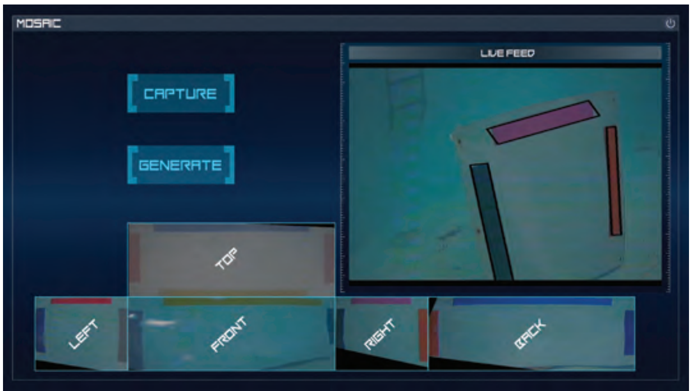
Thrusters Navigation and Validation

Vector-based navigation has been selected for our ROV to ensure the alignment of the motion along the axis of a specific camera view. Precision has also been improved by having all thrusters work continuously and applying opposing moments to achieve zero net motion and moment, making Neptune capable of slightly changing the speeds of specific thrusters to produce steady motion in the desired direction. This improves the response time and provides the capability of having a net speed lower than the minimum speed achievable when running together in a simple configuration. Enabling Neptune to move at any speed and angle in 3D space. For example, it can rotate, move laterally in any angle, upward, and roll all at the same time; achieving a high degree of maneuverability.

E. FEATURES

Mosaic

In this task, Neptune rotates around the cuboid and scans every edge by only taking two snapshots to achieve maximum time efficiency. The next step is to process the snapshots by detecting every color with every edge and mapping these images using designed algorithms to wrap the diagonal images into 2D projections. The resultant projections are the sides of the cuboid that are sorted together using colored edges with the advantage of their relative positions to the original snapshots.



Figure(15): Mosaic

Stitching and Mapping

After trying out several traditional image processing techniques for detecting objects underwater, it was found that the obtained results were unsatisfactory for performing the task; thus, a different approach was taken. By utilizing the YOLOv4 architecture, a custom Deep Learning model was implemented and trained on a dataset of 582 images that were manually captured and annotated.

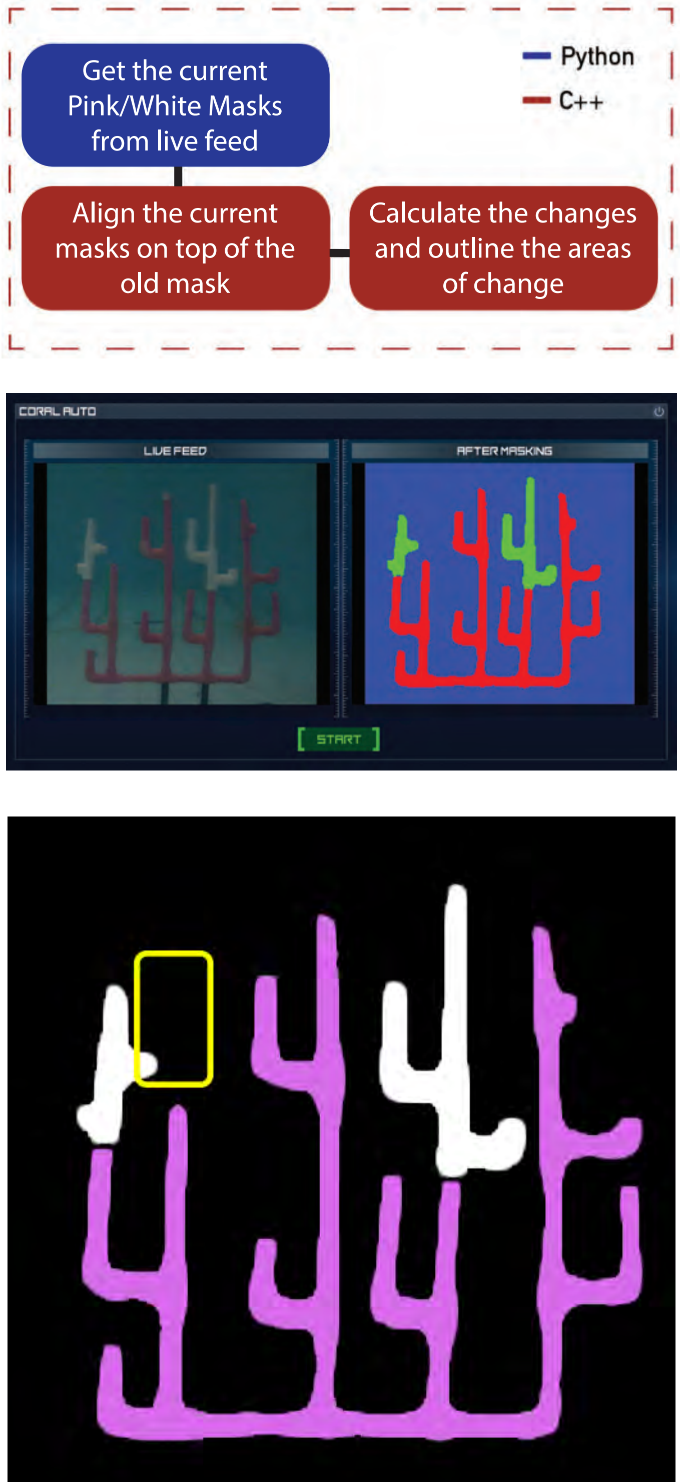
After training the model on 1500 iterations, it successfully reached an accuracy of 92%. To ensure that the task is performed in a time-effective manner, Neptune only passes once over the map to simultaneously line-follow and stitch the whole map into one photo. This was implemented by cropping unneeded spaces from the live feed then stabilizing the ROV with the aid of the PID control. After that, each frame is warped to make sure that we have a clear view of only the transect. The stitched picture is then divided into a row/column scale, where each row is split into three equally divided columns, resulting in the map's translation into a matrix of cells. Each cell is then numbered consecutively from 1 to 27 to facilitate the mapping process. Afterward, each cell is sent to the YOLO model, which in return outputs the class probability of each object. And since the number of the cells is already known from before, it is easy to specify the location of the identified object on the map.

