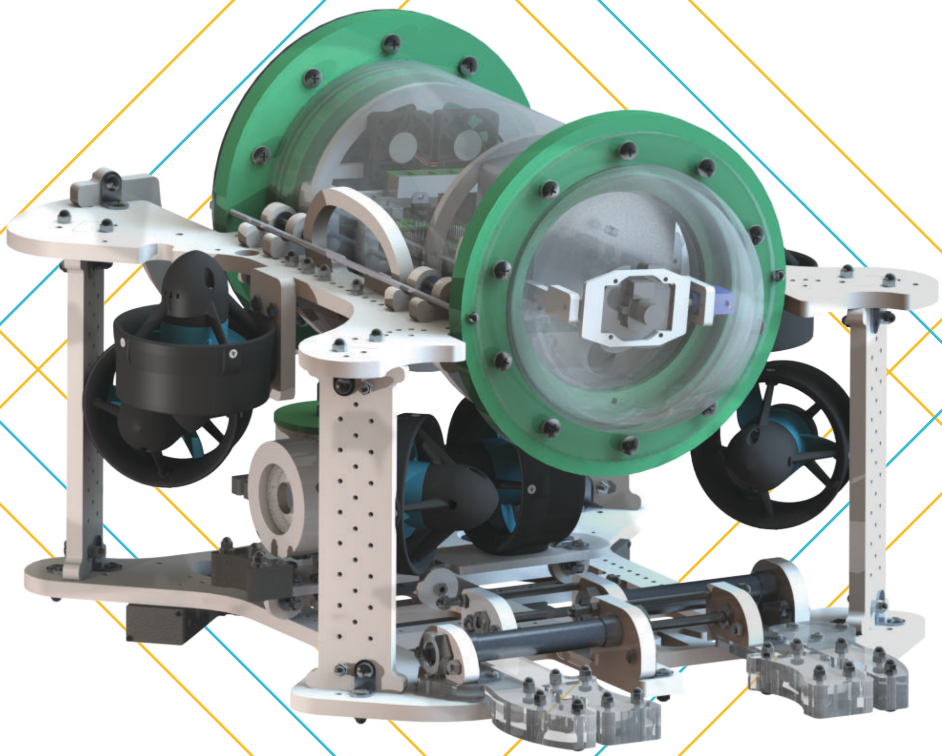
NAUTILUS

Aquaphoton Academy
Technical Report '21
Faculty of Engineering
Alexandria University
Alexandria, Egypt



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1 Introduction

1.1 Abstract

Since 2012, and after nine years of experience in the Remotely Operated Vehicles (ROV) industry, Aquaphoton continues to be a forward-looking team dedicated to designing ROVs that are built to last. This team, a sixteen-person workforce (figure 1), has always believed in the importance of doing its part in helping the environment by reducing its waste and diminishing carbon footprint, embracing the famous "Reduce, Reuse, Recycle" slogan as its core philosophy.

Nautilus, Aquaphoton's latest creation, is a novel ROV designed to address the ever-growing problem of plastic pollution, environmental degradation, and climate change. Adopting the chambered Nautilus—being the "canary in the coal mine" of the deep reef environment revealing its health where little ecological study is done—**Nautilus** can expertly clear up various types of plastic debris, assist in sample collection for testing, help maintain healthy waterways, and monitor the health of marine life impacted by climate change.

Nautilus is designed for optimal time efficiency, maneuverability, adaptability, and tooling flexibility while remaining cost-effective. Featuring a small and lightweight frame, a modular electronic system for easier servicing, a Variable Thruster Coordinate (VTC) system for better stability, a hybrid manipulator that enables multitasking, and many more tools and sensors, **Nautilus** is Aquaphoton's finest ROV, as it lays on the top of the team's optimization ladder.

This technical document encapsulates **Nautilus**' development process, showcasing what makes it the ideal ROV to help our world move in a more sustainable direction, meeting the global community's Request For Proposal (RFP).

Figure 1: Aquaphoton Members

Contents

2 Design Rationale

2.1 Design Evolution

After a thorough analysis of the global community's RFP, Aquaphoton decided to focus on coming up with efficient solutions to the presented challenges while keeping modularity, adaptability, and maneuverability in mind during the design process.

Nautilus, shown in figure 2, is the latest addition to Aquaphoton's ROV collection and is the product of years of experience in designing and building exceptional ROVs. Evaluating its past performances—assessing failures as well as excellences. Aquaphoton refined its design process and made notable upgrades, resulting in **Nautilus** being its greatest creation yet.

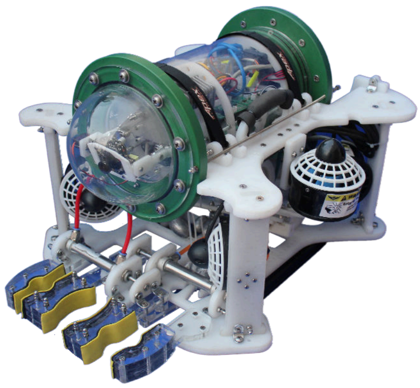


Figure 2: Nautilus' Real Life Photo

Nautilus' design stands out for being compatible with a variety of payloads, going beyond those made for 2021 challenges. This year's design features new sealing techniques, VTC, and a hybrid manipulator.

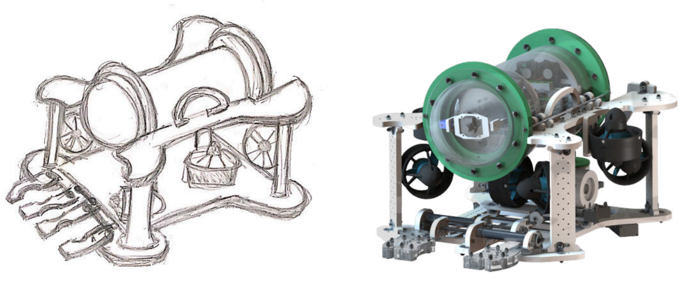
Examining the limitations and capabilities of the previous years' electrical system led to many aspects of it being reconsidered to reach a more stable and efficient design. The RS-485 communication protocol was replaced by the Controller Area Network (CAN) standard which meets **Nautilus**' demand for a robust and more orderly method for communication; new DC-to-DC step-down converters were added to the system, thus boosting the total current rating of **Nautilus**' power supply. A completely new feedback system was incorporated in **Nautilus**' system which widened the range of sensors used. One of the huge upgrades introduced to the new software system is the use of a custom-made bootloader, allowing the remote upload of **Nautilus**' firmware. These and other improvements are discussed in further detail in the sections that follow.

2.2 Design and Manufacturing Process

Aquaphoton's design process is a sophisticated procedure consisting of three major phases: conceptual, preliminary, and detailed designs. This process allows the company to pay attention to detail, and fully consider every part that comprises the ROV, without failing to see the full picture; successfully avoiding falling into the trap of short-sightedness.

Design Process

- **Conceptual design:**
  Extensive research coupled with brainstorming resulted in a collection of suggested ideas and solutions that meet the RFP. Different design concepts were judged based on various metrics including size, weight, cost, complexity, manufacturability, safety, and reliability. A trade-off matrix was then constructed to aid in choosing the most promising design.
- **Preliminary design:**
  Once a design concept was agreed on, a proof of concept with basic design ideas was then created, as shown in figure 3, after which the entire team reconvened to debate the prototypes' viability to reach optimum solutions.



(a) Nautilus' Hand Sketch **(b)** Nautilus Rendered

Figure 3: Design Process

- **Detailed design:**
  After the concepts were validated, the preliminary design was then 3D modeled using various software like Solidworks for mechanical designs, Fusion 360 to model Printed Circuit boards (PCBs). Flow simulations and force analysis were also carried out when necessary which allowed Aquaphoton to reach a detailed design that is ready to be manufactured.

Following this design process, the majority of the components were selected according to the results shown in table 1.

	Criteria	Weight				Material Options		
		Frame	Manipulator	Gland's plate	Casing	HDPE	Acrylic	Aluminum
						Score		
1	Cost effectivness and availabilty	0.3	0.1	0.1	0.1	9	8	5
2	Machinability	0.1	0.1	0.2	0.4	9	5	9
3	Specific gravity	0.3	0.1	0.1	0.2	9	9	7
4	Strength	0.3	0.3	0.5	0.2	6	7	9
5	Transperancy	0	0.4	0.1	0.1	0	9	0
	Total score formula	$\sum_{Criteria=1}^{n}(Weighting of component)_{criteria} \times (Material score)_{criteria}$						
	Total score	Frame				8.1	7.7	7.2
		Manipulator				4.5	7.9	4.8
		Cable gland's plate				6.6	7.1	7.5
		Casings				7.5	6.9	7.3

Table 1: Material Trade off matrix

Manufacturing Process

The manufacturing process ensures dimensional accuracy and build integrity, effectively rendering it as optimized and cost-effective as it can be. Cylindrical parts were manufactured using lathing, while acrylic and High Density Polyethylene (HDPE) plates were routed by a CNC machine. Files of 2D CAD drawings were prepared for CNC routing, taking into account using the least amount of space in a sheet to reduce wasted material. All parts were then assembled and ready to be tested.

2.3 Vehicle Core Systems

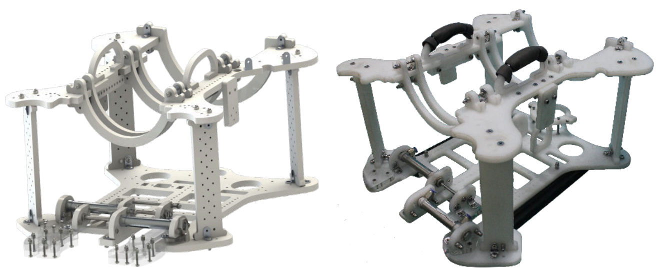
2.3.1 Mechanical

Frame

Nautilus' frame is built using HDPE since it's nearly neutrally buoyant, non-corrosive, easy to machine and commercially available. It's designed to be lightweight and compact: measuring at 45x21x24cm (Length x Width x Height), and weighing 2.3kg which is 1.8kg lighter than last year's design. Its adaptive design allows flexibility in mounting options for various parts and payloads, or the addition of new ones beyond those designed for this year's challenges.

As shown in figure 4, the frame consists of a split upper plate, whose sides are connected via the four C-brackets carrying the electric canister and another C-bracket for strain relief. Four vertical plates are mounted at a 45° angle in accordance with the thruster configuration, connecting the lower and upper plates, while the vertical thrusters are mounted on brackets fixed to the upper plate, all thrusters incorporate the VTC feature.

(For more details about the VTC feature, please refer to the Buoyancy and Stability)



(a) Rendered **(b)** Real life

Figure 4: Nautilus' Frame

All connections are made using mortise and tenon joints to increase contact area between parts, then secured using stainless steel L-fixations, thus preventing any wobbliness. The frame rests on four rubber bumpers, 28cm long, that act as a base; while special handles are added to the upper plate to ease the lifting and transportation of **Nautilus**.

Proving success in the previous years, a refined version of the electrical housing's fixation was introduced for ease of mounting, and remounting of the enclosure, facilitating troubleshooting. The housing rests on two C-brackets pairs and is held in place using Velcro straps. The upper plate terminals are especially designed to prevent the electrical housing from oscillating.

