VORTEX ACADEMY
THE ART OF THINKING

MATE

MAGNIFICENT VORTEX BEE

MVBEE

Technical documentation

Alexandria , Egypt

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I.Abstract:

It is crystal clear that the recent exploration in the eastern Mediterranean has sparked renewed interest in the greater region, highlighting its potential as an emerging front for marine exploration and attracting significant interest. The Red Sea has a unique environment, but as one of the most diverse marine ecosystems, it has great beauty and great tourist value.

Magnificent Vortex Bee was founded this year, by the mentoring of Vortex Robotics Company. The team consists of 24 mechanical, electrical and software engineers. We decided to build a ROV to be a part of the real marine.

M.V. Bee’s goal was to provide lower cost ROVs with higher efficiency such as Bumblebee. Bumblebee is built with a strong mechanical structure that can help everywhere underwater to achieve the best solutions to real-world marine technology problems, Bumblebee's strength lies in the artificial intelligence and control system, to achieve the required precision and development. Bumblebee is designed and built to support actions to combat climate change, provide clean energy, feed a growing world population, monitor the health of our oceans, preserve our marine history, and "deliver, together, the ocean we need for the future we want!"

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

Figure (1) M.V. Bee Company Team Members

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Design Rationale:

1. Design process

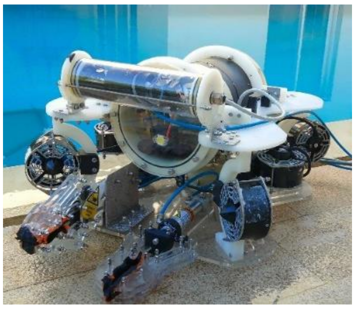


Figure 2:Bumblebee

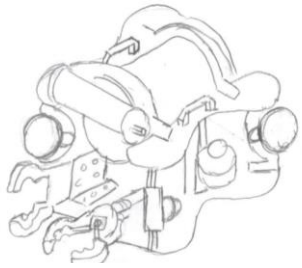


Figure 3: Bumblebee's Freehand sketch

Under the guidance of "Vortex robotics" which competed several times in MATE ROV competition & after thoroughly reviewing the tasks required by our client, Bumblebee came to life. Our goal was to create an ROV that was stable, lightweight, compact, easy to assemble, adaptable and cost-effective. Bumblebee's ultimate design was achieved through a series of processes where members of the team were instructed to brainstorm ideas of their proposed ROV's systems conception.
Mechanical team members freehand sketched their proposed designs, then discussed and modified these designs to establish the outlines of the final design. Electrical and software team members targeted a robust integrated electrical and control system that complies with the required missions and decided on the key components needed. Then, the space needed for the electrical system was estimated and upon receiving the dimensions of the electronic components, solid modeling Computer Aided Design (CAD) and Computer Aided Engineering (CAE) programs -as SolidWorks- were used to create and test our ROV. In-parallel our software team stared to research on the best controller, cameras and companion computer that provides all the needed tasks and still be cost efficient, afterwards they started using each of those components, running testing codes on every component, testing their compatibility and ways of communication with one another until the full software was finalized based on the given tasks and missions.

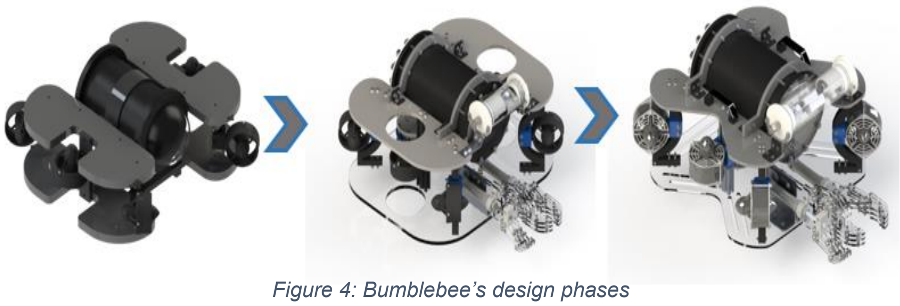


Figure 4: Bumblebee's design phases

2. Mechanical Design

A. Frame:

Figure 5 BumbleBee's frame

Our frame consists of a top deck, made of two 8mm-thick HDPE wings and a 6mm-thick laser-cut transparent PMMA base. HDPE was used over PMMA for the wings for its higher ductility which is the determining factor as the wings are the baring point of the eight of the ROV when carried from the handles. Although heavier, PMMA was used for the base over HDPE for its rigidity; to prevent any bending that might occur, and its higher density shifts the center of gravity downwards. Openings were cut from the PMMA base to decrease the ROV's weight and reduce the drag force in vertical movement.
8 10mm-thick HDPE supports -where each 2 are tangentially fixed together- hold the upper deck and the base together, mounted at the corners of the frame, at an angle 45^{o} to hold the thrusters at the desired orientation, along with two Aluminum supports The two wings are connected by four 10 mm-thick HDPE parts that are fixed to the top deck wings by L-shaped metallic parts, where the main electronics enclosure rests on them. Two Aluminum Alloy handles were added to the top deck wings for the ROV to be easily held. **Figure (7).**
U-shaped 3D-printed PLA parts **Figure (6)** were used to mount the thrusters on the inclined HDPE parts and on both Aluminum extrusion profiles.

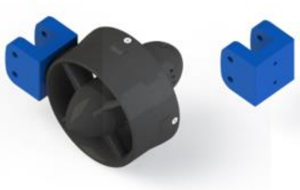


Figure 6: Thruster Fixed on 3D Printed Part

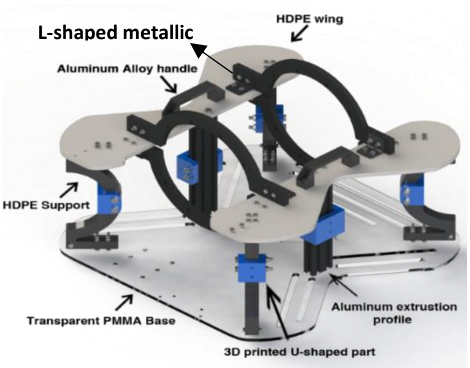


Figure 7: CAD rendering of BumbleBee's frame

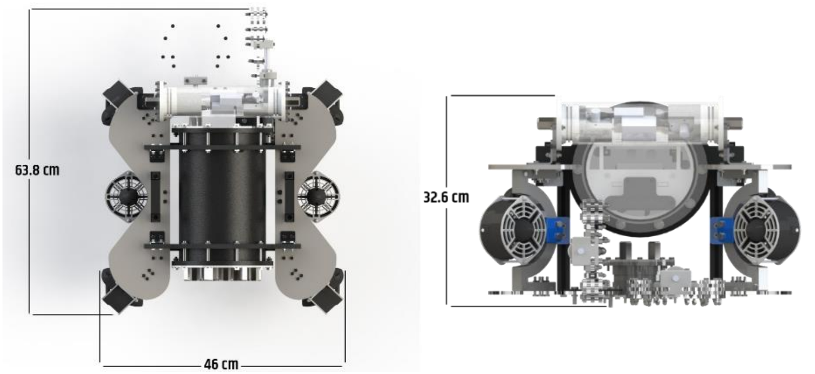


Figure 8: Bumblebee's dimensions

criteria		weight				material options					
		frame	gripper	Fastners	Brackets	Score					
						HDPE	PMMA	Aluminum	Stainless steel	PLA	PA type 6
1	Cost effectivness & availability	0.2	0.4	0.2	0.2	9	7	5	3	6	1
2	Machineability	0.1	0.1	0	0.3	7	5	9	1	9	9
3	Specific gravity	0.2	0.1	0	0.2	9	9	7	1	9	9
4	Strength	0.2	0.4	0.8	0.1	6	7	8	9	4	8
5	Ductility	0.3	0	0	0	5	1	2	3	7	4
Scoring formula		Total score=(weight of component x material score) per criteria									
Total score		Frame				7.6	5.2	5.5	3.6	6.8	5.7
		Gripper				6.1	7.2	6.8	5	6.2	5.4
		Fastners				6.6	7	7.4	7.8	4.4	6.6
		Brackets				6.2	4.4	4.1	1.8	6.1	5.5

Table1: Material Trade-off matrix

B. Buoyancy and stability:

Bumblebee occupies a displaced volume of 702484 cm3 and weighs 19.5kg in air. The largest displacement component is the electronics enclosure, occupying a displaced volume of 7755 cm^3; hence, it's placed at the top to shift the center of buoyancy upwards increasing Bumblebee's stability. The weights and the heavy payloads are placed at the bottom shifting the center of gravity downwards to achieve stability **Figure (9)**. Bumblebee's body is positively buoyant in water, so to maintain a neutral buoyancy, small weights were added evenly at the bottom to equalize weight with buoyancy. Also, foam was added to the tether at equal spacing to neutralize its buoyancy maintaining balance and stability of the vehicle.

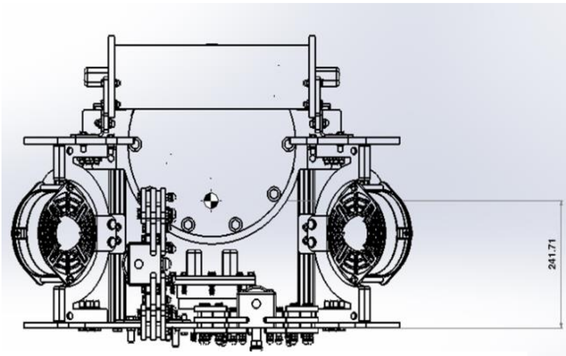


Figure 9: Bumblebee's center of gravity 241.71 mm from base

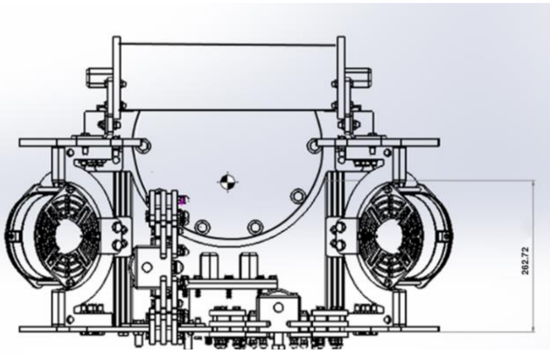


Figure 10: Bumblebee's center of buoyancy 262.72 mm from base

C. Propulsion:

We started by researching several types of thrusters where we aimed to reach a combination that provides sufficient thrust and all the degrees of freedom needed. Also, stability was a key factor in determining our thrusters because it is critical for missions as flying over a transect line and determine the average size of the fish cohort. We opted for using 4 T-100 Blue Robotics thrusters and 2 T-200 Blue Robotics thrusters as they have proved durability and dependability and we were able to reuse thrusters from prior years, so this was also a cost-effective decision. And most importantly, they can be integrated with our Pixhawk controller, which can identify the number of thrusters and their positions on the frame giving us maximum stability also it can control power reaching each thruster using its built in PID.

