ARAB ACADEMY FOR SCIENCE & TECHNOLOGY

ALEXANDRIA,EGYPT

BROTTA II

INVICTUS

TECHNICAL REPORT

MATE ROV COMPETITION 2021

MATE

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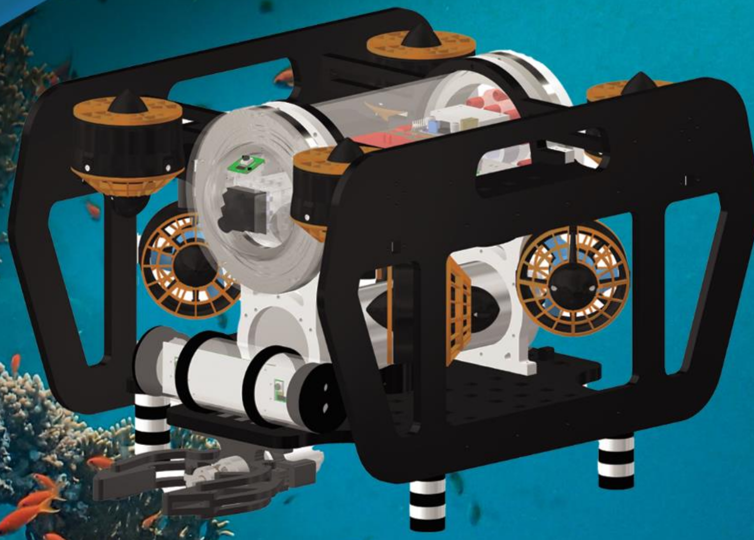

Abstract:

"*The wildlife and its habitat cannot speak, so we must, and we will.*" - Theodore Roosevelt.

Invictus' home country Egypt is blessed with the Red Sea where more than a thousand different fish species live among 250 kinds of coral. Red Sea reefs are among the richest in the world for overall species diversity. These species and reefs are endangered due to climate change as well as poor waste removal policies. Aiming to eliminate plastic pollution, protect coral reefs and maintain healthy waterways for rare species that enrich the Red Sea's heritage, we are glad to introduce the remotely operated vehicle (ROV) Brotta II.

Invictus was founded in 2015 with an aim to provide the industrial and research sectors with high-quality, low-cost ROVs. With four ROVs under our belt, Brotta II is our crown jewel. This ROV is designed for high modularity, serviceability, underwater speed, and power efficiency. Features such as modular assembly and optimum software makes Brotta II our most iconic product. It features a gripper and debris collector that are specifically built to remove plastic from the surface of waterways, and new cameras and software that help monitor the health of coral colonies and fish species.

This document illustrates the design, development, assembly processes, and specifications of Brotta II, designed idyllically to meet the global community's request for proposals (RFP).

Brotta II was designed to tackle environmental missions as addressing the problem of plastic pollution, ensuring the health, and nurturing of the coral colonies and maintaining healthy waterways.

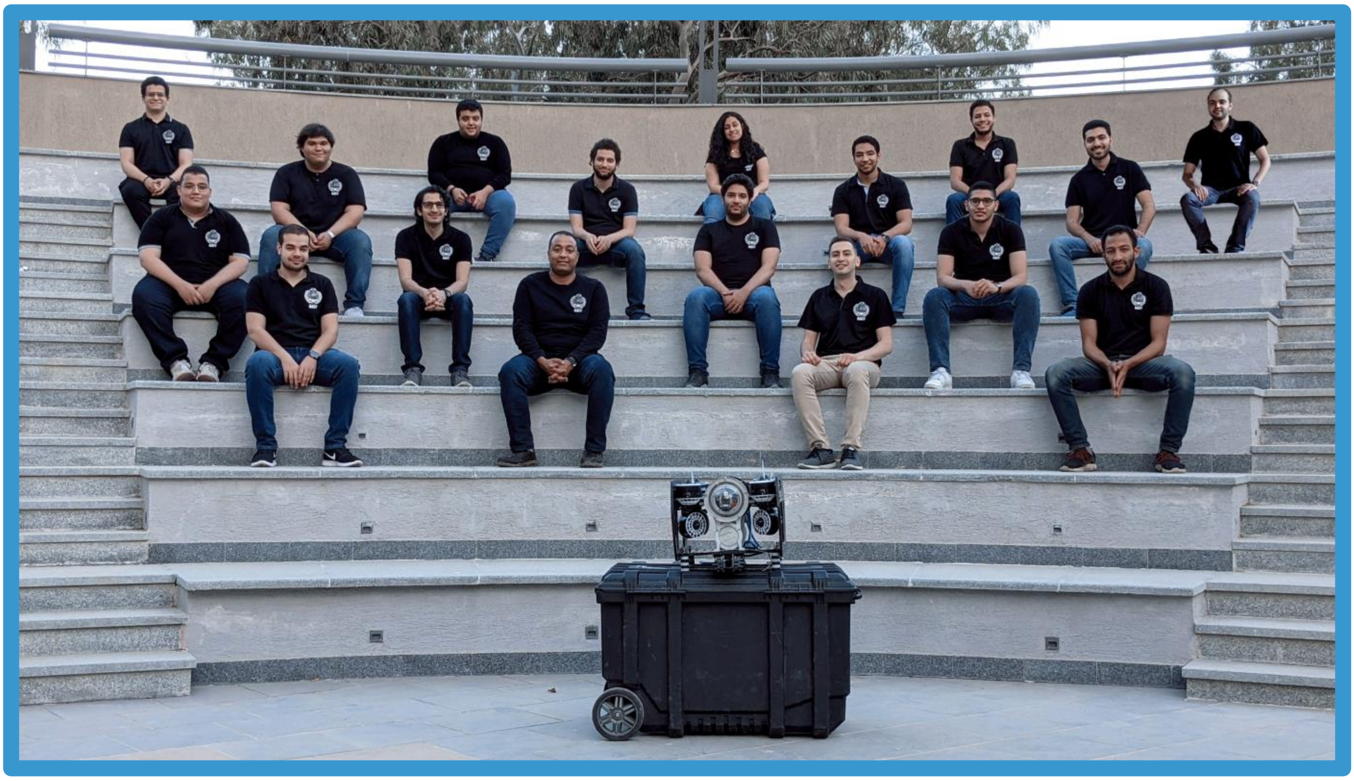

Figure 1: Invictus Company Members & Mentors with their latest innovate product, Brotta II.

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Design Rationale:

Design Evolution:

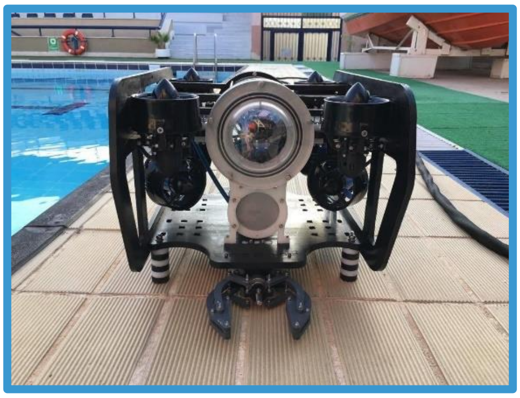


Figure 2: Actual Photo of Brotta II

Figure 3: CAD rendering Brotta II

Invictus holds an annual meeting for the executive and advisory committees (detailed in the logistics section) to evaluate and discuss the integral design of the new ROV and how it relates to our new client's needs. The first step is discussing which aspects of last year's vehicle can be improved and which are to be kept. Then, the executive branch lays out a tentative plan for the year detailing how time and resources will be divided between the different departments and employees to produce the new ROV (Figure 2 and 3). Finally, the documentation department produces a Gantt Chart from the tentative plan for the company to measure progress against.

As a result of this year's meeting, Invictus decided to stick with the same mechanical design as last year due to its proven effectiveness in previous demonstrations. In addition to that, Invictus decided to upgrade the electrical system for two main reasons: troubleshooting for any fault in or adding any circuitry for new mission-specific tools that required us to open the sealed electronics housings. Secondly, last year's camera system was very unreliable and would randomly malfunction, leaving the pilot blind.

Using the same mechanical design elements helped shape our company's new vs reused decisions as it was cost and time-effective to re-use components that did not need any modification as they were already performing on an optimum level.

