VORTEX ACADEMY
THE ART OF THINKING

MATE ROV COMPETITION

VORTEX TECHNICAL DOCUMENTATION

MATE

Vortex academy
Alexandria,Egypt

KRATOS

MATE24

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I. INTRODUCTION

ABSTRACT

Vortex, founded in 2022 and mentored by Vortex Academy, is committed to developing an ROV that meets stringent quality and safety standards while addressing global environmental concerns. With a team of 23 dedicated middle and high school students, the company has invested months in learning, planning, designing, testing, and refining our ROV, Kratos, and its float engine, Mako, to ensure their viability.

Kratos was meticulously designed to advance our understanding of oceanic processes and changes within the Ocean Observatories Initiative (OOI). Outfitted with specialized sensors, Kratos collects crucial data on ocean health and seismic activity for the SMART Cables initiative. It also implements innovative methodologies, such as probiotics for coral health restoration and conservation of Lake Sturgeon populations, aimed at safeguarding marine ecosystems. Mako, our floating engine, was crafted to establish a global network of chemical and biological sensors by deploying robotic ocean-monitoring floats worldwide under the NSF-funded GO-BGC Project.

Kratos ROV boasts advanced capabilities and specialized features for underwater exploration. With a state-of-the-art vision system, lightweight design, and two grippers for versatile object manipulation, it offers precise navigation and handling in diverse marine environments. Propelled by six thrusters and equipped with a custom-printed circuit board, Kratos ensures seamless movement and reliable performance for extended missions.

Figure 1: Vortex Company members taken by Regional Competition.

Back row (left to right): Ziad Khair, Mohamed Ashraf, our mentors: Omar Ahmed, Mahmoud Reda, Abdulrahman Essam, Ahmed Magdy, Abdelaziz Yousry.
Middle row (left to right): Yassin Elhamad, Adham Al-Hakem , Retail Khair, Haneen Ali, Rodayna Mohamed, Fares Hossam, Anas Karim, Salim, Abdulraof Fathy, Eyad Ahmed, Mustafa Hala.
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TABLE OF CONTENTS

II. DESIGN RATIONALE

DESIGN EVOLUTION

The evolution of our Kratos ROV design has been characterized by an ongoing pursuit of improved performance, versatility, and efficiency. In Kratos ROV, our focus is on ensuring basic functionality and ruggedness for various tasks. Throughout the competition contribution, advancements in ROV design concepts have led to the adoption of more durable and lightweight materials, resulting in sleeker designs capable of executing all missions effectively.

This year, the integration of sophisticated sensors, cameras, and manipulator arms has significantly expanded the capabilities of our ROV, enabling it to undertake a wide range of tasks. Additionally, enhancements in control systems and communication technologies have bolstered the operability of our ROV, enabling more precise and intuitive operation by our team members.

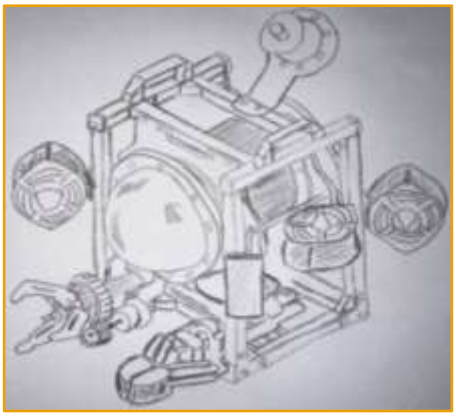


Figure 2: freehand Sketch of Kratos ROV by Retaj Tamer.

Figure 3: 3D Model of Kratos ROV by Solidworks.

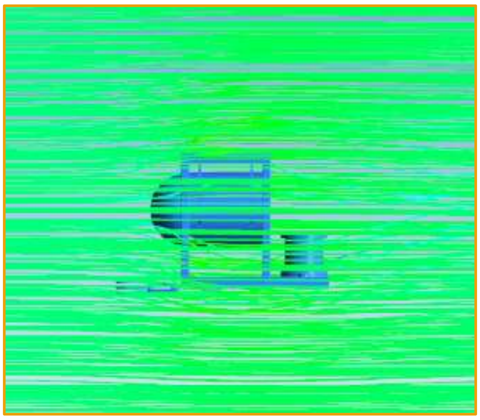


Figure 4: Water Simulation on Kratos ROV by Ansys fluent.

A. Mechanical Design Process

Kratos's design is completely distinctive. It is based and improves on previously manufactured ROVs. A considerable amount of time has been spent researching the advantages and disadvantages of the previous models, especially the 2022 & 2023 design concepts, as well as thinking about ways in which they could be improved. Following the design team's agreement on the schematics and the creation of freehand sketches-fig (2). The real work began with 3D modeling using SOLIDWORKS -fig (3) as a starting point. We simulated water flow through our vehicle by CFD using ANSYS fluent fig (4). So, we tested our design before Manufacturing. The mechanical design team put in a lot of effort, but their main challenge was getting our vehicle to move smoothly. This was achieved by our streamlined shapes that minimize the drag force on the design. The electrical team incorporated electronic components into our ROV through meticulous planning and close collaboration with the design team. This allowed for responsive control over the ROV's maneuvering path.

Figure 5: 2022 ROV (Left) & 2023 ROV(Right) captured by Retaj.

B. Vehicle Structure Approach

As we mentioned before Kratos ROV is the result of combining the 2022 ROV propulsion system - fig (6), which is represented by six thrusters - with the previous year's frame design - fig (5), where an aluminum extrusion profile is used with an opening design concept of the frame structure that minimizes drag force and reduces eddies in the water. This year's ROVs have more payloads such as two new cameras and a rotational manipulator.

Kratos ROV utilizes several innovative design features to retain excellent operational efficiency and control. For size, the main three dimensions of the ROV is 44.4 cm, 42 cm, and 52.6 cm. the vehicle was designed to fit in the launch and return area so it fits in 62 cm of circle diameter -fig (7) which is smaller than the 99 cm -fig (8) that the ROV must pilot through. For weight, The Kratos ROV weighs 11.4 Kg in the air, without a 25-meter Tether weight meeting the competition's weight requirement with the maximum bonus. In freshwater, the Kratos ROV can carry out missions deeper than 10 meters.

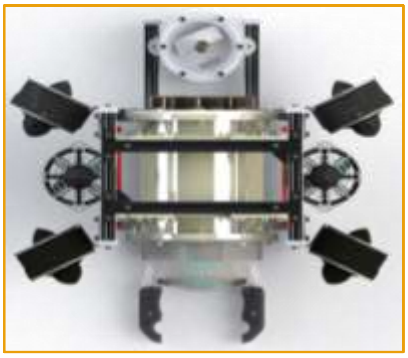


Figure 6: Propulsion system by SolidWorks.

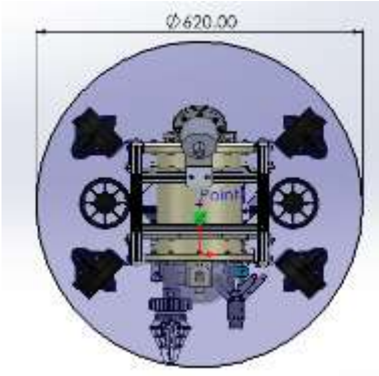


Figure 7: The Kratos ROV fits in 56.5 cm diameter by SolidWorks.

Figure 8: The launch and return area from prop building document.

C. Mechanical design Features and Modifications

1. Frame structure approach

There are several tradeoffs of materials, and structure base to be selected So, we selected the best material for the frame structure based on the nature of the component itself and the properties of each material, such as density, impact strength, flexibility, and cost -table 1.

Table 1: PMMA, HDPE, Aluminum, PLA, and stainless steel 304 materials properties.

Property	HDPE	Acrylic (PMMA)	Aluminum	PLA	Stainless steel 304
Density (g/Cm^3)	1	1.2	2.7	1.24	8
Impact Strength (J/m)	260	74	294	96.1	325
Flexibility (MPa)	24	71	90	80	540
Cost	Low	Moderate	Moderate	High	Moderate

The main structure of the frame -fig (9) consists of 20X20/20X40 Aluminum extrusion profile which is the main innovative decision by the mechanical design team that resulting in higher functionality at reduced cost. The AL-Extrusion profile consists of width of 20/40 mm and a thickness of 20 mm with different lengths. The easy accessibility previewed in the aluminum extrusion accessories such as aluminum corner, aluminum T shape, L shape, T nut and M5X8 bolt -fig (10).

Figure 9: Kratos ROV's main frame structure CAD design by solidworks

Figure 10: Al-extrusion and its accessories captured by Hoor.

2. Electronics Housing and Its Mounting

Aluminum extrusion profile is inserted to support the enclosure holding parts and to lock the rotation of the enclosure. The holder parts of the enclosure -fig (11) are made of HDPE (High-Density Polyethylene) material that was built using a CNC (Computer Numerical Control) router for its ductility, light weight, and density.

Figure 11: (Left) Enclosure and its holder CAD parts by Solidworks & (Right) Manufactured parts of the enclosure holders.

3. Dome

A 6mm thick transparent polymethyl methacrylate (PMMA) dome -fig (11) covers the front face of the ROV. The dome serves various objectives, including providing clear views of the surrounding area to the cameras, offering extra space to accommodate three cameras at different view angles, and lowering the overall drag force on the ROV as its shape is like a half sphere which has a coefficient of drag equal to 0.42-Fig (12) Vs the PMMA Face that its shape is like a circular disc, which has a coefficient of drag equal to 1.1- Fig (12) resulting in more efficient thrust power consumption.

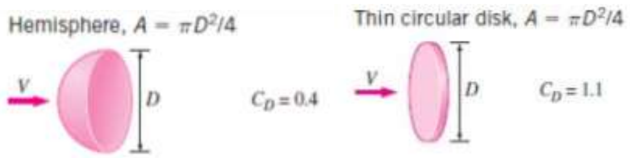


Figure 12: CD of Hemisphere Vs Thin circular disk from Reference of Fluid Mechanics: Fundamentals and Applications, 2nd Edition Yunus A. Cengel, John M. Cimbala McGraw-Hill, 2010

4. Aluminum Handle

For Easy lifting of the ROV we used the most rigid aluminum handles -**fig (11)** for two sides handling by two of the company members.