Figure(16): Stitching andMapping

Coral Reef

Instead of depending on regular color segmentation using OpenCV - which proved inefficient in different lighting conditions - we decided to make our software more reliable by utilizing the power of Machine Learning. First, we used a Semantic Segmentation Neural Network, our model is based on the U-NET Architecture. It classifies each pixel in the image into one of three classes (Pink Pipe – White Pipe – Background). We collected and labeled the data, it consists of 950 images with a 20% validation split. The validation accuracy of our model is 87%.

After the predictions are generated on the live feed frames in Python, they are streamed live to a local website using Flask to capture the prediction live feed in C++ in real-time. Afterward, to be able to detect the differences between the old coral colony and the new one, we constructed our own old coral colony masks. So after aligning both the old and new masks on top of each other we can subtract them to detect the differences using logical operations on the mask matrices.



Figure(17): ML Stages, Output Model, and Aligned Masks

P.I.D.

The tasks assigned to the ROV vary from sensitive movements to high-speed maneuvers; therefore, require high accuracy and fast responses. To achieve robust control of the ROV, PID (Proportional, Integral, Derivative) control has been proposed. PID provides a high level of control for performing tasks such as station-keeping, line tracking, maintaining the ROV at a constant depth level, overcoming major issues such as uneven weight distribution of ROV, disparity of propellers performance, system and environmental disturbances.

Figure(18): Control Tab for P.I.D.

Figure(19): Advanced Tab

Sensor Fusion in IMU

IMU is a MEMS (Micro-Electro-Mechanical System) accelerometer and gyroscope sensor that measures and reports Neptune's angular rate, and acceleration (providing a 6 degrees of freedom measurements). It provides the feedback signal to the PID controllers. A major disadvantage of using the IMU is that it typically suffer from accumulated error(from intergrating the outputs) To overcome this issue, embedded DMP (Digital Motion Processor) is used as a Kalman Filter to process and integrate the signals while limiting drifts and noises. The accelerometer and gyroscope readings are fused for ultimate accuracy. Moreover, a head-start PID calibration is applied to get the appropriate accelerometer and gyro constants and a periodic calibration is used for further optimization.

Validation

Drawing from experience, we realized the necessity of monitoring the current consumption of each converter in case of a current drop to avoid any possible failure of the converters. Hence, eight current sensors (ASC712) are placed on a fabricated PCB to measure the current of each converter using Ohm's law:

$$V = IR$$

Where, V: Voltage (V), I: Current Intensity (A), and R: Resistors (Ω)

Measurements of the voltage could be checked as well if needed.

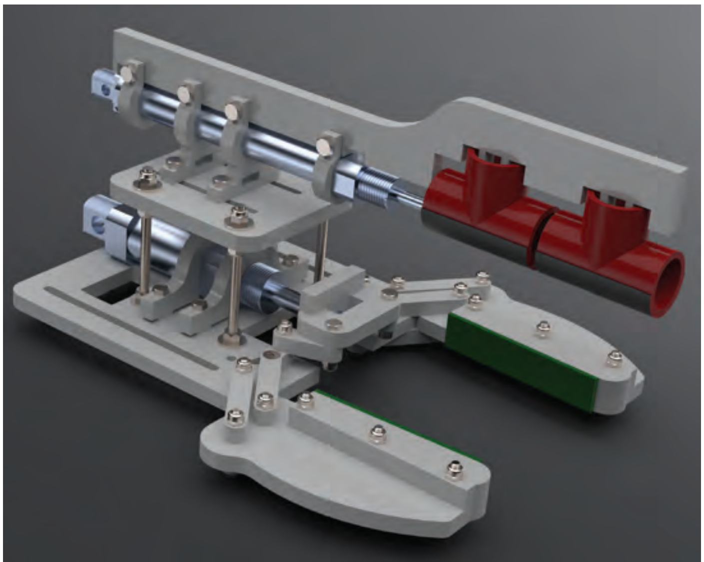
Figure(20): Validation Tab

Leakage Sensor

The SOS Leak Sensor can detect water leaking into improperly sealed watertight enclosures quickly before any major damage can occur. Although the quality of our watertight enclosures is high and a leak is unlikely to occur, the SOS Leak Sensor acts as a secondary shield to ensure the safety of the electronics. The sensor consists of four sponge-tipped probes with an adhesive backing allowing us to monitor all edges of a watertight enclosure, from the penetrators to the front and rear flanges. If a leak is detected, the signal is pulled high to VCC and a bright red LED shines, alerting the pilot with an indication of hazard.

