Robo-Tech Rangers

Technical Documentation

MATE International ROV Competition 2021

Members	Roles
John Youssef	CEO | Pilot
John Gaied	Co-Pilot | Electrical Head
Peter Emeel	Mechanical Head
Phoebe Atta	CFO | CFD Engineer
Abanoub Bakhoum	Design Engineer
Abanoub Hanna	Mechanical Engineer
Michael Ibrahim	Mechanical Engineer
Felopatir Shenouda	Mechanical Engineer
Mina Atta	Hardware Engineer
Rober Gad	Software Engineer
Matthew Abdelmalek	Computer Vision Engineer

Mentors

Karim Karousa
Rahma Mohamed
Ahmed Ibrahim
Mohamed Waheeb

Alexandria, Egypt

I. Introduction

Abstract

Master Oogway is the fourth consecutive Remotely Operated Vehicle (ROV) established by ROBO-TECH Rangers' team. This year, our vehicle was set up to meet the requirements of the proposal requests from oceans and the aquatic life in general, performing various insecure subaqueous tasks for man. For instance, it aids in water decontamination by removing debris and plastics, in addition to replacing mid-water seabins. Moreover, it intelligently contributes in resolving negative climate change impacts on coral reefs, and maintaining healthy waterways. For achieving the desired functionalities, ROBO-TECH team designed the vehicle with a specialized flexible configuration, tailored to its missions' specifications, and able to adapt to multiple tasks. Our company's primary target was to design an ROV featured by a smooth maneuver, reasonable budget and proficiency, concurrently meeting size and weight restrictions. Oogway's propulsion system relies on 6 thrusters, placed with an array that permits the vehicle to utilize 5 degrees of motion. Polyurethane was used as the main design structure, besides some customized aluminum parts. It comes equipped with two claws seizing both axis so as to perform numerous missions and grab a diverse range of objects. To add, surface mounted is a micro non-ROV device with a mounted camera and gripper, launched to pick sediment samples and check for contaminants. Our solution is an efficient and practical one that will reliably do the job. The entire development period of Oogway encompasses 140 days, performed by a group of eleven eager engineers, passionate to assist their planet.

Figure 1. Master Oogway

Figure2. ROBO-TECH Team Members

II. Table of Contents

III. Design Rationale

Mechanical System

1. Design Evolution

Being the 4th year to consecutively participate in MATE ROV Rangers' class, our engineers enthusiastically tend to enhance the ROVs. As shown in (fig 3.), each year we develop our system and overall design according to the desired functionalities and to meet new challenges in the ROVs' world, avoiding previous flaws.

Figure 3. Design Evolution by ROBO-TECH Rangers Through 4 Years

2. Design Process

During designing process, the prior aim and concurrent challenge was to design a lightweight ROV with a compact size that can fit in a 60 cm diameter circle. Taking into consideration its agility and maneuverability, in addition to the available fabrication methods. So as to achieve this, three phases were to be passed:

2.1. Brainstorming phase

To begin, each mechanical member drew several sketches independently, discussing them with other engineers, and editing the designs till finally reaching the desired one. The final choice was based on the theoretical functionality.

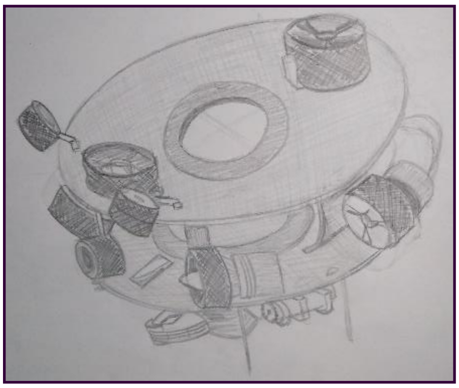


Figure 4. Free Hand Sketch

2.2. Decision-making Phase

After numerous discussions, we made up our minds and chose the design shown in (Fig 4.). The sketch was then sent to the electrical department to exchange notes from both ends till reaching the final layout.

2.3. Designing Phase

After taking all requirements into consideration, work on the mechanical design began. A fledged CAD model was created using SolidWorks®, creating a solid model and assembly of Master Oogway. Our engineers also used ANSYS® for the simulations and computational fluid dynamics, besides calculating several physical quantities such as drag and lift coefficients. Finally, AutoCAD® for preparing final files for parts to be cut.

3. Mechanical Structure

Setting the ease of assembly and the lightness of weight as priorities, the company mechanical department has designed Oogway, shown in (Fig 5.), totally fitting 60 cm diameter circle, as illustrated in (Fig 6.), to be light, efficient and easy to be composed of as few parts as possible.

Figure 5. CAD Model of Master Oogway

Figure 6. 2D Sketch of the ROV

3.1. Main Plates

Oogway's plates are considered the most critical parts of the whole structure, as they are the main fixation point to all other components. The upper plate holds the vertical thrusters and cameras, meanwhile the lower plate carries a manual slider where the grippers and the micro-ROV are mounted. This slider also allows the ROV to remain in size during measurement. The reason behind the oval shape owes back to the lower drag forces, and the fact that they are perforated is to reduce water resistance while in heave motion.

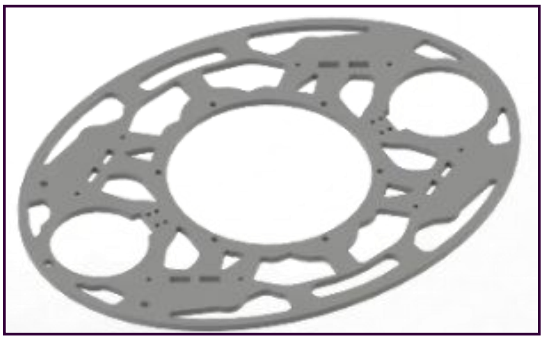


Figure 7. Upper Plate

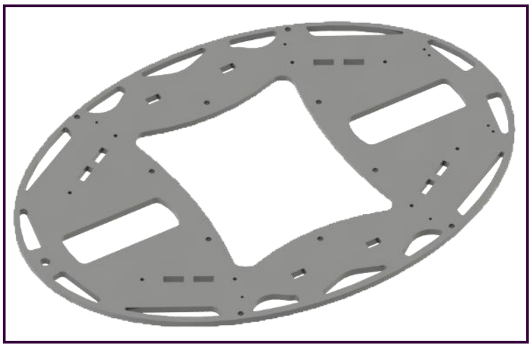


Figure 8. Lower Plate

3.2. The Connecting Tube and Plates

Instead of designing special ways for connecting the two plates, an advantage was taken of the electronics housing as a main connection point. And for support, four vertical poles were mounted, which were also used for installing the horizontal thrusters.

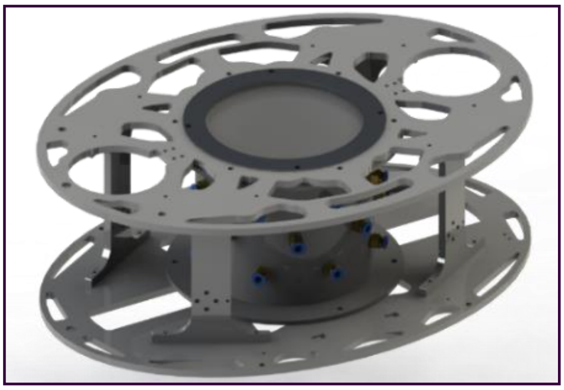


Figure 9. Oogway's Main Structure

3.3. Rods

Oogway has four stainless-steel 10 mm diameter rods emerging from the lower plate, acting as a main support for the ROV while on ground. The material was preferred based on its sturdiness and rust resistance.

3.4. Material Selection

Polyurethane was chosen as the main structure material for its superior mechanical and physical properties relative to other available materials. As it is lightweight, durable, relatively cheap and easy to fabricate. We took our designs to the next stage using CNC routing, laser cutting and lathing methods.

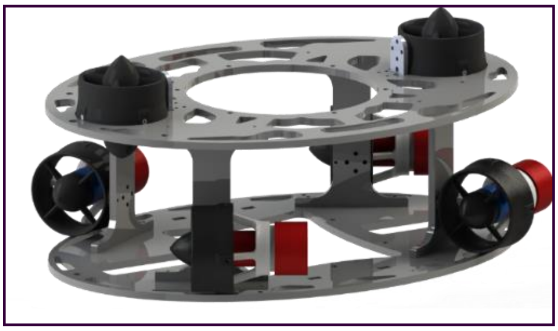


Figure 10. Oogway's Thrusters' Configuration

3.5. Thrusters and Propulsion System

Throughout our journey to build a cheap and an efficient ROV, our engineers realized that a full dependence on T100 Blue Robotics thrusters seemed to be out of budget. Consequently, we decided to hack bilge pumps by applying the T100 thrusters' propellers and kort nozzles using 3D printed parts designed by our mechanical members, leading to a smoother flow streamlined through the propellers.

Oogway's propulsion system relies on six thrusters, two T100 Blue Robotics thrusters mounted vertically on the upper plate of the body allowing Master Oogway to heave and pitch. Meanwhile the four modified bilge pumps are fixed on the vertical poles connecting the upper and the lower plates. They were constrained with an angle of 30° to 60° to achieve the best forward and backward thrust. The motors are also

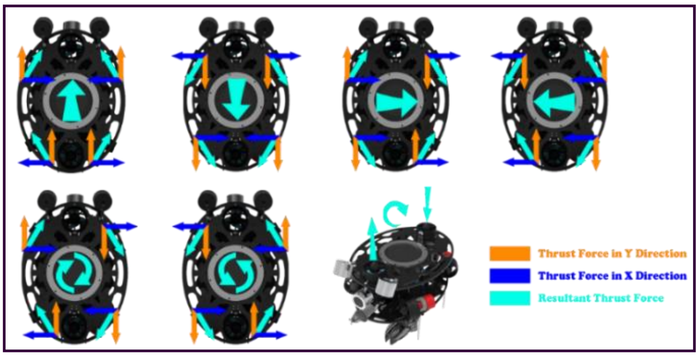


Figure 11. Oogway's Degrees of Motion Analysis

further away from each others to maintain the best moment for a better spin, allowing our ROV to seize five degrees of freedom as analyzed in (Fig 11.)

3.6. Sealing

The housing's layered sealing consists of an acrylic plate for transparency, above of which is fixed an aluminum end-cap to reduce the pressure on the acrylic and eliminate any deflections. Most importantly are the two O-rings which are set in their specified grooves, then pressed by fastening the plates tight to prevent water leakage. As for the cables sealing, pneumatic quick fittings were used to secure the cable in place and cut the leakage securely by inserting the cables into the pneumatic tubes and mount the tubes to the fittings, then the fittings are fastened to the electronics housing by a specific thread with applying Teflon tape to the fitting thread.

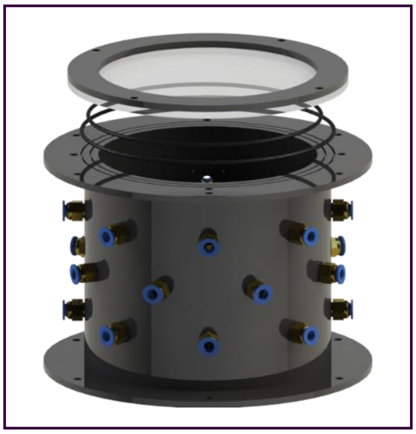


Figure 12. Electronics' Housing

3.7. Cameras

3.7.1. Cameras' Arrangement

Master Oogway utilizes four Cameras, some of which are featured by flexible positioning, hence providing the pilot a vast field of view. Arranged as follows:

The Pilot View Camera

A wide angled camera is centered between the two main plates to serve the pilot a suitable field of view for a smooth navigation.