Propulsion

Nautilus boasts six Blue Robotics thrusters that are reused to keep our design as cost-effective as possible. A performance test was done on each thruster before deciding to reuse them, ensuring that they are still as efficient and reliable as they were when used in previous years.

Four T100 thrusters are mounted horizontally on a 45° angle (X-shaped configuration) for lateral and rotational motion, and two T200 are used for vertical motion. The X-shaped configuration was selected to provide equal forces for lateral motion in the 3 axes, thus giving equal velocities at a constant drag.
Thrusters were chosen over other alternatives to overcome the maximum drag facing **Nautilus**. The maximum coefficient of drag was 0.8241 from the simulation shown in figure 5, where 63.46kgf drag at 1m/s sway speed and 0.1539 m2 projected area was calculated according to the drag equation: $F_D = \frac{1}{2} C_D \rho A v^2$

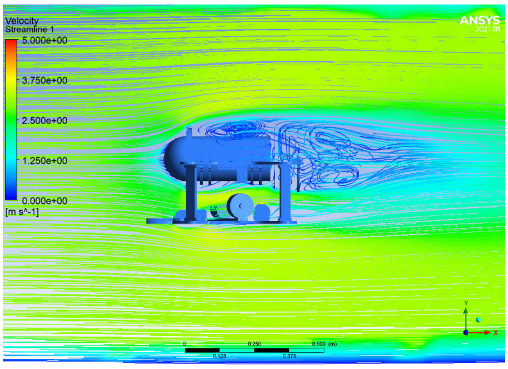
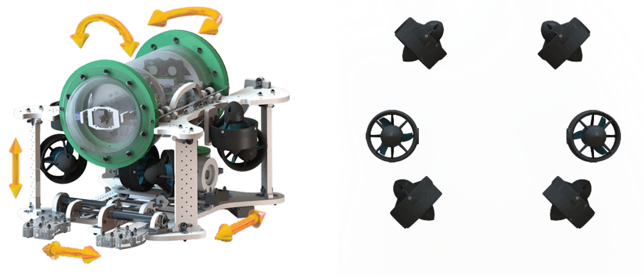


Figure 5: Flow Simulation on ANSYS

A T100 thruster has a maximum forward thrust of 2.36kgf. Accordingly, four T100 thrusters in X-configuration will produce 6.67kgf of thrust. While a T200 thruster has a maximum forward thrust of 3.55kgf which gives a combined maximum thrust force of 7.1kgf. Therefore, the used thruster configuration, shown in figure 6, has proven to be valid since the total thrust of each one exceeds the maximum drag.
Moreover, this configuration provides **Nautilus** with five degrees of freedom, making it easy to control and maneuver between missions while maintaining the best stability during motion.

Buoyancy and Stability

During the design phase, simulations were made on the design determining that the shift between the center of gravity (C_g) and the center of buoyancy (C_b) is 2.4cm to the left


(a) Degrees of Freedom **(b)** Thruster Configuration
Figure 6: Propulsion

and 1.7cm to the back. Therefore, counter lead weights were added to ensure that C_b lies above C_g and that both centers lie on the same vertical axis, providing maximum stability.

Furthermore, the VTC feature was introduced to **Nautilus** to ease the alignment of both drag and thrust lines of action to be on the same plane, providing fast adaptability to changes like adding payloads. This is achieved by altering the position of the horizontal thrusters in the vertical plane, and the vertical thrusters in the horizontal plane, as shown in figure 7.
One of the major design factors that were taken into consideration while designing the frame was to make it neutrally buoyant. Thus, excess material was removed, reducing **Nautilus**′ weight to 15kgf and its displaced volume to 17142cm3. To achieve neutral buoyancy, Archimedes′ principle was applied as follows: $F_{Buoyancy} = \rho V_g$, where this buoyancy force is 16.8kgf which is (greater/smaller) than **Nautilus**′ weight. Accordingly, weight of 1.2kg is added in order to reach a neutrally buoyant state.

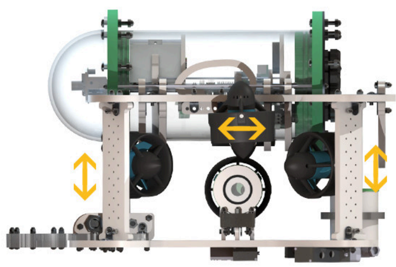


Figure 7: VTC Feature

Electrical Housing

Given how great it performed, Aquaphoton decided to reuse its electrical housing from the previous year, optimizing it to better accommodate its new and improved electrical system. This year, Directional Control Valves (DCVs) were moved out of the electrical housing and sealed using marine epoxy, providing the canister with more space to be compatible with the addition of new components. Hermetically sealed acrylic enclosure of 6" diameter and 28cm length, shown in figure 8, houses:

- A drawer-like sliding mechanism that carries out all electrical components as one unit, providing easy access to the inside; therefore cutting down maintenance time and securing components in place at all times.
- Two cameras, which are fixed on a tilting mechanism actuated using servo motors in order to expand **Nautilus**' range of view.

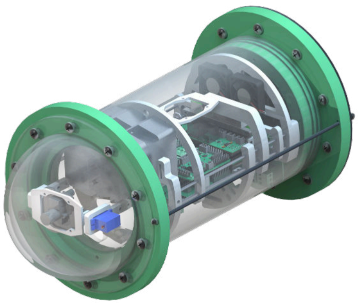


Figure 8: Electrical Housing

An acrylic enclosure was chosen according to the trade-off matrix shown in table 1, proving to be the most suitable material for the enclosure. Steel was chosen to be the material of the sliding rods due to its high rigidity and strength; while HDPE material is used for the fixations due to its shock resistance property.

Static analysis was performed using Solidworks to test the strength of the materials under extreme operating conditions, and it confirmed that our material selection was ideal.

Sealing

Electrical Housing Sealing

The electrical housing sealing is incorporated in its HDPE end caps: each end cap has two radial O-rings set in grooves machined according to Parker Co. standards. The O-rings not only keep the electrical components dry at all times, but they also cut down on maintenance time, as the caps can now be easily removed by hand without having to use any tools. Silicone grease is used with the O-rings to protect them from wear, extending their lifetime.

The back end cap was completely redesigned, as the type of cable glands previously used was no longer available. The new AGRO cable glands have a smaller threading length than that of the previous design (7mm instead of 10mm); therefore, to avoid reducing the thickness of the HDPE used and weakening it, the end cap, shown in figure 9, was split into two parts: the first part is a hollow HDPE end cap, the second part is a circular aluminium sheet of 3mm thickness, in which eighteen 16mm holes were drilled for the cable glands. The aluminium sheet was preferred as it retains its strength even at small thicknesses and won't pose a leaking risk. The two parts were then connected by bolts, and a face O-ring is used between them to seal the connection. Similarly, the front end cap was designed, but using an acrylic dome instead of aluminum to provide camera view.

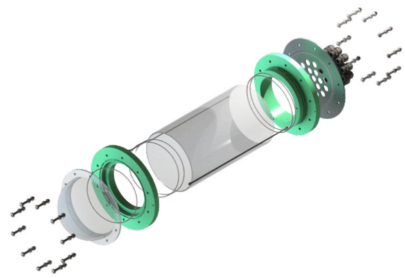
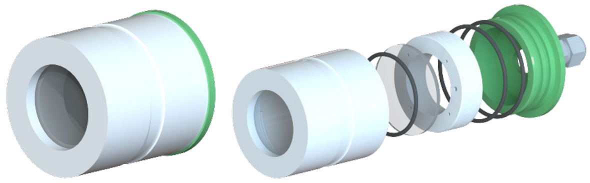


Figure 9: Electrical Housing Sealing

Camera Sealing

Adapting the idea of using a threaded part of the casing as the source of compression on the O-ring was the main inspiration for sealing **Nautilus**' five cylindrical HDPE camera cases. This sealing technique provided us with a more compact and lighter design, as it was sealed without using any single bolt.

The camera casing, shown in figure 10, consists of three parts: outer front case, camera fixation part, and back end cap. The outer front comprises a face O-ring along with an internal thread, while the camera fixation part contains the camera along with an external thread; these two parts are then fixed together, compressing the O-ring with an acrylic lens in between. The back end cap holds the AGRO gland that seals the camera's power cable.

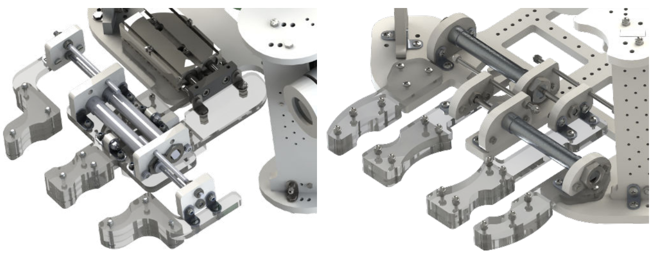


(a) Assembled View **(b)** Exploded View

Figure 10: Secondary Camera Casing Sealing

Manipulator

Nautilus' manipulator, shown in figure 11, is the product of a two-year design evolution. In previous designs, a double-grip manipulator was attached as a payload to the main single-grip one, enabling the pilot to grab multiple objects at once. As efficient as this design's idea was, it still had some shortcomings: its excessive number of pneumatic cylinders weighed the ROV significantly, its limited stroke, and the added-on time to install it.



(a) 2020 Manipulator **(b)** 2021 Manipulator

Figure 11: Manipulator's Design Evolution

Keeping these limitations in mind, a hybrid manipulator, shown in figure 12, featuring both a single- and double-grip manipulator, was designed for **Nautilus**. It comprises two pneumatic cylinders, each resting on a fixed jaw at the terminals while the middle jaw is split into two moving ones. This provides the cylinder with a full stroke and a full force which acts normally on the object to reduce any force dissipation. This setup provides the pilot with flexibility in holding multiple objects of various sizes at once or separately, such as out-planting two coral fragments at the same time, with a maximum stroke of 5cm each with extension force of 42.3N, or grab a single object with a maximum stroke of 10cm with a double retraction force 34.6N each.

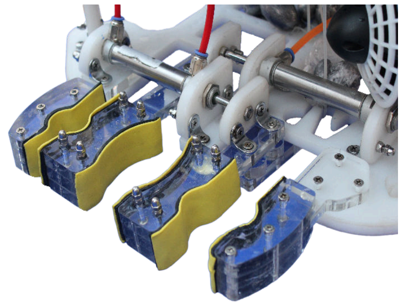
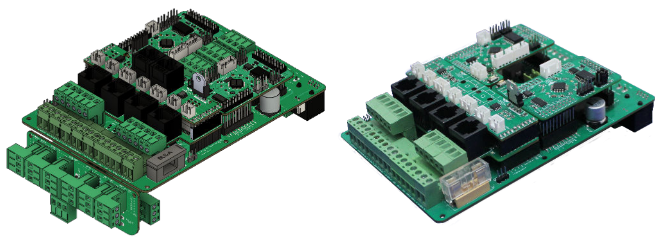


Figure 12: Real Life Image of The Manipulator

Pneumatics were used in **Nautilus**' manipulator, as it proved to be fast, efficient, easy to control, and reliable in previous years' designs. Guides are also added to eliminate the chance of any rotation of the end effector mid-mission. Acrylic is selected for the end effector, taking advantage of its transparency, lightweight, and resistance to normal stress. The end effector is covered with a thin foam layer to avoid direct contact with acrylic, thus protecting it against shocks and improving its grip.