Mechanical Design & Manufacturing Processes:

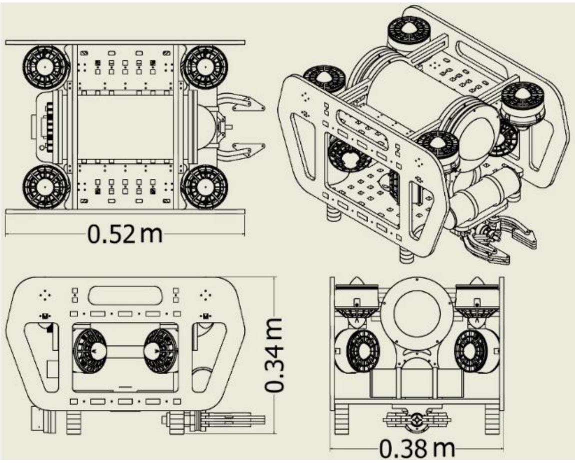


Figure 4: Brotta II Sketch & Measurements

After thoroughly reviewing the tasks required by our vehicle, different design ideas are brainstormed for tooling, payloads, and their arrangement. Next, a mock-up or a mechanical drawing is presented to discuss with the company's other departments and accommodate their feedback and suggested modifications. The process is repeated until the design is deemed optimal, where every design and implementation process is verified and validated - using the V model - by other departments to ensure integration and by the Government and Regulatory Affairs Officer to ensure that it meets the request for proposal (RFP) and the missions required.

One factor that heavily influenced our company's mechanical design process is our mission to provide our customers with cheap and efficient ROVs. Concepts were judged based on size, weight, cost, ease of manufacturing and serviceability, safety, and reliability. Hence, heavy consideration was paid to the available materials in the market along with the different manufacturing techniques available in our locality.

To help the company's different departments easily view the design and suggest any beneficial modifications, a computer aided design (CAD) was created, that was shared among all departments and on all Invictus' project platforms. Finally, the designs were converted into Drawing Exchange Format (DXF) and Standard Tessellation Language (STL) files in order to be sent to the 2D routers, laser cutters, and 3D printers available on campus which our university allowed us to use - an act of generosity from our university which we are greatly thankful for.

Mechanical Aspects:

Frame:

The frame (Figure 5) consists of a base, two sides, two cradles, two cradle supports, and two horizontal stabilizers. Invictus Mechanical department decided on maintaining the overall frame's design due to its modularity, versatility, and high underwater performance. However, the frame's base was redesigned to hold more payloads and cameras. The entire frame is assembled akin to a Lego structure; every element in the frame has designated ports in which specific elements are to be inserted, enabling us to robustly fit parts in the frame while needing much fewer nuts and bolts. The frame is manufactured using 2D routing machines from 10 mm thick high-density polyethylene "HDPE" costing 1.5$ per kg. HDPE was chosen due to its cheapness, high density-to-strength ratio, and high strength under nominal stresses.

Figure 5: Exploded View of the frame

Thrusters:

Brotta II is equipped with eight T200 Blue Robotics Thrusters (Figure 6). Upgrading to the new T200 thrusters was necessary as the T100 thrusters used in the previous vehicle are no longer supported. This upgrade led to a remarkable improvement in the overall ROV speed as BlueRobotics offers powerful, compact, and efficient thrusters at an affordable price of $173. Four heaving thrusters - one at each corner - and four surging thrusters that are mounted at 45° (Figure 7) around the central electronics housing at each corner of Brotta.

Figure 6: T200 Thruster with Protective Guards

The center of mass of the ROV is aligned with the center of thrust to maximize stability and obtain a stable vector drive, allowing all thrusters to contribute to the total propulsion in all cardinal directions and minimizing flow interference with the electronics housings in the center of the vehicle. Four -rather than two- thrusters were used for vertical control to allow the pilot to roll and pitch the vehicle whenever needed while executing missions.

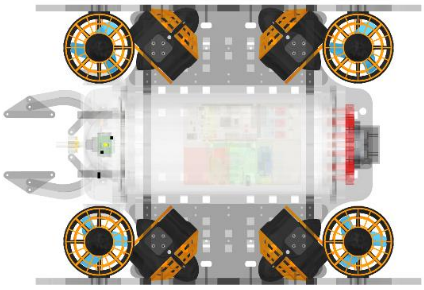


Figure 7: Thruster Layout

Enclosures & Sealing:

Brotta II comprises six sealed enclosures: Control Housing, Power Housing, two separate USB cameras, a Stereo Pi camera, and a DC motor for gripper control. The Control Housing (Figure 8) carries all control subsystems in a cylindrical-shaped enclosure. The cylinder is made of Poly (methyl methacrylate) (PMMA) acrylic which was chosen for its transparent nature; allowing us to instantly view the status of debugging LEDs in our systems. It is capped with two aluminum flanges and an acrylic dome at the front-to-house cameras. The Power Housing (Figure 9) encloses the Power conversion printed circuit board (PCB) in a cylindrical-shaped enclosure. It is manufactured from aluminum to increase heat conduction between the heat dissipating electronic components inside it and the surrounding water, increasing cooling.

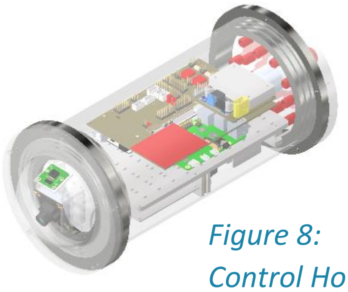


Figure 8: Control Housing

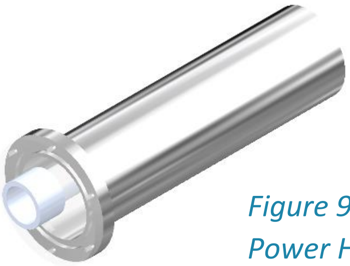


Figure 9: Power Housing

Since high-quality waterproof cameras are costly, our company was faced with an interesting build vs. buy decision; spend a large percentage of the company's financial resources on one or buy an HD camera and seal it in house. We chose the latter option and Polyamide-6 (PA6) cylinders (Figure 10) were machined to house USB and Stereo Pi cameras with a transparent 8mm thick acrylic sheet acting as a lens cover.

Figure 10: Cameras

To design a reliable gripper, we needed a reliable submersible motor that provides a high gripping force to the gripper assembly. Brushless DC motors are submersible without a water-tight seal, but their produced torque proved to be inadequate for achieving a proper hold on objects with our gripper. Hence, it was a must to seal a geared DC motor that would provide more torque. An 8.8 kg.cm-torque, 250 rpm geared DC motor was sealed in an aluminum housing, using a mechanical single-spring shaft seal (Figure 11), to isolate the rotary shaft of the motor from water.

Figure 11: Mechanical Seals

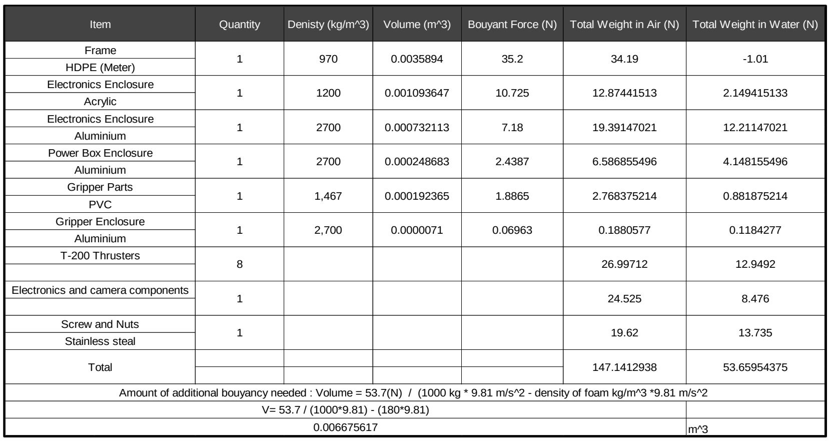
Water Sealing mechanisms are done using three main sealing methodologies: compressed toric joints "O-rings" (Figure 12), Marine Epoxy, and mechanical seals. The electronics and power housings are sealed with compressed O-rings, such that all cables run through penetrators which in turn are sealed with marine epoxy. Penetrators (Figure 13) were used instead of cable glands as they provide a better water seal. Invictus used to make its own penetrators in-house, but since the anodizing process that would make these penetrators corrosion-resistant involves the use of a very dangerous sulfuric-acid compound, Invictus put the safety of its employees first and elected to buy Blue Robotics Penetrators instead.

Figure 12: O rings

Figure 13: Penetrators

Buoyancy:

A spreadsheet (Figure 14) was made to record the densities of each part of the ROV. This data was used in calculating Brotta II's weight in both air and water. Once the ROV was manufactured and assembled, the actual and calculated total volume values were compared so that the addition of buoyancy devices -such as foam and weights- to the many dedicated ports in the frame's base could be fine-tuned.