Manipulators' View Cameras

Two cameras are mounted with an angle on top of the upper plate. Mainly focused on monitoring the manipulators' feed for more accuracy while gripping. Moreover, they are fastened to rotational holders. It was designed to increase the field of vision for the pilot by adjusting different angles for several applications.

Image Processing Cameras

As the need for image processing increases, it was vital to add a bottom-view camera with sharp qualities for high resolution images.

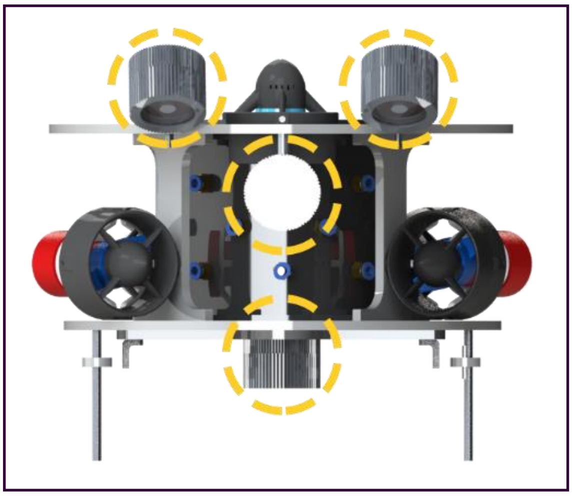


Figure 13. Oogway's Cameras' Configuration

3.7.2. Cameras' Sealing

In order to corroborate the sealing, an Aluminum case was designed by our engineers and fabricated using a lathe machine. The housing consists basically of male and female counterparts with O-rings specified to grooves in between. As for the wires, a pneumatic fitting is fixed at the back end of the housing with which a pneumatic hose is linked directly to the quick fitting in the main ROV's electronics' housing. Camera wires pass inside the hose ensuring no slight water leakage.

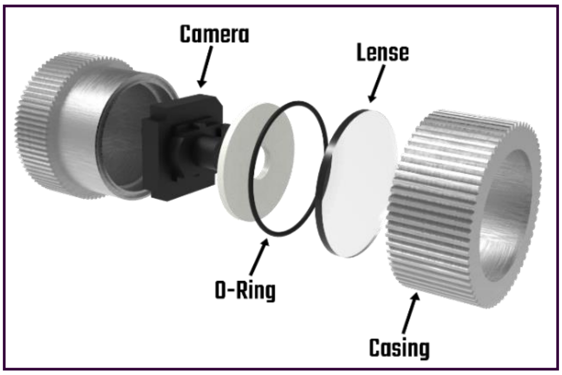


Figure 14. Cameras' Housing

4. Buoyancy

Referencing Archimedes' laws of hydrodynamics. Master Oogway was designed to be of slightly positive buoyancy to reduce the load on the thrusters, making it more stable while maneuvering. Mentioning that if Oogway broke down, it would float by itself without having to pull it from the tether. However, due to program errors, it turned out to be negatively buoyant, meaning that we needed to add some pressure-resistant foam to make it neutral. The center of buoyancy is at the electronics' housing as it is the widest hollow and sealed component in the vehicle. The center of gravity is vertically right under the center of buoyancy to maintain stability, both of which are at the mid-core of the ROV.

5. Simulation

5.1. Research and Development

This department specializes in ensuring the stability and strength of our company products and researching for new methods to optimize them. Computational Fluid Dynamics (CFD) simulation program is used to conduct several case studies on our ROV for the purpose of:

- Measuring of the drag and lift forces.
- Checking thrust force.
- Checking the center of pressure position.

5.2. CFD Fluent Analysis

Using fluent analysis, the physical conditions of the environment surrounding the ROV were simulated after finishing the solid model of Master Oogway.

5.3. Analysis Results

The results has shown the drag force to be of 46 N and the lift force to be 0.60 N. Besides, it was found out that the center of pressure is above the axial thrusters, so we decided to move the thrusters 10 mm upwards to have the center of pressure and the axial thrusters on the same horizontal plane so that there will be no moment around the center of our ROV, allowing Oogway to move with higher stability.

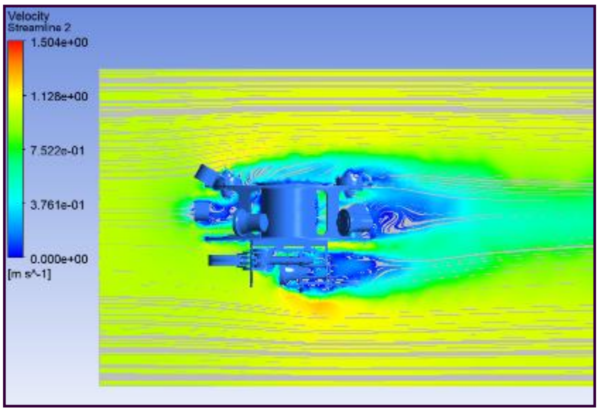


Figure 15. Lift and Drag Forces

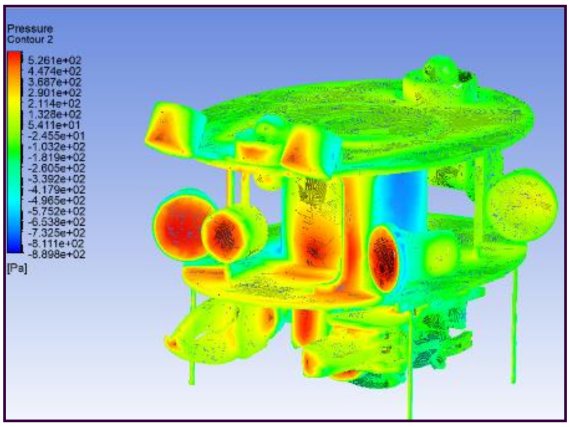


Figure 16. Virtual Analysis Results

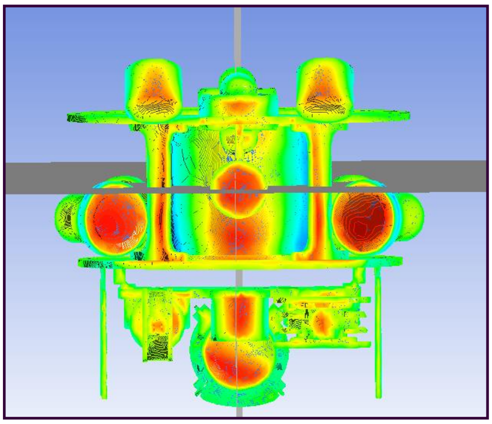


Figure 17. Centre of Pressure

Electrical System

An electric system SID can be found at **Appendix-A.** The components of Oogway's electrical system are as outlined below.

1. Hardware

1.1 Control Box

The topside control system is from the crucial designs of any ROV, since it is the direct interface to any user, that's why our control box strikes a balance between having the right components while maintaining simplicity in piloting. To ensure durability, all electronics are housed in a single layer portable sturdy polymer case that was built to protect the joystick and monitor, during both transportation and deployment of the ROV. A 220VAC bar is present to distribute MATE supply power to all components, which include the pilot view screen, Video Amplifiers and a DVR to display cameras' feed on the screen. Moreover, a video feed switcher is used to change the view between multiple cameras onboard the ROV. Finally, we used an IP witch to splice our onboard feed to the co-pilot and the image processing software. All cables are neatly labelled to ease troubleshooting, and the box guarantees rapid setup and easy assemble since all external connectors are laterally fixed.

Figure 18. Control Box

1.2. Tether

Oogway's reliable, manageable, and lightweight tether is designed to transport necessary signals, power, and pneumatics between the control unit and ROV. All cables are wrapped in a durable, flexible sheathing that protects the lines housed within and protects wires from interlacing. Its length is 22 m and weighing 3.5 Kgs.

It Includes:

1.2.1. Power Transmission

Two American 11 Wire Gauge (AWG) are used to supply 12V power to the ROV. The silicone wire was chosen for its low weight, compact size, excellent flexibility, and lower resistance in order to minimize the voltage drop and power loss across the tether. Which is calculated by the voltage drop formula of $\boldsymbol{V_{drop}} = \boldsymbol{I}_{\mathbf{wire(A)}} \times \boldsymbol{R}_{\mathbf{wire(A)}}$. Turning out to be a low percentage which would later be handled by onboard capacitors for ensuring a stable and smooth current flow.

Figure 19. Oogway's Tether

1.2.2. Signals and Communication

2 CAT6e cables were used to serve 5 cameras' feed and for the onboard to surface communication. They were preferred for their supreme speed in signal transmission reaching up to 250MHz.

1.2.3. Polyurethane Hose

Supplies compressed airflow to the pneumatic Valve.

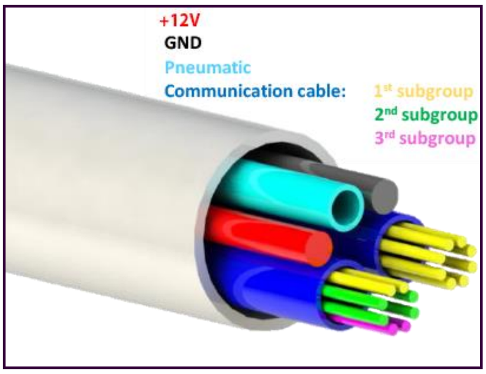


Figure 20. Cross Section of the Tether

1.3 Onboard Electronics Enclosure

The watertight electronics enclosure's contents are all secured to a removable tray to provide organization and modularity. This allows the ROV to be quickly configured to perform any tasks related to freshwater inspection and repairs.

For the sake of compactness and simplicity, our board was designed to fit into two 14 cm diameter circles as outlined in (Fig 21.), designed smartly so as to include the board components and the Motor drivers.

Notable components in the enclosure are:

- Four polarized capacitors among the Power distribution line, to smoothen the current flow.
- 12VDC Distribution blocks.
- 12VDC to 3.3VDC step-down buck converter.
- Two Blue Robotics Electronic Speed Controllers .
- Three 10AMPs Cytron dual channel H-Bridges for full easy. Control over the ROV's Thrusters and DC motors' speeds and directions.
- IRF540 MOSFETS for full easy access over digital controlled components as the solenoid.

Figure 21. Motherboard

1.3.1 Power Conversion

Our electrical system features a direct 12 to 3.3VDC conversion using a buck converter to avoid overheating. Current then passes through onboard capacitors to fix all voltage drops, filter any noise and smoothen the current flow. It is noteworthy that power distribution was performed using a series of terminal blocks to organize power and ground wires, which is important because in the event of electrical failure, fewer connections will result in faster troubleshooting.

1.3.2 Control and Interlinking

The micro-controller is the main link between powering and manipulating Oogway's components, as it has full access over all motor drivers, MOSFETs and sensors. All input wires and interlinking cables are easily pluggable, meaning boards and components could effortlessly be disconnected and inspected separately, a configuration which facilitates our debugging scheme and searching for internal issues.

1.4. Vision System

Oogway has a total of 5 HD cameras; three analog wide-angled small cameras with a 2.8 mm lens, two of them are used to monitor both arms movements while the third one is used in the ROV's main camera. One 1080p with a 3.6 mm lens was chosen carefully to show straight lines without any distortion, the camera is fixed vertically to look downwards, it's used to fly the transect line over the coral autonomously. One Hi-definition color CCD with a 480 TV line resolution used in the micro-ROV.