2.3.2 Electrical

The main design goals for this year's electrical system, shown in figure 13, were modularity, robustness, and backward compatibility. Through careful analysis and design, these goals were successfully met. Each circuit was implemented on a separate double-layer PCB with Surface Mount Device (SMD) technology.



(a) 3D Model **(b)** Real Life

Figure 13: Electrical System

Moreover, the new hardware system is completely compatible with last year's ROV. This allowed the team to stay operational and provide the station crew with an extended period of training, even while building the new ROV.

Power Distribution System

Nautilus is powered by a shore-side power supply delivering a DC voltage of 48V. This voltage is then fed to DC-to-DC converters providing 3.3V, 5V, 6V, and 12V. A dedicated converter supplies the sensitive vision system's components; therefore, decoupling them from electromagnetic interference (EMI) generated by inductive loads in the system (e.g., thrusters).

As shown in table 2, the maximum power consumed by **Nautilus** is approximately 937W, which draws nearly 19.5A of current from the 48V power supply. The peak current is multiplied by a 1.5 factor of safety, resulting in a maximum current of 29.28A, therefore the fuse used is 30A.

Component	Input Voltage:V	Maximum Current: A	Quantity	Power: W
Thrusters	12	12.5	Total: 7 At once :6 Speed: 90%	810
Analog Camera	12	0.2	2	4.8
IP Camera	12	0.2	4	12
DC Motor	12	2	4	96
DCV	12	0.33	4	16
Microcontroller	3.3	0.05	3	0.495
Total Power: W	———	———	———	937

Table 2: Power Chart

Nautilus' power distribution system is implemented on its backplane PCB, shown in figure 14. It is custom-designed to be the base of **Nautilus**' electrical system, connecting all the other PCBs as one unit. This PCB houses the electrical components comprising the power management circuit, the motor driving circuits responsible for controlling the payloads and the DCVs, and the Electronic Speed Controllers (ESC) connections.

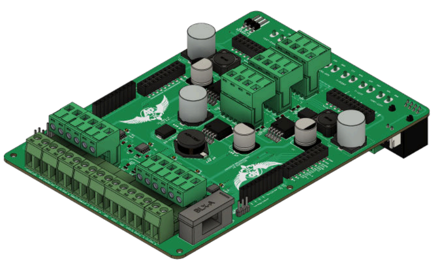


Figure 14: Backplane PCB

Communication System

With the increase in the number of independent subsystems in **Nautilus**' electrical system compared to Aquaphoton's previous ROVs, the search for a fast, long-range and robust communication protocol with multi-drop support was initiated. After researching, CAN protocol was chosen, having met our requirements.

The CAN protocol offers fast transmission rates, allowing the rapid exchange of messages between different system nodes and hence minimizing the overall system response time. Furthermore, CAN provides significant advantages over other serial protocols in terms of message handling, error-message checking, improved bandwidth, and providing a larger data field. Moreover, since CAN is a message-based protocol, any node on the CAN bus can send and receive messages from other nodes. This makes our design extremely flexible and scalable compared to the previously used RS-485 standard.

Nautilus' CAN bus interconnects a total of three nodes: Topside Control unit (TCU), Feedback, and the centralized communication PCB shown in figure 15, each consisting of microcontroller, CAN controller, and high speed CAN transceiver.

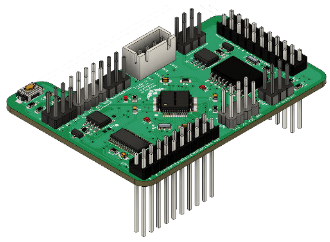


Figure 15: Communication System PCB

To make our system more reliable and fault-tolerant, an RS-485 bus was installed in parallel to the CAN bus, with the intent of using it in case of irrecoverable failures in any of the CAN bus components. This is achieved using a software monitoring program that would continuously check the state of the CAN bus and automatically activate the RS-485 bus as required, allowing **Nautilus** to remain functional during mission-critical tasks, even with a partially-damaged communication system. The full communication system is illustrated in figure 16.

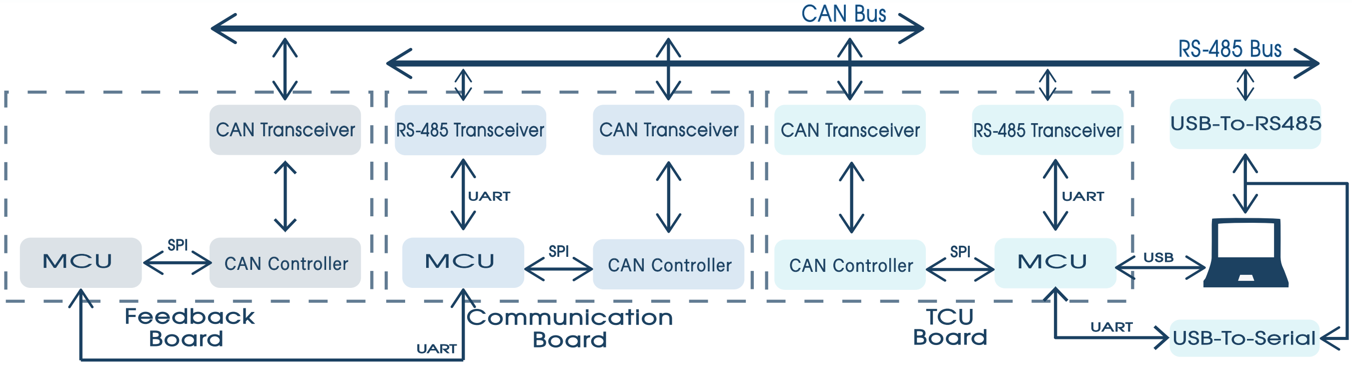


Figure 16: Communication System Diagram

Feedback System

Nautilus is equipped with a feedback system comprising a variety of sensors providing precise real-time measurements. This feedback system was implemented as a separate PCB, as shown in figure 17, maintaining the overall modularity of the electrical system.

Voltage sensors are utilized to monitor the output of each DC-to-DC power converter, detecting any voltage fluctuations. These sensors were built instead of buying off-the-shelf modules to reduce the cost and meet our specific requirements.

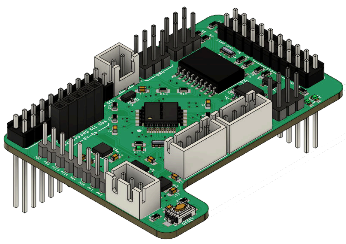


Figure 17: Feedback System PCB

Additionally, a leakage sensor is used to detect sealing failures and custom designed to cover a larger detection area, as opposed to buying off-the-shelf modules. Internal temperature sensors are also deployed to monitor the temperature of **Nautilus**' electrical canister. Moreover, an Inertial Measurement Unit (IMU) is used to calculate **Nautilus**' position and orientation. These measurements are fed to a Proportional-Integral-Derivative (PID) controller, improving its maneuverability during the transect line mission.

Vision System

Nautilus' vision system is the product of an iterative refinement process. It aims to maximize the pilot's field of view, as shown in figure 18, giving him a greater situational awareness, while reducing the system's overall cost. In contrast to the previous vision system, where analog cameras were used exclusively, this system includes both analog and IP cameras to get the best of both worlds.

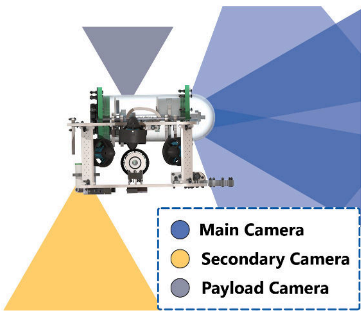
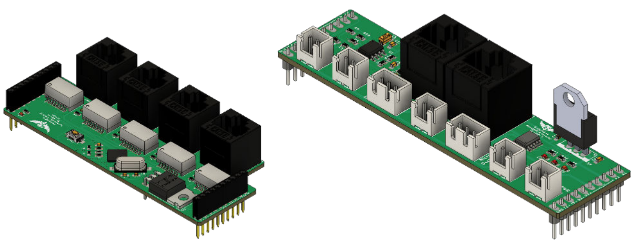


Figure 18: Cameras' fields of view

To achieve better signal integrity, we opted for implementing our vision system as two distinct PCBs, as shown in figure 19, separating the analog NTSC camera signals from the digital IP camera signals. This separation not only maintained the modularity of our system, but it also allowed our new vision system to be backward compatible with previous iterations of our electrical system.



(a) IP Cameras PCB **(b)** Analog Cameras PCB

Figure 19: Vision System PCBs

Shown in figure 20 is a hardware diagram of our vision system.

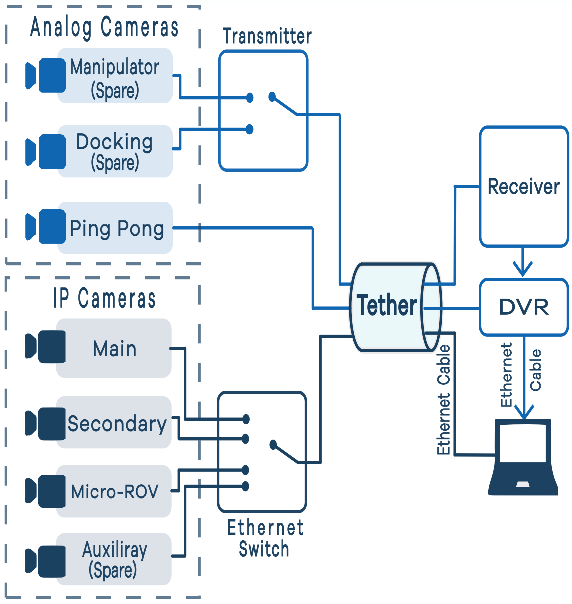


Figure 20: Vision System Diagram

Analog Cameras PCB

Being entirely dependent on analog cameras, the main drawback of the previous vision system was the loss of perceptual quality due to electromagnetic interference caused by high-current loads (e.g., thrusters). The close proximity of the signal- and current-carrying conductors in the tether allowed for the coupling of such noise, heavily deteriorating the analog video signal.

After months of research and prototyping, A stable solution was reached for the long-range transmission of analog signals in harsh environments. The solution is based on the concept of differential signaling, in which the signal is transmitted along with its inverse using a twisted-pair conductor. In this setting, noise is coupled equally onto both signals, thus allowing the receiver to extract the original signal using a simple differential amplifier circuit. Once the signal is reconstructed, it can then be fed to a frame grabber and displayed through USB ports.

IP Cameras PCB

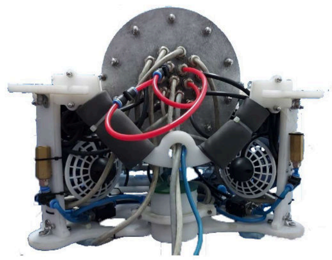
Besides having superior image quality over their analog counterparts, IP cameras also have the ability to be multiplexed onto a single cable using an Ethernet switch. Being constrained by the number of conductors available in the tether, this feature was found to be very alluring and beneficial. To this end, a novel IP cameras subsystem was designed around an Ethernet switch controller with the ability to handle 4 IP cameras.