Item	Quantity	Denisty (kg/m^3)	Volume (m^3)	Bouyant Force (N)	Total Weight in Air (N)	Total Weight in Water (N)
Frame HDPE (Meter)	1	970	0.0035894	35.2	34.19	-1.01
Electronics Enclosure Acrylic	1	1200	0.001093647	10.725	12.87441513	2.149415133
Electronics Enclosure Aluminium	1	2700	0.000732113	7.18	19.39147021	12.21147021
Power Box Enclosure Aluminium	1	2700	0.000248683	2.4387	6.586855496	4.148155496
Gripper Parts PVC	1	1,467	0.000192365	1.8865	2.768375214	0.881875214
Gripper Enclosure Aluminium	1	2,700	0.0000071	0.06963	0.1880577	0.1184277
T-200 Thrusters	8				26.99712	12.9492
Electronics and camera components	1				24.525	8.476
Screw and Nuts Stainless steal	1				19.62	13.735
Total					147.1412938	53.65954375
Amount of additional bouyancy needed : Volume = 53.7(N) / (1000 kg * 9.81 m/s^2 - density of foam kg/m^3 *9.81 m/s^2						
V= 53.7 / (1000*9.81) - (180*9.81)						
0.006675617						m^3

Figure 14: Buoyancy Spreadsheet Study

Brotta II relies on the two voluminous electronics housings as its major pieces for providing buoyancy. They both occupy a total volume of (6,650 x 10^{-6}) m^3 - 44% of the vehicle's total volume of (15,300 x 10^{-6}) m^3 - generating a buoyancy force of 150 N. Since our vehicle weighs nearly 147.1 N in air, we needed to add about (700 x 10^{-6}) m^3 of foam to make it neutrally buoyant. Conveniently, the two horizontal HDPE sheets in our frame are built with a dozen places where weights and foam can be added to readily adjust the vehicle's buoyancy.

Electrical & Control Systems:

Invictus' electronic design for Brotta II is rather simple so it can be robust but also modular to be easily maintainable. Occasional use of outsourced parts is necessary for mission-critical components so that replacements are readily available and easy to install. In-house manufactured parts are often used for saving costs and maintaining customizability in mechanical form and electrical function. Given Invictus's experience over the years, the electrical team has set a few in-house standards with which new generations of ROVs are built to ensure the safety of operators and equipment.

For the safety of our vehicle and employees, these standards include having electrical cables color-coded for different power busses: red for positives, black for ground/reference, white for logic signals, and yellow for switched/controlled power. A chart to gauge wire thickness for different current carrying requirements is used throughout the entire system. Fool-proof and fast assembly were guaranteed as all cables were marked on their connector-terminated ends either with a color or number tag. Polarized connectors (for example XT60 & MT60) are used wherever possible and especially where cross-connections will result in major damage instead of temporary malfunction. Positive fit connectors (for example Japanese Solderless Terminal Connectors (JST)) are used for data connectors for a secure fit against vibration during operation and handling. Debugging LEDs are used extensively throughout the system for indicating electrical signal, power, data connection as well as the presence of faults or warnings. Physical test and reset buttons are also incorporated where needed close to microcontroller boards and power electronics. All connections to the vehicle were galvanically isolated to ensure the safety of the operating crew while handling the system and avoid the risk of electrocution should there be any electrical failure. Overcurrent protection (OCP) devices were deployed throughout in the form of fuses and/or redundant OCP enabled equipment like the vehicle's DC-DC Converters.

Brotta II's system comprises three main subsystems: a topside control unit (TCU V3.0) which houses electronics that intuitively interface the operator to the vehicle through a joystick and an LCD screen. The tether system comprises the tether interface electronics and the tether itself. Finally, the main brain of the whole system is the onboard electronics that comprises two main components, the power electronics, and the control electronics.

Topside Control Unit:

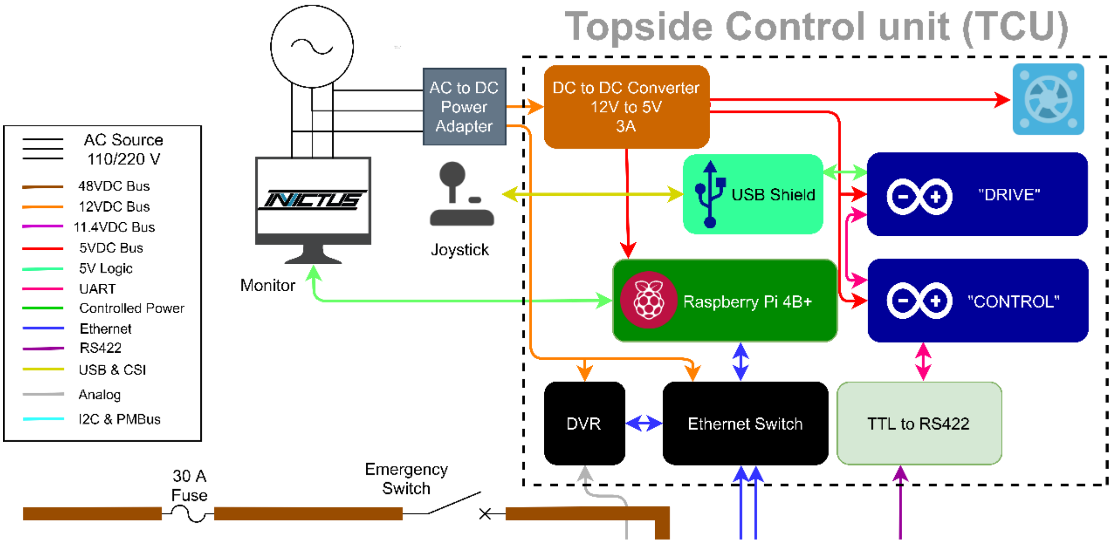


Figure 15: System Interconnection Diagram of the TCU

The topside control unit has reached its third major iteration, where the previous two iterations only used standard microcontroller-based electronics and analog cameras, this third iteration adds a single board computer (SBC) to improve the vision system by receiving camera feeds on an ethernet connection that is much more reliable and preserves the image quality. Arduino boards were chosen for use throughout the system as they come with their support circuitry built-in, thus simplifying its carrier board design. Moreover, their economic price means that replacing a faulty Arduino board is often easier and cheaper than replacing discrete components.

The TCU has two Arduino boards referred to as **CONTROL** and **DRIVE**. The **DRIVE** Arduino has a USB Host controller that interfaces the Logitech 3D Pro Extreme joystick to the system, reading all its inputs and packaging them appropriately to send to the **CONTROL** Arduino. The **CONTROL** Arduino interprets the user input according to the configured settings, packages it, and sends the data to the ROV through the tether interface electronics. A Raspberry Pi 4B+ is the newest addition to the TCU system along with an intranet network structure. An ethernet switch connects the Raspberry Pi inside the TCU with the two Raspberry Pi SBCs onboard the ROV and allows the co-pilot to connect their computer(s) on the network and access the video streams without added latency for image processing tasks. Computers on the network can also change the vehicle's settings such as its power limit and power distribution policies, update the firmware of various parts of the system, and provide debugging interfaces at various points.

The TCU's Raspberry Pi displays the video feeds received over ethernet on an LCD screen in an intuitive split-view style with minimum latency. It also displays telemetry data in a GUI that includes various gauges for voltages, external and internal temperatures, and pressures (Figure 16). The stereo vision system feed can also be displayed along with a depth map that improves the pilot's perception of depth and allows for accurate measurements in software.

Figure 16: Co-Pilot GUI

The Logitech 3D Pro Extreme flight stick is chosen for its ergonomic and intuitively placed controls that are highly representative of the ROV's motion.

The TCU is housed in a customized Invictus' Housing with a cooling system, for optimum performance and professionalism (Figure 17).

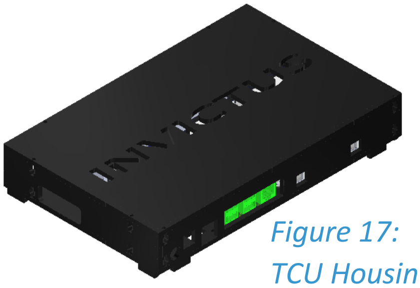


Figure 17: TCU Housing

Tether System:

The tether system consists of 2 main parts, the tether itself and the tether interface electronics. VideoRay tether was selected as it has a good electrical layout as well as neutral buoyancy and flexibility that allows the ROV worry-free maneuvering. Three lengths of VideoRay tether are used in parallel to increase the total current-carrying capacity of the tether system and have redundant paths for data transmission (Figure 18).

A cross-section of one VideoRay cable contains two pairs of 16 AWG silicon wire as well as three twisted pairs: Two 120 ohm twisted pairs for ethernet and RS422 data transmission which are inherently immune to noise, and one 75-ohm pair which is ideal for signal integrity and is suitable for backup video transmission. This also enables us to have three direct analog video feeds for backup without multiplexing or loss of quality while maintaining the lowest possible latency.