Name	T100	T200	DISKDRIVE 50
Current	7.86 A	8.32 A	7.58
Thrust	1.65 Kg f	2.71 Kg f	2.1 kg f
Price	(Reused) $170	(Reused) $200	$499
Availability	✓	✓	Not available
Microcontroller Integration	✓	✓	Not integrated
So, we chose to use 4 thrusters T100 and 2 Thrusters T200			

Table 2: Thrusters Trade-Off

Direction	Maximum Thrust
Forward	(2x23.15cos(45)) +(2x17.85sin(45))=57.98N
Backward	(2x23.15cos(45)) +(2x17.85sin(45))=57.98N
Up	2x36.38267= 72.76N
Down	2x28.4393=56.87N

Table 3: Thrust Force Calculation

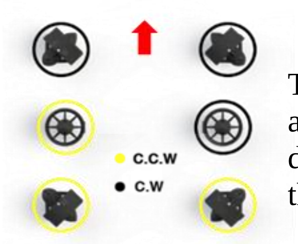


Figure 11: Thruster Configuration

The 4 T100 thrusters are horizontally vectored at 45° for surging, swaying and rotation, and the 2 T-200 thrusters for heaving. Each two corresponding thrusters use opposite direction propellers, one CW and the other is CCW, to counter-effect each other's moment thus eliminating the spin effect, making the ROV immensely stable.

Figure 12: Mesh on Thruster

Our mechanical team created meshes **Figure (12)** that meet the IP20 requirement. As a result, any foreign objects with a diameter of 12.5 mm or bigger are protected from the thrusters.

Drag force Equation: FD= ½ ρv2CDA= ½ x 1000x 12 x 0.10832223 x 172756.57 x 10-6= 9.35 N

- Calculation done at 1 m/s
- Frontal Area calculated using Solidworks
- CD calculated using Ansys Fluent

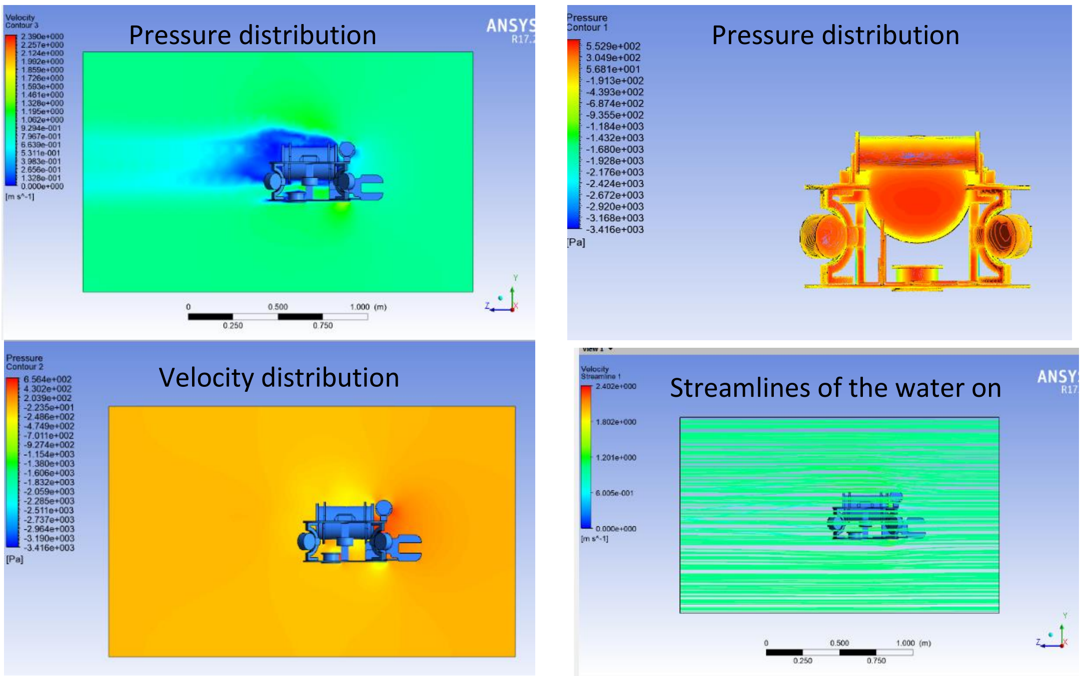


Figure 13: Flow Simulation Results done on Bumblebee Using Ansys Fluent

D. Electronics enclosure and sealing:

Bumblebee houses 3 sealed enclosures; the main electrical enclosure, one for the 2 CCTV cameras, and one for lowlight camera.

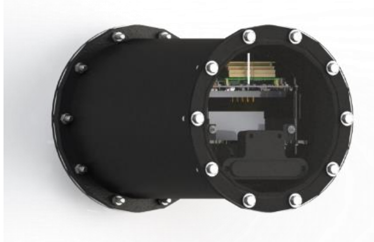


Figure 14: Bumblebee's Enclosure

The electronics enclosure **Figure (14)** of Bumblebee is a 30cm long flanged cylinder with a 16.5cm inner diameter and a 6mm wall thickness. Polyamide (PA type-6) was chosen as it is a non-porous, high-strength, and shock-resistant material. Either side of the cylinder is capped with a laser-cut PMMA facet allow for the O-ring compression checking and allow the vision for the OAK-D on the front side.

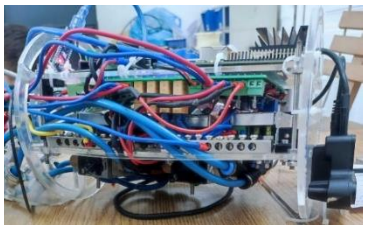


Figure 15: Internal Structure

The internal structure **Figure (15)** of the electronics enclosure is made up of PMMA shelves on which the electronic components are mounted. Heavier components, such as DCVs, are placed on the lower levels, while light components are placed on the upper shelves to increase stability.

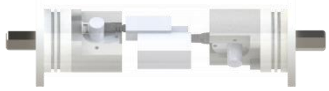


Figure 16: CCTV cameras Enclosure

The CCTV cameras enclosure is made of PMMA and sealed from each end using an HDPE cap, the lower enclosure which contains the low light camera is made of a machined Polyamide (PA6) cylinder covered with a transparent 4 mm PMMA sheet acting as a lens cover.

Figure 17: Low-light Camera Enclosure

Our company underwent a debate on whether to buy expensive waterproof cameras or buy normal cameras and build their sealing enclosures ourselves, and we decided on the latter option as it would in an effective vision system with less cost.

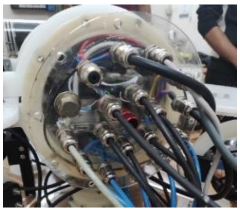


Figure18: Bumblebee's Glands

For Sealing, the 3 enclosures utilize O-rings which were selected according to the Parker sealing Handbook. O-rings were used as they could sustain a pressure differential of up to $5x10^5$ Pa. To seal between the cables and the cable holes through the enclosure, nickel-plated brass cable glands with an IP-68 rating are employed. These glands can withstand a pressure difference of around $5x10^5$ Pa and provide cable strain relief. To avoid damaging the undersea environment, no chemicals such as Silicon and epoxy were used for sealing.

Stress analysis **Figure (19)** was made on the enclosure to ensure that it could withstand more than the 5m pressure needed for the competition. The main electronic enclosure could sustain up to 11 m underwater with a FOS of 1.1.

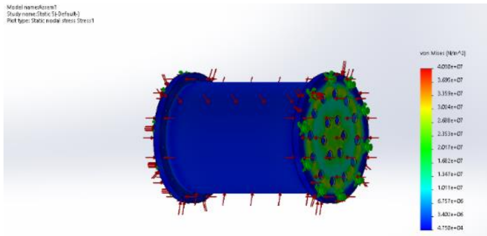


Figure 19: Von Misses Stress Simulation Results (11 m)

E. Pneumatic:

The pneumatic circuit **[shown in the Appendices section]** was first drawn and tested on FESTO software. We opted for using a pneumatic system to power our gripper over a standard motor, based on the availability of used pneumatic piston. Our pneumatic grippers proved to be far more efficient, faster & stronger than other motor-powered manipulators.

Our pneumatic system consists of 3 main parts; the top side consisting of the compressor & the relief valve, the 2 pneumatic pistons connected to 2 DCVs located in the ROV and the pneumatic cable that supplies the compressed air. Each pneumatic piston is controlled via a 5/2 DCV, the DCVs were selected in a manner where there would be no neutral position and connected such that each piston is normally closed. The pneumatic cable has an inner diameter of 4 mm and an outer diameter of 6mm and can withstand a pressure up to 10^6 Pa.

Figure 20: Pneumatic Circuit

F. Gripper:

Bumblebee is equipped with two pneumatic grippers **Figure (21)** one of them is horizontally fixed and the other is vertically fixed. The manipulators are designed to be multifunctional and adaptable to different types of objects. The horizontal gripper is designed to hold large objects up to 13cm in diameter or thickness while the vertical gripper could hold objects up to 10.5cm thickness.