1.5. Light System

Owing to the need of achieving greater efficiency in the image processing tasks, 2 flash modules are mounted in order to provide the needed illumination for both cameras used in image processing. Each flash module is mounted inside a metal casing designed with a specific angle and coated internally with a layer of reflective aluminum foil. This results in the reflection of light rays in one direction providing greater illumination intensity in order to obtain a clearer, illuminated field of view while capturing frames for better color detection and fast processing during maneuvering.

2. Software System

2.1. Top-Side Software

Master Oogway comprises 3 controllable ends:

- Arduino Microcontroller which exchanges data with the main computer and controls motors and mission specific features as it also receives onboard data.
- Main GUI computer, which exchanges data between ROV and surface equipment.
- Second laptop to complete image recognition and missions' specific features.

Oogway's main manipulation code is written in C++, focusing on OOP (Object Oriented Programming), hence creating a well-organized, readable and a modular code. Besides its smooth compilation, allowing us to perform using any processor. In addition, C++ provides the ability to multithread, which was implemented to make sure we can increase computational load on the program without any problems with the graphical interface.

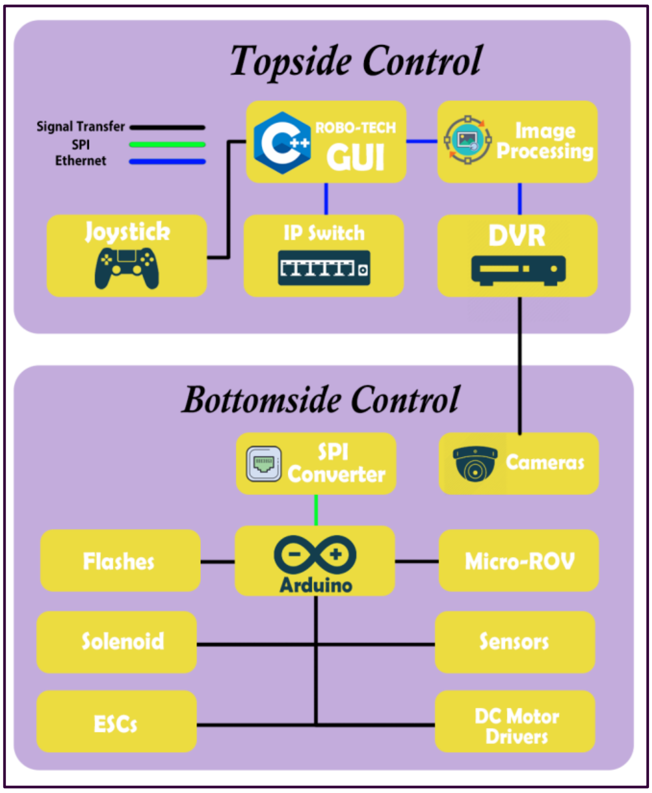


Figure 22. Software Architectural Diagram

2.2. Onboard Controller

The onboard computer is an atmega2560-based Arduino Mega-Pro board programmed using C++. Though it has a tiny size. It alone is responsible for manipulating thrusters, sensors, flashlights, and the micro ROV. This computer also reads several sensors and broadcasts their values to a custom-made frontend GUI on the Control Laptops. Relying on object oriented programming, we were able to optimize our code and make it extremely modular.

2.3. Communication

The computer creates a UDP/IP server on boot, via an Ethernet-SPI module enc28j60, to convert the data in form of bytes coming from the Ethernet into a Serial Peripheral Interface (SPI) protocol to be readable by the Arduino board by casting the bytes to an array of characters. That of which was used for its suitability in transmitting lengthy arrays of data on quick terms, and for its eligibility as a connection link for sending data faster than (TCP). Commands can then be sent to the onboard computer from the pilot or co-pilot, where they will be executed.

2.4. GUI (Graphical User Interface)

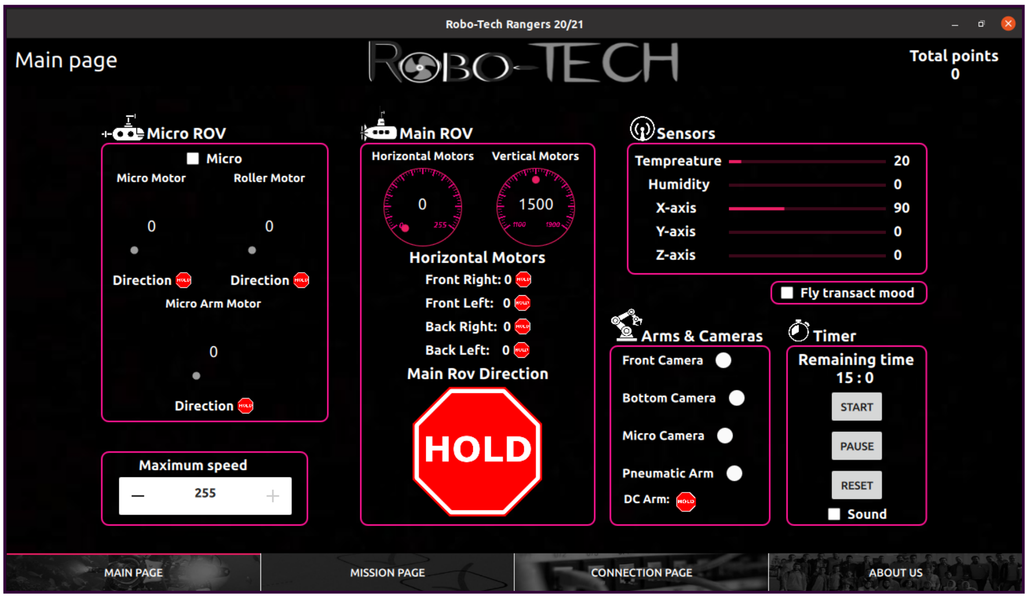


Figure 23. Graphical User's interface Main Tab

Our UI is made using Qt IDE framework, a free and open-source widget toolkit for creating UIs. It consists of four tabs. The main tab intuitively displays live telemetry from the ROV including motor speeds and sensor readings. It has a timer to notify the pilot with the remaining time during the product demonstration. The second tab is the mission tab. It shows the progress of Master Oogway during missions, calculates the total points, and solves specific tasks such as calculating the number of mussels in the mussel bed. The third tab is the connection tab. Along with other features, also helps us to control the constant values of the PID equation. Our backend was written in C++, seeking the highest performance. Meanwhile, our frontend was designed using QML language (Qt Modeling language) which is based on JavaScript as it creates a sophisticated and a nice looking interface, giving the pilot and the co-pilot an easy trace to all ins and outs. All data modifications and complex operations are done in the UI's backend, almost ending the need to disassemble the electronics' enclosure. When the UI is done with data and its modifications it converts it into the form of bytes and broadcasts it to the Arduino.

Build vs. Buy

Since ROVs' industry is always stereotyped as expensive and complicated. Our company decided to take an approach to prove the opposite. When building an industrial grade ROV, a company must consider the tradeoffs when buying components versus manufacturing others. However, under no circumstances were we going to sacrifice the comfort of our future buyers. Building our components not only reduced the budget, but also gave us the opportunity to gain valuable experience, and allowed us a great degree of freedom and customizability while designing.

For instance, instead of buying T100 thrusters, we only bought the T100 kort nozzle and applied it to bilge pumps using customized 3d printed parts designed by our mechanical engineers. To add, they took a further approach to design and build several parts such as our sealed customized electronics' housing, cameras' housing and both our grippers.

Speaking electrically, our electrical engineers manually fabricated all the electrical boards on their own. Moreover, they designed and built their control box with a usable configuration that would aid the pilot during station set-up and navigation. Buying commercial components is also necessary, offering fast and reliable solutions at times. That is why almost all surface mounted electronics are commercially bought since they are above our engineers' fabrication abilities.

New vs. Reused

Deciding whether to reuse a component was a critical decision, based on the product cost, relative to its current performance, that's the reason why tests were applied to all components to ensure their performance haven't changed through long-term usage.

Reused components include the 6 ROV thrusters, DC motors, Pneumatic piston, solenoid valve, and motor drivers. All of which their performance relative to their cost were proved to be an advantage.

Among other reused components are the SPI Ethernet module, buck converter and the compressor. These were all high-cost items, where buying new ones offered no real performance advantages. Four HD cameras with their flashes were purchased as an improvement to our vision system facilitating underwater navigation process and easing image processing missions. The Micro-Controller and our joystick controller were also bought as the old ones have started being defected on the long term.

IV. Payload Tools

Manipulators

Straightforward and functional designs are always a priority, which is why two manipulators were fixed onboard Oogway. Consequently, leading us to seize vertical and horizontal axes, and holding several objects with diverse shapes simultaneously.

1.1. Pneumatic Manipulator

Structure: Master Oogway's main arm, shown in (Fig 24.), is a manipulator which is pneumatically powered. A pneumatic piston was preferred for its rapid movement, strong grip and easy one-click control. The end effectors are linked to the pneumatic piston through an Aluminum base attached to the pneumatic cylinder. The end effectors are designed for holding cylinders with various diameters such as the sea-bin connector and also has a flat end for holding small or flat objects as the ghost net pin. It is manufactured using 6 mm transparent acrylic to give a better view for the pilot. The end effectors consist of 6 layers accumulated in order to increase the contact area with objects gripped. Besides, rubber bands are fixed on the jaw palms to ensure highest friction between gripper and objects.

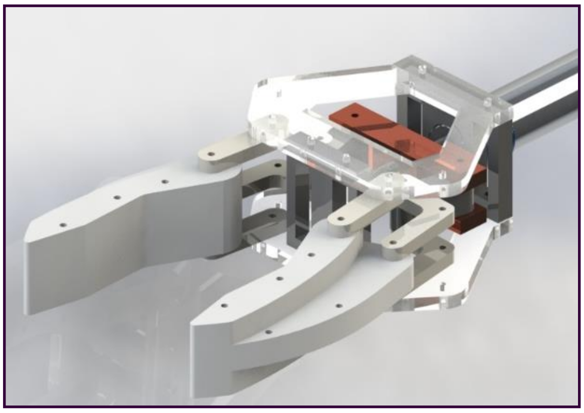


Figure 24. Oogway's Pneumatic Gripper

Features: It weighs 0.65kg.

1.2. DC Manipulator

To consume the least space, we took advantage of our micro-ROV's DC Gripper as one of the ROV's main grippers while it is fixed onboard.

Structure: Our main goal was to design an arm easy and fast manufactured. The end effectors of this arm were also made from acrylic for a better vision for our pilot and also designed especially for holding cylinders. The end effectors are linked to the shaft coming from DC motor by a copper base and a screw. Its gripping force is adjusted by controlling the speed of its motor, making it suitable for holding sensitive and breakable objects.

Features: It weighs 0.4 kg.