5. Sharp Edges Cover

3D printed part -fig (13) of PLA material to cover the sharp edges of the aluminum extrusion profile.

Figure 13: (Left) 3D printed part Thruster & (Right) sheet metal bent L mounting captured

6. Thruster Fixation

Thruster -fig (13) mounts of Stainless steel 304 sheet metal bent are fastened to four of the AL-profiles, two in front and two in back, at a 60/30-degree angle. We preferred the bent stainless steel rather than the 3d printed parts since the stainless-steel material has more strength, and rigidity but the PLA material of the 3d printed parts is fragile and absorbs water that makes it heavier.

7. The manipulator Mounting

The main manipulator is held in place by a 6mm thick PMMA (Acrylic) base -fig (14) that was built using a CNC (Computer Numerical Control) router and it is fixed on two profiles of 20X20 & 20X40 Aluminum Extrusion -fig (14). The Rotary manipulator is held by sheet metal bent L shaped Aluminum part and fixed into the Aluminum Extrusion by T-nut and M5 bolts.

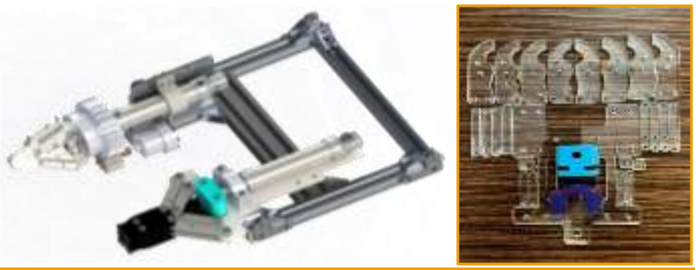


Figure 14: (Right) The manipulator and its PMMA base CAD design by SolidWorks & (Left)Real parts of the main manipulator and its base

Figure 15: (Left) Bottom camera mounting by Solidworks & (Right) Back vision camera and L shaped Aluminum Fixation.

8. Cameras Mounting

The rear bottom camera enclosure -fig (15) is mounted on a two 20X20 aluminum extrusion profile through T nuts and M5X8 bolts, and the back vision camera is fixed on a sheet metal bent L shaped Aluminum part that is fixed in the aluminum extrusion.

D. Buoyancy and Stability

The enclosure on the Kratos ROV displaces the most water, at 6055311.91 cubic centimeters, which is why it was put at the top of the ROV. The center of buoyancy (CB) is shifted upwards fig (16), counterbalancing the entire weight of the ROV and any payloads it may be carrying. The Kratos ROV has a great level of stability because the weights are placed at the bottom. As the foam is added, the result is a somewhat positively buoyant ROV that can be readily canceled out by the vertical thrusters when needed. Because of the symmetrical, the ROV's CB and CG are centered in the middle of the Kratos ROV and there are reference distance of X, Y, and Z with the origin point of the ROV.

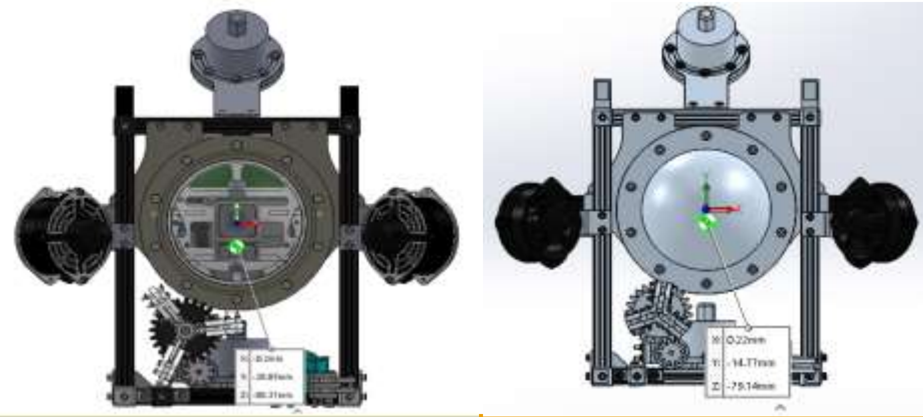


Figure 16: Centers of Gravity (Left) & Center of buoyancy (Right) by Solidworks.

E. Propulsion

Kratos ROV was designed to maintain all degrees of freedom required for maneuvering. As a first option, we could use two inclined T200 thrusters and two forward T100 thrusters to create a four-thruster configuration. This configuration was used in the 2023 ROV -fig (17), and it reduced power consumption and cost, but the thrust force in all directions was not sufficient to maneuver smoothly. Our second option was to utilize four thrusters T200, which were affordable, consumed more amounts of power, and slightly increased thrust force values, but did not include all degrees of freedom needed.

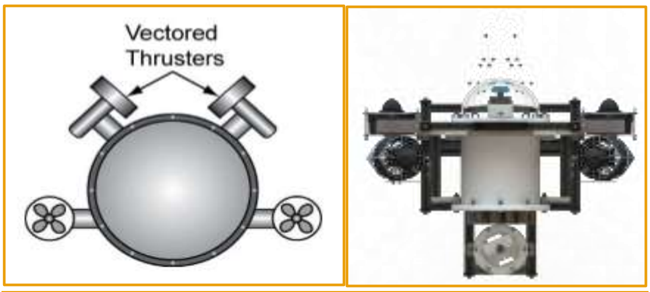


Figure 17: (Right)vectored thrusters' configuration from underwater robotics book & (Left) 2023 ROV's top view of four thruster configurations by SolidWorks.

So, the third option we have chosen is to upgrade the number of thrusters and change the overall configuration which is composed of 6 used T-200 thrusters manufactured by Blue Robotics-fig (17). T-200 thrusters are capable of producing thrust up to 3.55 Kgf in forward operation and 3.00 Kgf in reverse operation.

Two Vertical thrusters are placed on the center line of the Kratos ROV symmetrically to provide stability and balance for the ROV while propelling upwards or downwards resulting in the values of the upward and downward thrust forces -Table (2).

Figure 18: Kratos ROV's top view of thruster configuration by Solidworks.

The 4 horizontal thrusters are aligned with an angle of 45º providing a variety of maneuvering options in all directions with a good combination of speeds. Forward, backward, right, or left can be performed with 2 thrusters in forward operation during normal speed maneuvering or can be increased by using the 4 thrusters out of which 2 are forward operated and the other 2 reverse operated. The angle 45º was selected to give a good thrust component in the forward, backward, and lateral movement. This alignment of thrusters also enables Kratos Rov to rotate clockwise or anti-clockwise using 2 or 4 thrusters in the same way used for lateral movements.

After the first underwater testing, team members found that we needed a higher value of the forward movement than the lateral movement, so finally, we changed the four horizontal thrusters' angles from 45º to 60º resulting in the values of the forward, and backward maximum thrust forces -Table (2).

Alongside this combination of thrusters Kratos ROV, speed can be altered using our control system to give the best suitable speed for any specific mission or task.

Table 2: Maximum Possible Thrust Force Calculations.

Direction	Thrust Force (Kgf / N)	
	45º Angle orientation	60º Angle orientation
Upward	2 x 1.08 = 2.16 Kgf = 21.6 N	2 x 1.08 = 2.16 Kgf = 21.6 N
Downward	2 x 0.87 = 1.74 Kgf = 17.4 N	2 x 0.87 = 1.74 Kgf = 17.4 N
Forward	4 x 1.08 x sin (45) = 3.05 Kgf = 30.5 N	4 x 1.08 x sin (60) = 3.74 Kgf = 37.4 N
Backward	4 x 0.87 x sin (45) = 2.46 Kgf = 24.6 N	4 x 0.87 x sin (60) = 3.01 kgf = 30.1 N
Lateral	((2 x 0.87 x cos (45)) + (2 x 1.08 x sin (45)) = 2.76 Kgf = 27.6 N	((2 x 1.08 x cos (60)) + (2 x 0.87 x cos (60)) = 2.74 kgf = 27.4 N

Drag force calculations:

Coefficient of drag = 0.056883267 (Calculated from Ansys fluent)
Frontal area = 131803.81 mm^2 =0.13180381 m^2
Density = 1000 kg/m^3
Velocity = 1 m/s
Drag force = 3.75 N

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

where
F_D is the drag force
C_D is the drag coefficient
A is the reference area
ρ is the density of the fluid
V is the flow velocity relative to the object

Equation 1: Drag Force

F. Electrical enclosure and sealing

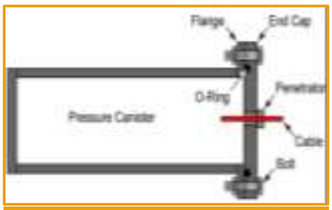


Figure 19: Cross section of the enclosure.

At the heart of our vehicle is an inclusive lathed machined pressure housing -fig (19) that is secured in place by a pair of rings linked to the top plate, giving it a sleek, hydrodynamic profile. HDPE enclosure with integrated flanges on both sides and 158x2.5 mm O-ring fitted in 1.5 mm deep slots. Because the O-rings -fig (19) are made of Nitrile, they operate as a robust sealant between the enclosure and the faces and were chosen according to Parker's Sealing Handbook specifications. In the enclosure, no chemical sealant was applied. Moreover, the enclosure has a 5mm-thick laser-cut clear PMMA face from one side -fig (21), and a PMMA dome -fig (19) from the other side, which were selected to provide clear vision for the cameras, as well as to check the compression of the O-ring. HDPE material was selected as there are no pores formed within the material, meaning that it can act as a perfectly sealed container. Stress analysis -fig (20) was made by SolidWorks static analysis to ensure that the enclosure can withstand a pressure up to 10 meters underwater with a factor of safety 1.1.

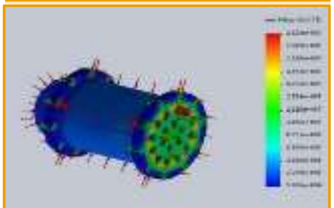


Figure 20: Stress analysis by Solidworks simulation.