Figure 21: Vertical (left) and horizontal (right) grippers

Also, the end effector has multiple curves to be able to handle different objects and PVC pipes sizes easily, the end effector is also coated with rubber to increase friction between the grippers and the held objects.
As the largest mission objects has outer diameter of 6.5cm/2in PVC, the grippers open wide enough to facilitate for the pilot manipulating all the mission objects making them suitable to do all the required missions, such as Removing the Marine Algae and transporting the non-ROV device.

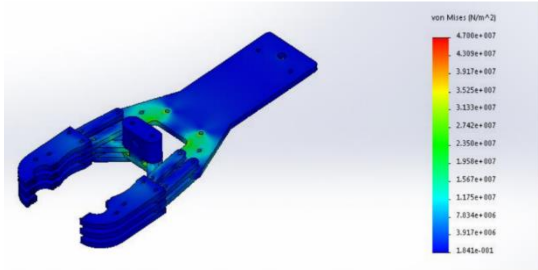


Figure 22: Von Misses Stress Simulation on the grippers

The manipulators are made of PMMA which was chosen as it is lightweight, durable, and most importantly transparent to provide for the pilot clear vision of what they are holding. The horizontal gripper is directly fixed to the base while the vertical gripper is fixed to two L-shaped aluminum parts that then are fixed on the base.

The grippers are comprised of two segments: a static side and moving side. The static side is fixed on the base of the frame whilst the moving side is fixed in rod of the pneumatic piston by using a nut embedded in 3D printed part attached to the piston's rod.

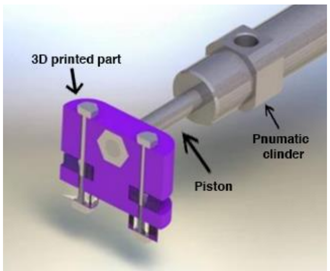


Figure 23: Part through which the piston passes

The pneumatic pistons have bore dimeter of 25 mm and stroke length of 50 mm and operate at a pressure of $25 \times 10^4 Pa$. The maximum force extended by the pistons can be calculated from the relation:

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

3. Electrical Design

Our electrical design was designed to be simple and reliable while still being modular to be readily maintained. In-house manufactured parts are frequently employed to save cost while maintaining mechanical and electrical customizability. To protect the safety of operators and equipment, the electrical team has established a few internal standards.

A. Power Distribution

First, we receive 48VDC from the power supply that goes directly to the bus bar inside the ROV. The bus bar then distributes the power to 4 12V DC-DC buck converters. We concluded that reusing the buck-converters, **table (4)**, as they proved, after thorough testing, to supply the voltage and current needed for the competition and the missions while being the cheapest option.
The 4 DC-DC buck-converters are connected to the main PCB by XT60 connectors. Each one of the first 3 12V DC-DC buck-convertors supplies power to 2 ESCs and each ESC powers and controls one thruster. The last 12V DC-DC buck-converter supplies power to the LEDs, camera s, DCV solenoids and the 5V DC-DC buck convertor that powers the Nvidia Jetson and OAK-D camera.

Figure 24: Distribution Buck-Converters

Name	Buck Converter 200W 15A DC-DC 8-60V	DCM3414B75H13C2C09
Weight	80g	248g
Size	70 x 38 x 31mm	85.93 x 35.54 x 9.4mm
Output Power	200W	320W
Price	(Reused) 81.08$	681.21$
Availability	Already available with spares	Not available in the country
So, we chose to use 4 Buck converter		

Table 4: Converters Trade-Off

B. PCB

Figure 25: The Main PCB

One of our major improvements in the 2022 season, is our main PCB. Where, for the first time, all the ESCs are mounted, saving us the trouble of 7 wires per ESC, hence, effectively saving the space taken up by these wires as well as eliminating the risk of short circuits or ESC damage. The main PCB contains: 5V DC-DC buck-convert or, connectors for thrusters, connectors for DCVs and LEDs, ESCs, connectors for Pixhawk connected to ESCs signal pads and 4 MOSFETs for controlling LEDs and DCVs. Before manufacturing our final PCB, we made a manual prototype to evaluate and test the entire system and debug any errors that emerged. One issue we found was with the control signal of the MOSFETS. The Nvidia Jetson was to control the gate of the MOSFETs, but while troubleshooting, we realized that the Nvidia's maximum output is only 3.3V while the gate needed 5V. So, to overcome this issue, an Arduino Nano, that can supply the 5V signal, was added to the system as a middleman between the Nvidia and the MOSFETS.

C. Power calculations:

The current supplied from the 48VDC power supply passes through a 25Amp fuse to reach the main electronics enclosure (200watts).

Component	Max current	Max voltage	max power	Quantity	Max power
T100	7.86A	12V	95.06W	4	380.24
T200	8.32A	12V	99.8W	2	199.6
Jetson	3A	5V	15W	1	15W
CCTV Camera	1.66A	12v	20W	2	40w
OAK-D camera	2A	5V	10W	1	10W
Low-light Camera	220mA	5V	1.1W	1	1.1W
DCV	0.8A	12V	9.6W	2	19.2W
LED	0.84A	12V	10W	2	20W
Sensors & other electronics					25W
Total power					710.14

Table 5: Power Calculation

- Current calculations= power/volt = 710/48= 14.79A
- Voltage drop=2*I*R*L
- {I= 22.185A, R= (5.2/1000), L=25m}
- Voltage drop=2*22.185*(5.2/1000) *25 = 5.7681 V
- Voltage drop percentage = 12.04%
- Voltage at the ROV side =42.22V
- Tether diameter= 2.08mm, AWG=12
- Fuse = 1.5*14.79= 22.185A
- FUSE USED IS 25A.

D. Tether

Our ROV is equipped with a 25-meter-long tether, which is a sufficient length to maneuver freely in the mission area. It consists of one 12 AWG power cable, 2 CAT6 (8-core) signal cables and 2 pneumatic cables **Figure (25).** One cat6 cable carries video signals of 2 CCTV cameras and the video signal of the low light camera to the TCU, while the second CAT6 cable transmits the Jetson Nano signal to communicate with Ethernet connection.

A management protocol for Bumblebee's tether was established for protection and easier handling and transportation. It is strain relieved to protect the cables against pulling on either ends. Also, once not in use, the tether is wound around a drum starting from the ROV side in a clockwise direction to protect it against tangling and possible scratches or breaks

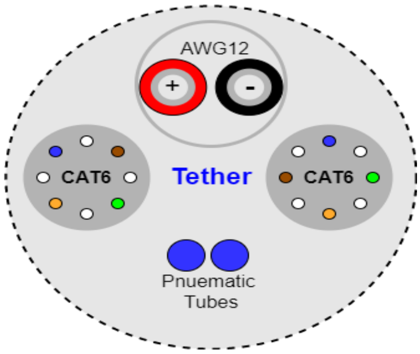


Figure 26: Tether

4. Software Design:

A. Vision System

The Bumblebee' Vision System consists of 4 cameras **figure (27).** It aims to maximize the pilot's field of view since different missions require different views of bumblebee.

First, The OAK-D is our front view camera placed in the main enclosure which we rely on for heading, measuring the wreck length (task 3.2) with its stereo vision, following the red rope (task2.1) as its frames go through the rope inspection software

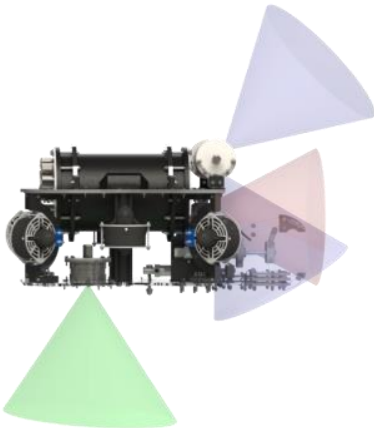


Figure 27: Vision System Camera Cones

We used a low light camera housed in a separate enclosure at the base of the Bumblebee for a bottom view used in creating the photomosaic (task 3.2). We connected the lowlight camera to our surface computer via an easy cap and also displayed its stream on the control unit.

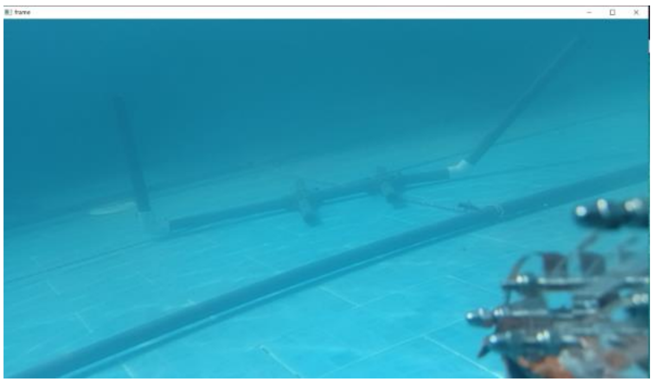


Figure 28: OAK-D view

We also installed A CCTV camera for Grippers view used in any payload missions like delivering the hydrophone (task 1.3), another CCTV camera was positioned upwards to view the hole in the ice and the broken float engine (task 3.1). The use of CCTVs reduced the total Cameras' budget.

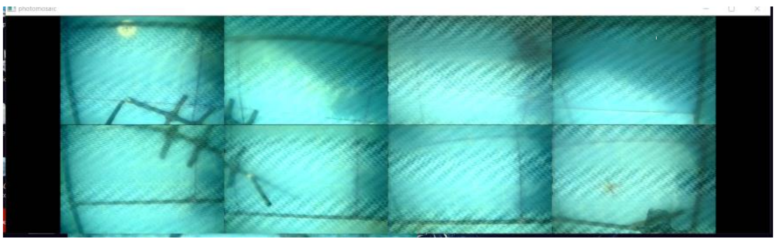


Figure 29: photomosaic captured by the bottom low light camera

B. Topside Control Unit

Our topside control unit (TCU) is built in a neat and workmanlike manner, without loose components or unsecured wires. The TCU was designed for easy transportation, setup, and protection. It contains 3 Power and 4 Ethernet connections to make it easy to either communicate with the ROV or power the TCU. The panel consists of a DVR and LCD screen. The DVR is used to display all the videos on the screen to enable the pilot to control the ROV in general and perform the tasks in specific, the data cables coming out of our ROV are only 2 RJ45 cables which makes it easy to plug and play Bumblebee.