Manipulator and Tee Mechanism

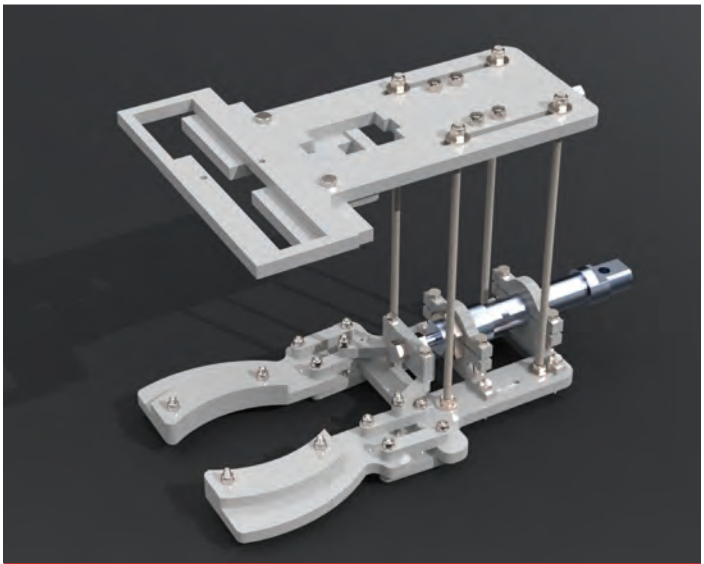
The main gripper is a multi-functional mechanism that allows the ROV to clamp objects underwater.
It acts as an essential hand of the ROV. Pneumatically-actuated 25 mm-diameter piston is used to power the mechanism, which applies a force in a range between (110 and 135 N) forward and backward respectively at 40 psi pressure.
The end effectors were designed to deal with various cross-sectional shape objects and with a capacity to hold up to 100 mm in diameter.
The mechanism design - based on the kinetics - allows the parallel motion of end effectors during the piston action, and provides a large contact area (along the end effector). The attached spacers to the end effectors increase the contact area in the vertical direction in addition to rubber, providing high friction with the required objects. Slots at the main base are used for pilot assistance, providing various positions of the gripper.
The gripper was fabricated out of 8mm high-density polyethylene (HDPE) using a CNC router cutting machine.
The Tee mechanism is a lightweight, quick, and precise tool for releasing two T-shape PVC (½ inch) with Velcro on the sea stars, pneumatically actuated by a piston with a 5/3 solenoid valve. This provides the precision it needs as the piston rod takes even sliding steps to allow releasing. It's positioned above the main manipulator to give the releasing operation more adjusting and accuracy to Velcro targeting.



Figure(21): Manipulator

Double Layers Mechanism

For the ocean cleanup mission, disconnecting and reconnecting the power are the most important procedures for a successfully working Seabin. In order to accomplish the task, the team designed a mechanism consisting of two parts: an upper releaser and a lower gripper, both are pneumatically actuated. The lower gripper holds the power connector port with its circular end effector. Hence, it works as a guide for the upper one; for precise operation with minimum time. Then, the upper releaser, which is designed based on the power connector dimensions, can easily catch and release it. This mechanism assembly is better in operation compared to other suggested alternatives as it accomplishes the mission whether the Seabin is stable in water or not.



Figure(22): Double Layers Mechanism

Three-Jaw Mechanism

For best control and good accuracy during the missions that need to be observed from the plane view, the three-jaw gripper was designed. It is mounted perpendicular to the main base in contradistinction to the other grippers of the ROV.
It is used mainly to hold the coral fragment and the sponge, and has been designed to have three jaws to maintain the coral fragment fixed vertically in position so it could be easily released at the designated areas.
The gripper is pneumatically actuated with a 25mm diameter piston and 25mm stroke length.
The end effectors are multi-tasking and allow a

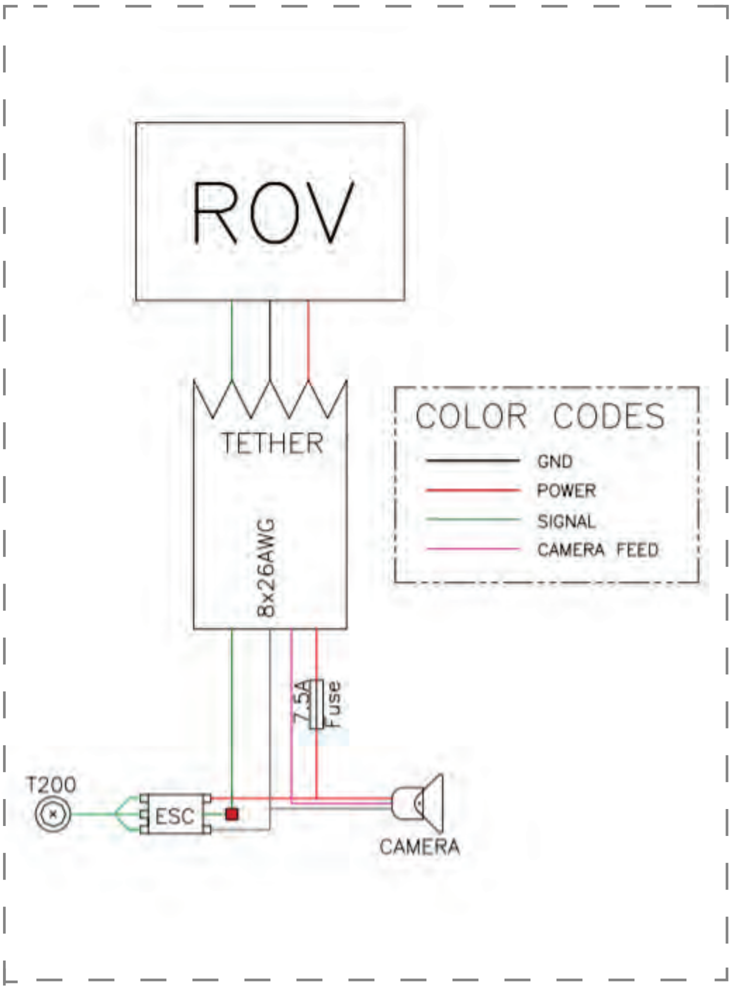
parallel motion for better contact with the required object.
They have a shape of non-coplanar arcs and were enhanced by adding a rubber layer which aims to ensure that the coral fragment is well locked.
The lower region of the end effector is used to get the sponge. Although the end effector was synthesized mainly for coral fragments and the sponge, the ROV could achieve other tasks. HDPE was used in the manufacturing process of this mechanism.