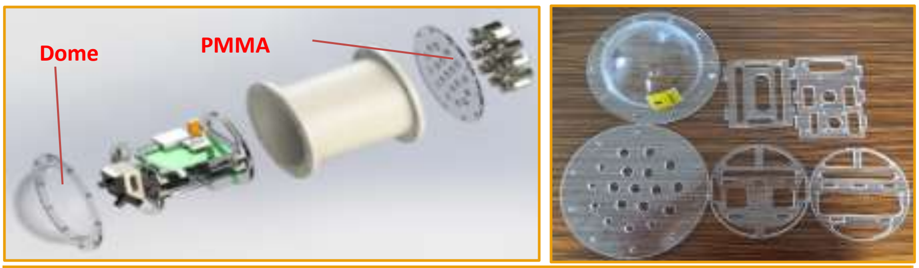


Figure 21: (Left) Kratos ROV's Exploded view of the electrical enclosure CAD design by Solidworks & (Right) Manufactured parts of the Electrical Enclosure.

G. Electrical System

Using pluggable wire connections, the underwater electrical system is designed to be straightforward, dependable, and simple to install. To minimize PCB size and accommodate large components like the Raspberry Pi, the electrical team specifically designed and produced a double-layer PCB.

1. Power Distribution and Calculations

The power supply from the 12-VDC source is directed through a 25 Ampere fuse located at the surface-end of the tether before reaching the onboard electrical system. However, fluctuations in power caused by voltage drop across the tether during increased loads disrupt the functioning of the cameras. To address this issue and stabilize the voltage, a repurposed buck-boost converter -fig (22) from Vortex Academy was integrated into the system. Notably, 12 volts are utilized to power various components such as DCVs, LEDs, ESCs, Arduino Nano, and cameras, while 5 volts from the Buck Converter -fig (23) are allocated to power the Raspberry Pi and Pixhawk.

Figure 22: buck-boost converter

Figure 23: Buck Converter

Particular emphasis is placed on propulsion control due to its significant impact on overall power consumption. To effectively manage power consumption, thruster movement is limited to one movement at a time, with speed limited to1680 µs -fig(24) input to the ESC. This required the development of a software locking system to regulate the current drawn by the thrusters. Basically, the maximum power consumption is limited to **352.56 watts**, with a peak current of **17.88 amps**. Therefore, although the required fuse is calculated to be **23.244 amps** based on a safety factor of **1.3**, a **25amp** fuse is still used as a precaution. Detailed power distribution is provided in Table 3.

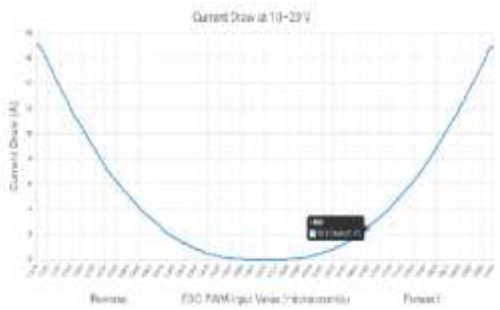


Figure 24: Thruster Power Curve by Blue Robotics

Table 3: Power Consumption Calculation

Component	Voltage (Volts)	Max current (Amperes)	Max power (Watts)	Quantity	Total Max power (Watts)	Total max current (Amperes)
T200	12	2.5	30	6	180	15
Bilge pump	12	10	120	1	120	10
Raspberry pi 4	5	3	15	1	15	3
Pixhawk	5	3	15	1	15	3
CCTV Cameras	12	0.275	3.3	4	13.2	1.1
Low Light Camera	12	0.22	2.64	1	2.64	0.22
DCV	12	0.28	3.36	2	6.72	0.56
Total power					**352.56watts**	
Maximum power consumption					**232.56watts**	
Actual Current Calculations					**17.88Amperes**	

Fuse Calculation:

ROV Overcurrent Protection= ROV Full Load Current * 130%

Fuse Rating = [(Blue Robotics Thrusters) + other system] *130%

Fuse Rating (horizontal thrusters) = [(4*2.5 Amps) +(7.88 Amps)] * 130%= 23.244 Amps

Fuse Rating (vertical thrusters) = [(2*2.5 Amps) +(7.88 Amps)] * 130%= 16.744 Amps

Maximum Fuse Rating = 25 Amps

The implementation of the software interlocking system, which imposes individual speed limits for each thruster, ensures that maximum power consumption is never attained. Moreover, this mechanism prevents all six thrusters from operating simultaneously at maximum speed. As a result, the actual maximum current draw is **17.88 amps.**

2. Main PCB

Last year, the electrical team embarked on developing a double-layer PCB -fig (24) to optimize space utilization in the bottom side electrical system of our ROV. Our primary goal was to accommodate all essential components while maintaining operational efficiency. Central to this Endeavor was the integration of protective measures, including a fuse, aimed at safeguarding the PCB from overcurrent during system operation. This meticulously designed board seamlessly incorporates vital elements such as the Arduino, ESCs, and IRF540 MOSFETS, ensuring robust signal connections and efficient power delivery.

Figure 25: Previous PCB

To enhances our design and accommodate potential system enhancements or upgrades, we recently integrated a Raspberry Pi 4 and a Pixhawk into the PCB. This addition aims to expand the capabilities of our ROV, improving its computational prowess and autonomy. Before finalizing the Gerber Files for production, we conducted comprehensive testing of our updated design using a prototype PCB. This rigorous testing phase was essential to validate the seamless functionality and compatibility of the PCB with the newly integrated components.

Furthermore, we implemented a circular design for the PCB -fig (26), and strategically positioned the components across the two layers to optimize space utilization within the enclosure. This innovative approach not only minimizes spatial constraints but also enhances the overall compactness and efficiency of the electrical system within the ROV.

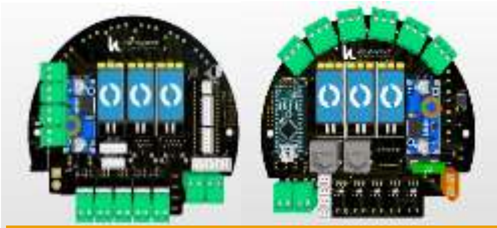


Figure 26: Main PCB

3. Control System

a. Thruster's control and Thrust force.

The control of the six T200 thrusters is facilitated by six electronic speed controllers (ESCs) -fig (27). In this configuration, the Pixhawk sends pulse width modulation (PWM) signals to regulate both the speed and direction of the thrusters. To simplify the internal wiring layout, the ESCs were incorporated onto the PCB, enabling them to receive both signal and power directly from the board.

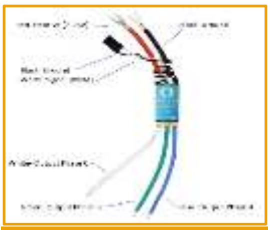


Figure 27: ESCs

b. DCV control:

We utilize IRF540 MOSFETs to control the two 5/2 DCV, managing the high power of the loads. These MOSFETs receive signals from the pixhawk Auxiliary pins. To prevent overheating, the temperature of the MOSFETs -fig (27), was closely monitored and discounted. both 5/2 DCVs are reused to regulate the airflow to the pneumatic cylinder connected to the clutch and the other one for our rotational gripper.

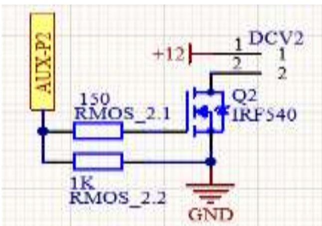


Figure 28: MOSFET Circuit

IRF640 MOSFET temperature calculations:

$\mathbf{I_D = 0.28\ A}$

$\mathbf{R_{DS\ (on)} = 0.18\ ohm}$

$\mathbf{P_{dissipated} = R_{DS\ (on)} \times I_D^{\,2} = 0.014\ Watt}$

$\mathbf{R_{th\ j\text{-}a} = 62\ °C/Watt}$

$\mathbf{\Delta T = T_{th\ j\text{-}a\ x}\ P_{dissipated} = 0.87\ °C}$

4. Tether

a. Communication

Data transmission from the station to the ROV is facilitated by two Category 6 (CAT6) Ethernet cables, each comprising four twisted-pair cables -fig (28). One of these cables links the RJ45 port to the Raspberry Pi-RJ45 and is responsible for carrying communication signals. Meanwhile, the other cable connects to the remaining four. Our choice of CAT6 cables is based on their serial transmission rate of 250 kbps (kilobits per second)

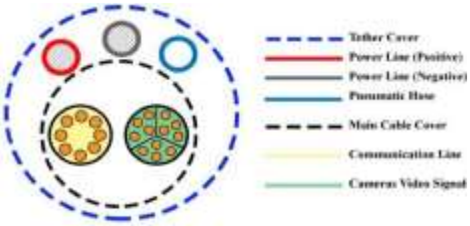


Figure 29: Tether Diagram

$$VDI = \frac{Current\ (Amperes) \times Length\ of\ wire\ (feet)}{\%voltage\ drop\ \times voltage\ (volts)}$$

Equation 2: Voltage drop index (VDI) and American wire gauge (AWG) Calculations

b. Power

Utilizing the AWG wire sizing chart, we selected a 6 AWG (4 mm) power cable to mitigate voltage drop across the tether ends and ensure a stable voltage supply to the system. Given our current limit of **23.244 amps**, our wire selection was determined through the following calculations:

Max power Consumption = 232.56watts
Max Current = 17.88 Ampere

Fuse Calculations:

17.88 X 1.3 = 23.244Ampere
Fuse used = 25 Ampere

c. Tether management system

As part of our tether management system, the tether is wound around a cable reel-fig (29) during transportation to prevent tangling and minimize damage. Additionally, during ROV deployment, the cable wheel facilitates the adjustment of tether length as needed.