Figure 30: Topside Control Unit

C. Software and Control System

Our product, Bumblebee, is made up of a unique set of innovative components that aid in the development of a high-precision ROV. Within the ROV software system, Bumblebee integrates joystick control as well as artificial intelligence automation. The software system consists of two subsystems

The first subsystem is the underwater system which mainly consists of:

- Nvidia Jetson Nano (computer on board)
- Pixhawk 1 (flight controller)
- Arduino Nano

A companion computer was preferred rather than a microcontroller as it can be used to interface and communicate with ArduSub on our Pixhawk via MAVLink protocol ,and due to its moderate computational power which made it powerful enough to handle video signals, and its useful peripherals (Ethernet) which facilitates the communication between the two subsystems .The Nvidia, was chosen as it can read the HD camera data with considerable frame rates and compresses it to be sent over vidgear after Raspberry pi 4 has proven having high latencies due to handling lower frame rates after being tested as a companion computer

Figure 31: Nividia Jetson Nano

Pixhawk1, is used to control Bumblebee's movement, it handles Bumblebee's stabilization and supports autonomous functionality using sensors to determine the ROV's state, the Pixhawk has many built- in sensors that our product uses such as: gyroscope, accelerometer, and magnetometer, and it enables configuring additional sensors such as the bar30 which we used instead of the built-in barometer ; all those sensors are fused using an Extended Kalman Filter to enhance our navigation system and enabling stabilization modes to be used like ALT_HOLD and STABILIZE flight modes supported by the Pixhawk, these flight modes enabled Bumblebee to fly along the red rope transect line and inspect the offshore aquaculture fish pen successfully (task 2.1),they also helped Bumblebee dock into the docking station (task 1.4) ,measure the fish length (task 2.3) create a photomosaic ,map and measure the length of the wreck (task 3.2) efficiently because of the high stability in picture capturing letting the Pixhawk take advantage over the Arduino. And pixhawk1 specifically was chosen over other versions of Pixhawk controllers because it is supported by a custom ROV firmware called Ardusub and compatible with many external sensors like our bar30 unlike its newer version pixhawk4 which we tested and it resulted in many compatibility issues with the sensors and the ROV system in general

Figure 32: Pixhawk1

Arduino Nano was used to send the 5-volt signal to the MOSFET needed to operate the gripper (DVC), considering that Jetson Nano only sends a 3.3-volt signal. The Arduino was chosen over the PCB for its smaller size, to fit in the main enclosure. Actuators Signals are sent by Arduino Nano when it receives Serial Data from our companion computer.

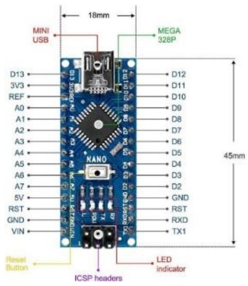


Figure 33: Arduino nano

Second subsystem is the topside computer:

1. It handles all the autonomous tasks and image processing
2. Receive sensor data and reads joystick input to send it as commands to the companion computer through network between them using socket python library.
3. Receive camera stream using Vidgear python library by UDP protocol.
4. Runs the GUI

Original software:

Our first approach for the main control system after picking the Pixhawk as our main controller was using Qground Control application to operate Bumblebee manually, then we started to develop our own control software based on the pymavlink library and the Mavlink protocol. This provided flexibility in managing control parameters like top speed and flight modes control and we were able to utilize the full capabilities of the pixhawk1 and use it in our autonomous missions like docking (task 1.4) and following the red rope transect line (task 2.1), we based our software on simple basics of OOP and socket communication which is further discussed in the next part.

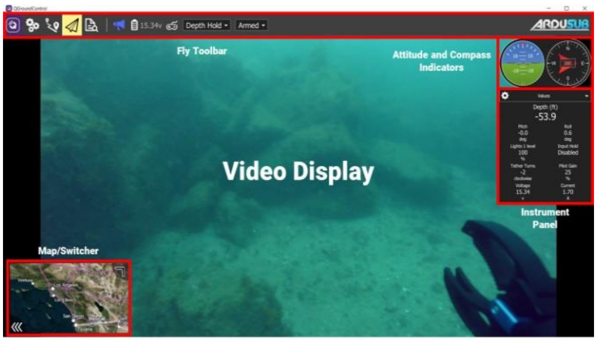


Figure 34: Qground Control

D. Topside communication:

Main communication system:

The two subsystems communicate using TCP protocol using a python library called "socket". The companion computer is the server which listens on a specified port for connection on the local IP address whereas the main laptop is the client. Data of interest are sent bidirectionally between Jetson Nano and our main laptop. The joystick signals are translated into indicators on the GUI and into control commands sent to the companion computer via the socket, the companion computer in turn communicates with the Pixhawk using pymavlink (a python implementation of the MAVLink protocol), and sends Serial Data to the Arduino Nano which sends actuator signals to operate the grippers. In the reverse direction, Pixhawk's sensors data are retrieved by the companion computer and sent to the main laptop to be displayed on the GUI via the same socket, the OAK-D frames are also sent to the main laptop via vidgear.

GUI

It Displays the indicators and readings needed for the pilot to control the ROV through the main Graphical User Interface (GUI) shown in Figure (35), which comprises multi-button controls for all autonomous tasks: docking, red rope transect line ,in addition to all image processing tasks: mapping, creating a photomosaic of the wreck, determining float destination making our product as simple as possible where it allows the user to have full control over the ROV easily.

Figure 35: Bumblebee's GUI

E. Software troubleshooting

To prevent problems in the first place, we implemented testing scripts that enables us to test each part in the structure of our control system separately before integrating the system as a whole unit but because of the numerous issues we encountered during the stages of development of our project and since software is the shortest route to handle a problem, it was inevitable to establish a fast effective software troubleshooting sequence to make it easier to debug any issue that might arise while integrating the codes or to make sure that the problem isn't software related.

If the system fails to operate, we first check whether our main laptop is able to communicate with jetson nano which is connected to our network using ping command in the terminal, then we check that the server in the bottom side has started listening on the specified port by making sure that the client on the surface is able to connect to it, after ensuring that the joystick is plugged in we test the communication between the top and bottom side through testing the Bumblebee's LEDs and grippers, then we arm our vehicle and test the thrusters to make sure there is no issues concerning the Pixhawk. If we faced any problem while running the codes, we return to the initial testing scripts as a reference to be able to specify whether the problem is related to the socket communication, GUI, etc.

F. Deep Learning in Bumblebee:

Deep Learning provides practical results if you have powerful computation resources available (GPU acceleration) and large amounts of precisely labeled data. Our top side is powered by Nvidia GTX 1050 TI which can run the latest CUDA libraries essential for the Deep Learning frameworks. Our data is mainly gathered from resources provided by Mate (Videos and Prop-Building Instructions). Having enough resources, we used Deep Learning instead of Classical Machine Learning. Bumblebee uses Deep Learning Detection/Segmentation Models in the following tasks:

- Autonomously inspecting the netting
- Differentiating Mort from Live Fish

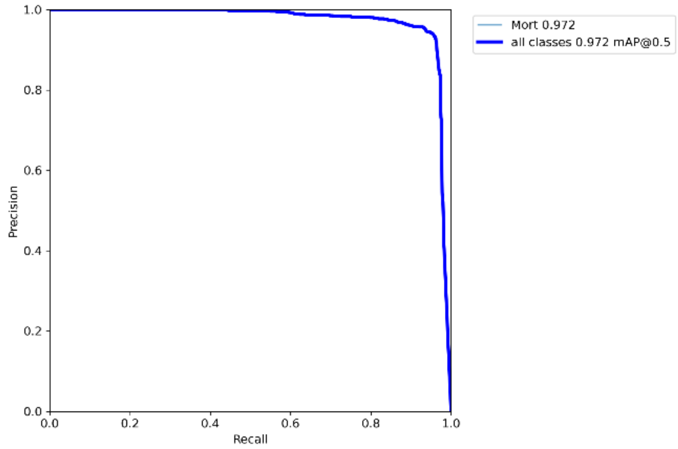


Figure 36: mAP = 0.972 and IoU=0.5

On the quest to find suitable models for our tasks, we trained and evaluated multiple state of the art DNNS. Our quest can be summarized in 3 steps

1. **Collecting and Augmenting Data**: In this step we collect data manually then we add to them a slightly modified copy from the existing data; this step helps reduce model overfitting.
2. **Training the Models**: Models are trained for 300 epochs, maybe less in some cases.
3. **Evaluating models using Mean Average Precision (mAP) metric**: mAP is a percentage that summarizes a **PR-CURVE** by calculating the area under the curve. Models with **higher** mAP percentage are chosen.

G. Stereo Vision in Bumblebee:

Stereo Vision is the process of comparing 2 or more views of the same scene and estimating the depth/disparity using relative points between the scenes. The required output here is a 3D map for the current scene. Using Depth/Disparity, we can estimate how far away objects are and possibly segment them if needed. A basic depth estimation algorithm is shown in Figure (37). Stereo Vision is needed for Autonomous docking task and Calculating fish length

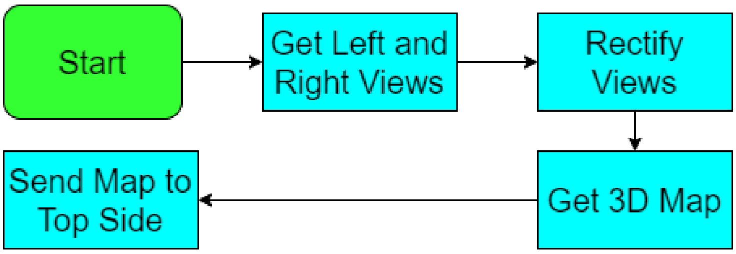


Figure 37: Basic depth estimation algorithm

The algorithm starts by capturing Left and Right views from a stereo camera, said views are rectified (each 2 corresponding points in the captured views must be on a horizontal straight line), then we get a 3D map that maps every pixel in one of the captured views to real life coordinates with respect to the camera.