Figure(23): Three Jaw Mechanism

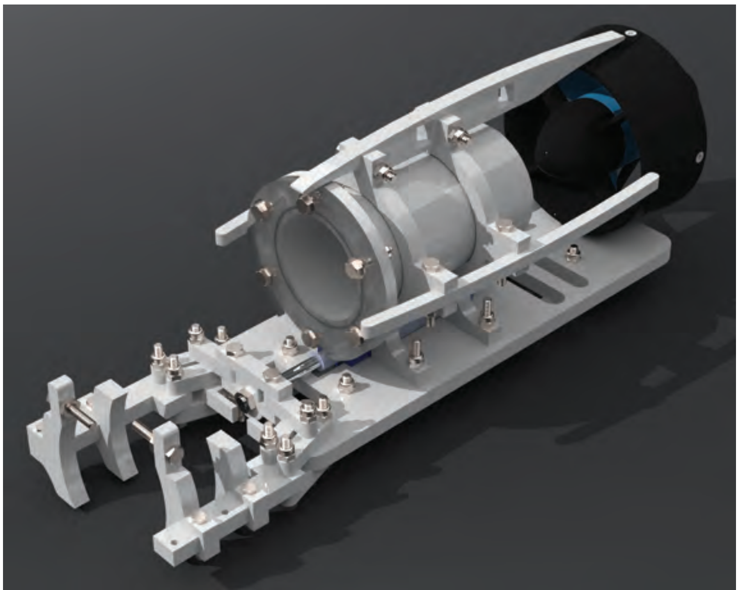
Micro-ROV

For pipe inspection and retrieving sediment samples purposes, Neptune is equipped with a micro-ROV. It consists of the main body, camera and electric control system enclosure, a single T200 thruster, and a pneumatically-actuated gripper. The main body is designed to minimize drag to facilitate the micro-ROV movement in the Corex drain pipe since the sides' streamlines are similar to those of water. The camera has a night vision feature; due to low light levels inside the Corex drain pipe. The T200 thruster provides the micro-ROV with the needed propulsion and speed. And the pneumatically actuated gripper is designed with a circular end effector that allows catching the sample no matter its size. The micro-ROV is intended to be as small and compact as possible.
The micro ROV is powered from the main ROV with a fuse of 7.5A attached to the point of connection to the ROV power by applying the same software constrictions that limit the power consumption of the T200 thruster to 78W only.

In material terms, it was agreed to develop a software system that enables controlling both ROVs using a single joystick to help in conserving resources and increasing both portability and speed.



Figure(24): Micro-ROV SID



Figure(25): Micro-ROV

Hook Mechanism

The hook is responsible for catching the mesh's bags instead of grippers, since they are placed in the lower half center. It is pneumatically-actuated double acting piston of 15mm Φ and 4mm stroke.

Figure(26): Hook Mechanism

3.TESTING AND TROUBLESHOOTING

Neptune's systems are designed in a modular way that makes troubleshooting much easier. To begin with, during the very first steps while designing the PCBs we always ensured to have spare connections and parts such as the sensors and the power sources; enhancing the flexibility of our designs and providing an alternative to any unexpected failure in the components. In addition, implementing the Validation PCB aided us in this regard in various ways by updating us with the consumed current by each of the thrusters to know if a problem is encountered as well as if each thruster receives the required power to operate well. Then we have the troubleshooting process which starts by initiating small test runs until the root problem is located by eliminating the other elements and isolating the faulty module. The module is then unit-tested to diagnose the error and to assign a suitable solution for it.

The tests began by performing a dry test on Neptune's basic functionalities which were followed by placing the vehicle into a practice pool to test its underwater capabilities. Afterwards, Neptune's performance and stability assessment in completing the missions took place. Throughout the testing phase, modifications never stopped to increase Neptune's efficiency in completing the tasks. The main advantage of long duration tests is the ability to discover hidden problems that would not emerge otherwise. Stated below are the strategies followed to test every subsection of the vehicle before it was assembled.

ELECTRONICS ENCLOSURE SEALING TEST

This test aims to ensure that the electronic enclosure sealing is perfect even in a very high-pressure head range compared to the maximum pressure head ROV may reach in the competition. The test starts by filling the electronics enclosure with water and increasing pressure gradually using a hydrostatic pressure test unit until 2.5 bars pressure is reached since this pressure is optimal for our test as it means that our ROV could operate in a pressure head of 25 meters of water which is a high-pressure head compared to the maximum pressure head in the competition of 5 meters of water.