Topside, an enclosure splits the tether into a power cable with an inline 30A fuse as a safety measure and a signal-carrying-cable bundle that goes to the TCU. This makes it even more mobile as this reduces the setup time by keeping the relatively fragile signal cables separate and free from the heavy 12 AWG power cable. The same enclosure has a red emergency stop switch that is always at an arm's reach to cut off power immediately in case of emergencies.

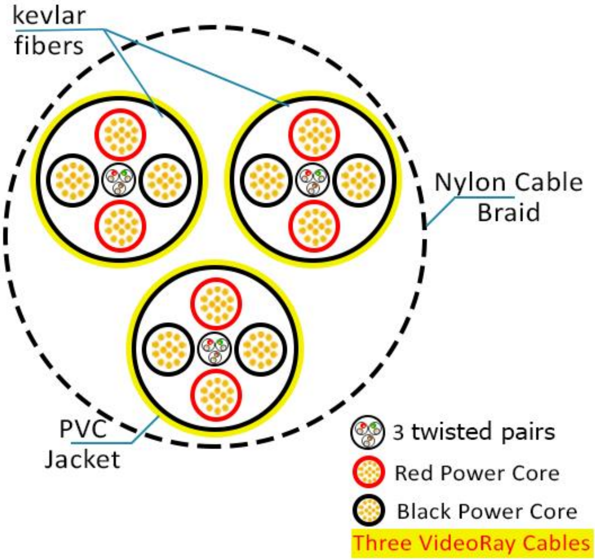


Figure 18: Tether Cross-Section

The TCU interfaces with the tether using three Registered Jack 45 (RJ-45) connectors that include one RS422 and two ethernet connections. The RS422 is a full-duplex (two-way simultaneous communication) link which transfers motion control data to the ROV. RS422 and ethernet were chosen specifically as they run differential signals on twisted cable pairs. In differential signals, data is signaled using the current direction in the loop and at the receiving end, the data is estimated by subtracting the measurements made on both wires. These twisted cable pairs are subject to interference and noise from the surrounding cables that carry high current. Since both wires in a pair are affected equally, the subtraction process removes the common noise thus extracting a clean signal. Since all communication signals in our system depend on a current loop instead of voltage, they can run much longer distances (up to 1200 meters at 230Kbps). In compliance with the in-house standards, the RJ45 connectors are colored appropriately, the RS422 transceivers used are galvanically isolated, and the ethernet is galvanically isolated according to its own standard.

Onboard Electronics:

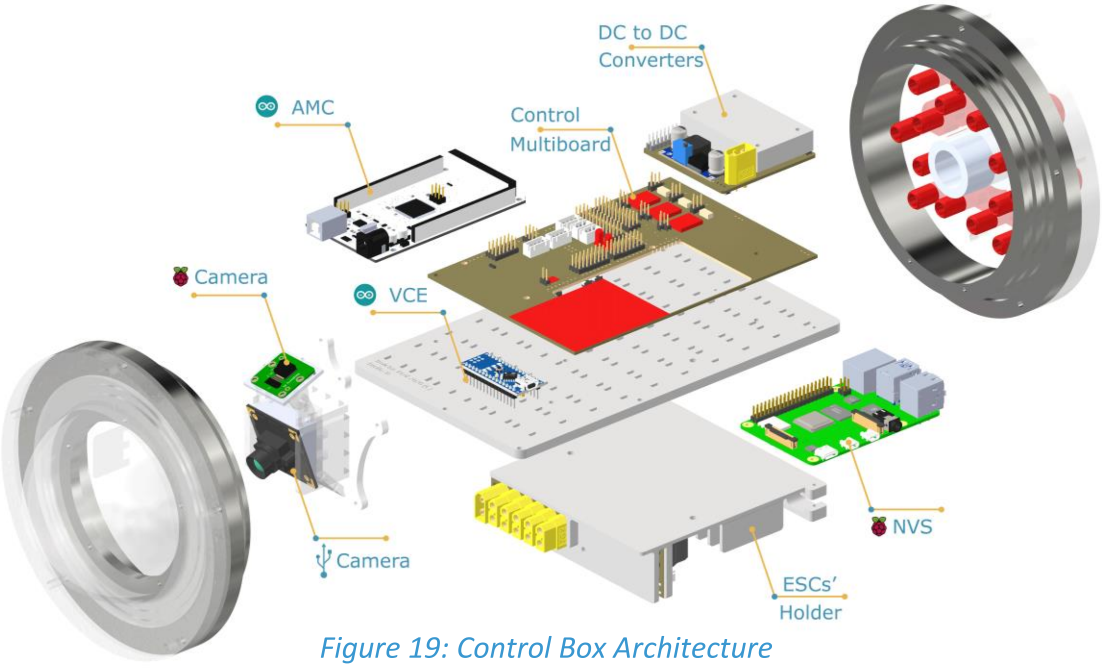


Figure 19: Control Box Architecture

Onboard the ROV, there are five subsystems inside the Control Housing manufactured in-house (Figure 19): a power subsystem, the Vector Control Engine (VCE), an Auxiliary Management Computer (AMC), the Network Video Streamer (NVS) and the Network Stereo Camera (NSC).

Power conversion from 48V to 12V is handled by two eighth brick digital DC-DC isolated bus converters with an excellent nominal efficiency of 95.5%. Older DC-DC converters of the same family have proven their reliability in our ROV systems in the past three years for their small size, low weight, and their ability to share loads in a parallel connection. Thus, models of the same family were used in Brotta II. The new models share all these qualities and offer even more power density than their predecessors; 605 Watt each compared to 420 Watt while also being half the size. Their smaller size allowed us to shrink the Power Housing by half. Their higher power density dictated that only two converters are needed instead of three, shrinking the enclosure even further. Their protection features allowed us to more confidently experiment with thruster power output compared to conventional DC-DC converters and unleash up to 60% of the T200 thruster maximum possible power.

Current (Ampere)	Wire Gauge (AWG)
<= 3.5	26
<= 13	20
<= 32	16
<=55	12

Figure 20: Cable Ampacity Chart

As the power conversion housing required the DC-DC converters to fit in a tight space, a challengingly small PCB was designed in-house. It carries the converters, handles the required current, and provides us with monitoring capabilities. This is possible as we can communicate to each converter digitally over an industry-standard Power Management Bus (PM Bus) to monitor the conversion process. For troubleshooting purposes, a Bluetooth link was installed to output a detailed report when protection circuits are triggered. After conversion, the 12V bus is distributed with another in-house manufactured PCB to thruster electronic speed controllers (ESCs) and other power-demanding components using 12 AWG & 16 AWG cables as detailed in (Figure 20). ESCs are needed to power the thrusters as they require three-phase power as opposed to regularly brushed motors that require simple H-bridges. Each ESC powers one thruster with high efficiency for optimal throttle response. Each thruster is programmed with an ID number and has its input and output cables numbered as per our in-house standards.

Temperature sensors are attached to ESCs for monitoring and added safety. Only ESCs with overcurrent and over-temperature protections are used to prevent as many failures and their consequent power surges as possible. The Vector Control Engine is a microcontroller-based modular unit that is dedicated to controlling all the ROVs' thrusters in unison and gives the ROV its smooth maneuvering abilities. The Auxiliary Management Computer is the Arduino responsible for communicating data up and down the tether on the ROV side. It also controls auxiliary non-flight-critical sensors internal and external to the ROV's insulation boxes as well as the lights and the gripper mechanism. As per our in-house standard, foolproof electrical connectors are used where disaster can happen should these connections become cross-connected during assembly, testing, or maintenance for safety. We also use color and numerical codes for similar connections which can only cause temporary malfunction without permanent harm to the system should two become cross-connected.

The Network Video Streamer (NVS) is a Raspberry Pi that streams all the cameras as User Datagram Protocol (UDP) servers on ports that can be accessed by any computer on the network at the station side. The Network Stereo Camera is a Raspberry Pi based SBC that has two Camera Serial Interface (CSI) cameras and special software to interpret the 3D world and create a depth map. This map can be streamed to the surface along with both left and right cameras to mimic the human vision system and improve the pilot's depth perception.

Vision System:

Brotta II has three Full HD USB cameras that have been deliberately chosen to be as compact as possible with a reasonable spectrum response that is close to the spectrum response of the human eye. They were also chosen for their high quantum efficiency, sensitivity, and high dynamic range that helps them excel in the low light conditions underwater. Additionally, a Raspberry Pi camera that was chosen due to the parallelism offered by the parallel CSI which does not sacrifice frame rate at the expense of resolution like traditional USB cameras do. We have adopted the methodology of IP Based Camera Network where all cameras are connected to the NVS on-board the ROV. All camera views are streamed simultaneously using MJPG-Streamer. This is a command-line application that utilizes UDP and was originally written for embedded devices with very limited resources in terms of RAM & CPU. It was chosen because even though it is running on a Raspberry Pi, it still provides superior image quality with a low latency of 15ms.