● Tether

After analyzing **Nautilus**′ mechanical and electrical systems′ demands, the tether requirements were clearly formulated.

From a mechanical point of view, **Nautilus**′ tether was designed to be: neutrally buoyant through the periodic addition of short rubber sheaths, sturdy and durable through wrapping it in a protective sheath, as shown in figure 21, and 18m long to be sufficient for **Nautilus**′ depth requirement. A tether management protocol is implemented to ensure the safety of the ROV as well as the employees, where a tether-man is completely responsible for handling the tether during operation. During its transportation, it is rolled up, eliminating tripping hazards. Moreover, the tether connectors on both sides also feature strain relief to avoid any excessive tension.

(a) Tether Sheath



(b) Tether Strain Relief

Figure 21: Tether Features

Electrical wise, high performance insulated silicone was used for power transmission to minimize resistive power losses and withstand **Nautilus**′ power consumption. Shielded twisted pairs were used in transmitting video signals to neutralize external noise.
In conclusion, the tether is made up of several components, as shown in figure 22; a 10-terminal cable, a shielded Ethernet cable, one pneumatic hose, and a protective sheath.

● Top-Side Control Unit

The TCU is the main method of control over **Nautilus**. Designed with mobility and durability in mind, as shown in figure 23, it comprises

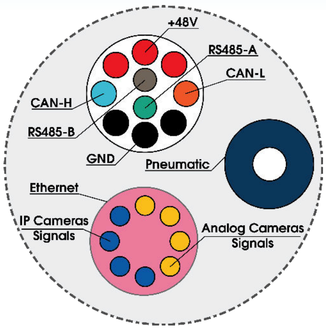


Figure 22: Tether Cross Section View

a 30x40cm case with an acrylic sheet fixed on top, providing a user-friendly and intuitive interface. It also shields all the wiring inside the unit.

Figure 23: Topside Control Unit

It is equipped with a 19" liquid-crystal display (LCD) responsible for the pilot's main view. The LCD is connected through an HDMI cable to a laptop hosting **Nautilus**' GUI and other mission-specific codes. Additionally, the tether interfaces with the TCU through a special waterproof connector embedded in the unit's frame. The connector incorporates a strain relief, to avoid accidental pulls from damaging the connector.

The unit houses a PCB, shown in figure 24, that acts as the main communication node between the station's laptop and **Nautilus**, relaying control measurements onto the CAN bus and receiving feedback. To increase the flexibility of the system, it is capable of receiving GUI commands through USB, UART, or RS-485 interfaces.

Moreover, the PCB includes the receiving end of our video transmission system. It is capable of receiving two differential video signals and extracting the NTSC signals

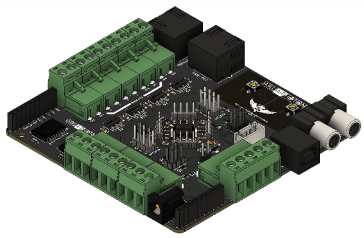


Figure 24: TCU PCB

before outputting them on dedicated RCA connectors.

2.3.3 Software

● On-Board Code

Nautilus' firmware, shown in figure 25, is distributed amongst its three microcontrollers to achieve better load balancing, maintaining the system's modularity.

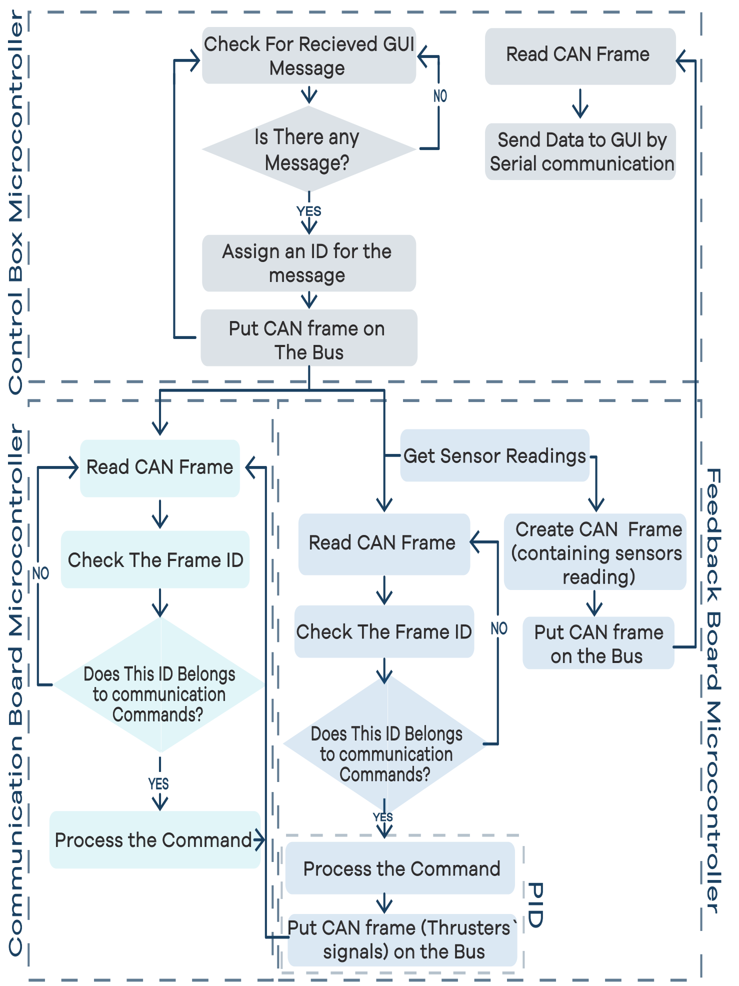


Figure 25: On-Board Code Flow Chart

Each microcontroller has a specific function and is programmed using the Arduino Integrated Development Environment (IDE). All microcontrollers have firmware implementing the CAN protocol, which allows for targeted communication with the TCU. Once a message is placed on the CAN bus by the TCU, all on-board microcontrollers examine its identifier before further processing and acting upon it.

A major limitation in Aquaphoton's previous ROVs was the firmware flashing methodology. This approach not only hindered the workflow, but also endangered the electrical system by stressing out the sealing mechanism, increasing the probability of failures. This year, **Nautilus** was equipped with a novel custom-made bootloader software allowing for rapid firmware updates. Written in C, the bootloader fetches the compiled firmware over the tether and flashes it onto the microcontroller's memory, totally eliminating the need to physically access the electrical housing.

Aiming for equipping **Nautilus** with fail-operate features, this firmware utilizes the strategy design pattern to make its communication system more robust and fault-tolerant. It makes use of watchdog timers to detect failures on the main communication bus and automatically switch to a backup bus in a transparent manner.

Graphical User Interface

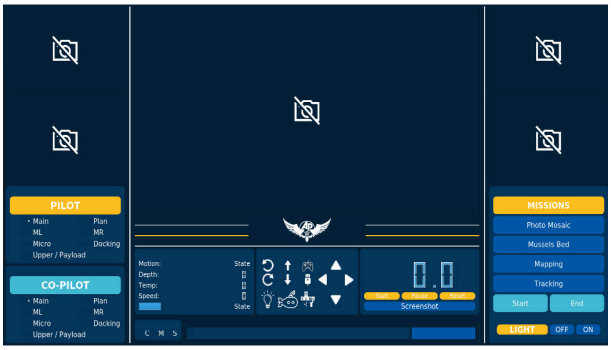
The TCU controls **Nautilus** through a Graphical User Interface (GUI), developed using Python and the Qt application framework. As the GUI is responsible for the first impression of a software system, Qt was chosen as it provided the tools and widgets needed to create a user-friendly, functional, and eye-catching interface. The back-end was implemented using Python, as it has extensive support libraries and was also used to create all mission-specific algorithms, which made it the best choice for the GUI back-end.

The GUI's main purpose is prioritizing time efficiency by maximizing the pilot's and co-pilot's ease of use through intuitive control, to achieve this, two different user interfaces, shown in figure 26, were created for the pilot and the co-pilot to match each one to his specific role.

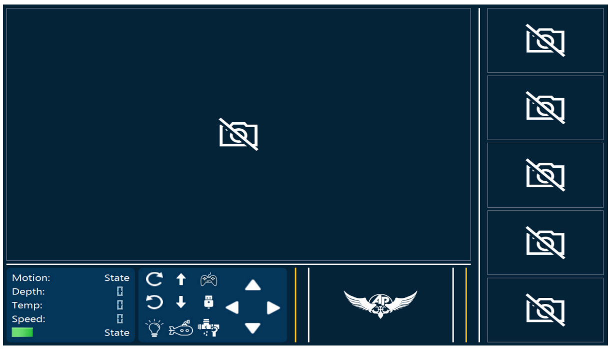
The co-pilot layout is divided into six sections:

- The Camera Feeds section which allows interchangeability amongst **Nautilus**' cameras. A new feature was added this year that enables the co-pilot to close any unnecessary camera feed enabling both the pilot and co-pilot to focus on a specific camera view without getting distracted during certain missions.
- The Feedback section displays real-time sensors' readings.
- The Control section allows the co-pilot to directly control **Nautilus**' speed and lights.
- The Serial Command section allows the co-pilot to directly communicate with **Nautilus** through a command-line interface (CLI), making testing and troubleshooting easier.
- The Current State section displays summarised real-time information about **Nautilus**' speed, movement, lights, cameras, and joystick connections as well as the state of the micro-ROV.
- The Missions section allows the co-pilot to navigate between different widgets customized for each mission, making the GUI more organized and user-friendly.

The main purpose of the pilot layout is to only focus on things the pilot needs as to not distract him.



(a) Co-Pilot Window



(b) Pilot Window

Figure 26: Two different GUI Windows

2.4 Mission Specific Auxiliary Tools

2.4.1 Surface Level Plastic Debris Collector

Nautilus provides a solution for collecting floating plastic debris, which has now become the most serious problem affecting the health of marine environment. Instead of relying on **Nautilus**' main manipulator to collect each piece of plastic debris one by one, Aquaphoton came up with a faster and more efficient collection mechanism. This mechanism, shown in figure 27, comprises a net that is used to collect multiple debris at once, and a pneumatic cylinder controlling the net. Inspired by the slider-crank mechanisms, the debris collector is made from specially designed HDPE links that convert the linear motion to rotational one, amplifying its 5cm stroke to double its value.
We went through several alternatives and iterations of this design, and had to carefully consider trade-offs to come up with a design that balances between the cost and efficiency. One of these alternatives was based on vortex generation from a thruster which was connected to a cavity to hold the plastic debris. However, this design didn't make the cut in order to reduce **Nautilus**' overall cost and power consumption.

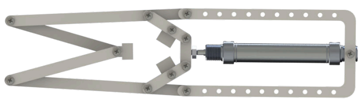


Figure 27: Debris Collector

2.4.2 Seabin Power Connector

The Seabin is a revolution in ocean cleaning technology. It will help create cleaner oceans with healthier marine life.

To replace the faulty Seabin's power connector, a new one is constructed using a 2" PVC pipe to be more cost effective, as shown in figure 28. It is sealed by using a two parts casing, axial O-rings, and an AGRO gland.