GRIPPER TEST

Optimizing the gripper mechanism was a tedious and laborious task, requiring a lot of designs and tests. Our goal is to maximize the gripper efficiency while minimizing power losses due to friction or any other form of power loss. Therefore, our company prototyped the gripper to analyze any malfunctions that may occur and devised solutions beforehand. As a result, we noticed that the piston stroke was not suitable enough to hold objects tightly, the friction between links was relatively large and that the end effector surface finish was smooth. Accordingly, our approach to fixing these issues was by increasing piston diameter and stroke to overcome the friction losses and adding a rubber layer to provide more friction for a better grip.

PNEUMATIC SYSTEM TEST

The team put great attention to ensure proper connectivity regarding pneumatic circuits by testing them several times to enhance the safety and performance of the pneumatic system.

ELECTRICAL TEST

Our main concern was the stability of Neptune's electrical system. We had to make sure that the voltage converters can supply stable power to the system even under full load. Our tests showed that the main power-hungry components were the thrusters, each drawing over 9A under full load. Because of their high power consumption, and the fact that we are using eight of them, the thrusters had to be distributed such that each thruster is connected to a separate DC-DC buck converter that could deliver up to 20A.

4.CHALLENGES

TECHNICAL

▪ Memory Optimization

The received command from the topside (serial communication) was in string format, which allocates larger space from the microcontroller's memory, hence, some readings were lost. In order to eliminate this issue, we used macros for some strings to save space in dynamic memory, excluded the concatenated strings, and used other types for the commands.

▪ Reliable Imaging System

The Signal to Noise Ratio (SNR) in cameras in the previous years needed to be improved, especially because this year there are nine cameras used. In this case, we designed a TCU board that takes the three Cat6e cables as inputs through the RJ45 socket and connects them to video baluns to increase the SNR and achieve the desired stability in addition to switching between two cameras instead of using an extra DVR.

▪ Material Selection

The 5083-Aluminum alloy was selected due to its high qualifications. It is the first time for M.I.A. company to use a non-ferrous metal alloy in the fabrication of its ROVs. The use of 5083-Aluminum alloy improved the strength and build quality of the ROV.

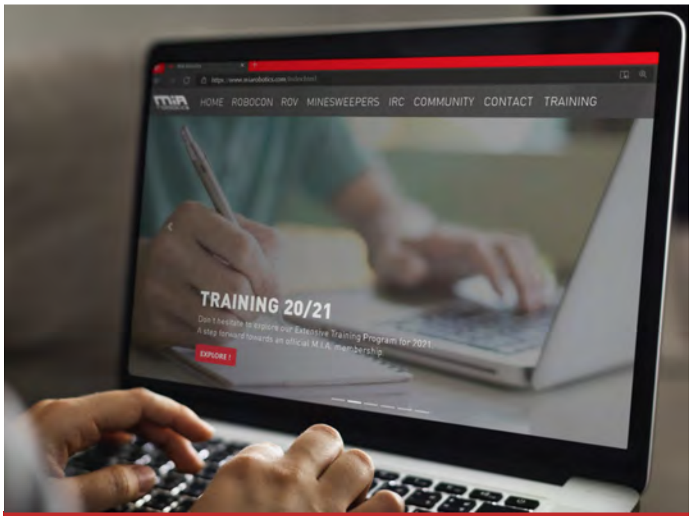
NON-TECHNICAL

The spread of the COVID-19 pandemic was an unprecedented crisis. For this reason, the company managed to organize the work to guarantee a safe environment. To limit the number of individuals in the workshop at any given time, the employees were divided into groups, and each group was assigned to finish specific tasks on-site for a specific period in the timeline. Also, groups were working online as coding and designing Neptune's parts and mechanisms. This methodology assured good performance, maintaining the work progress according to the timeline. Furthermore, one of the major challenges was funding. To overcome this issue, the company started reaching out to local organizations for financial aid.

5.LESSONS LEARNED

During the COVID-19 pandemic, the company took the advantage of its time in advancing its knowledge. Many global platforms offered online courses for free (e.g., Udacity, Udemy, Coursera, etc). This opportunity pushed the members to learn new technical skills, gain more experience and develop their mindset.

Believing in the value of sharing, M.I.A. recorded playlists discussing different topics such as programming in C++, hardware basics and advanced topics, SolidWorks, and fluid power. Since the world is steered by a different perspective in transferring knowledge, the company developed its own website and youtube channel to spread its experience.



Figure(27): Company's Online Sessions

6.FUTURE IMPROVEMENTS

STM MICROCONTROLLERS

Compared to Arduino (AVR-based architecture), STM (ARM-based architecture) is much more powerful. The clock frequency is 4.5 times faster, the number of hardware-serial pins is 3 times higher, and it is the same price as the Arduino. Based on these reasons, the company intends to switch to STM.

HIGH LEVEL CONTROL SYSTEM

The company achieved one of its targets which was PID Control implementation; however, it's considered a milestone. We aim to implement a higher level of control for path planning and the ability to dynamically load and execute new mission scripts based upon commands.

MORE EFFICIENT CONVERSION SYSTEM

Using DC-DC Buck converters with higher rated voltage and current at the output means using fewer of them. This reduction in converters number will lead to a smaller tube, less weight as well as harnessing the full power of the T200 thrusters.