Software and Control:

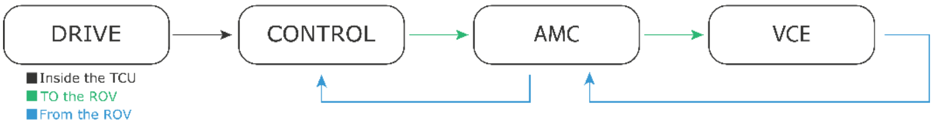


Figure 21: Control Flow in Brotta II

The system comprises four Arduino boards which communicate with each over in two directions: to and from the ROV as shown in Figure 21. In the TCU, the **DRIVE** Arduino is dedicated to reading the Joystick button states and axes values so it can handle the Joystick's interrupts without disrupting the rest of the system and introducing unnecessary delays. It interfaces with a USB host controller over serial peripheral interface (SPI) connection and relays the Joystick data to the **CONTROL** Arduino.

The **CONTROL** Arduino is mainly responsible for building a packet that contains all commands from the pilot and co-pilot and sending it to the vehicle. This packet includes joystick data that is formatted into the proper ranges and converted to translational and rotational commands. It also includes system settings such as navigation PID modes, actuation commands to the gripper and lights. As for its role in the From-the-ROV communication path, it is responsible for gathering the telemetry data from the ROV to be displayed on a separate GUI or sent to a debugging terminal.

Aboard the ROV, the AMC receives the data packet sent by **CONTROL** Arduino and executes all non-navigation related commands such as controlling the gripper and lights. It then relays the navigational commands to the VCE. It is also responsible for gathering sensor data such as temperature, voltage and current along with telemetry information from the VCE. It communicates this sensor and telemetry data back to **CONTROL** Arduino as part of its role in the To-the-ROV path.

At the end of the chain, the VCE is responsible for mixing the joystick data including the stick position, point of view (POV) hat and depth control buttons. It then calculates a velocity vector for each thruster and commands the ESCs accordingly. This is key to Brotta II's excellent maneuverability. It also takes into consideration the expected total power consumption of the thrusters as to not overwhelm the DC/DC converters, and reduces the power commanded to the thrusters as necessary. For current-hungry motor functions, an acceleration curve is applied when starting from a full stop or accelerating to a higher speed. This reduces the in-rush current to avoid accidentally tripping the overcurrent protection. As the thrusters decelerate, they produce back-emf which can trip the overvoltage protection, so a curve is also applied to avoid it. The VCE is also responsible for reading the Inertial Measurement Unit as well as the external pressure sensor for active altitude and depth control using PID loops to aid the pilot as needed. The sensor readings are sent to the AMC to be communicated to **CONTROL** Arduino in the TCU where they can be displayed.

Data throughout the system is packaged into packets before being sent. Each packet consists of a data segment and an error checking one. Each error checking segment comprises two nested Cyclic Redundancy Check (CRC) values calculated before transmission using the data segment. CRCs are used to detect transmission errors; the receiver computes the CRCs on its side using only the data segment and compares them against the CRCs received in the packets. It can then reject the whole packet if they do not match. An onboard LED is lit whenever there is a transmission error helping us diagnose problems with signal quality. After comprehensive testing, this error checking algorithm proved to be robust enough and was immediately implemented in every part of the system. The vehicle is halted if the packet rejection rate becomes too high for vehicle safety.

Payloads & Tools:

Gripper:

To be able to collect plastic debris, sponge samples as well as plant coral fragments, Brotta II features a gripper in the bottom of the vehicle. The gripper assembly comprises PVC parts that are bolted together and powered by a mechanically sealed DC geared motor. On obtaining a non-powerful grip in Brotta, Invictus' mechanical team developed an improved design of the motor's coupling leading to a better torque and grip in Brotta II.

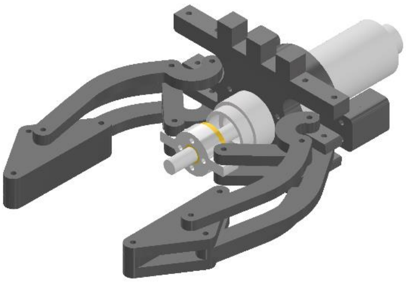


Figure 22: Gripper

Quadrat:

An 0.5 m x 0.5 m Quadrat was fabricated by our mechanical team to complete the task of estimating the number of mussels in a mussel bed. The Quadrat was equipped with a vertical T shaped PVC structure to act as a grip point for the ease of deployment.

Debris Collector:

A debris collector was designed by our mechanical team, to collect positively buoyant plastic debris. It is placed on top of the ROV, where the upwards tilted Raspberry Pi camera in the front dome of the electronics enclosure can observe it with ease. The collector is a funnel shaped assembly to collect floating debris with a net that secures the debris once the ROV submerges underwater.

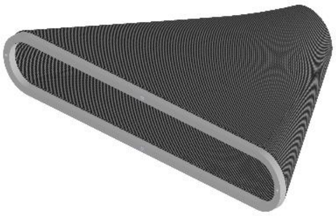


Figure 23: Debris Collector

Seabin Power Connecter:

Invictus designed a power connecter to replace the old connecter in the Seabin. It is made of an inductive coil that acts as a transmitter to the electrical power, where power is transmitted through mutual induction. It is powered by a 12VDC supply from the surface with approximately 700mA with a 1.5A fuse. The connecter is sealed with epoxy.

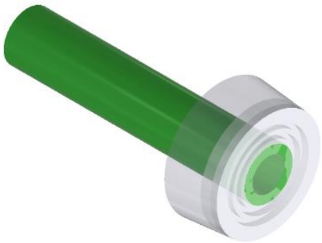


Figure 24 – Power Connecter

Cameras:

The vehicle is equipped with four monocular cameras and one stereo pair. Two USB cameras are fixed onto the bottom base of the frame, one facing downwards (referred to as USB-DOWN) and one looking at the gripper from behind (referred to as USB-GRIPPER). The remaining two monocular cameras are placed in the front dome of the electronics housing; one Raspberry Pi camera that is titled 60° upwards (referred to as RPI-DOME) and the other is a USB camera that is tilted 20° downwards (referred to as USB-DOME). Finally, the stereo pair is placed directly above the gripper (referred to as STEREO) as shown in Figures 25 and 26.

The front RPI-DOME camera is tilted as such to view the surface of the water to collect the floating plastic debris with minimal piloting maneuvers. The USB-DOME camera is tilted 20° downwards to capture an isometric view of the subway car without pitching. All these tilt angles are calculated based on the cone of vision of each camera to obtain the desired camera view. To tackle the problem of the transect line following, the USB-DOWN camera was mounted in such a way so that its view is perpendicular to the pool's floor to follow the line seamlessly. While the USB-GRIPPER camera is mounted in such a way to view the bottom side of any object that the gripper is holding. This assists the pilot in different ways throughout all three missions. The STEREO camera is placed right above the gripper with a 100° horizontal field of view to give the pilot a sense of depth perception and generate depth maps for image processing tasks.

Figure 25 & 26: Brotta II Cameras Configurations

Micro-ROV:

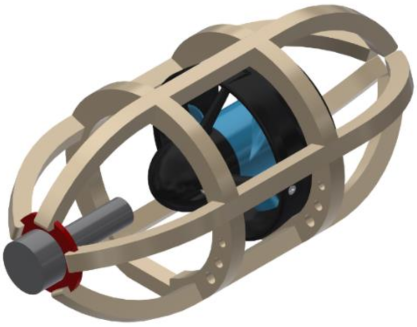


Figure 27: Micro-ROV

Our company examined multiple ideas for the design of a simple, durable Micro-ROV (Figure 27). After prototyping multiple design ideas and testing them, the simplest option proved to be the best one. We cut seven High Density Polyethylene (HDPE) parts using a CNC machine; two circular rings that house a thruster and five external splines that form the Micro-ROV's frame and support the rings.

Each spline is covered with Velcro hooks to be able to collect the sediment sample. A Blue Robotics T200 thruster is placed in the center of the frame (as shown in Figure 27). We have chosen to use a T200 thruster for its impressive efficiency relative to its size and cost, considering that other competitive models in this range of operation are much larger, heavier, and far more expensive.

In addition, an analog high definition (AHD) camera along with an LED is attached to the front of the assembly, thereby offering the Micro-ROV a fair field of view to facilitate pipe inspection. We have a double-ended bullet design that allows it to self-propel both forward and backward through the pipe and mainly depend on the wall of the tube to guide it.

To power this system, we use the 12V supply from inside our main ROV, which is originally converted from the 48V power supply provided by MATE. We transfer both the power and signals through copper wires running between the Micro-ROV and the main vehicle. After consulting with our company's Regulatory Affairs Officer, we ensured that the motor speed never surpasses a quarter of its top speed in order to follow MATE's maximum power and current specifications.