Figure 30: Cable Reel

H. Software

1. Vision system

Our system is meticulously crafted to optimize the pilot's field of view, acknowledging the diverse demands of different missions involving Kratos -fig (31). It incorporates four carefully selected purchased CCTV cameras and one Blue Robotics camera, each fulfilling a specific role. The first camera, angled at 60°, offers a gripper view crucial for various missions. The second camera, positioned at a 90° angle, supervises the upper equipment retrieval box, aiding in precise navigation during float missions. The third camera is dedicated to capturing the bottom side of the pool, ensuring convenient viewing of tether. The fourth camera offers a backward-facing view to monitor the tether and avoid entanglement with the propellers. Lastly, the primary Blue Robotics camera is forward-facing, providing the pilot's perspective and primarily deployed in tasks such as Autonomous Transplanting and 3D modeling.

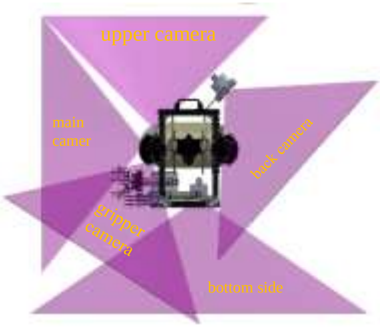


Figure 31: Camera Cones by Solidworks

2. Topside Control Unit (TCU)

The control panel of Kratos -fig (32), various components including four video baluns, a DVR, and the main power outlet are accommodated. The DVR was repurposed to establish a connection with the surface laptop via a local network using RJ45. All elements are securely mounted, with distinct separation and labeling of AC and DC power supplies to prevent confusion. Cable management is meticulously handled, ensuring no exposed wires and proper strain relief for incoming cables. Additionally, an enhanced communication module integrating an Arduino Nano and HC-12 module facilitates robust wireless communication between the TCU and the Mako float engine. To ensure compatibility and seamless integration of components, donated monitors and reused cases and DVR were utilized.

Figure 32: TCU by Adham

Furthermore, the decision to purchase the joystick was made judiciously to minimize overall costs, with prior confirmation of its compatibility with QGround Control for transmitting signals to the ROV.

3. Software and Control System

Kratos software serves two primary functions: managing input from the joystick and commanding and directing the ROV using Qground Control and the vision system. Our software is divided into two major subsystems: the underwater system and the topside system.

a. Underwater System

Previously, Kratos' Underwater System, controlled by an Arduino-based architecture utilizing finite state machines, directed the ROV into specific axes based on received commands.
The system has since undergone an upgrade to enhance reliability and versatility. The new configuration incorporates advanced components like the Pixhawk and Raspberry Pi 4, replacing the Arduino. This upgrade enables the implementation of innovative methodologies, including the utilization of probiotics for coral health restoration and the conservation of Lake Sturgeon populations.

1. Pixhawk

The Pixhawk 1 -Fig (33), serves as Kratos' flight controller, having been procured to ensure stability for the ROV. Its primary pins are dedicated to controlling the ESCs and driving the thrusters, while auxiliary pins manage grippers and LEDs.
Pixhawk 1 is essential for controlling Kratos' movement, ensuring stabilization, and supporting autonomous functionality by utilizing sensors to determine the ROV's state. Equipped with numerous built-in sensors, including a gyroscope, accelerometer, and magnetometer, the Pixhawk enables the configuration of additional sensors such as the bar30, which we utilized instead of the built-in barometer. These sensors facilitate stabilization modes like ALT_HOLD and STABILIZE flight modes supported by the Pixhawk. These flight modes have proven instrumental in Kratos' successful execution of various tasks, including releasing the recovery float, stabilizing frame capture for 3D Modeling, and measuring temperature.

Figure 33: Pixhawk 1

The selection of Pixhawk 1 over Pixhawk 4 was influenced by its compatibility with essential pressure sensors like the bar30, crucial for Kratos' depth control, especially during flight modes requiring precise altitude management.
Pixhawk was chosen over Arduino because of its compatibility limitations with sensors and the challenge of replicating Pixhawk's internal PID controller's efficiency. Additionally, the STM32 chip embedded in Pixhawk enables superior thruster control, compared to Arduino's ATmega328P chip, due to its advanced computational capabilities and extensive peripheral support.

2. Raspberry pi

Our system utilizes BlueOS as the companion operating system deployed on Raspberry Pi 4 -fig (34) to seamlessly integrate with Pixhawk for operating an ROV. Making it better suited for handling the complex tasks required for ROV operation. With its superior computational capabilities, Raspberry Pi can effectively manage communication with Pixhawk, enabling precise control and navigation of the ROV. Additionally, Raspberry Pi offers a wider range of connectivity options, including long-distance communication via RJ45, enhancing the overall functionality and flexibility of our system.

Figure 34: Raspberry pi 4

Furthermore, Raspberry Pi handles the main camera stream enabling seamless transmission to the topside. With the camera directly connected to it, this setup ensures efficient management of the main camera stream and real-time video feed to the topside, enhancing control during ROV operations. Thus, Raspberry Pi proves to be the optimal choice for implementing BlueOS and ensuring seamless integration with Pixhawk in our ROV operations. We utilized BlueOS endpoints to run scripts for autonomous missions, such as autonomous transplanting of coral brain.

b. Topside Software

Our topside software comprises two distinct modules, each serving a specific function to optimize user experience and enhance operational efficiency:

1. Control Unit:

The Control Unit is housed within a pilot laptop and is responsible for operating the ROV using QGround Control. By connecting via RJ45 to the laptop, QGround Control can directly access the saved configuration of the joystick, enabling precise control of the ROV's movements. Additionally, the camera connected to the Raspberry Pi appears on QGround Control, providing real-time visual feedback to the pilot facilitating smooth operation during missions.

2. Graphical User Interface (GUI):

The GUI -fig (35) hosts a pilot interface while GUI -fig (36) hosts copilot interface responsible for managing received communication data from the float and plotting pertinent data points. Data input options include selecting a CSV file or manual entry, with the flexibility to edit entered data for enhanced reliability. Furthermore, the copilot GUI utilizes camera streams to generate 3D models, enhancing situational awareness and supporting mission planning and execution. Powered by the Matplotlib Python library for plotting and developed using PyQt5 and QtDesigner, the GUI complements the Control Unit by providing comprehensive visualization and monitoring functionalities throughout ROV operations.

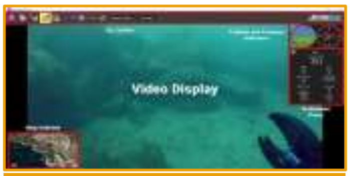


Figure 35: Pilot GUI

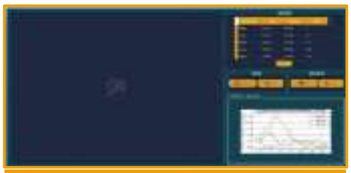


Figure 36: Copilot GUI

4. Mission Specified Software

1. 3D Modeling and Measurement

3D modelling is essential for comprehending underwater structures, conducting marine research, and managing aquatic industries. Additionally, it highlights the significance of aquatic plants in carbon storage and climate change mitigation.

Last year, our approach involved utilizing a Python script within Blender to construct a half-sphere - fig(37) model with a measured radius, based on known references. Texturing was accomplished using 2D images captured from a front camera. These images were processed with the OpenCV Python library to isolate the diseased areas of a coral head and the coral head itself, excluding the background. The object was symmetric, which made the modelling process relatively straightforward. While effective, this method was manual and time-intensive, requiring substantial human intervention to ensure accuracy and completeness.


Figure 37: 3D Coral Head

This year, we have adopted a more sophisticated approach leveraging generative artificial intelligence, significantly enhancing the automation and precision of 3D model generation. Our new method -fig(38)[a,b] to generate a high-quality 3D model automatically within approximately four minutes to generate a model on a laptop with GPU of GTX 4070 16 VRAM, we employ generative artificial intelligence, a state-of-the-art approach in AI. Our method comprises two stages and requires only a single image of the object.

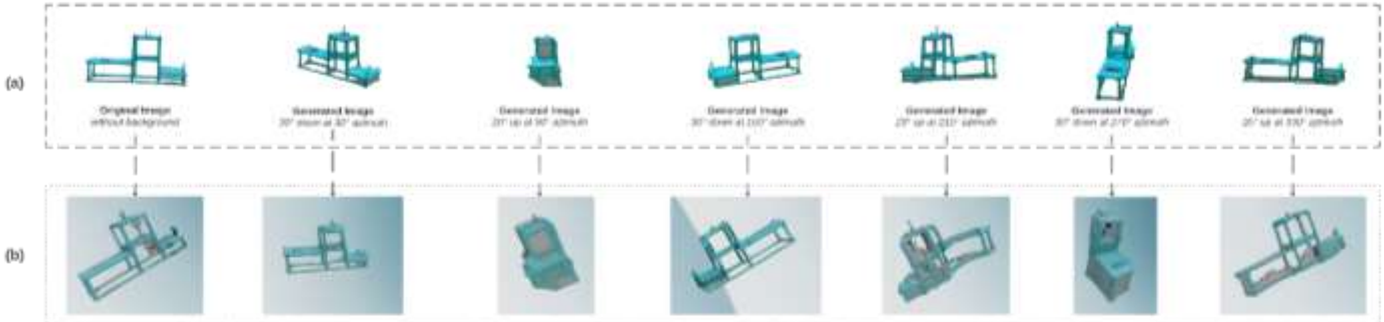


Figure 38: Workflow for Generating 3D Models from a Single Image Using Generative AI.
(a) The original image and six additional images generated from different angles.
(b) Seven distinct 3D models created from these images, with the most accurate model selected for further processing.

In the first stage -fig(37)[a], we generate six additional images of the object from various angles using a modified Zero123++ model, specifically adapted for underwater applications. The angles are 30° down at 30°, 150°, and 270° azimuth, and 20° up at 90°, 210°, and 330° azimuth. This process yields a total of seven images of the object: the original image plus six inferred images from different perspectives.

In the second stage -fig(37)[b], we utilize the TripoSR model to create a 3D model from a single image. Using the seven images generated in the first stage (one original and six synthesized), we produce seven distinct 3D models. From these seven models, we select the most accurate and clear one for further processing, such as scaling and additional refinement. Importantly, the new approach can handle asymmetrical objects, such as those found in coral restoration areas, making it versatile and robust for a variety of underwater applications.