7.SAFETY

COMPANY SAFETY PHILOSOPHY

At M.I.A. Robotics, we believe a safe workspace is crucial to produce a suitable environment to design, manufacture, and test. We always strive to meet MATE's safety requirements by ensuring all MIA personal adhere to the safety protocolsand warning labels. Our safety philosophy is centred around the welfare of the crew and always putting the employee's safety before the machine. In order to comply with MATE's safety regulations, a set of workplace guidelines and protocols are carried out during manufacturing and prelaunch. Appendix I.

LAB PROTOCOLS

At the beginning of each year, senior employees mentor juniors on how to use tools and machinery and how to replace worn out parts in case of damage. All crew members are committed to following lab protocols set by senior team members. Wearing protective clothing, safety goggles, and appropriate non-slip shoes is essential during operation. In addition to this, periodic safety checks are performed before deploying the vehicle in the water.

SAFETY PROTOCOLS STANDARDS

- Assigning proper PPE and avoiding actions that carry a potential for injury.
- Inspecting equipment prior to use.
- Using proper technique when using any sharp tools.
- Using vice of proper size and capacity to hold work objects.
- Using a barrier around a piece of equipment being pressure tested.
- Stop work when an unsafe condition or act could occur during operation; if in doubt, stop the job.
- Using insulated electrical tools including insulated fuse pullers, hand tools, and drills.

- Before working on any electrical equipment, it must be de-energized.
- Systematic safety checks are performed before every test.

SAFETY FEATURES

As required by the MATE Organization, a suitable-sized fuse is connected 30 cm from the Anderson Power-pole connectors. Strain-relief is applied to the tether on both ends to prevent strain on the connectors and to ensure uninterrupted connections. 3D printed shrouds cover the thrusters' intake and exhaust without disrupting flow. Kill-switches are present on the main power supply unit on the TCU. Power terminals are fused to provide overcurrent protection. Moreover, fuses are strategically placed on the power boards for quick debugging and replacement. The electronics housing, thrusters, and cameras are waterproofed to prevent short circuits or exposing personnel to any danger. Warning labels exist on the thrusters and electronics housing. The camera compartment is physically isolated from the electronics housing with the use of O-rings. The clear acrylic dome housing the camera allows for visual inspection in case of any leaks by searching for water droplets.

8.PROJECT MANAGEMENT

The company is organized into three main departments: Mechanical, Electrical, and Software. All team leads meet daily to discuss progress and propose changes to the designs according to how well they perform on the tests. Weekly company-wide meetings take place to brainstorm new ideas and set deadlines for the week after. Employees are assigned technical and non-technical roles to maximize productivity.

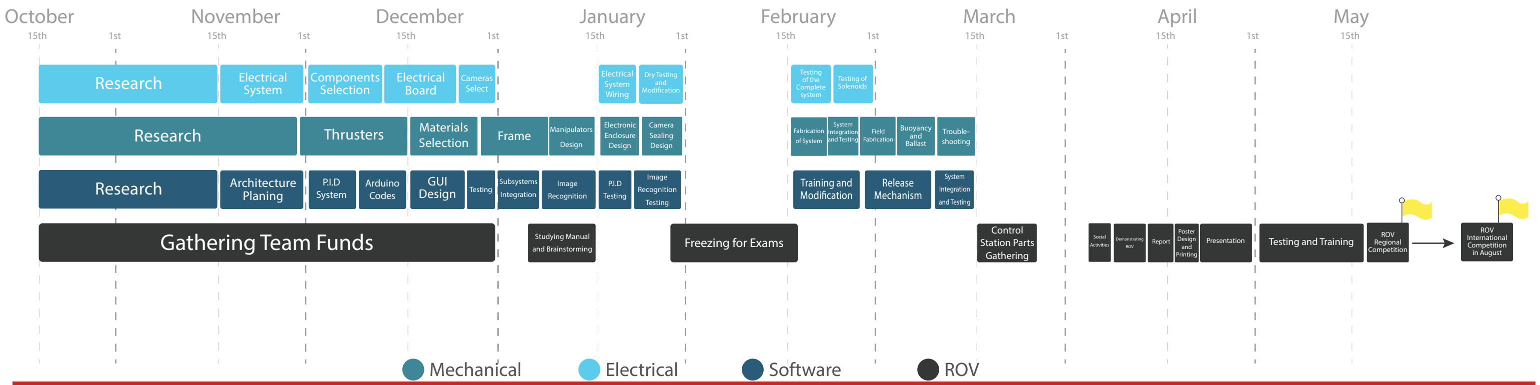
Before starting this year, a two-week training program took place in mid-September to train junior employees the basics of C/C++ programming languages, electronics, manufacturing methods, Computer-Aided Design, and fluid simulation. After each training session, junior employees were tasked with assignments for performance assessment purposes. The results of these assessments determined the strength points of each employee which later helped the board members assign specialities to the right candidates.

SCHEDULED PROJECT MANAGEMENT

Believing in time management, the company put a strategy to assign milestones periodically. With the guidance of experienced company mentors, a timeline was laid down to schedule work in real-time.
Following the detailed timeline, the company set sails by allotting the first month of work into Research and Development (R&D). Being aware of the impact of exceeding any deadlines on other departments, company employees worked hard to meet delivery dates.

Company Timeline

October, 2020 to May, 2021



Figure(28): Company's Timeline

ONLINE COLLABORATION

Online collaboration played a major role in delegating and distributing tasks, allowing company employees to work from home and increase productivity. Compared to other offline desktop-based solutions, Google Docs proved to be the better platform for writing the technical documentation. Its features like revision history and commentary allowed employees to author the file collaboratively and allowed department leads to propose changes and track progress. Google Sheets allowed the company CEO and CFO to update the cost sheet simultaneously and was used to track expenditures and consequently adjust spending.