Image Processing:

Autonomous Transect Line Tracking:

To autonomously track the two blue lines, the USB-DOWN camera at the base is used to live stream the captured grid for seamless line following. The captured images are masked at two specific Region of Interests (as shown in Figure 28). The mask hides everything in the image except for the blue lines to increase the accuracy and computational efficiency of the algorithm. Rather than using the tedious absolute color thresholding method, a feature extraction technique is used to detect the blue lines. This happens after the captured image is enhanced using Adaptive Gamma Correction and Image Denoising algorithms. They were used because they proved their robustness under various lighting conditions. After the blue lines are detected, intensive calculations are performed to calculate the desired pose of the vehicle. The desired pose is then sent as a package to the Vector Thruster Engine which applies the required thrust values until the ROV finishes following the line. The ROV then exits the autonomous line following mode giving control back to the pilot.

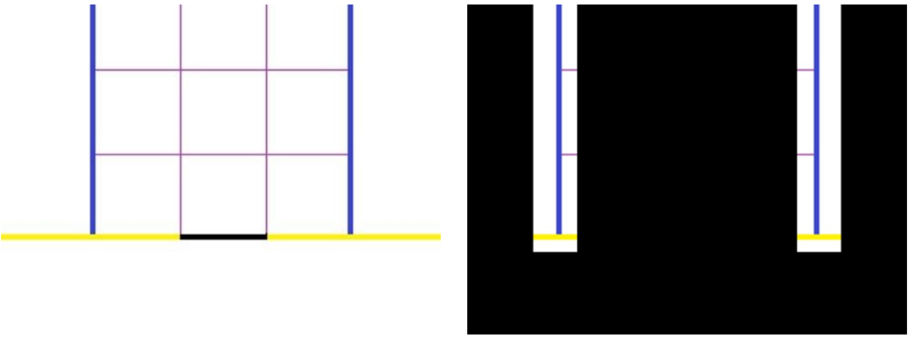


Figure 28: Coral Reef & Masked View Coral Reef

Autonomous Mapping of Points of interest on the reef:

To adapt to the changing lighting conditions and haziness underwater, we utilized a deep learning model rather than traditional image processing techniques for object detection. This helps classify objects at higher levels of accuracy. To help our deep learning model generalize well to the conditions it will encounter in the competition, several factors were considered while building the training dataset. Where we gathered images of the objects from different angles, under well-controlled lighting conditions, with ambient occlusion artifacts. This dataset was augmented using various strategies and used to train a Convolutional Neural Network (CNN). The trained CNN classifies the objects present in the USB-DOWN camera's stream. As for the position of the object along the rows of the grid, the acceleration data of the Inertial Measurement Unit (IMU) sensor is integrated twice while the ROV is autonomously following the blue line. When the ROV enters the autonomous line following mode, a dedicated timer is instantiated. As soon as the CNN detects an object, the time at which the detection occurred is logged. After the autonomous line following phase is complete, all the timestamps are used to compute the distance at which each object was detected relative to the initial position of the ROV at the start of line tracking. The final 9x3 grid map is displayed on the co-pilot's GUI where differently coloured circles are overlaid on the grid based on the detected object's type and position.

Autonomous Coral Colony Health Determination:

To determine the coral colony's health, a raw RGB image of the colony is captured from the USB-DOME camera at a close-enough distance to avoid unnecessary objects appearing in the background. The background of the image is removed adaptively (since the background has the least texture) leaving only the colony. In order to specify the differences between the captured and reference images, a bitwise operation is performed between the two images. That bitwise operation can occur only if the two images have approximately the same spatial relationships. A feature-based approach is used to find the common features (key points) between both images. Those are further filtered out using the standard False Matched Key Points Detection algorithm. Those matched key points are used to obtain the homography matrix that transforms the captured image into the same coordinate system of the reference image. After image transformation, adaptive color thresholding is used to extract the pink and white colors to determine the health of the coral colony. This is displayed on the co-pilot's GUI.

Autonomous Subway Car Photomosaic:

To tackle this problem, two isometric views of the subway car from the USB-DOME camera are captured (as shown in Figures 29 and 30). Rather than capturing images of the five individual sides and stitching them together, these isometric images are captured then enhanced to compensate for the light artifacts in them. After enhancing the isometric views, the co-pilot selects the 7 vertices visible in each view using a dedicated interactive GUI built using Tkinter and Python. Those selected vertices are used to automatically deduce the transformation required to unwrap the subway car as if each side is viewed orthogonally. Identifying which face is which in the cuboid is performed by analyzing the coordinates of each vertex. A photomosaic image is then generated by stitching together the left, right, bottom, and top sides as shown in Figure 31.

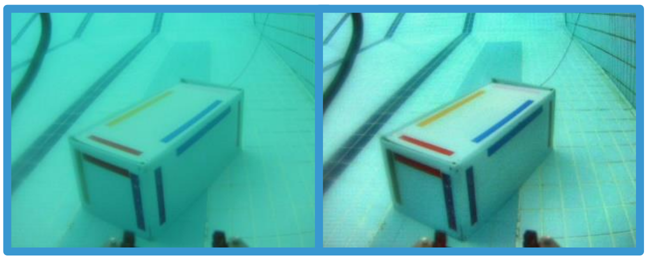


Figure 29: First Isometric view before and after enhancement

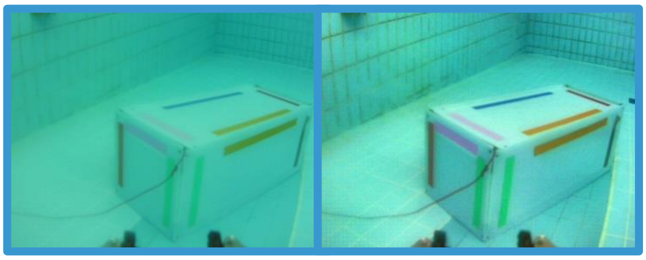


Figure 30: Second Isometric view before and after enhancement

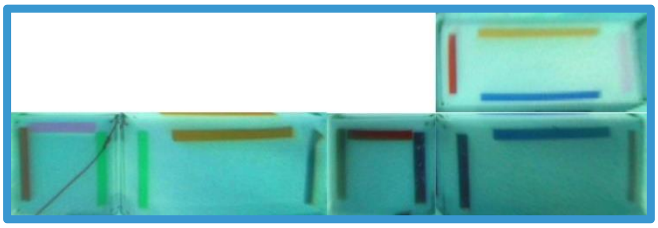


Figure 31: Photomosaic Image of Subway Car

Testing and Troubleshooting:

Testing and troubleshooting are the core objective for Invictus' engineers from the smallest mechanical part to the largest functional code. In line with our safety protocol and the implementation of the V model, vehicle testing consists of a four-step verification and validation processes that is carried out prior to attempting mission runs.

Phase One – Unit testing: For mechanical systems, 3D printed models were used to prototype design ideas in order to understand the nature of their assembly in the real world. Also, all sealed enclosures undergo a water test for a various number of hours to ensure water sealing before any electronic components are placed within. As for electrical systems, simulators such as SPICE analysis were used to test our electrical components for any spike in voltage signals and verify that the input values that were theorized generate the desired output. Moreover, in the real world they are tested individually in an isolated environment to avoid any major accidents. As for software, algorithms are tested by implementing "Statement Coverage" and "Decision Coverage" techniques where all statements especially decision-based ones are tested.

Phase Two – Integration testing: Once a new unit passes its unit test, it is integrated with the relevant subsystem. The subsystem is tested where specific inputs – obtained from truth tables, equivalence partition and boundary values techniques - are fed, and monitoring the corresponding outputs to ensure it works as expected. Debugging LED lights are positioned in various parts of the ROV where each LED indicates an error in a specific part of the system. Furthermore, interpreters are used to run partial code snippets to ensure the absence of critical bugs and guarantee safe operation of the code.

Phase Three – System testing: After testing all subsystems fully in simulation, and once the ROV has been assembled electrically and mechanically, it is tested in the real world. It has a dry run phase test where it is tested in a safe and functional environment on land. Once the dry run is complete, phase four of Invictus' testing protocol begins to test the ROV in water.

Phase Four – Acceptance Testing: The ROV is stress-tested underwater for many consecutive days to ensure that it can achieve its full capabilities. In case of any underwater malfunctions, a root cause analysis (RCA) is carried out to locate the malfunction. Once it is located, all department employees brainstorm solutions which are subsequently tested through the same four phases to ensure optimum functionality. If no malfunctions are found, the pilot uses the ROV to perform all missions. The score obtained in each mission is used to validate the acceptance test meeting the requirements set by the global community's request for proposals.