By following this method, we efficiently create a precise 3D model using only one initial image, ensuring both speed and quality in the final output. The transition from last year's Blender and OpenCV-based method to this year's AI-driven approach represents a significant advancement in 3D-modelling for underwater applications. The current method's efficiency, automation, and accuracy provide a robust framework for future research and operational applications in marine environments.

After selecting the optimal 3D model from the seven generated (specifically, the model derived from the original image without a background), we proceed with the subsequent tasks outlined in Task 3.3. These tasks include measuring the length, scaling, and subsequently measuring the height post-scaling.
To accurately measure and scale the dimensions of the 3D model, we utilize the Agisoft application due to its user-friendly interface and efficiency in performing these operations. However, given that the model generation process relies heavily on generative AI, minor dimensional inaccuracies may occur. To address this, we initially scaled the model based on a known length from the prop building documentation. Following this initial scaling, we complete the remaining tasks measuring the length, scaling to the actual length, and measuring the height using the Agisoft application -fig(39).

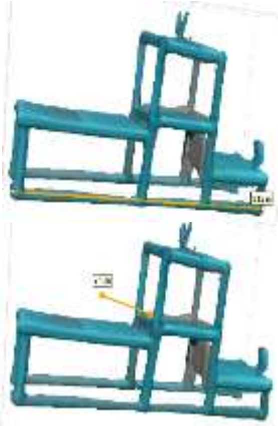


Figure 39: Measurement of length and scaling in Agisoft.

2. Autonomous Transplanting

Transporting an object underwater and accurately positioning it at a designated location involves complex challenges, necessitating precise interface definition and rapid movement. This process employs a sophisticated script integrating computer vision with control mechanisms to ensure success.

The procedure begins with the ROV pilot securing the object and aligning the ROV with the target station. The pilot then runs a script to set the ROV at the correct depth and issues a "forward" command. The ROV advances until it detects a red square on the primary camera feed, using the YOLOv8 model, which has been fine-tuned for accurate red square identification. while detecting the red square in the base camera -fig(40) and centralizing it, the system transmits a stop signal, halting the ROV and positioning it precisely above the square. The ROV then retreats slightly to ensure the accurate placement of the object.

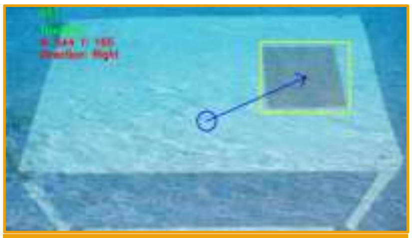


Figure 40: Red square tracking using YOLOv8

I. Payloads and Tools

1. Main Manipulator

After studying the required missions, our design team decided to use a pneumatic actuated manipulator -fig (41) to perform them successfully. The actuator is a pneumatic cylinder (bore 25 mm and stroke 50mm). It depends on the parallel jaw mechanism to convert linear motion of the cylinder to gripping action. The jaws of the gripper were designed specifically for the missions.

Figure 41: Horizontal Manipulator by SolidWorks

Gripper features for missions:

- Manufactured from transparent acrylic (PMMA – Poly Meta Methyl Acrylate) which doesn't block the view of the pilot.
- 4 layers of jaws maximizing contact with the gripped object to 24 mm.
- Horizontal orientation was made to be appropriate for the largest number of missions such as inserting the power connector into the smart repeater.
- Radius of curvature specially designed to grip the half inch PVC pipe which is the most used size in this year missions such as branching coral at the top of the coral restoration.
- Releasing the multi-function node by pulling the pin by the gripper tip which is made specially for this mission and will be used also during the catching of U bolt.

2. Rotary Manipulator

The rotary manipulator -fig (42) is an electro-pneumatic arm composed of a pneumatic cylinder responsible for opening and closing the gripper while an electric motor rotates it. The gripper rotates continuously in both directions with an electronic controlled speed. The motor is coupled to the gripper by a custom-made gear system with teeth ratio to increase the torque of rotation performed by the gripper.

Figure 42: Rotational Manipulator by SolidWorks

The design contains bearings to facilitate the rotation of the gripper by minimizing frictional torque between moving parts. The rotary motion gives us the ability to turn the valve in both directions to either stop or restore the flow of water to the platform. The fingers of the gripper were specially designed to grab the valve from its tied cross by three fingers to decrease the possibility of releasing.

In addition to the previous usage, it will also be used in successfully placing the smart cable repeater by contributing to cables handling.

3. Payloads (tool)

Simple hair piece will be used to grip sediment sample easily -fig (43) which will be effective according to its catching ability using the scissor mechanism and overlapping ends with easily reaching to the lowest points unlike any other tool with very low cost and time.

Figure 43: (Left) Tool & (Right) Sediment sample.

4. Payloads (Camera)

According to the vision of the team it was a must to have a back vision camera to handle the possibility of sticking because of the large number of cables -fig (44), in order to successful locating for the float engine, one more camera is added inside the enclosure to preview the surface of the water to the pilot in the float deploying area -fig (45). We mentioned before more details about the 3 cameras that are mounted inside the enclosure.

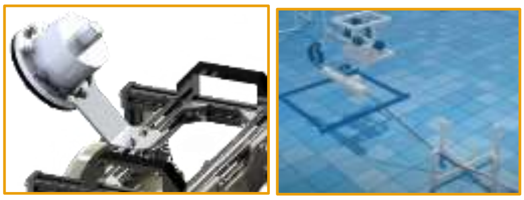


Figure 44: (Left) Back vision camera cad design by SolidWorks & (Right) Smart cables.

Figure 45: (Left) Surface camera and its vision cone by SolidWorks & (Right) Float deploying

Figure 46: Temperature sensor positioning

5. Payloads (Sensor)

Waterproof temperature sensor is used to check the smart cable readings with marine epoxy to seal the metal start end which is fixed -fig(46) to facilitate the positioning process to the pilot by fixing it in the field of vision in the nearest the 2 sensors as could as possible.

We developed a Python script that employs socket programming to read the temperature data. This script facilitates communication between the sensor and our system, ensuring that temperature readings are accurately captured and transmitted. This setup allows us to efficiently gather temperature data alongside other sensor readings within the BlueOS environment.

J. Non-ROV Device Vertical profiling Float: Mako

1. Mechanical Design

MAKO -fig (47) was designed to flawlessly complete several vertical profiles. After reviewing numerous ideas and tests, the final design was created. The float consists of one enclosure made of PMMA that houses the float's brain and water storage volume that stores the water in it to increase the weight and change the buoyancy. Six syringes are activated by a nut that travels on a spinning threaded rod that functions as a power screw to suck the water in or out by a DC motor driving. The PMMA enclosure is sealed from both ends with HDPE caps and O-rings with a PMMA face. Pneumatic cables are used to help the water flow inside the float.

Figure 47: Vertical float engine

The water tank is designed and positioned in such a way that the float remains stable while operating, allowing for successful vertical profiles with a low center of mass.

Two sets of four 4 mm diameter stainless steel rods hold and support the shelves of the electrical components.

2. Electrical Design

Our float engine -fig(47) primarily relies on 16 AA batteries, organized into two sets of eight batteries connected in series to provide a 12V supply. To meet the required current demand, these sets are connected in parallel. The PCB features an Arduino Nano powered by a 7805 regulator to ensure a stable 5V supply. Additionally, the PCB includes pin headers for connecting power and signal cables to the DC motor, alongside integration for the HC-12, HC-05, and SD Card module.

Last year, frequent battery replacements during simulations led to significant expenses and raised budget concerns. To address this challenge, we integrated a switch onto the PCB. This switch enables a seamless transition of the power supply from batteries to a direct source exclusively for simulation and code testing purposes. Through collaboration with the mechanical team, we isolated the power supply cable to facilitate extensive testing. This approach not only optimized performance but also effectively managed our budget constraints.

Table 4: Power Consumption Calculation of float engine

Component	Voltage (Volts)	Max current (Amperes)	Max power (Watts)	Quantity
Arduino Nano	5	0.03	0.15	1
Bar30	5	0.1	0.5	1
DC Motor	12	2	24	1
HC-12	5	0.1	0.5	1
HC-05	5	0.04	0.2	1
SD Card module	5	0.08	0.4	1
Maximum power consumed			**26 watts**	

3. Software Design

As in the previous year, The HC-12 was reused to allow two Arduinos to communicate wirelessly. The first, known as the Transmitter, will be situated inside the floating engine, while the second, known as the Receiver, will be connected to the station laptop via USB. We chose the HC-12 module since it has 100 channels that can be switched between, each channel has its own frequency, and its range is 433.4 - 473.0 MHz; so, we may switch between them to minimize interference if required. However, HC-12 can communicate over a long distance (approximately 1 km). On the other hand, we control the movement of the float using a DC motor and bar30 sensor was purchased for pressure and depth readings.

a. Transmitter:

To enable serial data transmission, we incorporated a battery powered RTC module with the DS3231 code on the floating engine Arduino. This module furnishes us with the UTC time. However, configuration of the RTC module is required before we can transmit the UTC time along with the company number to the topside Arduino. Additionally, we integrated a bar30 pressure sensor and an I2C level converter to facilitate its connection with the Arduino. The bar30 sensor provides accurate pressure and depth readings, essential for various operations. Furthermore, an SD card module is employed to store readings during the profiling process, allowing for data accumulation before transmission to the topside Arduino. This setup ensures comprehensive data acquisition and seamless communication between the floating engine and the topside system. The HC-05 module is employed for over-the-air code flashing to enhance functionality and streamline the testing process for the mechanical team without the need to physically access the ROV's internal components. This approach eliminates the requirement to open the enclosure each time a new code needs to be uploaded, thereby saving time and effort during testing and development phases.

b. Receiver:

The receiver comprises an Arduino nano and an HC-12 module. The HC-12 module must be set to the same channel as the transmitter to receive data sent from the float engine. The received data is integrated into the Copilot GUI and visualized using the Matplotlib Python library. This integration allows for real-time plotting of the received data directly on the GUI interface, providing immediate visualization and analysis capabilities. By leveraging Matplotlib, the Copilot GUI enhances user experience by offering comprehensive graphical representation of the acquired data, facilitating efficient monitoring for the data received. A detailed diagram for Mako float engine in figure 48.