Figure 38: left, right and disparity frames.

To acquire Stereo View, we can use out of the box cameras e.g. (ZED2 and OAK-D) or Two USB Cameras. It is recommended to use out of the box cameras as it offers less error than a two-camera setup.

Point of Comparison	Stereo Vision Camera	Two-Camera Setup
Capturing Views	A Stereo Vision Camera captures 2 frames by Hardware Triggering such that two images are taken at exactly the same moment	With multiple camera setup, views are taken one at a time.
Lenses	Lenses in a Stereo Vision Camera don't move resulting in accurate camera calibration	Lenses in a multiple camera setup can move easily which affects camera calibration

Table 6: Cameras Trade-Off

Bumblebee uses OAK-D camera mainly for its price and its embedded **Intel® Myriad™ X Visual Processing Unit** which is enough for running modern neural network (if needed) and depth estimation on the camera instead of our main computer (Jetson Nano). It is recommended to use ZED or Intel RealSense cameras given enough Budget and Resources to consume as they provide better depth estimation and mapping.

Figure 39: OAK-D Camera

Bumblebee's OAK-D was calibrated and tested using **charuco board calibration image.** In short, the calibration algorithm uses the intersections in the image to determine the orientation and distance of the charuco board. So, the greatest accuracy will be obtained by a clear print or display of the provided board image on a flat plane. After the calibration if we get a reasonable **epipolar error (less than 1)** we should have a practical depth map. Bumblebee's epipolar error is **0.2**.

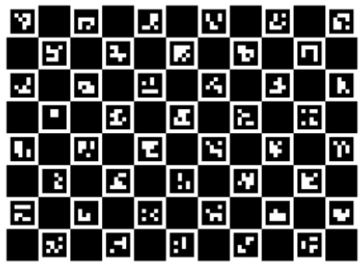


Figure 40: Charuco board calibration image.

H. Mission Specified Software

Drawing Wreck, Determining GO-BGC Float Destination and Determining Fish BIOMASS:

OpenCV Modules (high-up and imgpro) and basic mathematics were used to create a simple intuitive system for the missions outlined above. The chosen OpenCV modules provide us with basic drawing tools and callback functions which are enough to get the required output as shown.

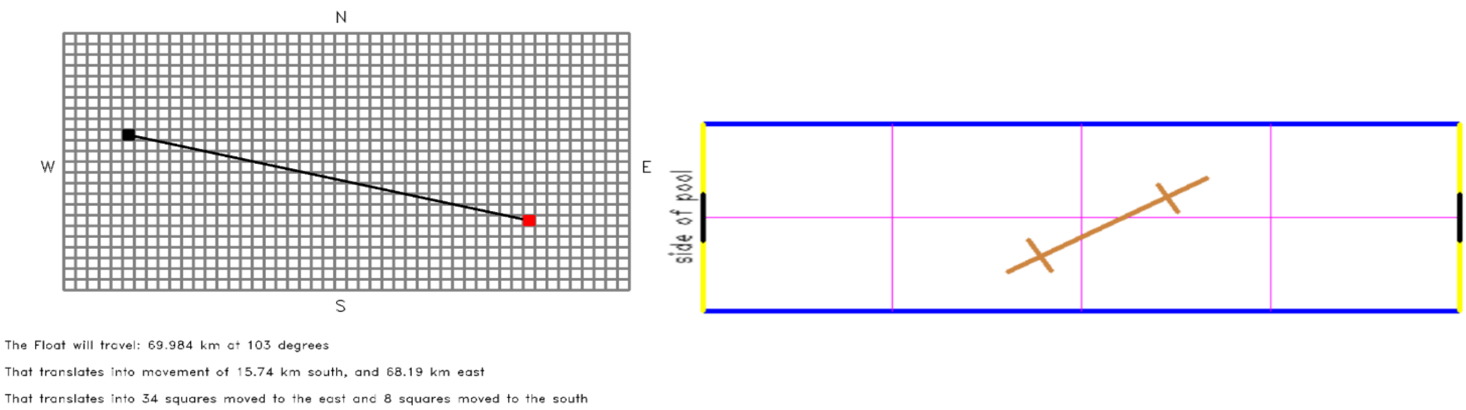


Figure 41: Float Destination and Drawing Wreck

Measuring Fish and Wreck Length:

Using Bumblebee’s stereo vision, we extract the 3D coordinates of the objects to be measured and calculate the distance using the Euclidean distance formula as shown in figure (42).

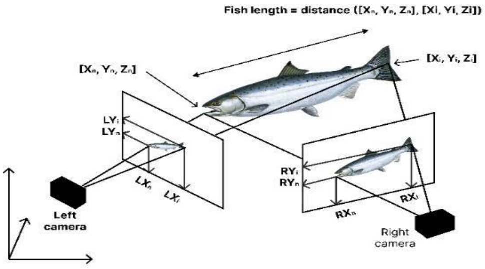


Figure 42: Estimating length Stereo vision

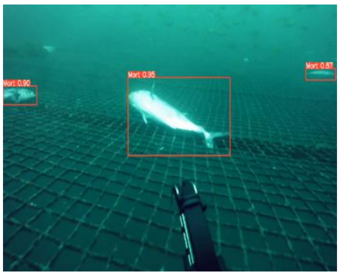


Figure 43: Detecting the Mort

Differentiating Mort from Live Fish:

using Bumblebee’s Deep Learning Models we can detect Mort

Autonomously inspecting the netting:

Using Bumblebee’s Deep Learning Models we can segment the red rope and find its slope. Using Bumblebee’s PID Control we can Guide Bumblebee accurately. By integrating both features we can do an autonomous inspection of the red rope.

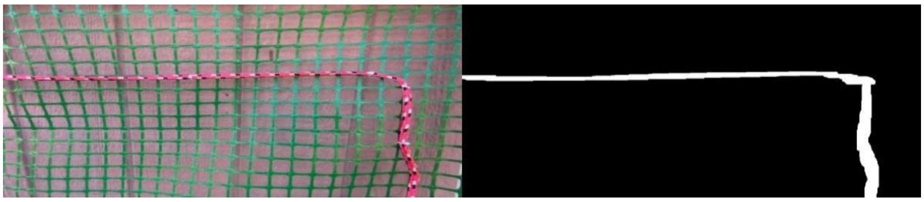


Figure 44: Segmenting the red rope

Autonomous Docking:

Using Bumblebee’s Stereo Vision and PID Control we can segment the red button, find its location with respect to our stereo camera (OAK-D) and guide Bumblebee to it.

Autonomous Creation of the Photomosaic:

To create the photomosaic of the wreck site, Bumblebee flies over each rectangle and takes snapshots using Bumblebee’s low light camera, those snapshots are mapped to a specific region in the photomosaic. After mapping all the rectangles, we get a full photomosaic as shown in the figure below. Also, our program can crop the mapped regions and switch them if needed.

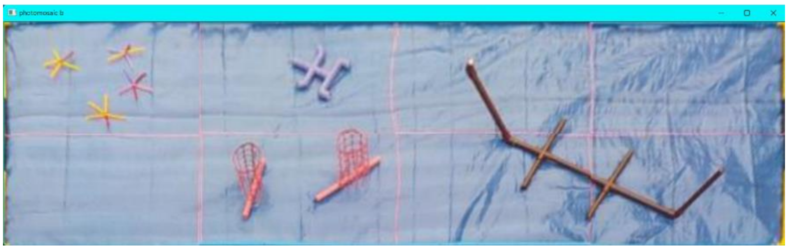


Figure 45: Full Mosaic

5. Non-ROV Device Vertical profiling Float - Dumblebee

BumbleJR is a Profiling Float designed to complete several Vertical profiles flawlessly. The float Compromises of 2 Separate enclosures, The Electric enclosure that holds up the brain of the float & a small water tank that holds 600 CCs. The two enclosures are connected via a HDPE connector.

The Float operates On a Buoyancy engine that utilizes two R385 Water pumps with a 3/2 DCV that is connected to the pumps in series. When the float is powered, the pumps starts filling & emptying the water tank, the DCV keeps the flow of water in the right direction. As water begins filling the tank, the float begins sinking then the pumps empties the tank making the float rise again.

The Electrical enclosure is made of PMMA and sealed from both ends with HDPE caps & O-rings, the water tank is made of HDPE and sealed from the top with a PMMA face. Pneumatic cables are used to facilitate the flow of water inside the float.

BumbleJR's Design **Figure (46)** was achieved after reviewing numerous ideas & tests. The Water tank is designed and positioned so that the float is stable while operating, Executing successful vertical profiles with a low center of mass. The electric components are also housed in a separate container from the water to avoid any harm to the float.

Figure 46: BumbleJR

We use a set of 8-in series 1.5V alkaline batteries in parallel with a same set, to reach 12V from the series connection and increase the mAmpH usage from the parallel connection. A fuse of 4Amp installed within 5 cm of the battery positive terminal.
The float consists of H-bridge , pump, solenoid actuated valve and Arduino nano to give the float the required signal. Once the float has been deployed, it would attempt to complete vertical profiles by touching the bottom and returning to the surface, and so on.

Component	Max current	Max voltage	max power	Quantity	Max power
Pump	0.3A	12V	3.6w	2	7.2W
solenoid actuated valve	0.4A	12V	4.8w	1	4.8W
Arduino nano	0.019A	5V	0.095w	1	0.095W
L298N	-	-	20w	1	32w
Total power					8.496W

Table 7: Buoyancy Engine Power Calculation

Logistics:

1. Company Organization and Teamwork

Magnificent vortex Bee (M.V Bee) consists of three main technical departments; mechanical, electrical and software departments. Each department is subdivided into several project groups. Each department first started with an engineering training program by our mentors. Once the training had ended, the CEO, CTO of the team and the leaders of each department were selected based on their performance in the training program and their personal skills. The leaders held frequent meetings and constantly gave tasks with deadlines to the team members to make sure that we were following our timeline.