Safety:

Safety Philosophy:

"Tomorrow: your reward for working safely today." Attributed to Robert Pelton. Our company's motivation is derived from this quote as it compels us to put the safety of our employees at the forefront of everything we do. Employees are committed to meet all guidelines published by MATE, providing a safer working environment to prevent workplace injuries, protect tools, and improve overall productivity. The company's training, working protocols, safety procedures, and safety checklists allow employees to execute the proper course of action in case of emergencies and avoid possible accidents. With this in mind, as soon as Egypt issued a stay-at-home order in March 2020, Invictus immediately adopted a work-from-home policy.

Figure 32: Mechanical Head, Abdallah on a safe working day using PPE

Lab Protocols:

Lab Safety protocols are significant as even the slightest oversight may cause a lethal accident. Every Invictus employee is assigned Personal Protective Equipment (PPE) which are obligatory to use while working in the lab. Moreover, every employee is required to fill a sign-in sheet when entering the lab. This sign-in sheet specifies what machine was being used, when and by whom. This is done to keep a documented track of working employees which will be helpful to review the cause of accidents. Due to the on-going Covid-19 outbreak in Egypt, the Lab Safety protocols were updated to make mask-wearing mandatory as well as limit the number of employees inside the lab at any given time by proper scheduling between departments. In addition to periodic overall lab and workshop sterilization.

Training:

Senior employees closely supervise and mentor new ones as they begin to use equipment. After new employees show safe and proper operating practices, they are permitted to work independently. Our employees are trained to have knowledge on what to do and how to handle our equipment as to avoid unnecessary faults or accidents. In addition to that, safety drills for various scenarios are conducted on a quarter-annually basis which helps our employees remain calm and be able to act quickly in case of a real emergency. As a consequence to the Pandemic, Online trainings and lectures were held to maintain the workflow of the company and the learning of its recruits.

Vehicle Safety features:

Annually, a companywide meeting is held, led by Invictus' CEO and Safety Officer to map all safety features with executive departments. Brotta II is designed to meet MATE and Invictus Safety Features. Brotta II's frame design is based on the absence of sharp edges to avoid cuts and cap nuts are used to mitigate the sharpness of screws' ends. Protective guards are placed on either side of the thrusters' propeller to prevent any person from hurting themselves while checking the operation of thrusters, also, to prevent debris larger than 11.5 mm from penetrating the thrusters' body and damaging it. Our software team built an emergency stop software which initiates an auto-lock on the thrusters once the pilot loses control of the vehicle. The software prevents the thrusters from operating until the pilot regains control eliminating the cause of any injury or damage. Compressed O-rings and Marine Epoxy are used to seal all electronic components, keeping them dry and protecting the ROV and personnel from hazardous situations. In case of any leakage, an emergency stop pedal at the station allows for a quick shutdown mid-operation if the need arises. Brotta II is then retrieved from the water manually. For overcurrent protection, the ROV is allowed a maximum current of 30 A at which point the fuse on the tether breaks the circuit.

Operational and safety checklist:

Safety protocols dictated by Invictus' Operational, and Safety Checklists (Appendix E) are closely followed before, during, and after ROV deployment. Employees also follow operational JSAs for ROV launch, recovery, and waterside safety.

Logistics:

Company Organization and Workflow:

Invictus has a bureaucratic company organization, composed of two main entities, Executive and Advisory. The advisory committee comprises all Mentors, ex-Team Members, and the main supervisor, while the executive committee comprises three main departments: Mechanical, Electrical & Control and Software (Figure 33).

Invictus' Company Organization:

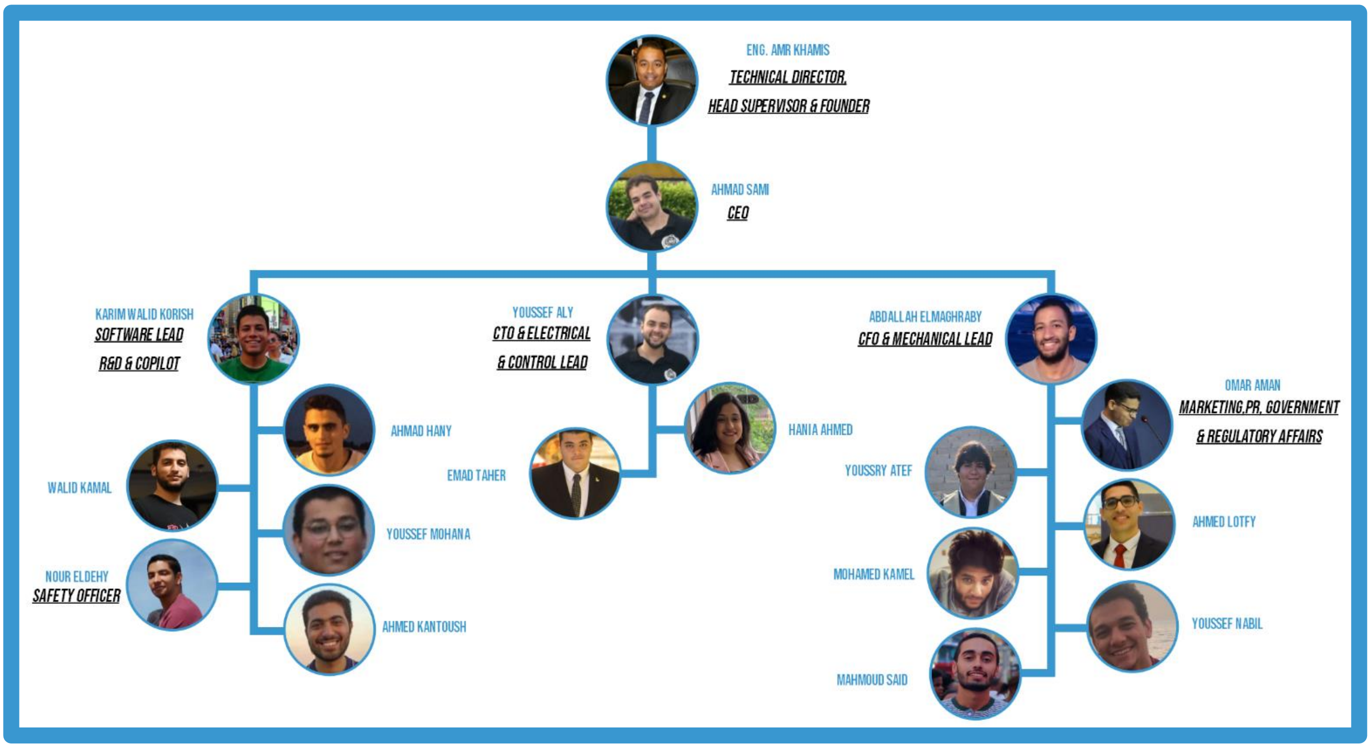


Figure 33: Invictus Company Hierarchy

- *Chief Executive Officer:*
  Ahmad Samy Zaghloul, 4th Year Computer Science, with 10 years' experience in Robotics including 3 years with ROVs.
- *Chief Financial Officer:*
  Abdallah Osama El Maghraby, 2020 Graduate, with 8 years' experience in Robotics including 5 years with ROVs, ***Mechanical Lead.***
- *Chief Technical Officer:*
  Youssef Aly, 2020 Graduate, With more than 8 years' experience in Robotics, ***Electrical Lead, Pilot.***
- *Software Team:*

- Karim Walid Korish, 5th year Electronics Engineering, with 2 years' experience with ROVs, ***Software Lead, Co-pilot.***
- Ahmad Hany, 5th year Electronics Engineering, with 3 years' experience in Robotics, Software Team member.
- Walid Kamal El-din, 3rd Year Computer Engineering, Software Team member.
- Nour El-Dehy, 4th year Computer Engineering, Software Team member, ***Safety Officer***.
- Youssef Ahmad Mohana, 4th Year Computer Science, Software Team member.
- Ahmed Kantoush, 4th year Computer Engineering, software Team member.

- *Electrical & Control Team:*

- Emad El Din Ahmed Taher, 5th year communications and electronics engineering, with 2 years' experience in Robotics, Control Team member.
- Hania Ahmed, 5th year Electronics Engineering, with 2 years' experience in Robotics, Electrical Team member.