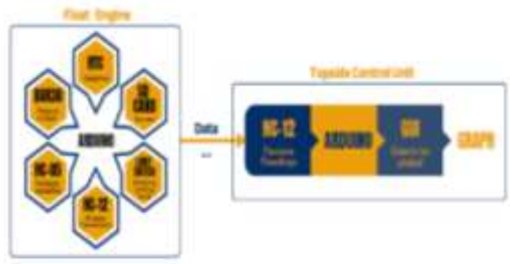


Figure 48: Float communication diagram

III. TROUBLESHOOTING AND TESTING TECHNIQUES

A. Troubleshooting

Our troubleshooting methodology follows a systematic approach, commencing with software-based tests to detect potential issues, then progressing to hardware inspection if needed. We develop scripts for component testing to thoroughly assess each aspect of the control system independently, ensuring a comprehensive examination of individual components. Critical components undergo extensive checks, including verifying the compressor's regulator and power supply settings to ensure proper functionality. Direct connections are established, allowing commands to be sent directly from the joystick via applications like Qground control. In cases of communication issues, a direct link between the laptop and the Pixhawk is established to control thrusters. External component tests are conducted to validate functionality and pinpoint potential issues with the main PCB, eliminating software-related concerns and focusing on hardware troubleshooting when necessary. Safety checks are prioritized, with meticulous inspections for electricity and adherence to established safety protocols throughout the testing process.

To integrate the DS18B20 temperature sensor into our system, we connected it to the Raspberry Pi using the one-wire interface. However, we encountered an issue as this setup was not directly compatible with the BlueOS system. To resolve this, we installed a Raspbian image on the Raspberry Pi and subsequently ran BlueOS using its Docker image to support the one-wire interface. This configuration successfully enabled the effective utilization of the DS18B20 sensor, allowing us to gather accurate temperature readings.

B. Testing Techniques

To ensure fair testing conditions, any factors that could bias results are eliminated at the outset. Sealing integrity is evaluated by introducing pneumatic hoses into enclosed areas and increasing pressure with a compressor, with the presence of bubbles indicating insufficient seals. System connectivity is then verified to confirm proper connection and communication among components. If connectivity issues arise, individual components are examined, and the communication system is tested. These strategies enable our company to identify and rectify system issues effectively, ensuring optimal performance and reliability.

IV. SAFETY

A. Company Safety Rationale

Our company members are our most valuable resource, and their personal safety is paramount. We firmly believe that all accidents can be prevented, which is why safety has remained our top priority throughout the manufacturing and operation of the Kratos ROV. To safeguard our team members, we have implemented stringent safety standards for tool usage -fig (49) before handling tools under the supervision of our mentors ensuring that all members receive proper training in the proper safety protocols of the Environmental Health and Safety (EHS) policies and our team's Job Safety Analysis (JSA).

During Kratos ROV testing, team members are required to work away from the pool edge, with the exception of the tether man, and running on the pool surface is strictly prohibited. Additionally, we have incorporated various safety features into the Kratos ROV design to further ensure the safety of vehicle operators and divers as follows.

Figure 49: Example of safety in our workshop of Retaj captured by Hoor.

Safety Instructions:

- During testing or manufacturing, at least two safety instructors must be present in the workshop.
- It is mandatory to use safety equipment such as goggles, gloves, and appropriate footwear while machining or working with pneumatic circuits.
- Company members should ensure their hands are dry when handling power supplies.
- When lifting heavy equipment, team members should use a natural lower back position to prevent spinal disc injuries and avoid lifting objects above shoulder height.
- Regularly inspect overall insulation and waterproofing elements.
- Use a holder for the welding iron while soldering PCBs.
- First aid kits and fire extinguishers are provided in case of emergencies.

B. ROV And Float Engine Safety Features and Precautions

1. Mechanical Safety Features:

Numerous safety practices and protocols are enforced to ensure that all members are working in a suitable and safe environment as Safety instructions are always considered during designing, building, handling, and testing of the ROV and the float engine.

Our mechanical engineers ensured the presence of no sharp edges on the ROV, so cap nuts are used to eliminate any exposed threading. Also, moving parts, such as thrusters, are shrouded with customized Aluminum meshes (Shrouds) designed by our mechanical team to meet IP20 standard. Thus, protecting the thrusters from any foreign objects of 12.5 mm diameter or greater based on MATE specification MECH006. To ensure that all individuals interacting with the ROV, and float engine are fully informed about potential hazards, warning labels are affixed to thrusters, moving parts, high-pressure components, PMMA parts susceptible to fracture, and electrical components. For visual reference, photographs of these warning labels, See DOC-001, Company Safety Review for proof of compliance to MATE's protocol. Our float has smooth curved edges and no sharp corners to prevent harm or injury when handled. The float engine is designed upon the principle of the piston seal of the cap that will open directly in case of a sudden increase in pressure within the housing which will act as a release container.

2. Electrical Safety Features:

A fuse box, positioned between the 12V power supply and the tether, incorporates inline 25 Ampere fuses to safeguard the system. To prevent inverted connections, polarized connectors, and color-coded cables are employed for both power and signal transmission throughout the entire system. Additionally, a 25 Ampere fuse is installed on the PCB to prevent excessive current draw from the power supply. Within the float engine, no exposed wiring is present, and an additional safety measure is implemented with a 5 Ampere fuse placed on the float engine's PCB.

3. Safety Procedures: Operational and Safety Checklists

Throughout ROV operations, Vortex' Operational and Safety Checklists are strictly followed. Employees are also required to follow operational JSAs for ROV launch, recovery, and waterside safety. **[A detailed safety checklist in Appendix C].**

V. LOGISTICS

A. Scheduled Project Management

Vortex operates through a structured project management system, comprising three primary technical departments: mechanical, electrical, and software. Each department is further subdivided into project groups, with defined roles and responsibilities. The initiation of each department involves an engineering training phase, followed by an Election phase to select key leadership positions, including the CEO, CTO, CFO, and project leaders, based on performance and personal capabilities demonstrated during the training program.
Subsequently, a research phase is conducted to thoroughly examine the requirements of each project, followed by the design phase to develop comprehensive solutions for the tasks at hand. The implementation phase follows, wherein designated members from each department oversee specific tasks related to their expertise. For instance, members from the mechanical department oversee the design of the vehicle frame, tools, and payloads, as well as the electronics enclosure, sealing, and pneumatic systems. Similarly, members from the electrical department manage tasks such as PCB design, power calculations, control panel development, and enclosure rewiring. Meanwhile, members from the Software team focus on aspects like ROV control system development, deep learning and vision integration, and float system management.
The final phase of the project management process involves training and piloting, where team members undergo practical training on prop building and conduct extensive testing to ensure that the final product meets all project requirements and specifications. Through this structured approach, Vortex aims to effectively manage and execute projects while ensuring adherence to quality standards and task objectives.

B. Company Organization

1. **Single Point of Responsibility:** This organizational structure ensures clarity in roles and responsibilities, with each member understanding their specific duties within the company. The CEO serves as the central point of authority, overseeing the entire team and providing direction.
2. **Improved Focus:** With clearly defined roles and a hierarchical structure, team members can focus on their assigned tasks without ambiguity or distractions. The CEO sets the overall direction, while department leaders and project managers ensure that their teams remain focused on achieving objectives.
3. **Improved Communication Among Team Members**: Regular interactions, facilitated by general meetings led by the CEO and departmental meetings led by department leaders, promote effective communication among team members. This ensures alignment of efforts and promotes collaboration across departments.
4. **Improved Reporting:** The structured hierarchy facilitates efficient reporting mechanisms, with leaders providing regular updates on progress to the CEO and receiving guidance and feedback in return. This enables better tracking of project milestones and ensures accountability.
5. **Resource Flexibility:** The organizational structure allows for resource allocation and reallocation as needed to support project requirements. Department leaders and project managers have the authority to adjust resources within their respective areas to optimize efficiency and productivity.

This refined organizational structure has adeptly aligned with the company's unique requirements. Leaders have been strategically designated for every department and project, fostering transparent communication channels and seamless coordination. Departmental leaders meticulously supervise their respective team members, while project leaders serve as conduits for communication between departmental leaders, ensuring project milestones are achieved within the designated timeline -fig (50). Consequently, this structure fosters efficiency, cultivates accountability, and facilitates the successful execution of projects.

Figure 50: Team Timeline

C. Version Management

Our company leveraged state-of-the-art communication platforms, including the Slack application, to streamline internal communication processes.

Within Slack, dedicated channels were established, each serving a distinct purpose. The "Project Management" channel, for instance, served as a forum for the CEO, CTO, CFO, and department leaders to foster interdepartmental communication and facilitate resource allocation as needed. Additionally, individual channels were designated for each department, providing members with a platform to seek clarification on tasks and projects. Furthermore, project-specific channels were created, enabling project leaders and their team members -fig (51) to collaborate, discuss project-related matters, and coordinate meetings effectively.

To manage task distribution and workflow seamlessly, our company utilized the Trello application. Through Trello, tasks were organized into individual cards -fig (52), each representing a specific phase of the project. The progression of these cards was closely aligned with our scheduled meetings, where team members convened to assign tasks, assess project status, and ensure timely progress.

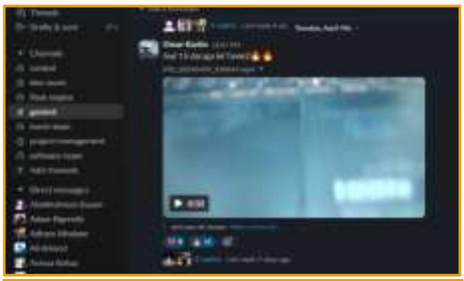


Figure 51: Vortex's Slack Workspace

Figure 52: Vortex's Trello Board

VI. BUDGET AND PROJECT COSTING

Vortex company develops a budget plan based on previous years' actual costs and critical aspects of the ROV project at its inception. To ensure proper procurement, all purchases are subject to confirmation by the company's CFO and technical mentors once the budget has been approved. Purchase requests are submitted for evaluation and authorization to maintain budget integrity. Transactions are tracked on a project budget sheet in **Appendix B**, and pricing is verified from multiple sources before purchases are made. A significant portion of expenses is allocated to materials and hardware, including aluminium extrusion, a control panel, and components for the vertical float engine. A detailed breakdown of costs and donations in **Table 5**.