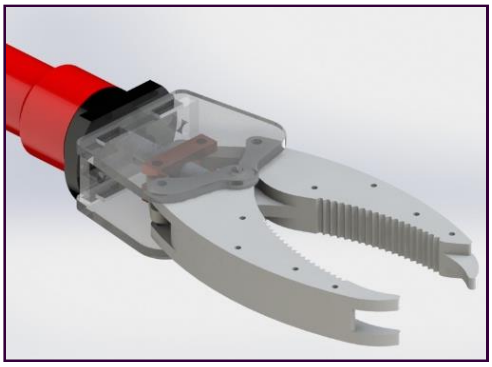


Figure 25. Oogway's DC Gripper

Micro Non-ROV Device

This year, a micro non-ROV device is required to be deployed in dark and narrow passageways such as dams, to retrieve the sediment samples and analyze for contaminants. In addition to this task, the device permits the pilot an extra field of view while attached to the ROV, which is extremely helpful for capturing side images for the submerged subway car. The main structure of the device are 2 Polyurethane rings connected by four rods. Four smooth supporters are mounted diagonally on each ring across the device, smoothening the maneuver inside the pipe's corrugations. It is propelled using a reused bilge pump modified with the nozzle of a T100 thruster, eventually giving us the desired thrust through the 3.2m pipe. And since the micro-ROV only utilizes one degree of motion, buoyancy control was not a priority, as the angular momentum of the propeller and the outside supporters allow the device to smoothly hover in the pipe without being obstructed. A compact DC screw gripper is mounted at the front of the device for sample collecting. In addition, an HD camera is present to provide a clear feed to facilitate navigation.

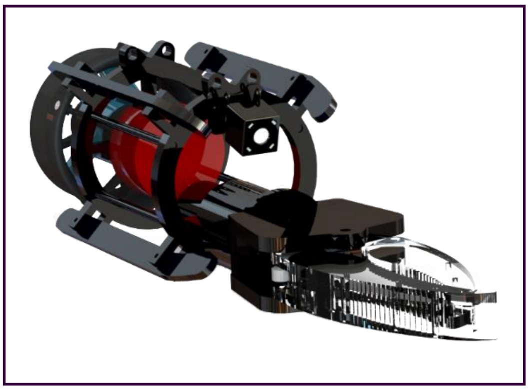


Figure 26. Micro Non-ROV Device

The non-ROV device is powered from the primary ROV, connected via a tether with the aid of an auto-winding reeler. The spindle is controlled by a DC motor that unwinds whenever the micro-ROV is in motion. A suitable ratio was deduced to compromise the micro-ROV speed to the winding speed, relative to both motors' torques and RPM. When the mission is done, the winder reverses its rotation pulling the device out of the pipe to re-enter the ROV. The tether winder also plays a main role in stabilizing and holding the micro-device to the main ROV before being deployed.

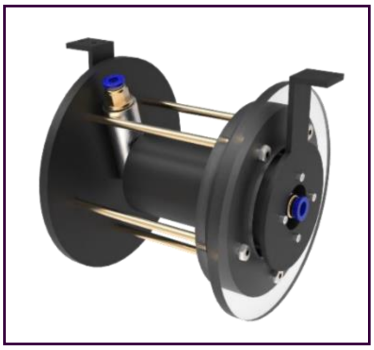


Figure 27. Auto Winding Reeler

Debris-Collector

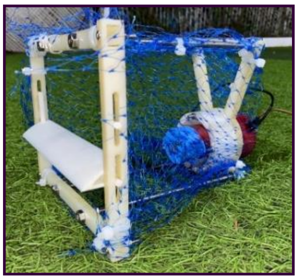


Figure 28. Debris Collector

For the sake of decontaminating water by removing floating debris, our company designed this custom mechanism consisting of a frame, net, arm and actuator. The arm moves vertically, hence collecting floating debris and throwing them in the net. Being perforated, it has the ability to face least resistance. All solid components are made using Polyurethane for its solidity and relatively low weight.

Image Processing

Annually, we aim to enhance our knowledge and skills in various fields, that's why image processing was a separate department only focusing on underwater vision quality, AI Algorithms, various masks, filers, and libraries.

1. Software

1.1. Mini-GUI

An independent python-based mini-GUI was created to handle all the computer vision tasks' scripts employing multithreading, custom arguments, and easy interface for the co-pilots.

1.2. Camera Calibration

At close proximity, cameras exhibited a distortion error (commonly known as fish eye effect) which decreased the effectiveness of any camera-dependent algorithms therefore we utilized an OpenCV algorithm with the help of a chessboard to compensate for this distortion and return the image to true state as shown below.

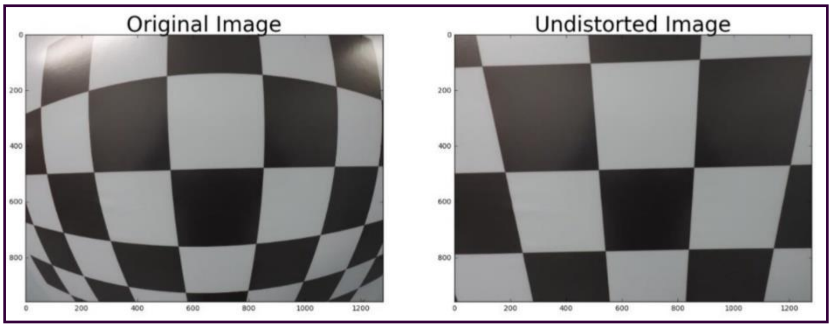


Figure 29. Camera Calibration

2. Tasks

2.1. Creating a Photomosaic of a Subway Car

In this mission, the pilot flies around the subway car in a specified sequence so the photos are taken in a known order. White borders are detected and cropped, hence, a quick sort-by-date algorithm is applied and the photo mosaic is created.

Figure 30. Final Stage of Photomosaic Generation

2.2. Using Image Recognition to Determine the Health of a Coral Reef Colony

The first step the program executes to reach the final outcome is to align both last year's image with the current image using SIFT feature and the image's homography, which was found to be working perfectly even with different angles. However, several filters had to be applied first in order to reduce the noise and distortion, such as the median blur and blur filters. After alignment, we determine the colonies' death or growth by subtracting both images and locating differences. Meanwhile to detect bleaching or recovery, masks and contours were implemented on both images, finding the average color difference in each contour. Hence, locating all dissimilarities and labeling them in colored boxes according to the case.

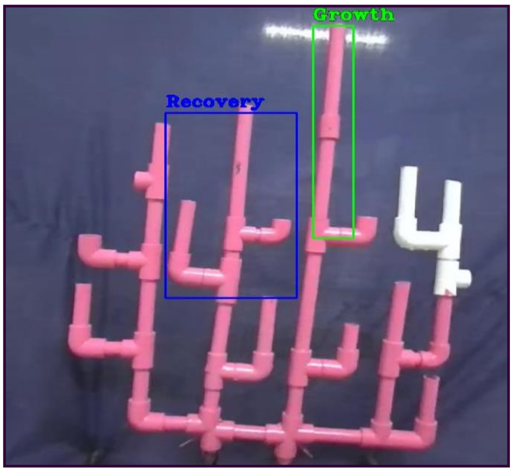


Figure 31. Climate impact on coral reef

Flying Over a Transect Using PID Control

As Oogway is being featured by several autonomous characteristics, most important of them is to independently fly a transect line over a coral reef. The process is done by the aid of an IMU device (Inertial Measurement Unit) fixed in the electrical housing. At first, our image processing software detects any deflections in the ROV's positions according to the two blue lines, then it positions the ROV to the desired height, angle and shift, which act as our desired set-point values. These values are then sent to the IMU and to the co-pilot's GUI. Then by Implementing PID (proportional, Integral, and Derivative), we can calculate the ROV's movement error which is the difference between the set-point value and the instant IMU reading, potentially subtracting them and getting back on track.

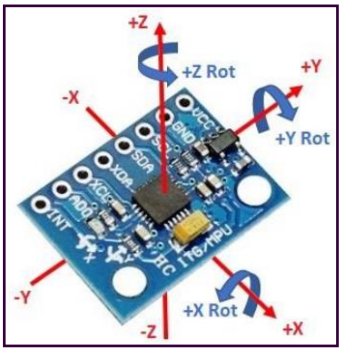


Figure 32. IMU Rotational Analysis

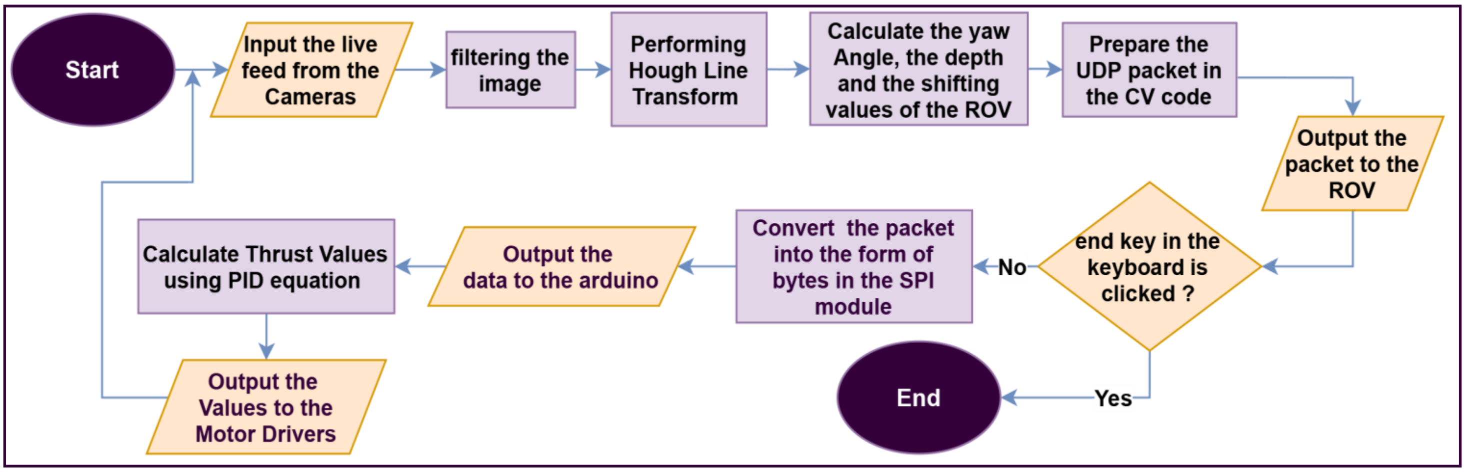


Figure 33. Flying over a Coral Reef Transect Mission Flowchart

V. Safety

Safety Philosophy

At ROBO-TECH, Personnel's safety is a standardized paramount. It is the company's philosophy that is being taught to all members, and referenced by the valuable saying of F.S Hughes "Safety brings first aid to the uninjured." Meaning that extra effort was to be offered for the sake of safer solutions and procedures.