The CTO held frequent meetings with the leaders to direct them and follow up the progress. The CEO held general meetings such that the three departments communicated regularly and followed the progress of one another.

Tasks were assigned such that each member had a specific role to play. For the mechanical department, one member was responsible for each of the following: designing the frame, the manipulators and payloads, the electronics enclosure and sealing, pneumatic systems, manufacturing. For the electrical department, two members were responsible for each of the following: PCB, SID & power calculations, Control panel and rewiring the enclosure. For Software, two members were responsible for each of the following: Controlling system of ROV, Deep learning and Vision.

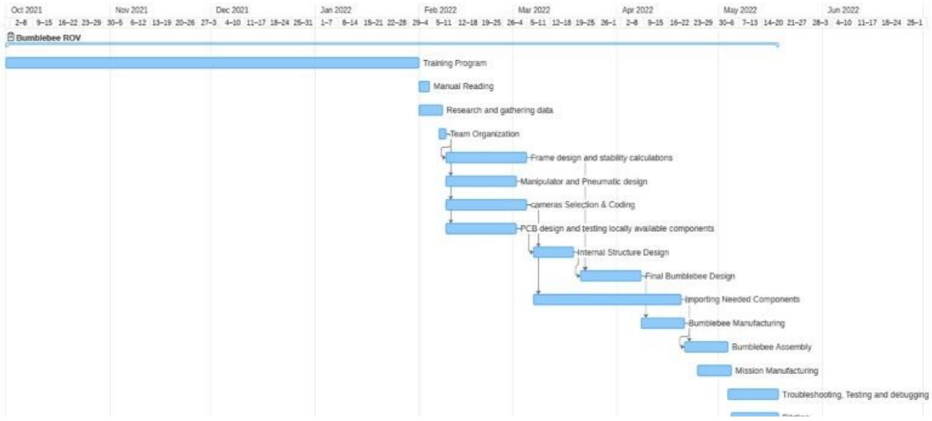


Figure 47: MVB's Gantt Chart

2. Project management

Our team was established after joining an engineering program that lasted for about four months and included all the needed information for building a well-functioning ROV. After finishing the program, a detailed schedule was prepared and deadlines were set to finish the entire ROV in three months, followed by pilot training until the regional competition. M.V. Bee team not only used a Gantt Chart but also used Trello to illustrate and distribute the tasks. Also, the team uses Slack application to communicate especially at Covid-19.

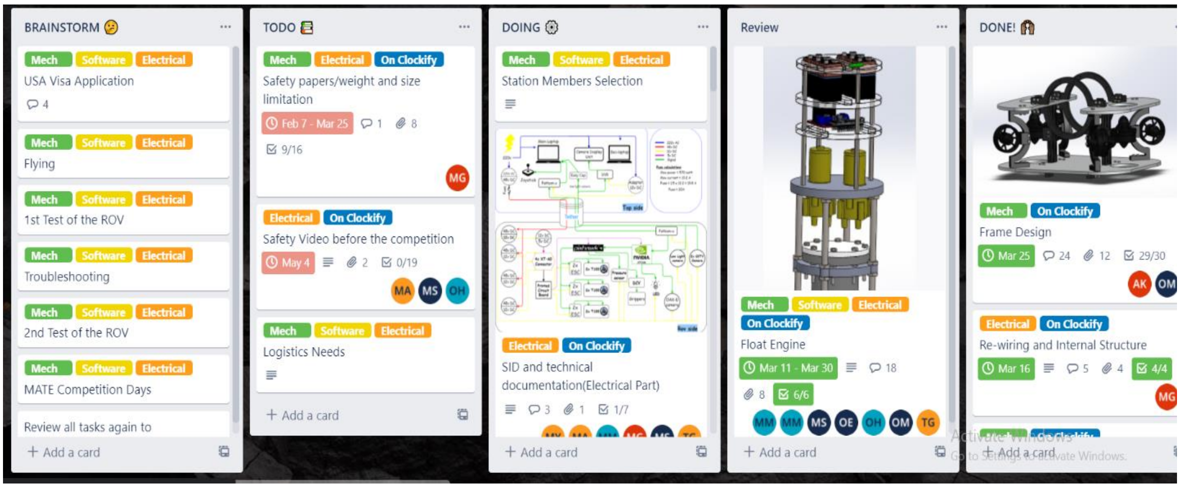


Figure 48: Our Trello Tasks

3. Accounting

Budget and Cost Planning:

After reviewing the RFP, we began selecting suitable components that was available at Vortex for our ROV. Next, we estimated the budget needed to buy & manufacture the remaining parts for bumblebee, travelling to the international competition, registration and accommodation ($27,322). We then collected the needed funds from our members equally; the total raised figure amounted to ($27,500). Both Budget & Project Costing can be found in Appendices B and C. M.V.BEE would like to thank Vortex Robotics for supporting & funding us. We really wouldn't be where we are now without them.

Conclusion

1. Testing and Troubleshooting

We have three parallel ways for testing, and we follow a specific strategy for each department.

Mechanical: to test the sealing made on Bumblebee, we insert the pneumatic hose inside every enclosure or component inside which we do not want the water to reach, Bumblebee is then placed in water, then we increase the pressure inside each component by using a compressor so that any improperly sealed component releases bubbles inside the water.

Electrical: The first step in any electrical device is to check for power to make sure the device is safe to work on, make sure that the system is connected correctly, if there a problem, we test all component separately in the internal structure, check the communication network.

2. Safety

Safety philosophy Figure (49) Example of safety in our workshop Throughout the construction and operation of our ROV, safety has been our highest priority. By employing safety protocols for using tools and requiring adult oversight during meetings, we worked efficiently and ensured the safety of our team members. All members were taught the proper operation of each power tool before they began using them with the supervision of one of our mentors. We are required to wear safety goggles, gloves, masks, and close-toed shoes when working with power tools. Also, to prevent accidents during fabrication, we cleaned all floors and organized all surfaces after every meeting. While testing, running on the pool deck was prohibited and all members (except the tether man) worked away from the pool edge. In addition to safety precautions taken during fabrication and testing, we developed many safety features onboard our ROV to ensure the safety of vehicle operators.

Figure 49: Example of safety in our workshop

Safety Instructions:

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

ROV safety features:

Mechanical Safety Features:

Our company prioritizes safety above all else and believes that all accidents are preventable by implementing strict safety measures. Therefore, numerous safety practices and protocols are enforced to ensure that all members are working under a suitable and safe environment as Safety instructions are always considered during designing, building, handling, and testing of the ROV.
Our mechanical engineers ensured the presence of no sharp edges on the ROV. Also, moving parts, such as thrusters, are covered with 3D-printed meshes designed by our mechanical team to meet IP20 standard. Thus, protecting the thrusters from any foreign objects of 12.5 mm diameter or greater. Cap nuts are used to eliminate any exposed threading.

Pneumatic Safety Features:

A pressure relief valve is added to the compressor and is set to 10 bars (106 Pa), which is the maximum allowable pressure for the tank, and the pressure regulator is always adjusted to 2 bars (2x105Pa). Pneumatic fittings either have O-rings, or Teflon tape is wrapped to prevent leakage. Also, all the pneumatic hoses are rated up to 10 bars (106 Pa) of pressure.

Electrical Safety Features:

- A fuse-box between the 48-volt DC power supply and the tether, which has an inline two fuses of 25 Amp was installed.
- Polarized connectors and color-coded cables are used to prevent inverted connections for power and signal transmission across the whole system.
- ROV's static sealing was tested against a pressure up to 2 bars and confirmed its potential for tolerance, and a water detection sensor is placed to detect any leakage.
- Glands work as strain relief for electrical wires.
- The Float Engine has a fuse of 4Amps.

Warning Labels:

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

Acknowledgement

- **Vortex Academy -** generously sharing their expertise and bringing in knowledgeable mentors.
- **MATE CENTRE AND MARINE TECHNOLOGY ASSOCIATION ACKNOWLEDGMENTS** - Thank you for the trials that have made us new dreamers in this profession.
- **AASTMT Arab Academy for Science Technology & Maritime Transport**– for Organizing the regional competition
- Thanks for the fantastic **Trello and Slack** management software, which really aided the team's task management processes.
- **Alexandria Language school** - For allowing us to test the ROV and for responding quickly to our request for swimming pool services.
- **SolidWorks™** – for providing us with student licenses.
- Collab Pro - thanks for faster GPUs.
- **GitHub** - Providing private code repositories for free
- **Adobe photoshop** - for providing license
- **Our Mentors** - for helping and guiding through every step of the way
- **Our Families and friends** - Their unwavering encouragement and support

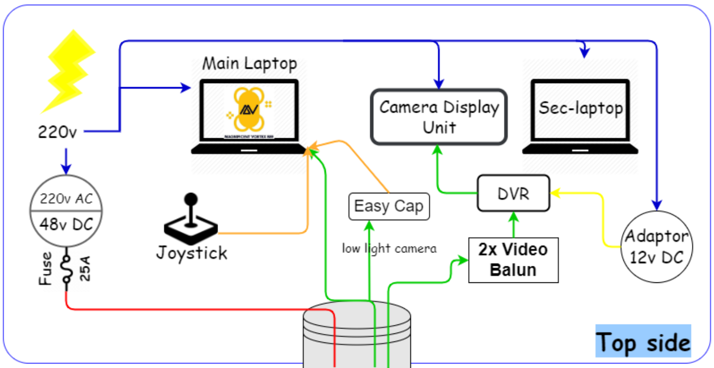
References:

- Parker O-ring handbook. 50th Anniversary Edition
- Fluid Mechanics Fundamentals and Applications by YunusCengel and John Cimbala 3rd edition
- Blue Robotics T100 Thruster Documentation https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t100-thruster-core/
- Blue Robotics analog camera Documentation https://bluerobotics.com/store/sensors-sonars-cameras/cameras/cam-usb-low-light-r1/
- Blue Robotics ESC Documentation https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/
- Blue Robotics Bar30 Pressure Sensor Documentation https://bluerobotics.com/store/sensors-sonars-cameras/sensors/bar02-sensor-r1-rp/
- object detection Documentation https://github.com/ultralytics/yolov5
- camera streaming Documentation **https://abhitronix.github.io/vidgear/v0.2.5-stable/**
- (AI) library Documentation https://pytorch.org/
- python Documentation https://www.python.org/
- Pixhawk protocol Documentation https://www.ardusub.com/developers/pymavlink.html
- main controller Documentation https://developer.nvidia.com/embedded/jetson-nano-developer-kit
- thruster controller Documentation https://pixhawk.org/
- MATE ROV Competition Manual Explorer https://files.materovcompetition.org/2022/2022_EXPLORER_Manual_21_JAN_2022.pdf

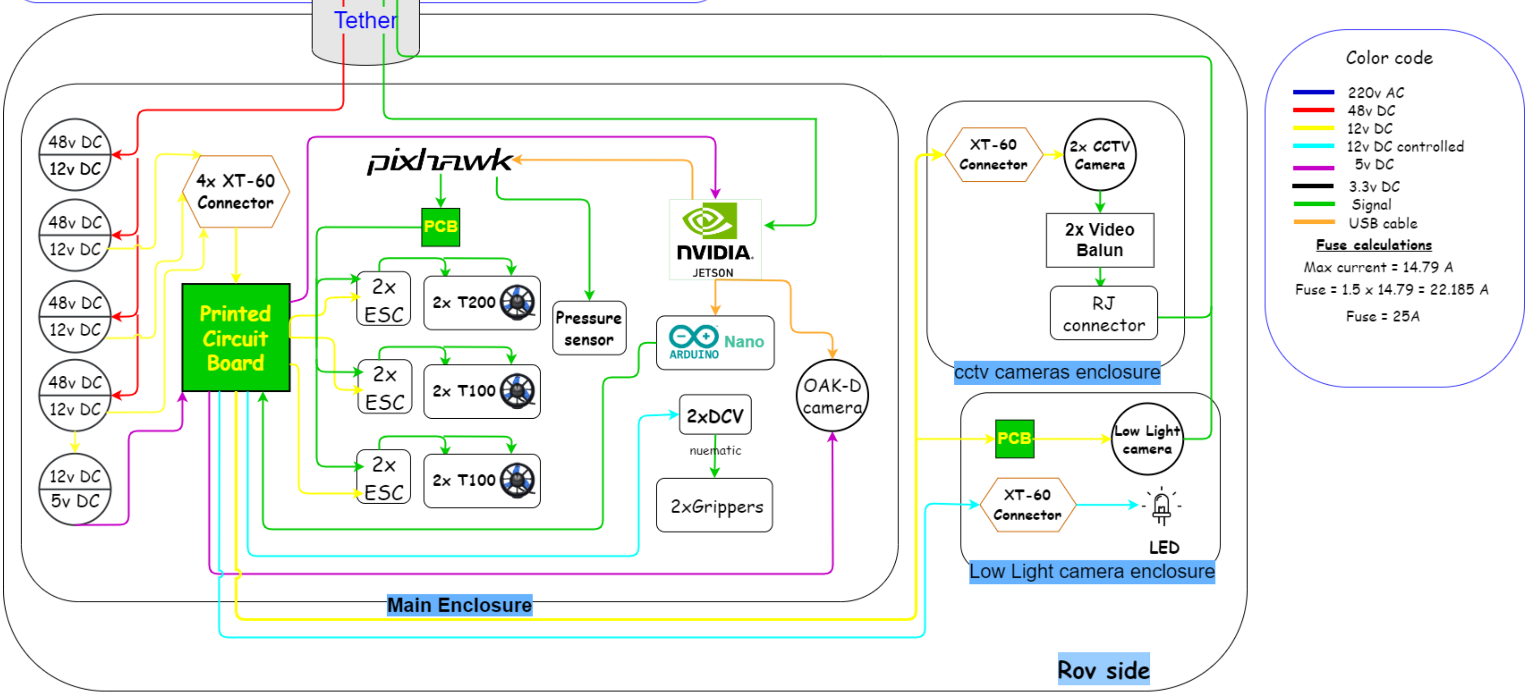
Appendices:

SIDs:

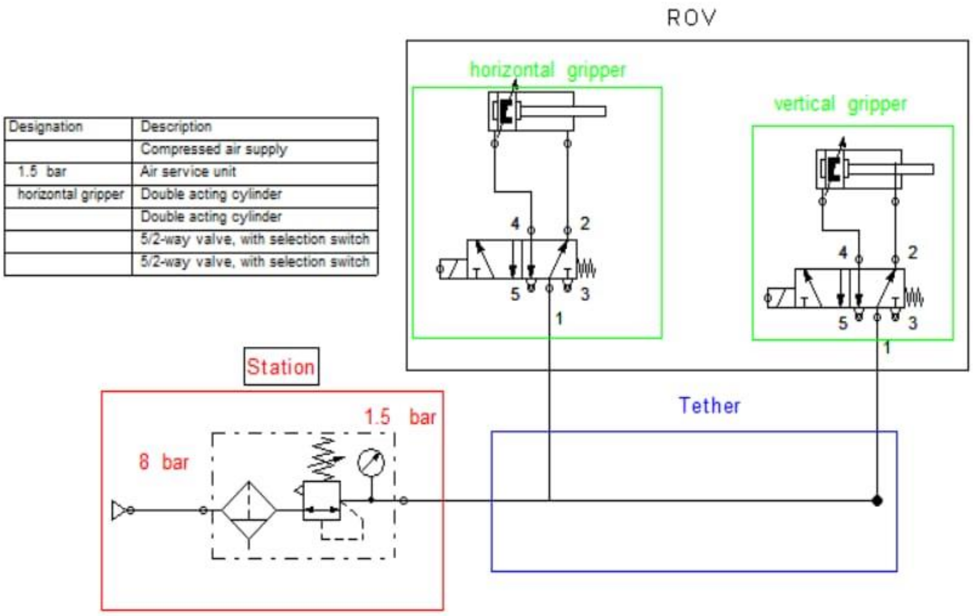
Main Electrical SID



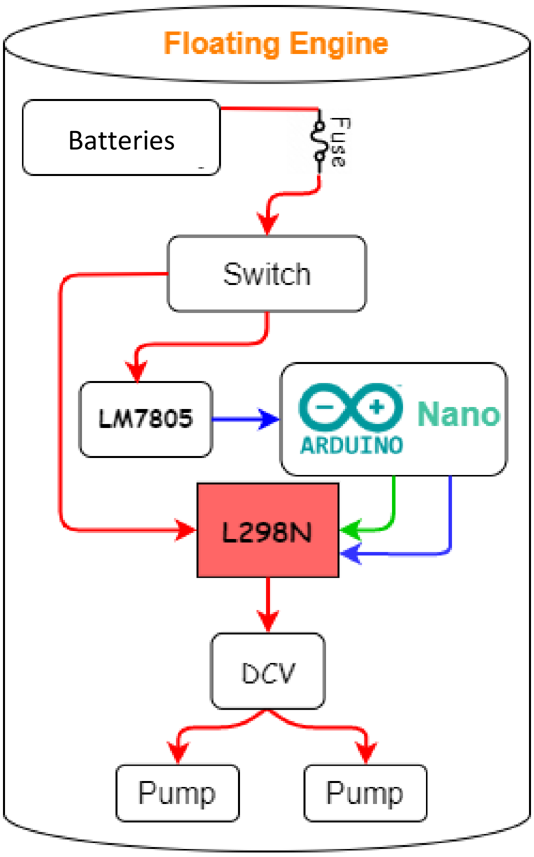
Component	Max current	Max voltage	max power	Quantity	Max power
T100	7.86A	12V	95.06W	4	380.24
T200	8.32A	12V	99.8W	2	199.6
Jetson	3A	5V	15W	1	15W
CCTV Camera	1.66A	12v	20W	2	40w
OAK-D camera	2A	5V	10W	1	10W
Low light camera (blue robotics)	220mA	5V	1.1W	1	1.1W
DCV	0.8A	12V	9.6W	2	19.2W
LED	0.84A	12V	10W	2	20W
Sensors and other electronics					25W
Total power					710.14



Pneumatic SID



Buoyancy Engine SID



Color code

5v DC

12v DC

Signal

<u>Fuse calculations</u>

Max current= 2.6A

Fuse= 2.6 x 1.5 = 4A

Component	Max current	Max voltage	max power	Quantity	Max power
Pump	0.3A	12V	3.6w	2	7.2W
solenoid actuated valve	0.4A	12V	4.8w	1	4.8W
Arduino nano	0.019A	5V	0.095w	1	0.095W
L298N	-	-	20w	1	20w
Total power					32W