Build vs Buy

Customized parts are cost-effective and customizable. The camera enclosures this year reflect this as they were designed by the mechanical team members and also, they machined the aluminum extrusion profile on the miter saw. Another custom-fabricated component of our ROV is the frame, which was milled out of sheets of High-Density Polyethylene (HDPE). It was easy for the team to develop buoyancy using foam, a propulsion mounting using sheet metal bent L-shaped part placed by 60º angle to meet all mission requirements, and a rotational gripper also designed by the mechanical team members. Some of the vertical float engine components were bought such as the SD Card module, temperature and pressure sensors, and switch while the rest of the components of the float were reused. Purchased components are sometimes important since they provide a quick and typically more reliable answer to any problem. Almost all the electronics onboard, for example, Raspberry Pi, Cameras, control panel, and the screen are purchased equipment. This approach is significantly more time- and cost-effective than other options.

New vs Re-used

The company had to carefully evaluate both cost and ROV performance when deciding which parts would be purchased fresh and which parts would be reused from prior years' designs from our organization's "vortex academy". In our project expenditure, we adopted a strategic mix of purchasing new components and repurposing existing ones to optimize cost-effectiveness and resource utilization. New components, such as the Blue Robotics Lumen Subsea Light, main PCB, Bilge Pump 1100 GBH, and various electronic modules, were procured to ensure compatibility, functionality, and reliability in critical areas of the ROV system. On the other hand, re-used components like the Raspberry Pi, Pixhawk, low-light HD USB camera, and hardware materials were leveraged to capitalize on existing resources, minimize costs, and streamline the assembly process. This balanced approach allowed us to achieve our project goals efficiently while maintaining financial prudence and maximizing the value of available resources.

Table 5: Project Budget

`	Income	Source	Amount(USD)	
		Self-Funds from Team Members	**$4,500**	
	Type	Description	Projected Cost	Budgeted value
Tether	Re-used	Power Cable (30 Meters)	$45.30	
	Re-used	Pneumatic Cables (32 Meters)	$22.30	
	Purchased	Cat 6 (30 Meters)	$45.60	$45.6
	Re-used	Anderson Connector	$19.00	
Electronics	Re-used	ESCs (5 Units)	$190.00	
	Purchased	ESCs (3 Units)	$114.00	$114.0
	Purchased	Prototype PCB	$20.00	$20.0
	Purchased	Bluerobotics _Lumen Subsea Light_ 4 lights	$640.00	$640.0
	Purchased	Main PCB	$62.50	$62.5
	Re-used	Raspberry Pi 4	$61.00	
	Re-used	Pixhawk	$193.00	
	Re-used	Low-Light HD USB Camera	$99.00	
	Purchased	CCTV Cameras (3 Cameras)	$32.00	$32.0
	Purchased	Analog Camera	$6.20	$99.0
	Purchased	Buck Boost Converter	$11.00	
	Purchased	Buck Converter	$4.00	
	Purchased	M200 Motor	$160.00	
	Purchased	Arduino Nano	$11.00	
	Re-used	Power Supply 30A	$82.00	
	Purchased	Bar30 Pressure Sensor	$85.00	$85.0
Float Engine	Purchased	Materials & Fabrication	$63.50	$63.5
	Re-used	Arduino Nano	$11.60	
	Re-used	HC-12	$5.00	
	Re-used	DC Motor	$12.00	
	Re-used	DS3231 RTC Module	$2.70	
	Re-used	HC-05 Bluetooth Module	$5.60	
	Purchased	Limit Switch	$1.60	$1.6
	Purchased	VNHSP30 Motor Driver	$4.20	$4.2
	Purchased	SD Card Module	$0.88	$0.9
	Purchased	Bar30 Pressure Sensor	$85.00	$85.0
	Purchased	I2C Level Converter	$25.00	$25.0
	Purchased	PCB	$33.30	$33.3
	Purchased	Switch	$3.00	$3.0
	Purchased	Batteries	$52.00	$52.0
Control Panel	Donated	Screen	$220.00	
	Purchased	Xbox - Joystick	$72.00	$72.0
	Re-used	Case	$134.00	
	Re-used	8 Channels DVR (1 Unit)	$112.00	
	Purchased	Case Accessories	$35.00	$35.0
	Purchased	Video Baluns (6 Units)	$8.00	$8.0
	Purchased	Arduino Nano	$11.60	$11.6
	Purchased	HC-12	$5.00	$5.0
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)	$35.0	
	Purchased	Plugs	$22.0	$22.0
	Purchased	Grippers Material (PMMA)	$41.0	$41.0
	Purchased	Grippers Manufacturing (Laser-Cutting)	$29.0	$29.0
	Purchased	Aluminum Extrution	$112.0	$112.0
	Re-used	Agro Glands (35 Units)	$150.0	
	Purchased	O-Rings	$5.6	$5.6
	Re-used	DCVs (3 Units)	$51.0	
	Re-used	Pneumatic Piston	$48.0	
	Re-used	Fittings	$32.0	
	Purchased	Bolts & Nuts	$70.0	$70.0
	Purchased	3D Printed Parts	$112.0	$112.0
	Re-used	T200 Motor (2 Motors)	$400.0	
	Purchased	T200 Motor (4 Motors)	$800.0	$800.0
	Purchased	Trusters' Mesh	$40.0	$40.0
	Re-used	Compressor	$135.0	
Customs and Shipping	Purchased	Customs and Shipping for all imported items	$465.0	$465.0
Total Income			**$4,500.00**	
Total Expenses			**$5,623.48**	
Total Re-used			**$2,115.50**	
Total donated			**$220.00**	
Total Expenses - Re-used - donated			**$3,287.98**	
Final Balance (Available for next year's project)			**$1,212.02**	

VII. ACKNOWLEDGMENTS

MATE Centre and Marine Technology Education – for developing such a professional competition where engineers can pursue their interest in marine education.
AASTMT Arab Academy for Science Technology & Maritime Transport – for organizing the regional competition.
Vortex Academy and AASTMT School - for providing technical support throughout the competition as well as moral support and encouraging us to bring out our full potential.
Trello, Slack, Clockify and Google Drive – for assisting us in keeping track of our tasks and successfully functioning as a team.
Collab – Their faster GPUs aided us in the development of deep learning models.
Agisoft – to help us with generating 3D models.
Our mentors – for their continued technical support and encouragement.
Our families and friends – for their assistance in overcoming obstacles and achieving our objectives.
Ansys, **SolidWorks™, VS Code Editor and Adobe photoshop** - For providing us with a student license.

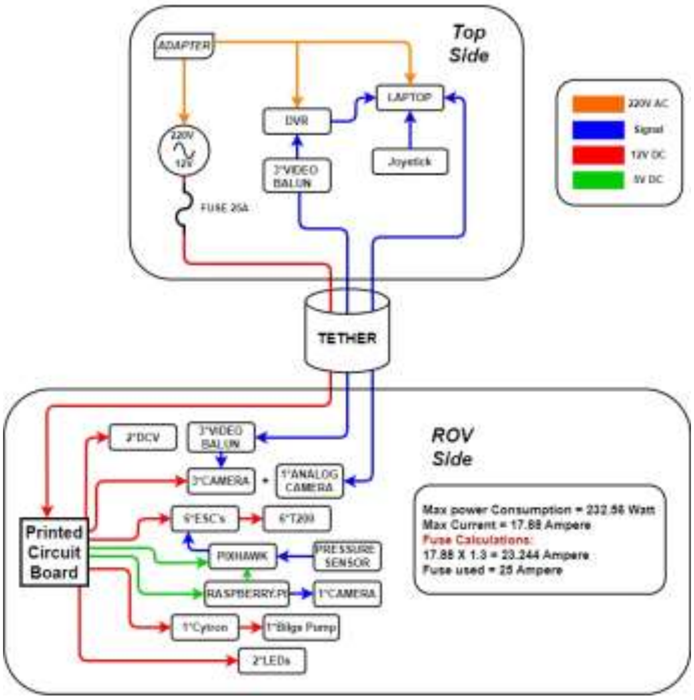
VIII. REFERENCES

- Blue Robotics. "T100 Thruster Documentation.": T100 Thruster Documentation
- Blue Robotics. "T200 Thruster Documentation.": T200 Thruster Documentation
- Blue Robotics. "ESC Documentation.": ESC Documentation
- MATE. "MATE ROV Competition Manual Rangers.", 15 Dec. 2023.
- MATE. "MATE ROV Competition Video.", 10 Mar. 2023.
- BLENDER. "Blender 3.5 Python API Documentation.", 10 Apr. 2023. https://docs.blender.org
- OpenCV-Python Tutorials: https://docs.opencv.org
- Object Detection Documentation: Object Detection Documentation
- Camera Streaming Documentation: Camera Streaming Documentation
- (AI) Library Documentation: https://pytorch.org/
- Python Documentation https://www.python.org/
- Arduino home http://www.arduino.cc/
- Simple Shape OpenCV with python 3: https://pysource.com
- Parker O-ring handbook. 50th Anniversary Edition
- Fluid Mechanics Fundamentals and Applications by Yunus Cengel and John Cimbala 3rd edition
- IRF640 MOSFET Datasheet: http://www.alldatasheet.com
- PLA Material Properties: https://plastics.ulprospector.com
- Awg Wire Sizing Chart: https://homequicks.com
- Underwater Robotics: Science, Design and Fabrication by Steven W. Moore
- The ROV Manual: A User Guide for Observation-Class Remotely Operated Vehicles by Robert D. Christ and Robert L. Wernli Sr.
- https://www.rovplanet.com/