A general training was made by senior engineers to ensure each member was aware of the tools' safe procedures, and each member tried the tools under the supervision of our mentors. In addition to this, firm In-Lab construction and On-deck strict safety procedures were established and could be found in **Appendix-D.**

ROV Safety Features

Table 1. ROV Safety Features

Mechanical	
Rounded Edges	All round edges were filed or smoothened to avoid any injuries while ROV handling
Shrouded Thrusters	Custom 3D printed parts were designed to shroud our thrusters to prevent harm from rotating parts
Waterproofed electronics	All our Electronic components are sealed in the Electronics watertight housing, or either using waterproof shrinks, epoxy and silicon.
Electrical	
Strain Relief	Strain reliefs are present at the tether's both ends to prevent any harm to the electronic components
Cut-off switch	accessible 12VDC and 220VAC Double pin single throw switches are present in the surface control box
Electronics' housing Sensors	humidity, temperature and pressure sensors are present in the Electrical housing, and their telemetry is displayed on our GUI, allowing our engineers to detect dangerous situations such as a leakage or overheat
Fast-blown fuse and hazardous labelling	A 25A fuse is present 30 cm from the power supply, and a number of hazard labels are present among ROV components

Figure 34. Strain Relieved Tether

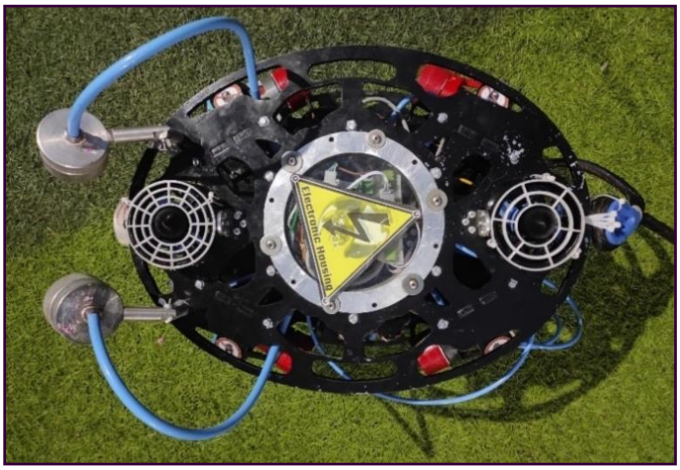


Figure 35. Shrouded thrusters and hazardous labeling

VI. Project Management

Company Structure

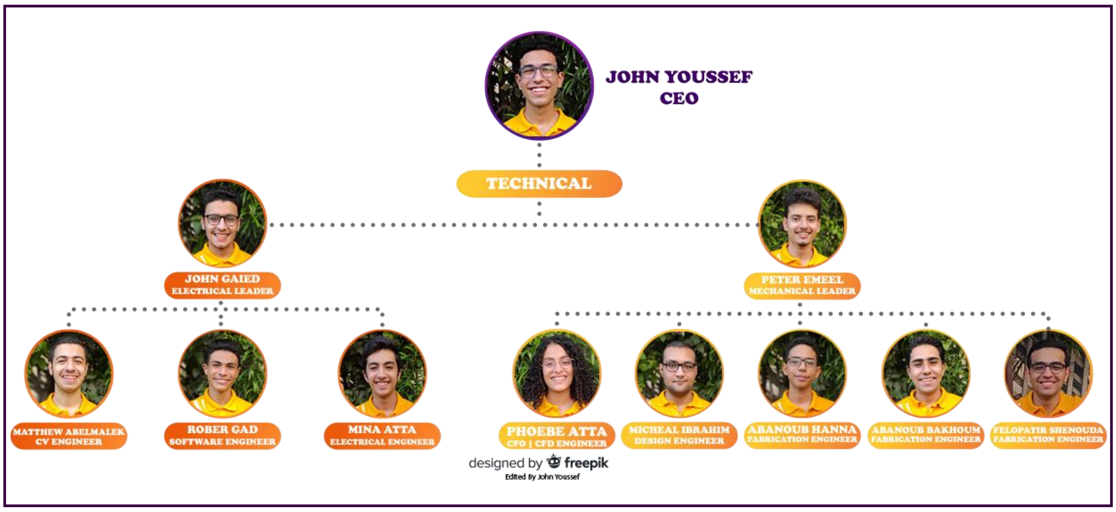


Figure 36. ROBO-TECH Rangers Internal Structure

Our company has always focused on maintaining a healthy working environment, thus leading to more productivity and promising work results. At the beginning of the project, team roles had to be assigned. While the ROBO-TECH company encourages its employees to gain experience in multiple domains, having each employee work in one primary department lead to a very efficient and organized project. The technical section is divided into two departments, and each department comprises several units. The non-technical sections are usually joined by all our engineers as a secondary job which helps them refine their soft skills furthermore

Job Assignments and Timeline

ROBO-TECH Rangers team prides itself with being extremely well-organized, which can be noticed through the team's design and manufacturing schedule, planned in November 2020. A visual illustration could be found at **Appendix-C**.

Our timeline directly started after being recruited in the company and proceeding a 2 months technical training, consequently providing equal opportunities to all members in learning technical, soft, time management and various constructive skills that were meant to be a major factor in the manufacturing of Master Oogway. At the end of the training, a meeting was set to announce each engineer's position, which was smartly mapped by our senior engineers according to the technical training scoresheet, taking into consideration each member's personal interest and characteristics as a priority. Eventually leading to a healthy working environment among us where each individual was satisfied in his field, integrating in the full image. While aspiring, the planned schedule lead us to a successful outcome as expected, leaving plenty of time for testing, troubleshooting and debugging. Besides, it simplified work organization amongst all required tasks such as our marketing poster and technical documentations.

To add, bi-weekly meetings were set so as each sub-team would communicate his progress with other teammates, keeping all members up-to date and discussing the current progress and the next step. In addition, it was a perfect timing for brainstorming periods and tasks allocations amongst members.

Work Management

Several procedures were taken in order to ensure the best systematization. For instance, each sub-team had an online group chat on social platforms to be able to discuss around the clock. Furthermore, our team used some collaboration tools to smoothen the workflow, most useful of them was the team's google drive. Another technologies used were Trello and GitHub, those of which were to ensure the transparency and publicity of our digital progress to all engineers, and allowing each one to learn and collaborate in all documents in real time.

VII. Critical Analysis

Testing and Troubleshooting

1. Prototyping

After accomplishing our designing phase, prototyping has always been a priority. In order to set the seal on the least mistakes and less time wasted on malfunctions, a prototype was to be made before any fabrication process. For instance, our motherboard was digitally simulated using Proteus®, theoretically verifying the validity of our circuitry. Moving to a further step, most complicated circuits were prototyped on a basic breadboard, creating a replica of our final motherboard. As for the mechanical department, computational fluid dynamics and simulations were applied to our SolidWorks® model using ANSYS®. All prototypes played a significant role in spotting defects which later saved us time, effort and money.

2. Testing

Believing in RCA (Root Cause Analysis), our engineers tested every single component onboard Oogway before fabrication and assembly, understanding its behaviors and determining its criteria, consequently being certain that the component was ready for the whole ROV's integration. Examples of testing processes are as outlined below:

1. Waterproofing test

1.1 Sealing test

Cameras' sealing and our electronics' housing were connected to a compressor via an air hose, and pressure was applied increasingly to ensure the validity of the housing.

1.2 Free- electronics sealing test

The ROV was left in a pool for no less than 10 minutes free of any electric components within, then checking all the housings, hence validating our watertight enclosure without any damage.

2. Max Current Draw Test

This test involves setting all thrusters to maximum sensitivity and power simultaneously in order to create a large current draw for a period of time, ensuring that other components are receiving enough power.

3. Power-On and Power-Off Tests

This test ensures that all controllers boot upon power-up, that all sensors read nominal values, and that all components of the ROV are powered on. Upon power-off, all components should return to a safe state, and should be OK to power-on once again.

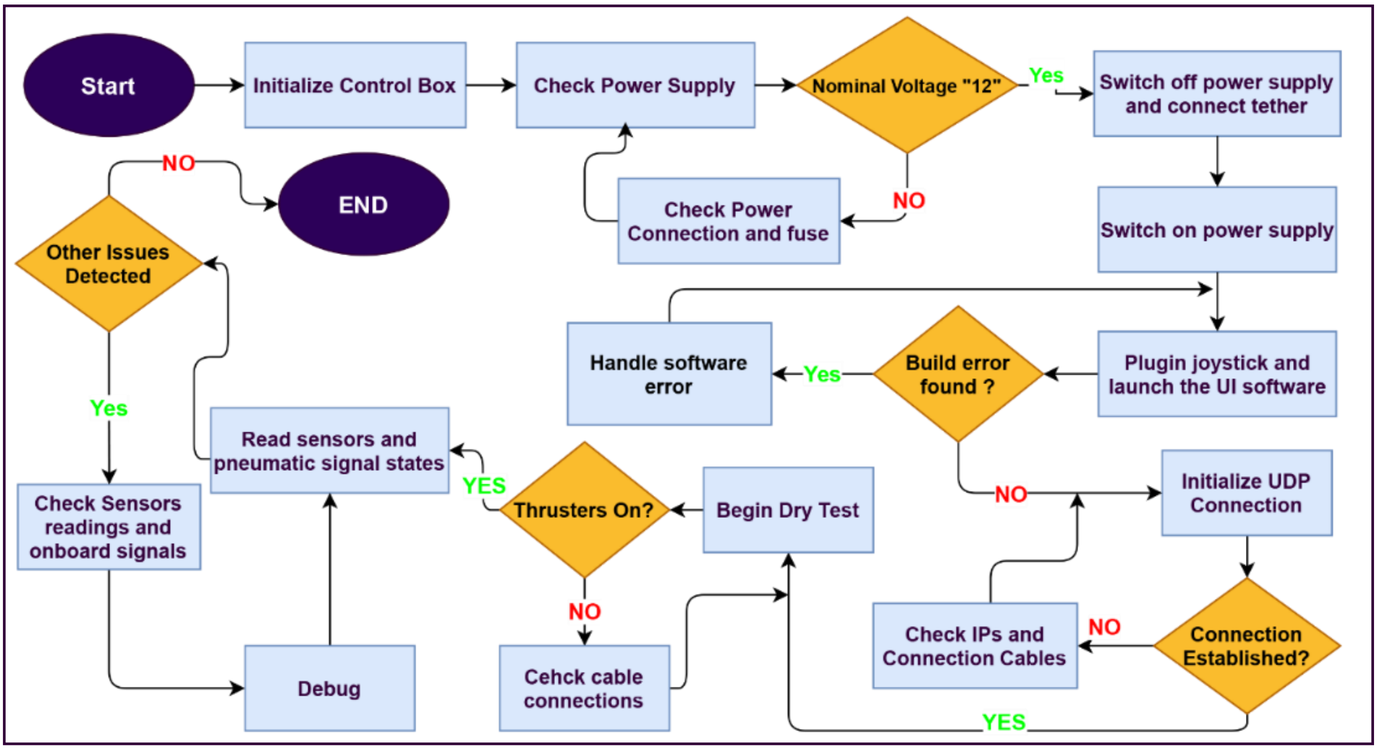


Figure 37. Oogway's testing protocol

Challenges and Problem Solving

1. Technical

Since we were all newcomers, the whole manufacturing process was not an easy task, as we lacked knowledge and experience, having to learn "on the go".

The greatest challenge in our design was to submit to size restrictions, for decreasing our size meant having no place for the payload tools. However, after brainstorming and integrating several ideas, the right place for each component was found, consuming least space with full functionality.

Another difficulty faced by electrical engineers was to fit all components in the 16 cm diameter housing. Even so, they were able to brilliantly reach the idea of semi-circle shaped boards, consequently leaving space for all motor drivers to fit in our housing. One more issue we realized during testing periods was that a full operation of all the ROV's systems would cause exceeding in the withdrawal of MATE current limitations, but in no time was the solution presented by our software engineers, where they modified their code so it would automatically disable some ROV systems while others are launched. For instance, vertical thrusters are disabled while the ROV is moving horizontally.

2. Interpersonal

A serious problem we faced at the beginning of our working period was the interference between the team and members' personal academic studies, which caused lack of progress in both ends. Nevertheless, a schedule was put and members took turns in working, until each one was able to manage his time efficiently. Most importantly was the period when team members started losing passion towards the ROV's work due to the increasing errors in all fields. The struggle was resolved by taking a few days break, re-organizing our working place with a different configuration, and finally brainstorming to reach a solution to each issue individually. Even though many things were difficult for us, we handled most of them, but that was only possible thanks to the joint efforts of the whole team.