The sealed case itself holds a very small portion of the connector's body for water to enter the case and reduce its buoyancy. The rest of the connector was made of PVC pipes. This connector contains an inductive coupling, powered by a 12V source. It acts as a transmitter, generating a magnetic field that induces a current in the underwater receiver, effectively returning power to the Seabin.

Figure 28: Seabin Power Connector

2.4.3 Sediment Sample Retrieval Device

A Micro-ROV was specifically designed, as shown in figure 29, to be deployed from **Nautilus** in order to retrieve samples from places that are hard to reach. With a cylindrical HDPE body that is 7cm in diameter, and powered by a T200 BlueRobotics thruster, it is the perfect device to fit in all those nooks and crannies.

(a) Rendered **(b)** Real Life

Figure 29: Micro-ROV

2.4.4 Software Algorithms

- **Transect Line Algorithm**

To autonomously fly a transect line over a coral reef, a Lane-Keep-Assist System (LKAS) was designed. The LKAS algorithm, shown in figure 30, is divided into two sections: perception and motion planning.

Starting with perception, the algorithm utilizes an image segmentation machine learning model which extracts the edges.

These edges are then used to form a lane that **Nautilus** must stay in as it flies the transect line.

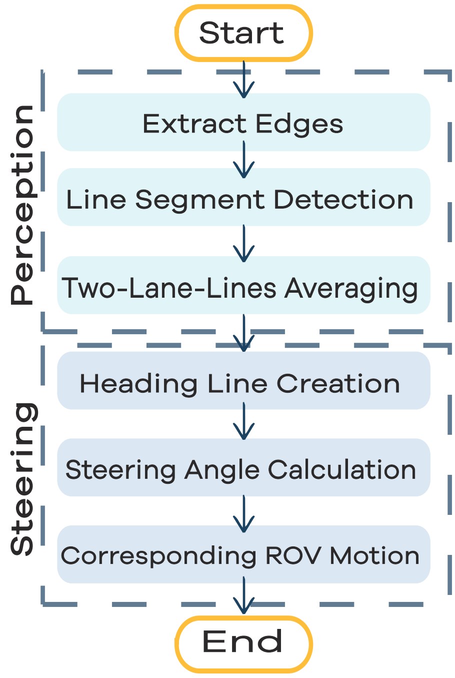


Figure 30: Transect line Flow Chart

Afterwards, the motion planning section ensures the ROV is automatically steered to keep it in the middle of the previously detected lane. Trigonometry is used to calculate the **Nautilus** steering angle based on its position and the desired transect line's endpoint.

Mapping

Over the past few years various researchers have been looking for new methods to locate and identify sea creatures to facilitate monitoring their population and behavior. Thus, an algorithm, shown in figure 31, was developed utilizing a pre-trained deep learning model, which was fine-tuned to map the six points of interest on the coral reef. The custom-made dataset was prepared by collecting images of the points of interest in diverse conditions to achieve higher detection accuracy, as shown in figure 32.

Two screenshots of the coral reef region are captured, and are then passed to the model to identify and locate the points of interest within the detected coral reef region. The collected data from the two separate screenshots is combined and passed to another algorithm,

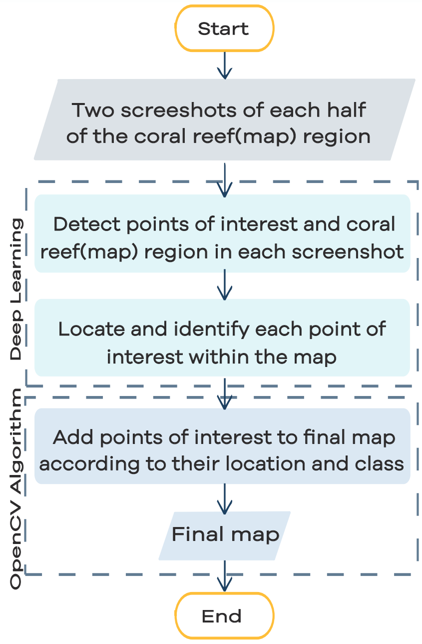


Figure 31: Mapping Flow Chart

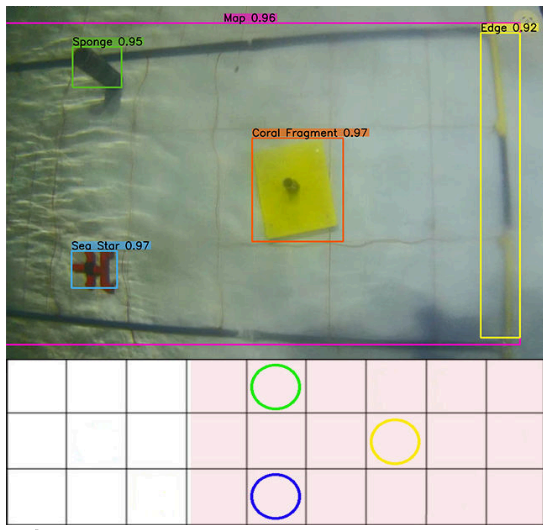


Figure 32: Detection of Points of Interest

implemented using OpenCV library in Python to form the complete map of the coral reef by adding the detected points of interest to their designated areas displayed on the grid map.

Coral Colony Health Assessment Algorithm

Preserving marine wildlife is of central importance to our mission. Therefore, A fully autonomous multi-stage system is designed for assessing the health of coral colonies is essential.

The system, shown in figure 33, takes two inputs: the current image of the coral colony along with an image from one year prior. It then outlines the areas of change, illustrating in what ways the coral colony has changed by comparing the two images. The main stage is the alignment step, in which we attempt to align the two input images, such that they share a common coordinate frame. This is accomplished using a novel deep neural network, especially designed to match according to the image features. Next, a pair of binary masks are extracted from each image, where each pair locates pink and white areas of the coral colony in its corresponding image and then compared by subtracting them leaving out the areas of change highlighted as required.

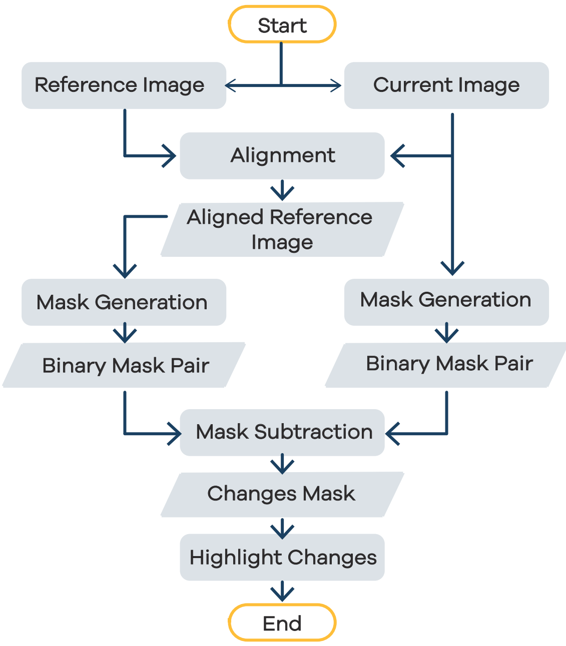


Figure 33: Coral Colony Flow Chart

Photomosaic of a Subway Car

As natural coral reefs are struggling, artificial reefs created by sinking obsolete subway cars are seen as salvation for endangered fisheries.

For this specific mission, a pre-trained model was fine-tuned to autonomously detect and crop out each side of the subway car. These cropped images are then passed to an image processing algorithm, utilizing OpenCV library in Python. The algorithm extracts the color of each region to stitch the images together, creating a photomosaic of the submerged subway car, as shown in figure 34.
Shown in figure 35 is the photo-mosaic code's flowchart.

Figure 34: Photomosaic One Side Detection

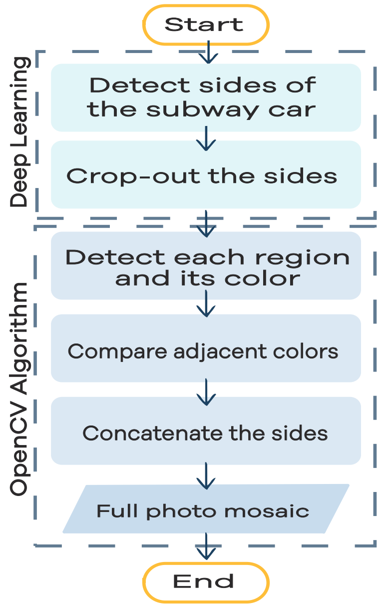


Figure 35: Photomosaic Flow Chart

3 Safety

3.1 Safety Philosophy

Safety is an inherent part of Aquaphoton's culture, as employees are the company's most valuable resource. Aquaphoton believes that all injuries are preventable by implementing strict safety measures; as a result, the company's main priority is to provide all employees a safe working space and the training necessary to handle all equipment safely.

This emphasis on safety translates to an ROV that keeps the crew, the work environment, and itself safe during operation. Aquaphoton is committed to exceeding all safety guidelines published by MATE; consistently passing the safety inspection, year after year.

3.2 Workshop Safety Protocols

Aquaphoton implements rigid safety protocols in its workshop to ensure a safe

work environment.
Workshop Safety Protocol:

- Safe operating parameters are defined before any process and underscored in written procedures.
- Sanitized proper personal protective equipment (e.g. gloves, goggles, and earmuffs) are worn when performing any task, as shown in figure 36.
- Maintenance and repairs are performed proactively.
- Emergency kits (including fire extinguishers and first-aid kits) are checked regularly to make sure they're stocked and functional.
- Hazardous materials are clearly marked and stored separately to ensure they're handled carefully.
- Sharp Tools are handled carefully; when not in use, they are stored in racks and boxes, and their sharp edges are covered with a cap -if available.
- All manufacturing and machining operations requiring the use of power tools are limited to a specific area in the workshop that is out of the way.
- Any in-water tests are performed far away from the Electrical Team's work area.
- The work area is well ventilated, and additional fumes extractors are used– to avoid the inhalation of harmful fumes when working with epoxy, glass fiber, etc... or soldering.

Figure 36: Mechanical Team Member Safety Practices

Given the global situation regarding the spread of the novel coronavirus (COVID-19), exceptional safety protocol features are strictly followed to ensure a healthy, safe, and Corona-free workspace. Visual reminders, shown in figure 37, are posted on the walls of the workshop to keep safety at the forefront of the minds of all employees.

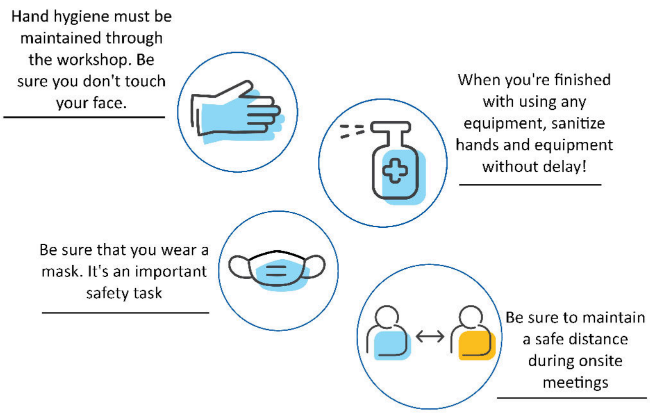


Figure 37: COVID-19 Safety Reminder Sign

3.3 Safety Training

Driven by their loyalty to the team, past members take it upon themselves to acquaint the new employees with the ins and outs of Aquaphoton Academy. All trainees are briefed on the workshop protocols during their trial period. New employees are then given extensive safety training: a one-on-one training session is held for each new employee to ensure that they fully grasp the workshop safety protocols. New employees first observe an experienced member performing each task several times before they are allowed to attempt the tasks themselves.