Budget

Category	Income	Source	Amount(USD)	
		Self-Funds from Team Members	$2,500	
	Type	Description	Projected Cost	Budgeted value
Tether	Purchased	Cat 6	$55.00	$55.00
	Purchased	Power	$45.30	$45.30
	Re-used	Pneumatic Cables	$22.30	
Electronics	Re-used	DC-DC Conveters	$103.00	
	Re-used	ESCs	$210.00	
	Purchased	Main PCB	$76.60	$76.60
	Purchased	Prototype PCB	$37.00	$37.00
	Purchased	Nvidia Jetson	$306.00	$306.00
	Purchased	Pixhawk	$135.00	$135.00
	Re-used	Arduino Nano	$11.60	
	Re-used	OAK-D Camera	$210.00	
	Re-used	CCTV Cameras	$92.00	
	Re-used	Low Light Camera	$45.00	
	Re-used	Power Supply	$82.00	
	Purchased	Pressure Sensor	$40.00	$40.00
Float Engine	Purchased	Materials & Fabrication	$63.50	
	Re-used	Arduino Nano	$11.60	
	Purchased	Water Pump	$16.60	$16.60
	Purchased	PCB	$15.00	$15.00
	Purchased	Batteries	$55.00	$55.00
	Purchased	Switch	$10	$10
	Re-used	DCV	$25.50	
Control Panel	Re-used	Screen	$120.00	
	Purchased	Joystick	$115.00	$115.00
	Purchased	Case	$134.00	$134.00
	Re-used	DVR	$112.00	
	Re-used	Video Baluns	$36.00	
	Re-used	Easy cap	$8.00	
	Purchased	Case Accessories	$35.00	$35.00
Hardware	Re-used	Main Enclousure Material (PMMA & PA type6)	$190.00	
	Re-used	Camera box (Face Seal)	$80.00	
	Re-used	Camera box (Piston Seal)	$35.00	
	Purchased	Grippers Material (PMMA)	$41	$41
	Purchased	Grippers Manufacturing (Laser-Cutting)	$29.00	$29.00
	Purchased	Aluminum Extrution	$112.00	$112.00
	Re-used	Glands	$150	
	Purchased	O-Rings	$5.60	$5.60
	Re-used	DCVs	$51.00	
	Re-used	Pneumatic Piston	$48.00	
	Re-used	Fittings	$32.00	
	Purchased	Bolts & Nuts	$70	$70
	Purchased	3D Printed Parts	$112.00	$112.00
	Re-used	Thrusters T100	$680	
	Re-used	Thrusters T200	$400	
	Re-used	Trusters' Mesh	$40.00	
	Purchased	Copmressor	$135.00	$135.00
Travel	Purchased	Round-trip to long beach california	$21,630.00	$21,630.00
	Purchased	Travelling in the country	$405.00	$405.00
Accommodation	Purchased	7 days in Long beach california	$3,244	$3,244

Total Income	**$2,500**
Total Expenses	**$29,717**
Total Re-used	**$2,795**
Total Expenses - Re-used	**$26,922.00**
Total Fundraising Needed	**$24,422.00**

Project Costing

Date	Type	Category	Descrption	Sources/Notes	Amount	Project Cost	Running Balance
1/4/2022	Cash donated	General	Self-Funds from Team Members	Used for general veicle construction	$2,500		$2,500
7/13/1905	Re-used	Electronics	DC-DC Conveters	Vortex Company	$103.00	$103.00	$2,500
	Re-used	Electronics	ESCs	Vortex Company	$210.00	$313.00	$2,500
6/4/2022	Purchased	Electronics	Main PCB	Signal & Power distribution	$76.00	$389.00	$2,424
6/4/2022	Purchased	Electronics	Prototype PCB	Testing the system of the main PCB	$37.00	$426	$2,387
6/4/2022	Purchased	Electronics	Nvidia Jetson	Companion computer	$306.00	$732	$2,081
6/4/2022	Purchased	Electronics	Pixhawk	Main motor controller	$135.00	$867	$1,946
	Re-used	Electronics	Arduino Nano	Vortex Company	$11.00	$878	$1,946
	Re-used	Electronics	OAK-D Camera	Vortex Company	$210.00	$1,088	$1,946
	Re-used	Electronics	CCTV Cameras	Vortex Company	$92.00	$1,180	$1,946
	Re-used	Electronics	Low Light Camera	Vortex Company	$45.00	$1,225	$1,946
	Re-used	Electronics	Power Supply	Vortex Company	$82.00	$1,307	$1,946
9/4/2022	Purchased	Electronics	Pressure Sensor	To get the ROV depth	$40.00	$1,347.00	$1,906.00
9/4/2022	Purchased	Float Engine	Materials & Fabrication	Float fabrication	$63.50	$1,410.50	$1,842.50
	Re-used	Float Engine	Arduino Nano	Vortex Company	$11.60	$1,422.10	$1,842.50
9/4/2022	Purchased	Float Engine	Water Pump	Profiling	$16.60	$1,438.70	$1,825.90
9/4/2022	Purchased	Float Engine	PCB	Controlling float	$15.00	$1,453.70	$1,810.90
9/4/2022	Purchased	Float Engine	Batteries	Float power	$55.00	$1,508.70	$1,755.90
9/4/2022	Purchased	Float Engine	Switch	Initialize the float	$10	$1,518.70	$1,745.90
	Re-used	Float Engine	DCV	Vortex Company	$25.50	$1,544.20	$1,745.90
	Re-used	Hardware	Main Enclousure Material (PMMA & PA type6)	Vortex Company	$190.00	$1,734.20	$1,745.90
	Re-used	Hardware	Camera box (Face Seal)	Vortex Company	$80.00	$1,814.20	$1,745.90
	Re-used	Hardware	Camera box (Piston Seal)	Vortex Company	$35.00	$1,849.20	$1,745.90
10/4/2022	Purchased	Hardware	Grippers Material (PMMA)	Grippers	$41	$1,890.20	$1,704.90
10/4/2022	Purchased	Hardware	Grippers Manufacturing (Laser-Cutting)	Grippers	$29.00	$1,919.20	$1,675.90
10/4/2022	Purchased	Hardware	Aluminum Extrution	Frame support	$112.00	$2,031.20	$1,563.90
	Re-used	Hardware	Glands	Vortex Company	$150	$2,181.20	$1,563.90
10/4/2022	Purchased	Hardware	O-Rings	Sealing	$5.60	$2,186.80	$1,558.30
	Re-used	Hardware	DCVs	Vortex Company	$51.00	$2,237.80	$1,558.30
	Re-used	Hardware	Pneumatic Piston	Vortex Company	$48.00	$2,285.80	$1,558.30
	Re-used	Hardware	Fittings	Vortex Company	$32.00	$2,317.80	$1,558.30
10/4/2022	Purchased	Hardware	Bolts & Nuts	fastners	$70	$2,387.80	$1,488.30
10/4/2022	Purchased	Hardware	3D Printed Parts	Holders	$112.00	$2,499.80	$1,376.30
	Re-used	Hardware	Thrusters T100	Vortex Company	$680	$3,179.80	$1,376.30
	Re-used	Hardware	Thrusters T200	Vortex Company	$400	$3,579.80	$1,376.30
	Re-used	Hardware	Trusters' Mesh	Vortex Company	$40.00	$3,619.80	$1,376.30
10/4/2022	Purchased	Hardware	Copmressor	Pneumatic system	$135.00	$3,754.80	$1,241.30
16/4/2022	Purchased	Tether	Cat 6	Signal	$55.00	$3,809.80	$1,186.30
16/4/2022	Purchased	Tether	Power	Power	$45.30	$3,855.10	$1,141.00
	Re-used	Tether	Pneumatic Cables	Vortex Company	$22.30	$3,877.40	$1,141.00
	Re-used	Control Panel	Screen	Vortex Company	$120.00	$3,997.40	$1,141.00
1/5/2022	Purchased	Control Panel	Joystick	Controlling	$115.00	$4,112.40	$1,026.00
1/5/2022	Purchased	Control Panel	Case	TCU	$134.00	$4,246.40	$892.00
	Re-used	Control Panel	DVR	Vortex Company	$112.00	$4,358.40	$892.00
	Re-used	Control Panel	Video Baluns	Vortex Company	$36.00	$4,394.40	$892.00
	Re-used	Control Panel	Easy cap	Vortex Company	$8.00	$4,402.40	$892.00
1/5/2022	Purchased	Control Panel	Case Accessories	TCU	$35.00	$4,437.40	$857.00
22/5/2022	Cash donated	General	Self-Funds from Team Members	For travel and accommodation	$24,500		$25,357
25/5/2022	Purchased	Travel	Round-trip to long beach california	Tickets	$21,630.00	$26,067.40	$3,727.00
25/5/2022	Purchased	Travel	Travelling in the country	Car gas	$405.00	$26,472.40	$3,322.00
25/5/2022	Purchased	Accommodation	7 days in Long beach california	Hotel	$3,244	$29,716.40	$78.00

Total Raised	**$27,000**
Total Spent	**$26,922**
Final Balance	**$78**

A- Operation and Construction Safety Checklists

Procedure	Check Mark
Pre-Power Checks	
• Everyone on the team is wearing safety gear.	
• No running at the pool.	
• Communication is loud and clear	
• Before conducting the safety check, power is turned off.	
• Make sure the fuse isn't blown.	
• Clear obstructions from propellers, shafts, and manipulators.	
• Electrical connections are waterproofed, and cables are tied down.	
• Make sure the working environment is clear of obstructions.	
• "Safe" should be shouted.	
Pre-Water Checks	
• Connect the tether cable to the control station and turn on the power of the system.	
• Test the video system.	
• Compress the electronics enclosure to the called dive's rated depth.	
• Verify that the internal pressure reading at the control station corresponds to the descent.	
• Turn off the system and say, "Water Ready."	
• Lower the ROV into the pool by two team members and the tether man.	
• "In Water," say it loudly.	
In-Water Checks	
• Check the warning lights after turning on the system.	
• Verify that the internal pressure is steady at the surface.	
• Check for air bubbles and look for leaks visually.	
• "Pilot in Command," say it loudly.	
Communication breakdown	
• Restart the ROV	
• Send another test package.	
• If there is no communication, turn off the ROV.	
• Bring the ROV to the surface with the tether and inspect it for damage or leakage.	
Recovery Checks	
• Make sure the ROV is at the surface and looking away from the pool wall.	
• Turn off the system and say, "Crew in Command."	
• Lift the ROV from the pool onto land by two crew members and a tether guy.	
Safety officer signature:	
Entering the Lab or Workshop	
• Wear the facemask and PPE provided by the company.	
• Sign and timestamp the Signing Sheet for Employees.	
Operating Power tools	
• Wear all PPE necessary for the tools.	
• Always keep your hands away from the tool's head.	
• Keep long hair tied back and spinning sections free of strings, ropes, and flexible fabrics/materials.	
Working with Electrical Components and Soldering	
• Use a solder fume extractor	
• keep the soldering iron or hot air hand tool in its holder, When not in use.	
• Check all electrical connections to ensure they are not in contact with liquids.	
Employee Signature:	