Lessons Learnt

Most of the tasks we faced while preparing for the MATE ROV competition were new to us as it was a totally new experience. The whole team attended a two months full technical training, learning a whole batch of valuable knowledge, technical skills, and CAD programs. For instance, we learned SolidWorks CAD, Eagle CAD, plus sealing and fabrication methods, manually fabricating complex boards and programming concepts such as polymorphism and inheritance. After being split, each sub-team deepened in his field. Software engineers have mastered the methods of working with microcontrollers, studied C++ and learned Qt Framework. Mechanical engineers learned about Computational Fluid Dynamics using ANSYS CAD and learned dealing with various machinery such as 3D printers and several tools.

From a non-technical point of view, MATE also demanded a lot from us. During the preparation for the competition, we had to learn such personal qualities as time management, brainstorming when needed and overcoming challenges. Presentation skills were significantly developed by learning basics of a sophisticated presentation and training with our senior engineers. Moreover, the work enhanced the co-operative spirit between members of our company and hence in their daily lives.

VIII. Future Improvements

We are always analyzing and looking for future innovations to make our product more usable and professional. After much experimentation, we decided on the following improvements to tackle next season.

Mechanical: Over the years we've been using Polyurethane (known as Artilon) as our main design structure material, however we found out that it could be so vulnerable, risking the solidity of the ROV. Hence we aim to use Aluminum or carbon fiber as our main material. We also intent to design an enhanced ROV frame, permitting us better hydrodynamic properties and a smoother flow.

Electrical: We are willing to learn manually fabricating double sided PCBs to save space inside our Electronics' enclosure, since it was one of our challenges to fit our boards inside. Moreover, we're studying the idea of using fiber optics for signal transmission, as it would result in supreme speed transmission and almost no noise distortion.

Control and GUI: An objective we're seeking to achieve is to add more visuals throughout our GUI and screens that would facilitate the pilot's navigation, such as a model for the ROV's position in midwater relative to its starting point.

Image Processing: Improving our skills and knowledge in the wide field of Computer Vision and the use of C++ instead of Python for the sake of faster processing speeds.

Non-Technical: Owning a wider place for work and a pool, which would save money, effort and time.

X. Accounting / Budget Analysis

At the beginning of the project, all team members met to discuss and formulate a provisional budget. Once finalized, all team members adhered to the budget during the ROV's build phase. To ensure reasonable spending, all purchases had to be cleared by the company's CFO or another senior member. In addition to this, all parts were sourced from multiple vendors before purchasing to ensure that all prices were fair. A full budget along with travel estimates can be found at **Appendix-E**.

A detailed breakdown of the ROV's cost can be found at **Appendix-F**. The team adhered to the budget very well, and no funds were wasted or misallocated.

XI. Acknowledgments

We would like to offer our deepest gratitude to several individuals and associations that had a significant role during the manufacturing time. First of all, we offer sincere appreciation to all our mentors for their knowledge, experience and invaluable mentorship. Next, we would like to thank the Engineering Sciences Academy for welcoming us to work inside and having such supportive crew. Finally, we would like to thank MATE for organizing this competition, giving us an irreplaceable chance to develop our knowledge and skills, and the Arab Academy for Science, Technology & Maritime Transport for hosting the regional competition in Egypt.

We also appreciate all our parents for keeping us fed, loaning us financially, technically, and morally supporting us throughout all the working period.

Figure 38. Logos

XII. References

1-Books and Manuals

- MATE. "MATE ROV Competition Manual. Ranger 2021" 27Oct, 2020.
- The OpenCV Reference Manual. 3rd release. June 25, 2014.
- ANSYS. Introduction to ANSYS ICEM CFD. 13th edition. December 2010.
- Robert D. Christ and Robert L.Wernli Sir, The ROV Manual: A User Guide for Observation-Class Remotely Operated Vehicles .1st edition 2007.
- Jeremy Blum, “Exploring Arduino: Tools and Techniques for Engineering Wizardry”

2-Websites

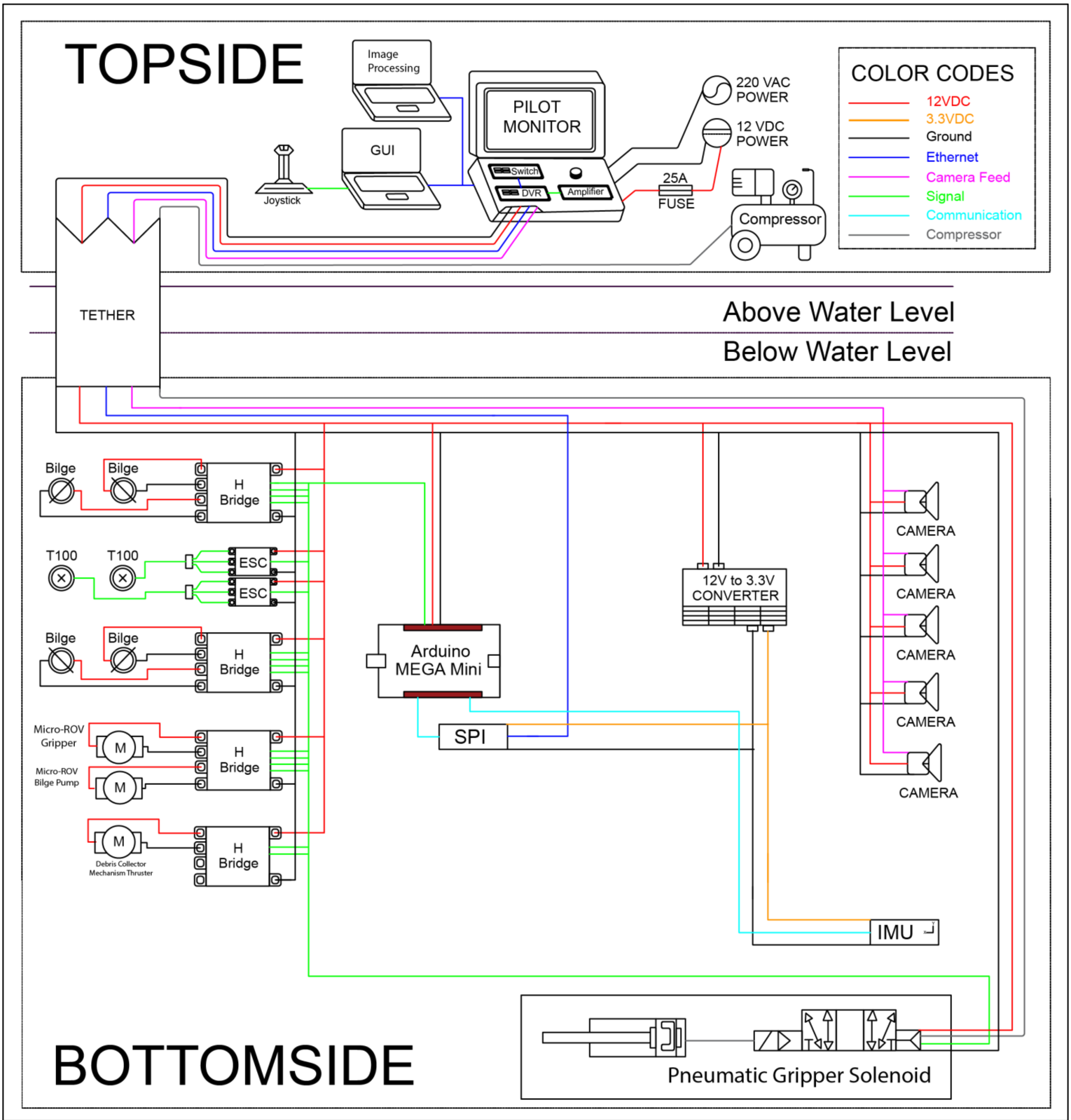
- Qt Documentation
- Python Reference

3- Research Papers

- Eng. YH, Lau WS, Low E., Seet GGL and CS Chin. (2008). Estimation of the Hydrodynamics Coefficients of an ROV using Free Decay Pendulum Motion.

XIII. Appendices

Appendix-A | Electrical SID



Fuse Calculations:

Arduino and Ethernet Module = 0.4A
4 Analog HD Cameras = 4 X 0.05A = 0.2A
Solenoid Valve = 0.4A
4 Bilge Pump Thrusters = 4 X 3A = 12A
2 T100 Thrusters = 2 X 7A = 12A
* T100 thrusters are throttled down by software
Bilge Pump = 3A

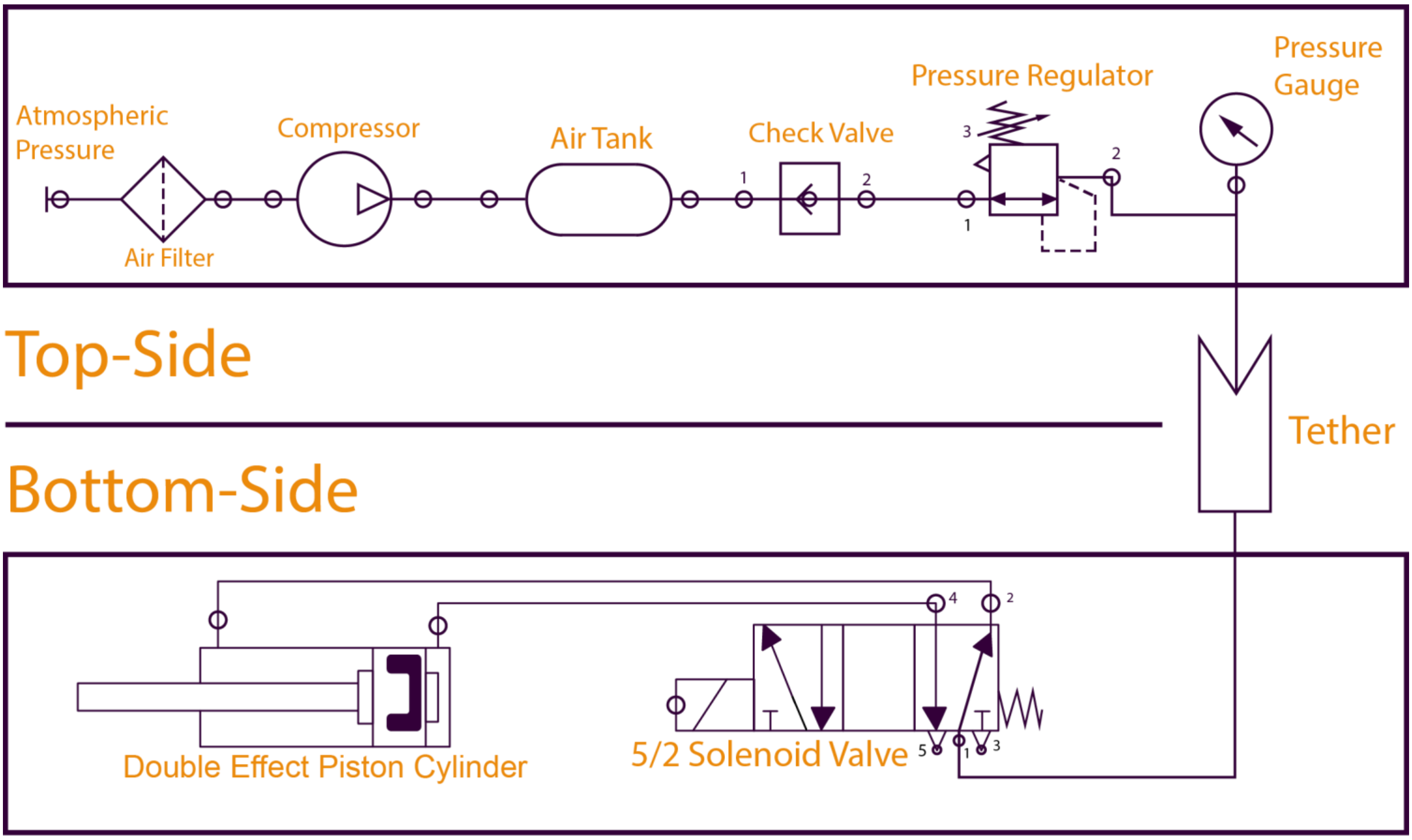
Micro-ROV

Note: Micro-ROV is powered from the main ROV
Micro-ROV Bilge Bump = 3A
Micro ROV DC Arm = 0.5A
Micro-ROV HD Analog Camera=0.05A
Total Current Withdrawal = 31.5X 150% = 47A
ROV Uses 25Amps Fuse
Note: Not all ROV systems operate concurrently (i.e. Grippers / flashes / micro-ROV / Vertical Thrusters are automatically disbaled while ROV is moving horizontally and vice versa, Consequently not exceeding current limitations)