3.4 ROV Safety Features

Aquaphoton's emphasis on safety isn't only reserved for those building the ROV; **Nautilus** is safe to handle, safe to operate, and safe for the environment. After carefully reading all of MATE safety requirements, **Nautilus** was designed with them in mind, implementing various safety features in all core systems.

Nautilus' frame has no sharp edges, all exposed bolts are covered with caps, and all thruster propellers are shrouded on both ends.

Strain relief is added to the tether on both the ROV side and the power station side in order to protect all cables. Additionally, a convenient handle is added so that the ROV can be handled safely during launch and retrieval.

Nautilus′ electrical system is designed with the goal of protecting both the user from electrical hazards and the system itself from environmental hazards.

Its software also incorporates emergency sequences to prevent failures during autonomous mission or due to conflicting commands in case of human operating errors, protecting the ROV.

3.5 Safety Checklist

As safety is paramount, the protocols dictated in Aquaphoton's safety checklist are strictly followed by all company members before, during, and after **Nautilus**′ deployment. Safety inspections are continuously conducted well before reaching the poolside, starting from the workshop, and until the ROV is safely retrieved from the water.
Aquaphoton's complete Safety Checklist can be found in Appendix B.

4 Testing and Troubleshooting

4.1 Mechanical

All components comprising **Nautilus**′ mechanical system were first prototyped to validate design ideas, for instance, the plastic debris collector was tested using wooden links, to be more economically efficient. Accordingly, a refined version of this prototype is manufactured using HDPE for the final design.

Separate tests were done on each component before being assembled, effectively eliminating compounded problems that are harder to troubleshoot once the ROV is fully assembled. The frame is first tested for stability by loading and subjecting it to high vibrations to ensure that all fixations are sound. Pneumatic manipulators and their DCVs are also tested to ensure full mobility of the end effectors. However, the most important test is the sealing one, shown in figure 38.

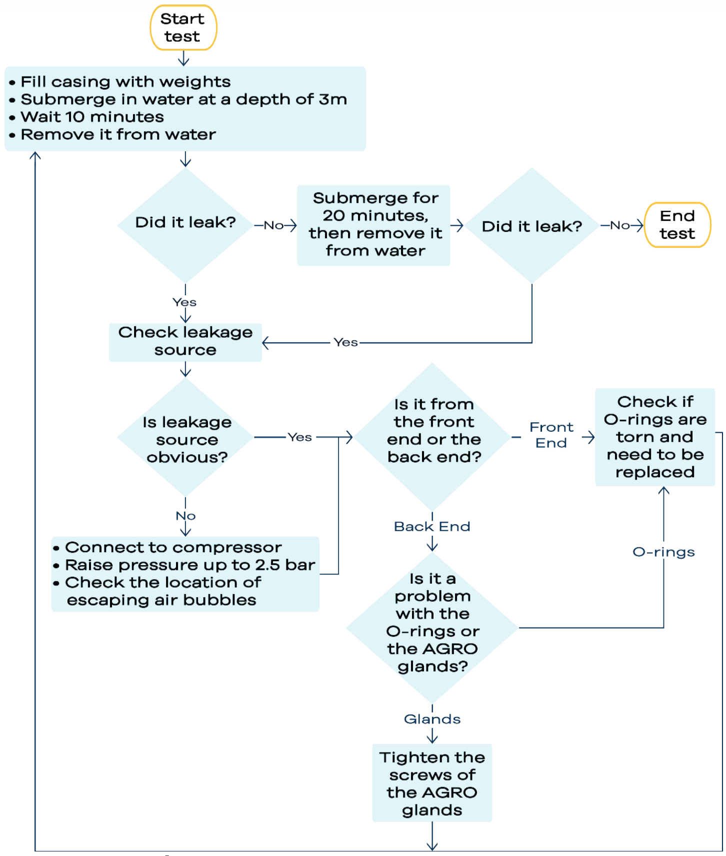


Figure 38: Sealing Test Flow Chart

4.2 Electrical

A prototype PCB was designed to test the new video transmission circuits. After debugging and reaching a reliable state, the modified version of these circuits were then implemented on the final IP and Analog PCBs.

At the very early stage of assembling **Nautilus**′ electrical system, each PCB is tested separately before connecting it to the system, making troubleshooting a much easier and time-effective process. Shown in figure 39 is our electrical testing and troubleshooting plan.

4.3 Full System Testing

Full-system testing procedures are carried out on **Nautilus** before any operations. This is illustrated in the flowchart in figure 40.

5 Logistics

5.1 Company History

Aquaphoton Academy is -and always will be- an entirely student-run company from

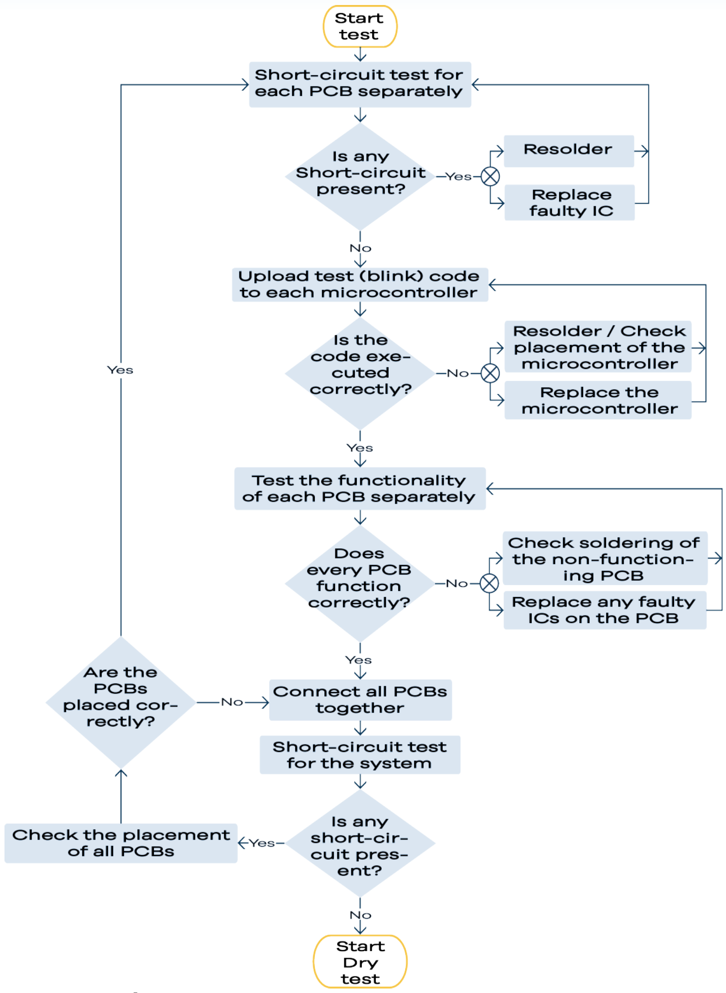


Figure 39: Electrical Testing Flow Chart

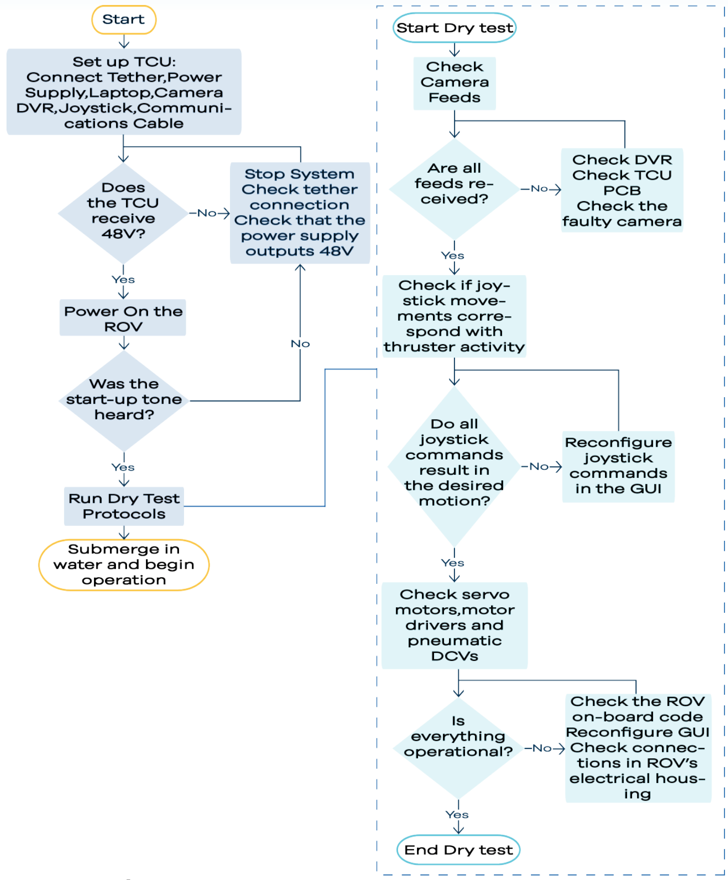


Figure 40: Full System Testing Flow Chart

Figure 41: Aquaphoton Academy's ROVs

Alexandria University. Ever since its formation in 2012, Aquaphoton has been proudly taking part in the annual MATE ROV Competition; ranking 1st in Egypt's Regional Competition in 2014, and finishing in 6th place in the International MATE ROV competition held in Michigan, USA. Moreover, the knowledge gained through Aquaphoton is not obsolete once you leave the team. Former team members who have graduated have gone on to achieve amazing things and are still a huge part of our family, gifting the team with their expertise and support every step of the way.

Continuing to grow and evolve, every year a new innovative ROV is added to Aquaphoton's arsenal, as shown in figure 41, each better than the last one.

5.2 Company Structure

Aquaphoton's company structure is not a strict hierarchy. The 2021 team is a sixteen-person workforce that is divided into five main departments: Mechanical, Electrical, Software, Media and Documentation, Administrative and Social Media; in which members aren't restricted to only one. Technical departments are further divided into several project groups that focus on specific parts of the vehicle systems, ensuring that no detail is overlooked. The entire team is led by the CEO, under whom two CTOs head the technical teams, various heads who take lead on the non-technical project groups, and a CFO handles the finances of the company.

Please refer to Appendix C for the company structure chart and detailed job descriptions.

5.3 Management and Scheduling Assignment

This year, Aquaphoton moved its project management process over to a digital platform. The company now uses a Trello board to keep track of important deadlines, tasks to accomplish, and overall monitor its progress. The online board, shown in figure 42, is a great way to oversee all project groups and specific tasks while keeping an eye on the bigger picture.