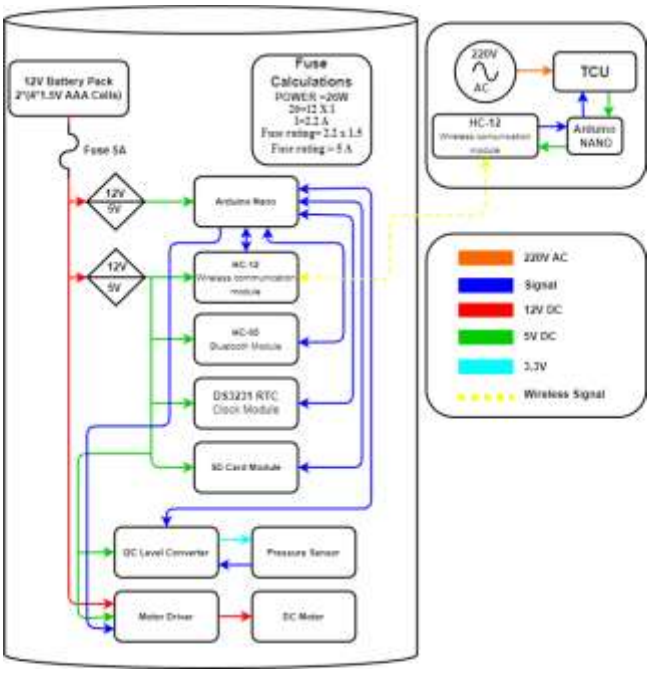
IX. APPENDICES

Appendix A: System interconnection diagrams

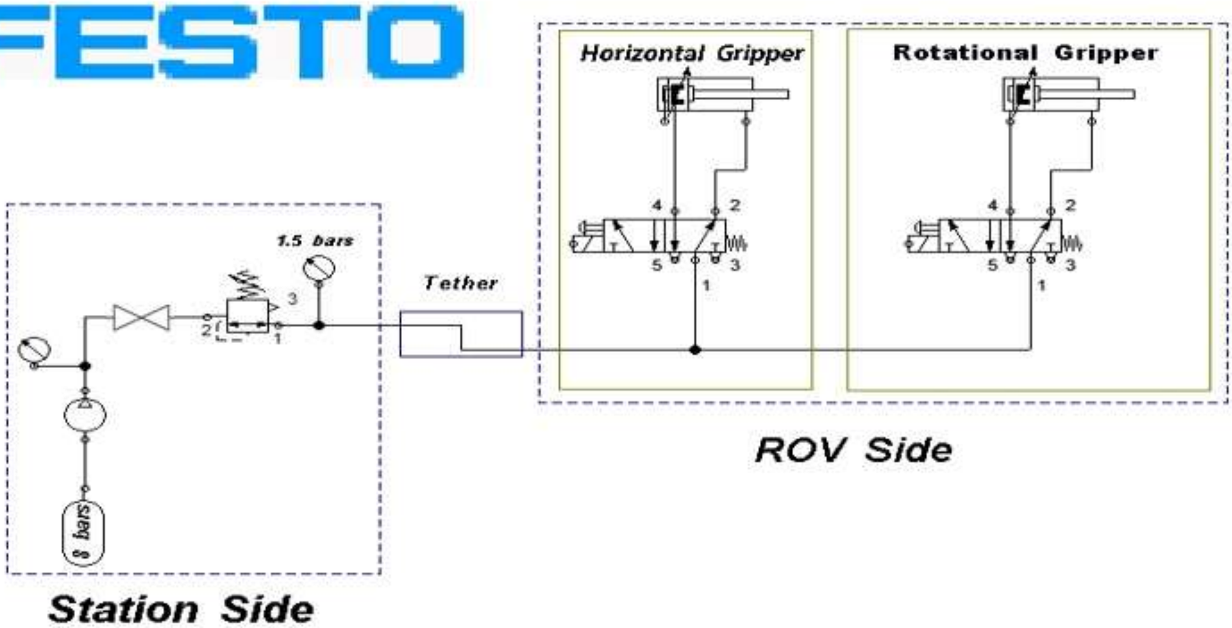
1. Electrical SID of ROV



2. Electrical SID of Non-ROV Device



3. Pneumatic SID of ROV



Appendix B: Project Costing

Type	Category	Descrption	Amount	Project Cost	Running Balance
Cash donated	General	Self-Funds from Team Members	$4,500.00	$0.00	$4,500.00
Re-used	Tether	Power Cable (30 Meters)	$45.30	$45.30	$4,500.00
Re-used		Pneumatic Cables (32 Meters)	$22.30	$67.60	$4,500.00
Purchased		CAT 6 (30 Meters)	$45.60	$113.20	$4,454.40
Re-used		Anderson Connector	$19.00	$132.20	$4,454.40
Re-used	Electronics	ESCs (5 Units)	$190.00	$322.20	$4,454.40
Purchased		ESCs (3 Units)	$114.00	$436.20	$4,340.40
Purchased		Prototype PCB	$20.00	$456.20	$4,320.40
Purchased		Bluerobotics _Lumen Subsea Light_ 4 lights	$640.00	$1,096.20	$3,680.40
Purchased		Main PCB	$62.50	$1,158.70	$3,617.90
Re-used		Raspberry Pi 4	$61.00	$1,219.70	$3,617.90
Re-used		Pixhawk	$193.00	$1,412.70	$3,617.90
Re-used		Low-Light HD USB Camera	$99.00	$1,511.70	$3,617.90
Purchased		CCTV Cameras (3 Cameras)	$32.00	$1,543.70	$3,585.90
Purchased		Analog Camera	$6.20	$1,549.90	$3,579.70
Purchased		Buck Boost Converter	$11.00	$1,560.90	$3,568.70
Purchased		Buck Converter	$4.00	$1,564.90	$3,564.70
Purchased		bilge pump	$160.00	$1,724.90	$3,404.70
Purchased		Arduino Nano	$11.00	$1,735.90	$3,393.70
Re-used		Power Supply	$82.00	$1,817.90	$3,393.70
Purchased		Bar30 Pressure Sensor	$85.00	$1,902.90	$3,308.70
Purchased	Float Engine	Materials & Fabrication	$63.50	$1,966.40	$3,245.20
Re-used		Arduino Nano	$11.60	$1,978.00	$3,245.20
Re-used		HC-12	$5.00	$1,983.00	$3,245.20
Re-used		DC Motor	$12.00	$1,995.00	$3,245.20
Re-used		DS3231 RTC Module	$2.70	$1,997.70	$3,245.20
Re-used		HC-05 Bluetooth Module	$5.60	$2,003.30	$3,245.20
Purchased		Limit Switch	$1.60	$2,004.90	$3,243.60
Purchased		VNHSP30 Motor Driver	$4.20	$2,009.10	$3,239.40
Purchased		SD Card Module	$0.88	$2,009.98	$3,238.52
Purchased		Bar30 Pressure Sensor	$85.00	$2,094.98	$3,153.52
Purchased		I2C Level Converter	$25.00	$2,119.98	$3,128.52
Purchased		PCB	$33.30	$2,153.28	$3,095.22
Purchased		Switch	$3.00	$2,156.28	$3,092.22
Purchased		Batteries	$52.00	$2,208.28	$3,040.22
Donated	Control Panel	Screen	$220.00	$2,428.28	$3,040.22
Purchased		Xbox - Joystick	$72.00	$2,500.28	$2,968.22
Re-used		Case	$134.00	$2,634.28	$2,968.22
Re-used		8 Channels DVR (1 Unit)	$112.00	$2,746.28	$2,968.22
Purchased		Case Accessories	$35.00	$2,781.28	$2,933.22
Purchased		Video Baluns (6 Units)	$8.00	$2,789.28	$2,925.22
Purchased		Arduino Nano	$11.60	$2,800.88	$2,913.62
Purchased		HC-12	$5.00	$2,805.88	$2,908.62
Re-used	Hardware	Main Enclousure Material (PMMA & PA	$190.00	$2,995.88	$2,908.62
Re-used		Camera box (Face Seal)	$80.00	$3,075.88	$2,908.62
Re-used		Camera box (Piston Seal)	$35.00	$3,110.88	$2,908.62
Purchased		Plugs	$22.00	$3,132.88	$2,886.62
Purchased		Grippers Material (PMMA)	$41.00	$3,173.88	$2,845.62
Purchased		Grippers Manufacturing (Laser-Cutting)	$29.00	$3,202.88	$2,816.62
Purchased		Aluminum Extrution	$112.00	$3,314.88	$2,704.62
Re-used		Argo Glands	$150.00	$3,464.88	$2,704.62
Purchased		O-Rings	$5.60	$3,470.48	$2,699.02
Re-used		DCVs	$51.00	$3,521.48	$2,699.02
Re-used		Pneumatic Piston	$48.00	$3,569.48	$2,699.02
Re-used		Fittings	$32.00	$3,601.48	$2,699.02
Purchased		Bolts & Nuts	$70.00	$3,671.48	$2,629.02
Purchased		3D Printed Parts	$112.00	$3,783.48	$2,517.02
Re-used		Thrusters T200 (2 Motors)	$400.00	$4,183.48	$2,517.02
Purchased		T200 Motor (4 Motors)	$800.0	$4,983.48	$1,717.02
Purchased		Trusters' Mesh	$40.00	$5,023.48	$1,677.02
Re-used		Compressor	$135.00	$5,158.48	$1,677.02
Purchased	Customs and Shipping	Customs and Shipping for all imported	$465.0		$1,212.02
Purchased	Logistics	poster printing	$50.0		$1,162.02
Cash donated	For travel and accommodation	Self-Funds from Team Members	$24,500.0		
Purchased	Travel	Round-trip to Tennessee	$21,630.0		$4,032.02
		Travling in the country	$405.0		$3,627.02
Purchased	Accommodation	7 days in Tennessee	$3,244.0		$383.02
Total Raised			**$29,779.00**		
Total Spent			**$29,395.98**		
Final Balance			**$383.02**		

Appendix C: Operations and Safety Checklist

Procedure	Check Mark
Pre-Power Checks	
Station members are wearing safety gear	
Check that Thrusters and Manipulators are not obstructed by anything	
No running at the pool	
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" say it loudly.	
Pre-Water Checks	
Connect tether to the control panel	
Test the video system	
Compress the electronics enclosure to the called dive's rated depth.	
Check that compressor pressure is below 2.75 bars	
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.	
Rearrange the tether neatly	
Safety Keeper 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:	