Designed Using AutoCAD®

Figure 39. Oogway's Electrical SID

Appendix-B | Pneumatic SID



Designed Using Adobe Illustrator®

Figure 40. Oogway's Pneumatic SID

Appendix-C | Timeline Gantt chart

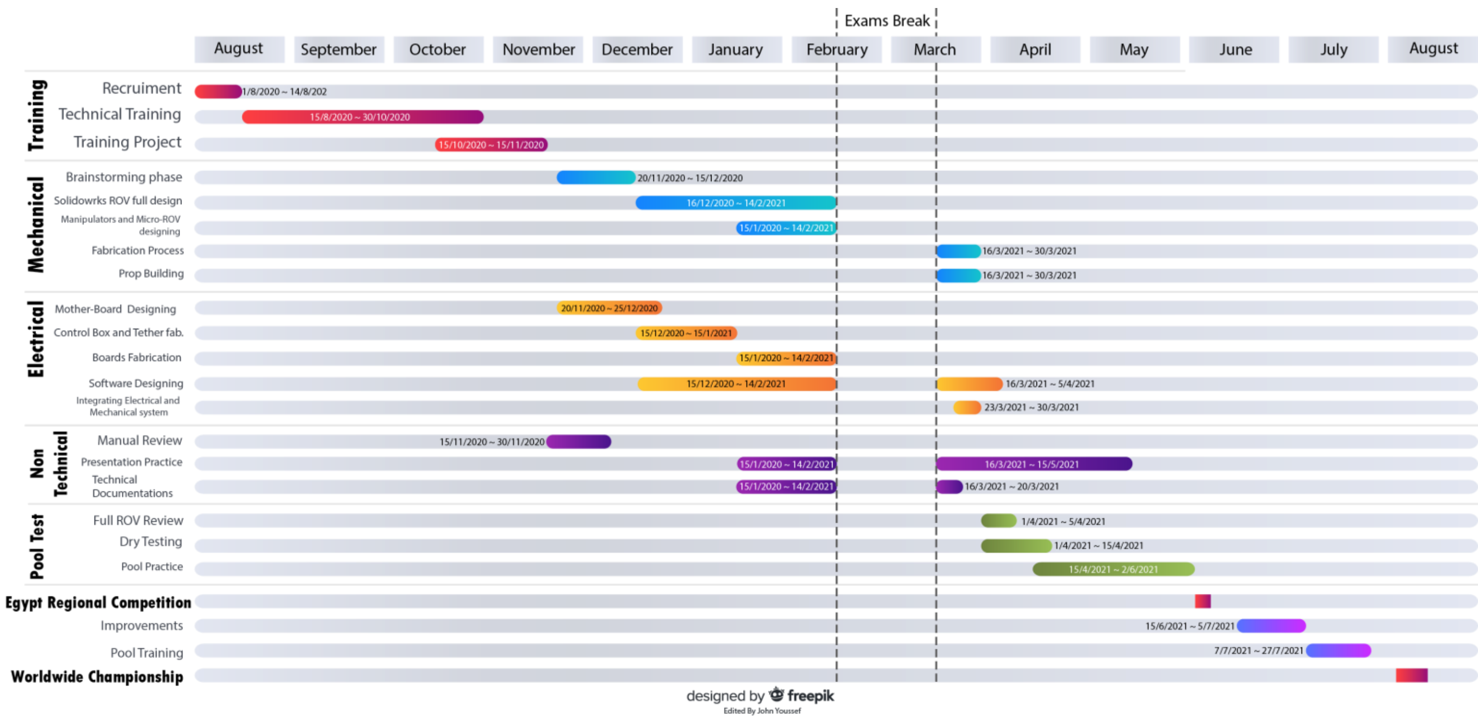


Figure 41. Timeline

Appendix-D | Safety Procedures

Table 2. Safety Standards and Checklist

<table>
<tr><th>In Lab</th><th>On Deck</th></tr>
<tr><td>General Checklist
✓ All engineers are trained.
✓ Unplug power tools when not in use.
✓ Organize workshop, no tripping hazards.
✓ PPE worn depending on the task.
✓ No less than 2 members are present when performing any task.
✓ No loose clothing is worn.
✓ Al shoes are tied.
✓ Long hair tied back.

Soldering
✓ Inform others before soldering to avoid any arbitrary movements.
✓ Wear goggles and mask.
✓ Turn on ventilation.
✓ Clear workspace of any obstacles and ensure no wires are live.</td><td>Setup, Booting, Launching
✓ Ensure no Tripping hazards.
✓ Tether is uncoiled.
✓ Tether is securely connected to the ROV via strain relief from both ends.
✓ Verify all wire labeling and ensure no loose or exposed wires.
✓ Visual inspection by all team members.
✓ Ensure each member is in his place.
✓ Turn on 220VAC and power supply switches.
✓ Check for any leakage from the compressor.
✓ A dry test by checking communication, thrusters, active manipulators and camera feed.
✓ Check sensor readings are nominal.
✓ Deploy the ROV.</td></tr>
<tr><td>Chemicals
✓ Turn on ventilation.
✓ Wear rubber gloves.
✓ Clear working space and inform members.
✓ Prepare Cleansing stuff.</td><td>Retrieval
✓ Pilot notifies crew.
✓ Pilot surfaces the ROV and disables the system.
✓ 2 members carefully maintain the ROV to the surface.</td></tr>
<tr><td></td><td>Maintenance
✓ Visual inspection for any physical damage.
✓ Reboot communication protocol.
✓ A dry test verifying each component is functioning.
✓ Retighten screws and re-set the ROV.</td></tr>
</table>

Appendix – E | Project Budget

Table 3. Oogway's Budget Analysis

Company Name: ROBO-TECH Rangers		From: 15/8/2020	
Mentor: Karim Ibrahim		**To: 15/5/2021**	
Master Oogway's Development (USD)		**Income (USD)**	
Mechanical Components	$1080	Company Members Contribution	$3100
Electrical Components	$970		
Workspace Expenses	$400		
Training Pool Expenses	$320	**Total Income**	$3100
Registration Fees	$300		
Operations Sub-Total	$3070		
Balance			**$30**

Note: Our Company is competing telepresence category from our hometown so, we did not pay for any travelling expenses.

Appendix – F | Project Costing

Table 4. Oogway's Project Costing

Date	Type	Item Description	Function	Qty.	Price
Electrical Components and Devices					
23/10/2020	Purchased	T-100 Thruster	Master Oogway's Maneuvering	2	$200
03/10/2018	Re-used	Bilge Pump Motor	ROV/Micro Non-ROV Device Maneuvering	5	$200
06/12/2019	Re-used	DC Motor	Manipulators	2	$38
02/11/2020	Purchased	Arduino Mega mini pro	Master Oogway's Controlling	1	$15
2/11/2010	purchased	Dc-DC Converter 3A	Converts from 12VDC to 3.3VDC		$2
02/11/2020	Purchased	Ethernet-SPI module	Communication Device	1	$7
01/10/2018	Re-used	Electronic Speed Controllers	T100 Thrusters Control	2	$60
03/10/2018	Re-used	Cytron 10A	Bilge Pump and DC motors control	4	$100
01/2/2021	Purchased	Temperature Sensor	Temperature Measuring	1	$2.50
01/2/2021	Purchased	Humidity Sensor	Monitors moisture inside the control box	1	$6.50
01/2/2021	Purchased	IMU	Determines Master Oogway's Orientation	1	$4.50
01/2/2021	purchased	Tether-Station Connector	Signal Connection to station	2	$2
01/2/2021	purchased	Anderson Power pole Connector	Connects power from MATE supply	2	$5
01/2/2021	purchased	2 Pins Screw Connector	Distributes power to all components	6	$2
01/2/2021	purchased	XT-60 Connector	Receives power from Tether	1	$2
01/2/2021	purchased	Pluggable Screw Connector	Signals internal Connections	5	$1
01/2/2021	purchased	Ethernet to PCB Connectors	Connects ROV signals to tether	2	$1

01/2/2021	purchased	Signal Connectors 4-5 pins	Connects signals from and to the boards	6	$1.5
01/2/2021	purchased	Capacitors	Smoothen Current flow	4	$2
01/2/2021	purchased	IRF540 MOSFETS	Control flashes and solenoid	3	$2
24/11/2020	Purchased	HD Analog Camera	Maneuvering View	5	$80
23/2/2021	Purchased	Raw copper Boards	Master Oogway's Motherboard	3	$5
25/2/2021	Purchased	Flash	Supports Camera's View	2	$12
05/01/2021	Purchased	Power Cables 10 AWG	Master Oogway's Tether GND and +12	46m	$31
05/01/2021	Purchased	CAT6 Cable	Tether Signals Transition Cables	46m	$16
05/01/2021	Purchased	Tether Mesh	Covering Master Oogway's Tether	23m	$63
Control Unit					
20/01/2021	Purchased	LED Display Screen	Displaying Cameras' View for Pilot	1	$35
20/01/2021	Purchased	DVR	Receiving the Camera's Signals	1	$20
06/10/2019	Re-used	Network Switch	LAN Network	1	$10
24/11/2020	Purchased	Analog Camera Amplifiers	Noise Filtering	5	$10
10/04/2018	Re-used	PS4 Joystick	Pilot Maneuvering	1	$20
15/01/2021	Purchased	Control Box Case	For Station Assemble	1	$15
Electrical Components Sub-Total					**$970**
Mechanical Components					
02/01/2021	Purchased	9mm Polyamide 6 Sheet	Master Oogway's Frame	1	$76
02/01/2021	Purchased	6mm Acrylic Sheet	Manipulators and Electronics Housing	1	$35
02/01/2021	Purchased	Polyamide 6 Solid Cylinder	Electronics Housing	1	$125
03/02/2021	Purchased	CNC Service	Master Oogway's Fabrication	-	$154
11/04/2021	Purchased	3D Print Service	Master Oogway's Fabrication	-	$100
12/01/2021	Purchased	Lathe Cutting Service	Master Oogway's Fabrication	-	$150
02/02/2021	Purchased	Camera's Case	Camera's Sealing	4	$80
02/02/2021	Purchased	Flash's Case	Flash's Sealing	2	$30
28/01/2021	Purchased	O-Rings	Sealing	10	$5
15/01/2021	Purchased	10mm Stainless Steel Rod	To support Oogway on ground and fix slider	2m	$25
28/01/2019	Re-used	Pneumatic Piston	Pneumatic Powered Manipulator	1	$25
28/01/2019	Re-used	Solenoid Valve	Pneumatic Powered Manipulator	1	$10
21/02/2021	Purchased	Bolts, Nuts and Nails	All-over Master Oogway for parts fixation	-	$50
25/03/2021	Purchased	Pneumatic Hose	Pneumatic Path, Cables Sealing	30m	$8
15/10/2018	Re-used	Compressor	Pneumatic Feed	1	$94
28/01/2019	Re-used	Tools	Master Oogway's Manufacturing and Fabrication	-	$80
24/03/2021	Purchased	Gasket Maker	Sealing	5	$7
24/03/2021	Purchased	Pneumatic Fitting	Electronics Housing Sealing	25	$16
Mechanical Components Sub-Total					**$1080**
Cost Projection Total					**$2050**