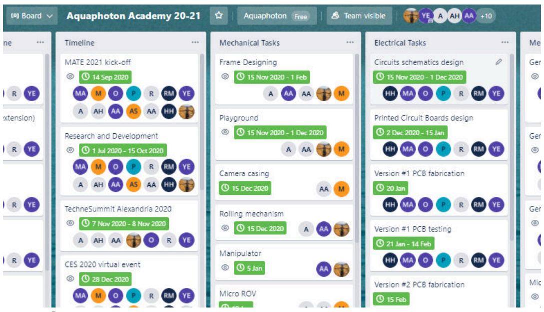


Figure 42: Aquaphoton's Trello Board

The Trello board also contains the timeline created by the CEO at the start of the project. This timeline, shown in figure 43, is for the entire duration of the project, setting deadlines for certain milestones. Additionally, there are weekly timelines created by the two CTOs relating to more immediate tasks. General meetings are held to deliver progress reports, to ensure that all employees are aware of what other project groups are working on.

5.4 Workspace Management

Aquaphoton's headquarters is more than its workshop, it serves as a second home for its employees. It's divided into several designated areas: a PCB manufacturing station, a water testing area with a pressurized tank, a machining area, a storage room, and a general lounge area. Two workshop directors are appointed to ensure that everything stays clean and organized. They routinely inspect the workspace, and perform any repairs or improvements necessary to maintain it.

5.5 Shared Files and Libraries

To facilitate collaborative projects and establish proper communication between departments, Aquaphoton relies on cloud storage to store all its work files. An easily accessible Google Drive is used to share design files, submit tasks, and access years of archived corporate knowledge, making it easy to work away from home. Google Docs is used for all documentation tasks, while the main technical document is a collaborative LaTeX document on Overleaf; making it available to all members to read and add comments, while simultaneously allowing the restriction of editing privileges to a selected few.

GitHub, a Version Control System (VCS), is used by Aquaphoton's software team, as it allows seamless parallel code development across the members. Using GitHub ensures members are all working on the most recent version of the code, while still having access to its edit history. Shared Fusion 360 models of **Nautilus**' PCBs are used by the electrical and mechanical team, allowing all members to stay up-to-date about the PCBs' 3D design at all times to ensure that every PCB fits its enclosure. Moreover, a shared Library.IO library is employed to catalog all components used while designing the PCBs on Eagle, saving time that would otherwise be wasted searching through endless libraries for specific components.

5.6 Budget and Cost Accounting

A CFO handles all of Aquaphoton's finances. They set the budget, collect payments, and act as a bookkeeper.

As Aquaphoton is self-funded, its budget is limited and must be utilized carefully, avoiding frivolous purchases. An excel sheet is used to document all Aquaphoton's future purchases based on the previous year's purchases and the improvements the company plans to implement. This sheet is used to estimate the budget, and payments from staff are then requested accordingly. Another excel sheet is used to record all purchases made and transactions completed, all confirmed by receipts. Please refer to Appendix D and Appendix E for more details about the project's projected budget and its actual cost.

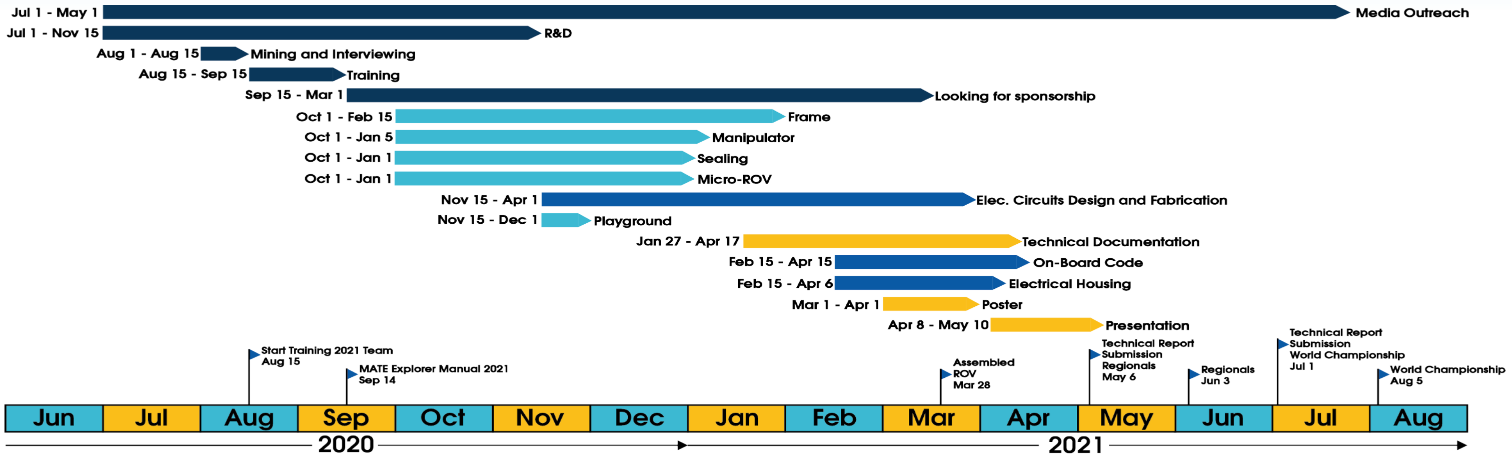


Figure 43: Project Gantt Chart

6 Conclusion

6.1 Challenges

Technical

Despite every effort to keep the process of designing and building **Nautilus** running as smooth as possible, naturally, challenges arise that the company must contend with.

One of these challenges was several manufacturing mistakes that led to overshooting deadlines. Additionally, there was a shortage of parts that were used in previous year's ROV and needed to be repurchased.

Another challenge we faced was the incompatibility of the newly purchased Murata converters with our system. The converters kept disconnecting every time the thrusters passed half its speed due to a safety trigger caused by the tether's voltage drop. This voltage drop forces them to disconnect if supplied with less than 44V. To temporarily solve this issue, a third DC-DC converter was added to the system instead of using the Murata ones, allowing more time for research.

Non-Technical

With 2020 being a remarkably difficult year for all of us, the greatest challenge we faced was getting our way through the COVID-19 global pandemic and adapting to the digital transformation incurred by the virus spreading.

Unlike other years, we had to offer our freshmen -the newly welcomed members- a hybrid training, mostly conducted online in order to keep everyone safe and limit the spread of COVID-19.

Not only have we managed to deliver the training program successfully and efficiently, but also took this chance to record and document our sessions in the process.

6.2 Lessons Learnt

It is only by contending with the challenges that arose over the course of designing and building **Nautilus**, that Aquaphoton could learn, and ultimately, evolve. One of the biggest lessons learned this year was to allow more room for error and unforeseen circumstances by trying to expect the unexpected, so as to be better prepared to handle any curve-balls, instead of scrambling to fix a problem while striving to stay on schedule.

On a more personal note, employees gained many important soft skills over the course of this project. Alongside implanting the importance of teamwork in its employees, this experience pushed the company's more timid members to be assertive and confident in their work.

6.3 Future Improvement

"There is only one corner of the universe you can be certain of improving, and that's your own self." – Aldous Huxley

Aquaphoton believes that the key to success is to continuously innovate and evolve, rendering its own designs outdated before its competitors do. One of the things the company wants to use in its next creation is the Jetson Nano board. It can run a wide variety of advanced deep learning models, including the full native versions of popular machine learning frameworks like TensorFlow, PyTorch, Keras, and others.

Aquaphoton also plans to replace its old buck converters and using new muRata converters instead. These converters with their higher power rating can accommodate **Nautilus**' more elaborate thruster configuration and allow it to run at full speed.

Another major improvement would be to use electric linear actuators, instead of pneumatic cylinders for the manipulator. It would reduce the number of cables to seal, in turn reducing the number of AGRO glands in the end cap by three, therefore making the sealing easier by decreasing the number of possible leakage points.

6.4 Reflections

Ibrahim El Shenhapy:

"I feel proud and grateful every day that I got the chance to be part of this team. Thank you to each one for being a valuable member and a part of well oiled-machine.
All my gratitude and thankfulness to MATE Competition for always aspiring for effective learning and growth."

Perla Hatem:

"I want to extend a genuine thank you to everybody involved in making this year's experience such a life-changing one.
To Aquaphoton, this place inspires individuals every year to fulfill their true potential by providing different experiences to help us learn far beyond the curriculum areas."

6.5 Acknowledgments

Aquaphoton would like to extend a special thank you to:

- Dr. Mostafa Elhadary for his continuous guidance.
- Parents and friends for their moral support.
- MATE ROV for making this experience a reality.
- AAST for organizing the Regional competition.
- ASRT for their support.
- PCBWay and BlueRobotics for their discount on our components.
- SolidWorksTM, ANSYS, Fusion 360, 3DS MAX, Eagle, and Proteus for providing us with student licenses.