For it is widely adopted by industry professionals, GitHub was used by the software department as the main Version Control System. It allows managing the main Version Control System. It allows managing code and ensures organized parallel software development. GitHub allows reverting to previous versions which can be useful if a problem arose. Moreover, software employees were responsible for committing messages every time a code update is made to inform their colleagues about these changes.

9.REFLECTIONS

Ahmed Nour

CTO 2018-19

" Participating in this competition for three years had a great impact on my decision-making skills. It taught me to pay attention to the finest of details, consider all of the available options, and that there is always a simple solution to any problem. "

Sherif Ashraf

CEO 2018-19

" This team was an opportunity to grow and explore. It helped me not just in improving my technical skills, but also in enhancing my soft skills. I consider it the best way to invest college time and a vibrant experience to deeply learn engineering. "

Abdelrhman Hisham

CEO 2019-20

" Leading the team towards professionalism was not an easy task, but it was what should be meant. This was the team's goal from day one and my priority as well. Working so hard to reach that target was a great journey where I enjoyed each step and each challenge we faced to stand proudly afterwards and confidently say that we belong to M.I.A. Robotics Team. "

Karim Refaei

CFO and Mechanical Lead 2019-20

" It was a great honour to participate in MATE ROV Competition, to be one of the M.I.A. Robotics Team's leaders. It was worth getting through all these milestones that developed my personality and my technical skills. All these graved memories and experiences could never exist without this team. "

Abdullah Salah

Competition Lead 2019-20

" I participated in the MATE ROV Competition for three years and I can definitely avow that there's nothing better than learning by experience. It gives the power to think outside the box, to analyze and to have good problem solving skills. This phase of my life shaped me to who I am today. "

10.ACKNOWLEDGEMENTS

- MATE Center for sponsoring this year's competition and for their generous awards.
- Hadath organization for organizing the local and regional competitions.
- Arab Academy for Science and Technology (AAST) for hosting the regional competition.
- Alexandria Fertilizers Company - For making their workshops available for fabrication.
- Team supervisor: Prof. Dr./ Hassan Warda.

MATE Center

Hadath Organization

AAST

Alexandria Fertilizers

Figure(29): Organizations' Logos

11.REFERENCES

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- J. Sahili, A. E. Hamoud and A. Jammoul, "ROV Design Optimization: Effect on Stability and Drag force,"
- Blue Robotics store *(www.bluerobotics.com)*
- Qt documentation *(https://doc.qt.io/)*
- OpenCV documentation *(https://docs.opencv.org/3.4.5/)*
- Tensorflow documentation *(https://www.tensorflow.org/api_docs)*

12.APPENDICES

SAFETY CHECKLIST

Pre-Power Test

- Area clear/safe (no tripping hazards, items in the way).
- Verify power switches and circuit breakers on TCU are off.
- Tether flaked out on deck.
- Tether connected to TCU and secured.
- Tether connected and secured to ROV.
- Tether strain relief connected to ROV.
- Electronics housing sealed.
- Visual inspection of electronics for damaged wires, loose connection.
- Nuts tight on electronics housing.
- Thrusters free from obstructions.
- Set compressor output to 2.75 bar.
- Power source connected to TCU.
- TCU receiving 48 Volts nominal.
- Control computers up and running.
- Ensure deck crew members are attentive.
- Power on TCU.
- Perform thruster test/verify thrusters are working properly (joystick movements correspond with thruster activity).
- Verify video feeds.
- ROV lights indicate "Safe Mode" (green).
- Test accessories.

In Water

- Check for bubbles.
- Visually inspect for water leaks.
- If there are large bubbles, pull to surface immediately.
- Engage thrusters and begin operations.

Loss of Communication

- Cycle power on TCU to reboot ROV.
- If no communication, power down ROV, retrieve via tether.
- If communication restored, confirm there are no leaks, resume operations.

Pit Maintenance

- Verify thrusters are free of foreign objects and spin freely.
- Visual inspection for any damage.
- All cables are neatly secured.
- Verify tether is free of kinks.
- Visual inspection for leaks.
- Test onboard tools.
- Verify camera positions.
- Washdown thrusters with deionized water.

Fig(30): Shrouded Thrusters

POWER BUDGET

Components	Quantity	Voltage (V)	Current (I)	Power/Component (W)	Total Power (W)
T200 Thruster (Main ROV)	6	12	10	120	720
T200 Thruster (Mechanism)	1	12	5	60	60
Basic ESC	7	12	0.3	3.6	25.2
Arduino Nano	4	12	0.2	2.4	9.6
Solenoid	9	12	0.2	2.4	9.6
IMU Sensor	1	5	0.01	0.05	0.05
Pressure Sensor	1	5	0.01	0.05	0.05
Leakage Sensor	1	3.3	0.01	0.033	0.033
Camera	8	12	0.3	3.6	28.8
Micro ROV	1	12	7.1	85.2	85.2