Appendix – G | Flowcharts

1- Oogway's Full System Flowchart

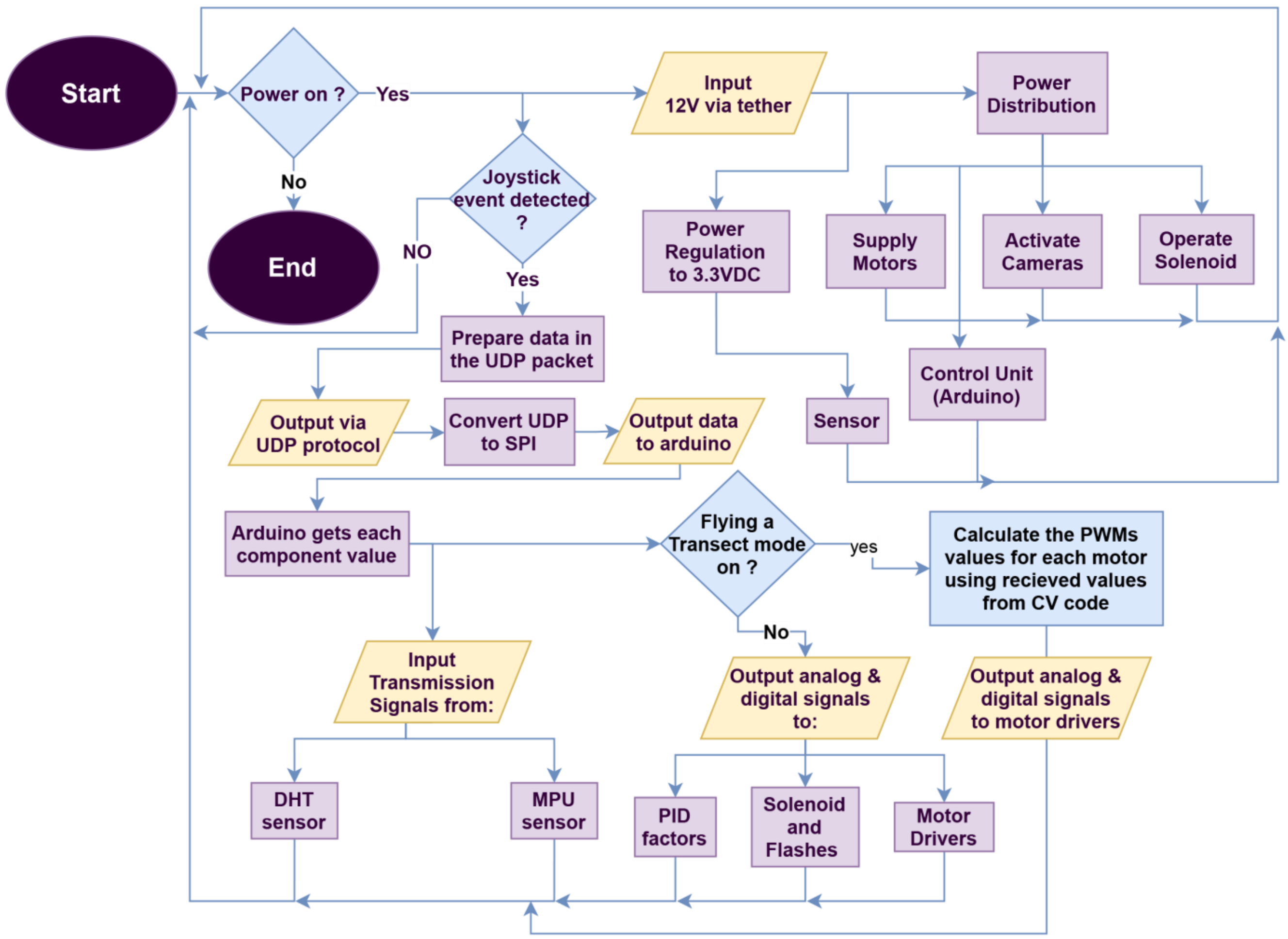


Figure 42. Full system Flowchart

2- Station to ROV Flowchart

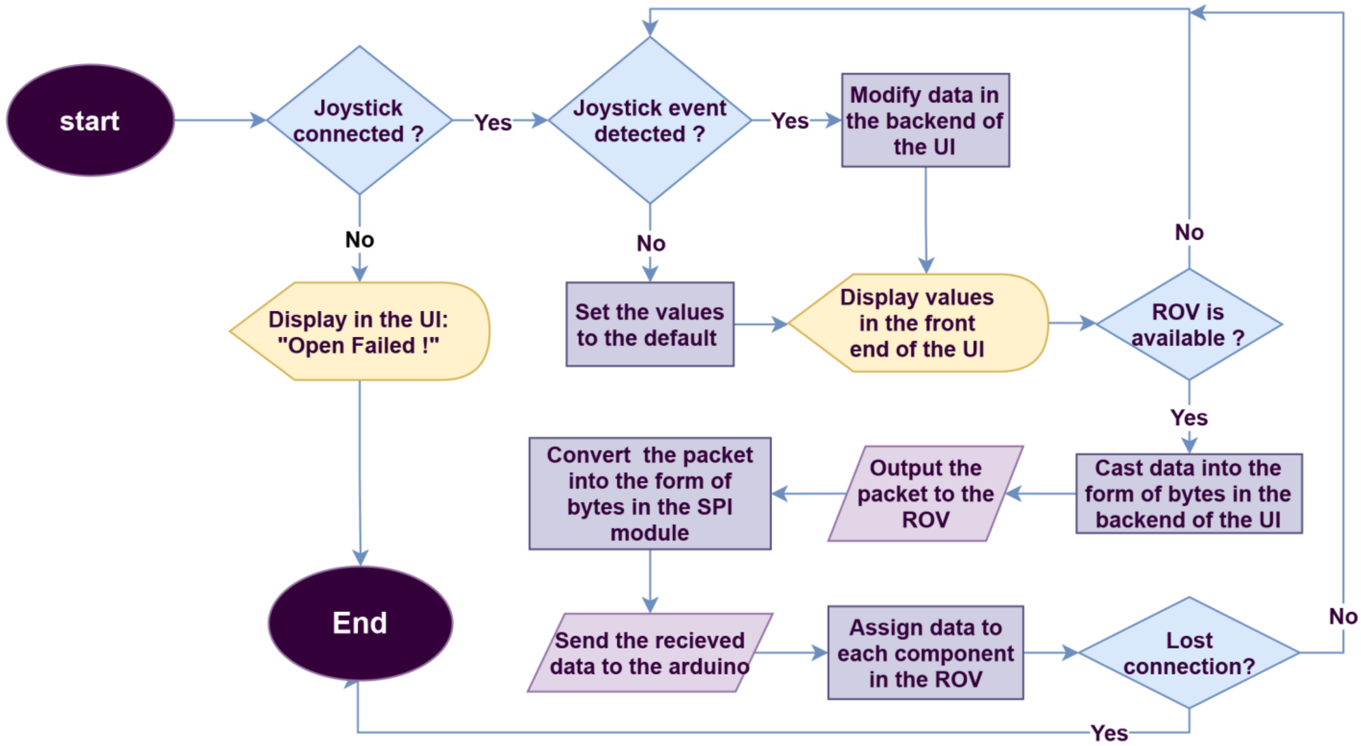


Figure 43. GUI Flowchart

3- ROV to Station Flowchart

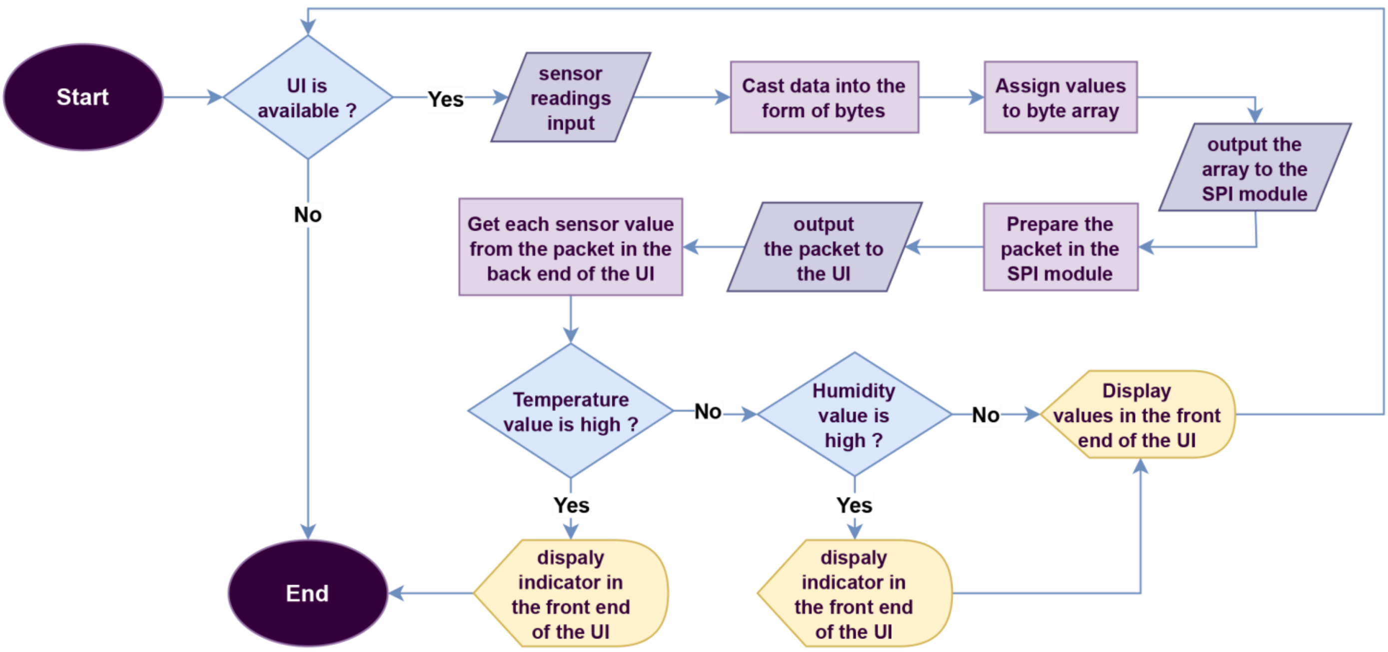


Figure 44. Arduino Flowchart