Figure 44: Acknowledgements

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7 Appendices

A SIDs

A.1 Pneumatic SID

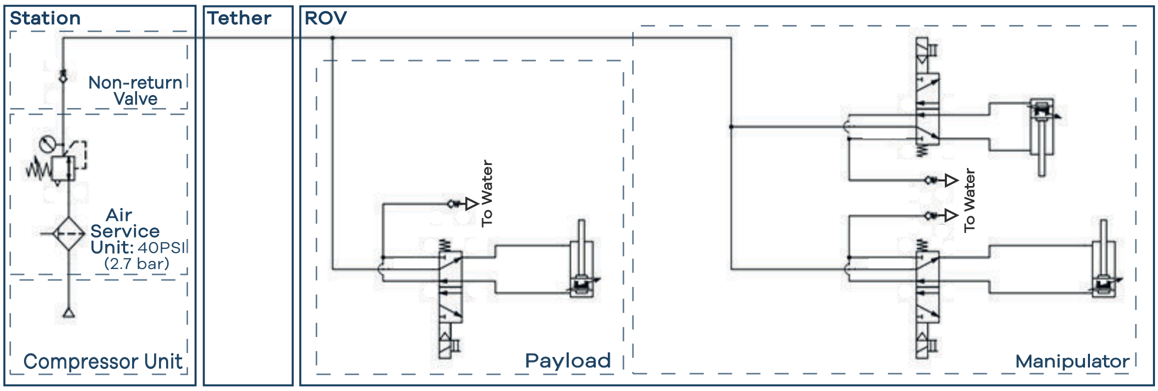

Figure 45: Pneumatic SID

A.2 Electrical SID

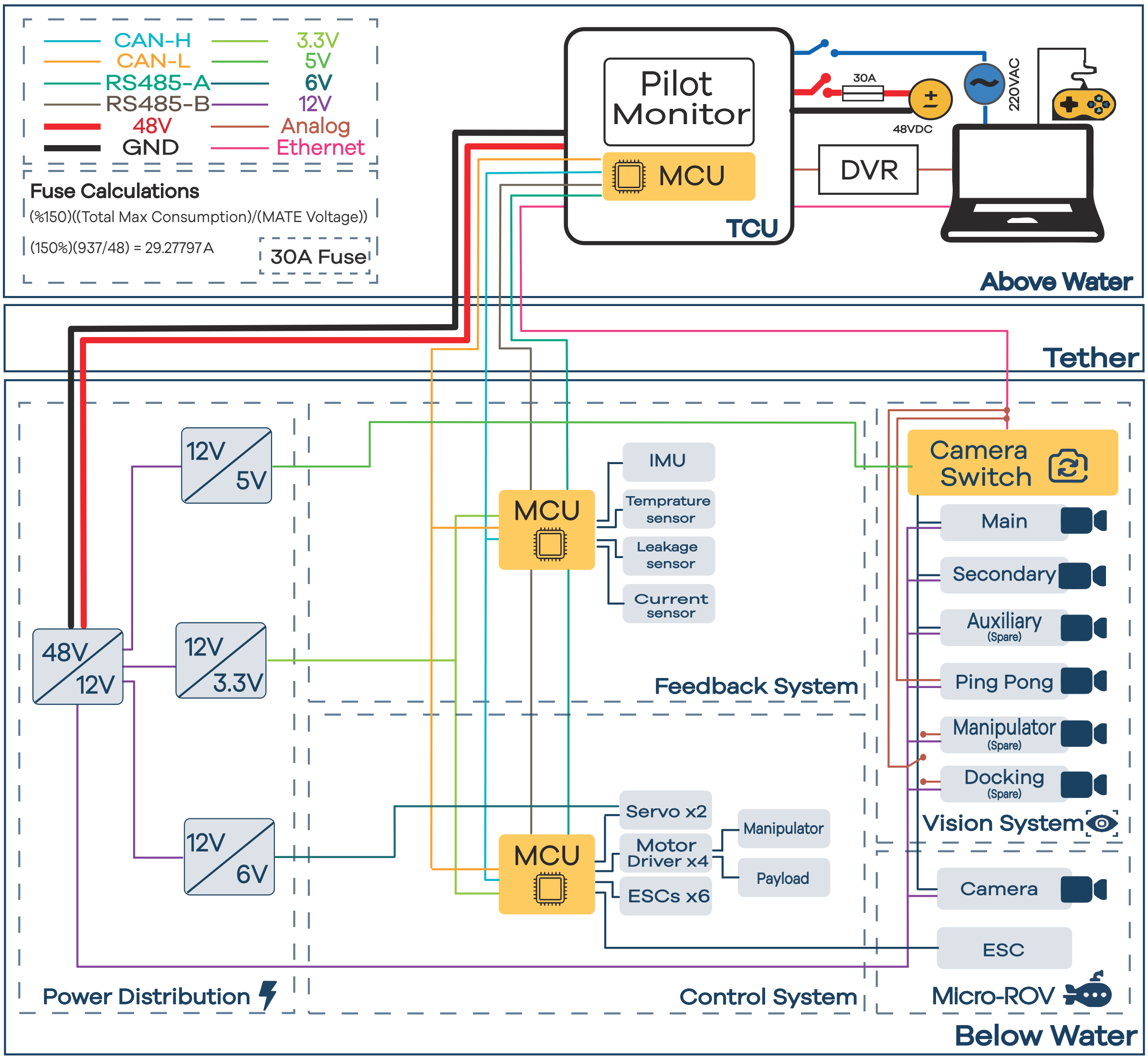

Figure 46: Electrical SID

B Safety Checklist

Before Deployment

- ☐ Only designated crew members on deck.
- ☐ On-deck crew wearing proper safety attire.
- ☐ Power is OFF.
- ☐ Poolside is clear of obstructions.
- ☐ Tether is untangled and connected to ROV through the strain relief.
- ☐ Tether is connected to Control Unit.
- ☐ No exposed wires or loose connections.
- ☐ Electronics housing is sealed.
- ☐ Control computer is running.

Powering Up

- ☐ Control Unit receives 48 Volts.
- ☐ Dry test thrusters, manipulators, and payloads.
- ☐ Check all video feeds.

Launching and In Water

- ☐ Two members are handling the ROV.
- ☐ Tether-man has hold of the tether.
- ☐ Visually inspect for leakage, check for air bubbles.
- ☐ Test thrusters, manipulators, and payloads.

Loss of communication

- ☐ Reboot ROV
- ☐ Resend test package.

If no communication:

- ☐ Power down ROV.
- ☐ Bring to surface via tether, and check ROV is free from damage or leakage.

Retrieval

- ☐ Pilot surfaces the ROV then turns off the thrusters.
- ☐ Designated on-deck crew members grab hold of the ROV by its handles.
- ☐ ROV is secured on deck.
- ☐ ROV and Control Unit are powered down.

C Company Structure and Job Description

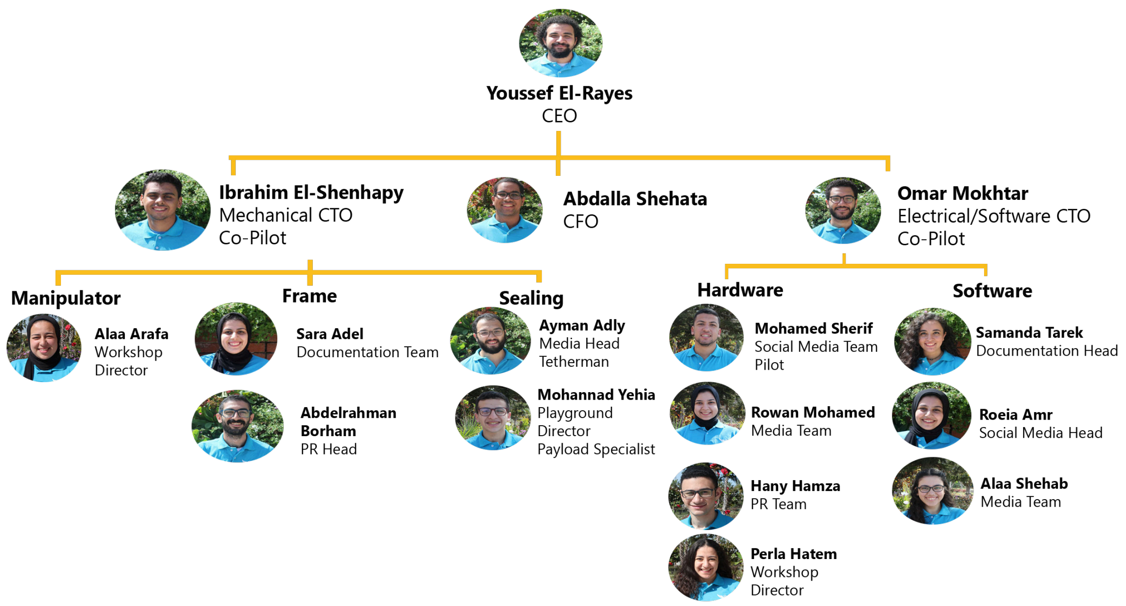

Figure 47: Company Structure

CEO: the official representative of the company, interdepartmental coordinator.
CTO: manages project groups and day-to-day operations.
CFO: bookkeeper, handles the company finances and sets the budget.
Documentation team: led by a head, responsible for documents submission.
Media team: led by a head, responsible for all graphic designs and media displays.
PR team: led by a head, and is responsible for all the public relations affairs.
Social Media team: led by a head, manages all social media accounts, creates and follows a seasonal plan.

Workshop Director: maintains working order of the workspace, performs routine maintenance.
Playground Director: simulates the ROV's operating conditions, coordinates the in-water testing.
Pilot: controls the movement of the vehicle from a cabin or other indoor location on the surface.
Co-Pilot: assists the pilot during mission tasks.
Tether-man: responsible for handling the tether while the ROV is underwater.
Payload Specialist: handles all payloads, unloading samples, and plastic debris gathered by the ROV.

D Projected Budget

Budget		Status	Total (USD):
Income	UWRC	Award	937.50
	Ebdaa 9	Award	28.13
	Employee Dues	Payments	1125.00
	PCB Way	Sponsor	81.25
		Total (USD) :	$ 2,171.88

	Component	Total (USD)
Reused	Thrusters	1188.00
	Pneumatic System & Actuators	85.63
	Control Unit	81.25
	Compressor & Power Supply	174.38
	Playground	97.81
	Total (USD):	$ 1,627.07

Budget		Total (USD)
Estimation of new items	Frame	218.75
	Manipulator	93.75
	Tether	137.50
	Cases	187.50
	R&D	375.00
	Tools	93.75
	Printables	50.00
	T-Shirts	156.25
	Training	250.00
	Miscellaneous	125.00
	Registration	437.50
	Total (USD)	$ 2,125.00

Figure 48: Projected Budget

E Cost Breakdown

	Component	Description	Total (USD)	Status
Product Cost	Thrusters	4*T100, 3*T200,7*ESC's	1188.00	Reused
	Material	HDPE (Sheet+Cylinder), Aluminum Sheet, Acrylic (Sheet,Cylinder,Dome)	137.50	New
	Fabrication	CNC Routing, Laser Cutting, 3D printing,Lathing	83.75	New
	Pneumatic System	Pistons, Valves, Fittings, tubes, DCVs	65.63	Reused
	Fasteners	Screws (Stainless), Counter Nuts, L-Fixations (Nickel-Chrome), Caps (Stainless Steel)	43.75	New
	Sealing	O-Rings, Oil Seals, AGRO Glands, Marine Epoxy	43.44	New
	Elecrtical System	PCBs, Electronic Components, 3*DC Converter	293.75	Upgrade
	Vision System	3*IP Camera, 2*Analogue Camera,Ethernet Switch	157.50	New
	Actuators	DC Motor, 2*Micro Servo Motor	20.00	Reused
	Tether	Sheath, Power Cable, Ethernet Cable, Pneumatic Cable	125.00	New
	Control Unit	Control Box, Monitor, Buttons, Joystick, AWG-6 Wires	81.25	Reused
	Miscellaneous	Zipties, Heatshrink, Velcro, V-Slots, Weights, Buoyancy Foam	15.94	New
	Vehicle Safety Equipment	Shrouds, Caps, Stickers, Fuses	43.75	New
		Total (USD) :	$ 2,299.26	
R&D Costs	Future improvements	Jetson Board, Test Board PCB, Murata Converter	360.94	New
		Total (USD) :	$ 360.94	
Running Costs	Playground	PVC pipes, PVC Connectors, Spray Colors, Ropes, Corex Drain, Corrugated Sheets	97.81	Reused
	Competition Registration	Mate, Mate Egypt , Fluid Power Quiz	428.13	Entry Fee
	Printables	Brochures, Business Cards, Poster, Banners, Technical Report, Flyers, Safety Documentation	37.50	New
	T-shirts	Company Staff T-Shirts	135.00	New
	Traininng & Testing	Pool, Transportation	181.25	
		Total (USD) :	$ 879.69	
Equipment	Compressor	25 Litre Compressor Unit + FLR unit	111.88	Reused
	Power Supply	2* 48V - 20A	62.50	Reused
	Mechanical Tools	Driller, Screw Drivers, Sand Paper, Piller, Wax	34.38	Upgrade
	Electrical Tools	Soldering Iron Station, Flux, Solder, Avo Meter	33.13	New
		Total (USD) :	$ 241.89	
		Total Cost (USD) :	$ 3,781.78	
No travel expenses are needed due to the participation in the telepresence category.				
All prices include shipping and taxes.		*1 USD = 16 EGP*		

Figure 49: Cost Breakdown