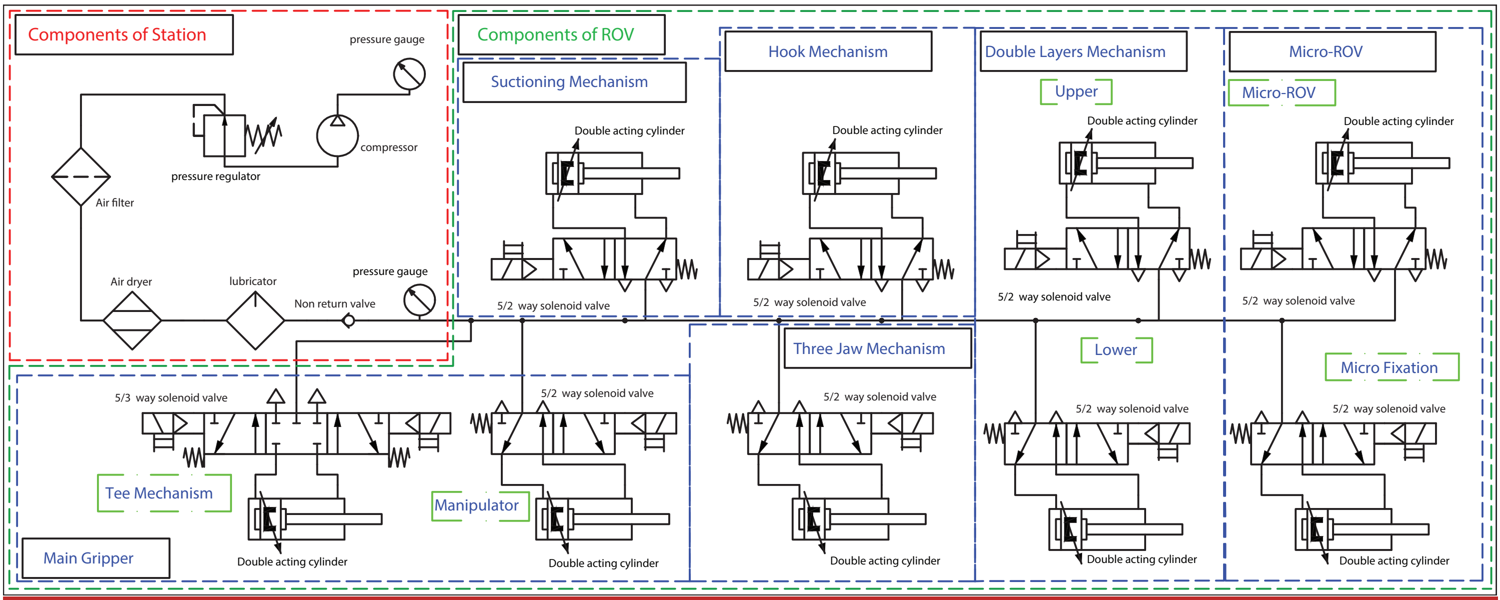
Total Power Consumption = 938.533 W
Current drawn from MATE Power Supply = 938.533/48 = 19.553 A
Fuse value = (150%) x19.553= 29.33A ≈ 30 A

MICRO ROV

Components	Quantity	Voltage (V)	Current (I)	Power/Component (W)	Total Power (W)
BlueRobotics Thruster (T200)	1	12	6.5	78	78
Basic ESC	1	12	0.3	3.6	3.6
Camera	1	12	0.3	3.6	3.6

Total Power Consumption = 85.2 W
Current Drawn from the ROV = 7.1 A
Fuse Value = 7.5 A

PNEUMATIC SID



Figure(31): Pneumatic SID

BUDGET

Source	Income ($)	Type			
Self-fund	3800	Income			
Alexandria Fertilizers	335	Machining (Lathe)			
Thrusters T200	1120	Re-used Items			
Total	5255				
Production Expenses	Budget ($)	Type	Description	Cost ($)	Difference ($)
Fabrication	340	Production	CNC, Lathe	331.36	8.64
Electrical components	200	Production	Arduino Nano, UART	184.8	15.2
Vision system	330	Production	Digital Video Recorder, Cameras, Baluns	357.22	-27.22
Pneumatic system	325	Production	Solenoids, fittings, tubes	297.77	27.23
Materials	260	Production	Acrylic, Artelon, aluminium 5083	229.4	30.6
Tether	135	Production	Sheathing, Cat6, AWG-16	105.55	29.45
TCU	275	Production	Joystick, LCD, Hardcase, valves, fittings	254.89	20.11
Miscellaneous costs	115	Production	Epoxy, heatshrink, strain-relief, zip-ties	90	25
Electronics	25	Production	PCB fabrication	30.15	-5.15
Micro-ROV	130	Production	Pneumatic system, bilge pump, wheels	93.6	36.4
Total	2135		Total	1974.74	104.01
Operation Expenses	Budget ($)	Type	Description	Cost ($)	Difference ($)
Mission props	155.55	Production materials	MATE mission props	138.88	16.67
Registration	400	MATE entry fee	Regional & International registration	400	0
Printings	85	Media production	Banner, Poster, Flyers, Business Cards	72.77	12.23
Fluid Power quiz	15			15	0
Total	655.55		Total	626.65	28.9
Capital Expenses	Budget ($)	Type	Description	Cost ($)	Difference ($)
Compressor	75	Upgrade	25-Liter compressor unit	69.44	5.56
Tools	50	Maintenance	Ratchet, screwdri vers, wrenches	61.15	-11.15
Electrical tools	50	Maintenance	Hot-air gun, soldering station	32.5	17.15
Total	175		Total	163.09	11.56
Total Budget and Cost ($)	Project Cost ($)	Difference ($)			
Income	3800				
Production Expenses	-1974.74	104.01			
Operation Expenses	-626.65	28.9			
Capital Expenses	-163.09	11.56			
Available Funds	1035.52				