➢ *Mechanical Team:*

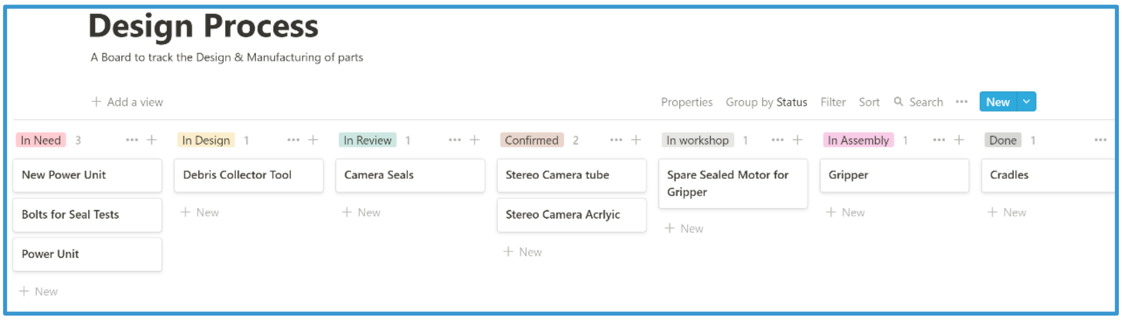
- Mahmoud Said Mahmoud, 2020 Graduate, with 3 years’ experience in ROVs, Lead Designer.
- Omar Abdelaziz Aman, 3rd year Mechanical Engineering, Designer, Manufacturing & Assembly, ***Government and Regulatory Affairs, Marketing and PR.***
- Ahmed Lotfy, 3rd year Mechanical Engineering, Designer.
- Mohamed Kamel, 3rd year Mechanical Engineering, Designer.
- Youssef Nabil, 3rd year Mechanical Engineering, Manufacturing & Assembly.
- Youssry Atef, 2nd year Mechanical Engineering, Manufacturing & Assembly.

Management:

At Invictus, management and collaboration between our Mechanical, Electrical, and Software teams is the key to our progress in the production of Brotta II. The CEO arranges company-wide meetings on strategic and operational levels at the beginning of each working day with the executive members to identify the progress in the design and assembly processes. The company’s operational objectives are assigned as actionable tasks to each department. At the end of the day, there is a minor meeting held with all departments’ heads to report their progress and notify the CEO and CFO of any additional resources they need. For more demanding tasks, cross-department teams are created to open opportunities for teamwork between employees of different departments.

Collaborative Workspace:

To ensure the sharing of valuable knowledge and experiences gathered across different competitions that our company participated in, all of Invictus’ documents and soft data are shared on a cloud-based platform “OneDrive”. Microsoft apps such as Teams and the Office suite have made it easy to update information, review and edit files simultaneously with multiple individuals without interference. Furthermore, utilizing project boards and cards within Teams (Figure 34) has helped our team track the progress of different tasks while working remotely, where each card can be assigned to members and have a detailed description of the required task.



Design Process

A Board to track the Design & Manufacturing of parts

In Need 3	In Design 1	In Review 1	Confirmed 2	In workshop 1	In Assembly 1	Done 1
New Power Unit	Debris Collector Tool	Camera Seals	Stereo Camera tube	Spare Sealed Motor for Gripper	Gripper	Cradles
Bolts for Seal Tests			Stereo Camera Acrlyic			
Power Unit						

Figure 34: Project boards & cards

Code Management:

Invictus software team uses GitHub for code storage and maintenance. Invictus has compared many Version Control System (VCS) websites and chose the one most accommodating to our software team members. GitHub integrates seamlessly with Microsoft Teams and developers working together in a repo are notified whenever any change is made. Finally, GitHub allows people to code together without gathering physically, facilitating remote work.

Project Schedule:

After the RFP was released in September 2020, our CEO and department heads created a schedule for the development, production, and servicing of Brotta II. The aim behind this schedule was twofold: to dedicate an adequate amount of time training and on-boarding our newest employees and get through the vehicle design phase as quickly as possible, leaving enough time for the iterative design and testing of integrable mission-specific tools once the RFP comes out. As an added bonus, that afforded the pilot enough time to get as familiar as possible with the new vehicle, to be able to successfully execute the required missions efficiently within the specified time limit. Consequently, the company planned to dedicate a minimum of 8 weeks for training of new employees, 200 hours for vehicle testing and pilot training. The company actually clocked in 360 over a period of 6 weeks as illustrated in the Gantt chart (Figure 35).

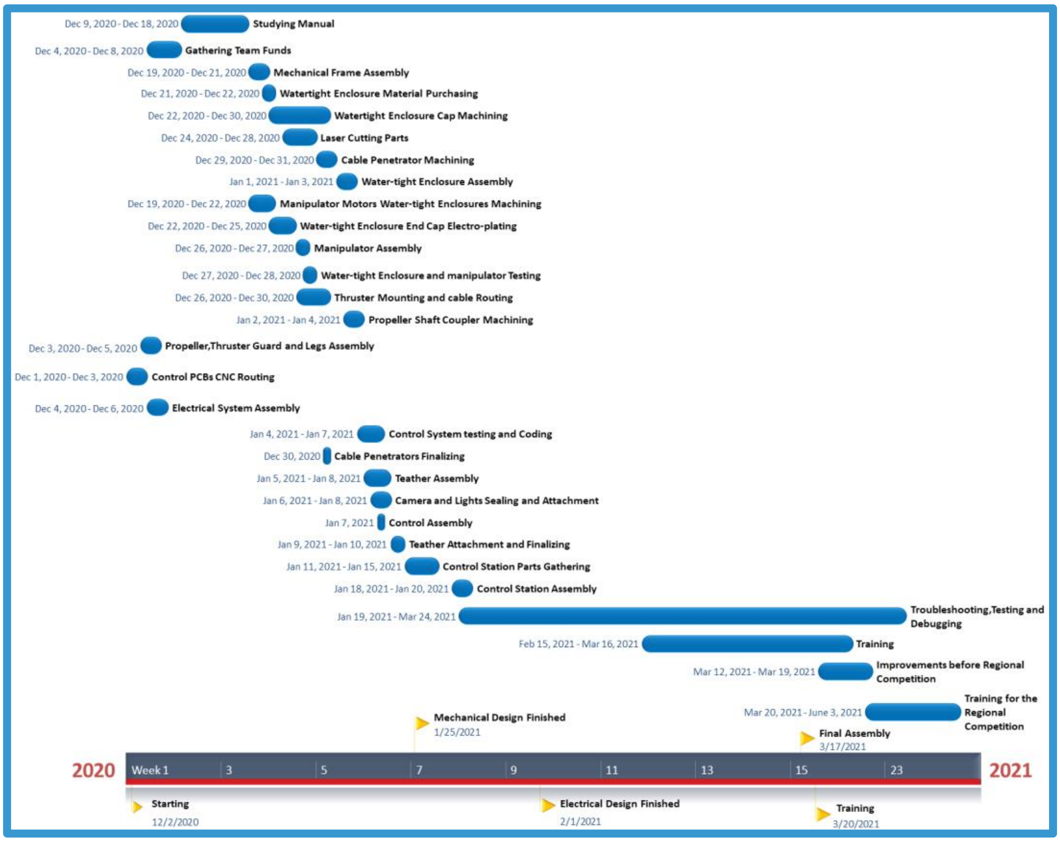


Figure 35: 2020/2021 Gannt Chart

Budget and Cost Planning:

We calculated the total amount spent on our 2019 vehicle ($ 1,672.67), reviewed the RFP, and based on our experience from previous years, projected the amount of money required to prototype and manufacture new mission-specific tools and upgrade our electrical and vision systems. Next, we accounted for the fact that our university would pledge a total amount of $ 1000.00 for vehicle development. Our company planned the design and build process accordingly. Both Budget & Project Costing can be found in Appendices B and C. Invictus would like to thank The Arab Academy for Science, Technology and Maritime Transport and Banque Misr for being our main financial sponsors. We would not be where we are without them.

Acknowledgments:

Invictus would have not been founded nor able to overcome the challenges it faced without the help of these organizations and individuals:

- Arab Academy for Science, Technology and Maritime Transport - for funding our company in all previous years, as well as funding our new vehicle Brotta II and supporting us, and for hosting this year's regional competition.
- Regional Informatics Center (RIC) - at AASTMT Alexandria - for Organizing the Egypt Regional Competition and its constant Support.
- Banque Misr – For their constant support and sponsorship.
- Industry Service Complex (ISC) - at AAST Alexandria - for aiding in the ROV's manufacturing.
- MATE Center - for creating such a highly competitive and professional competition, that allows makers to explore their passions and develop their engineering skills along the way.
- Our supervisor, Eng. Amr Khamis - for his constant support and always pushing us to perform better.
- Dr. Amr Ali Hassan, Dr. Mohamed Abo ElAzm and Dr.Ayman Adel - for their relentless support and continuous encouragement.
- Dr. Ahmed ElShennawy from the RIC - Dean of the RIC for his constant support.
- Our current mentors and former team members: Mohamed Samir, Hossam Samir, Abdelrahman Elkanishy, Hesham Fadl, Abdelrahman Elshoura, Ahmed Eldawansy, and Mohamed Lotfy.

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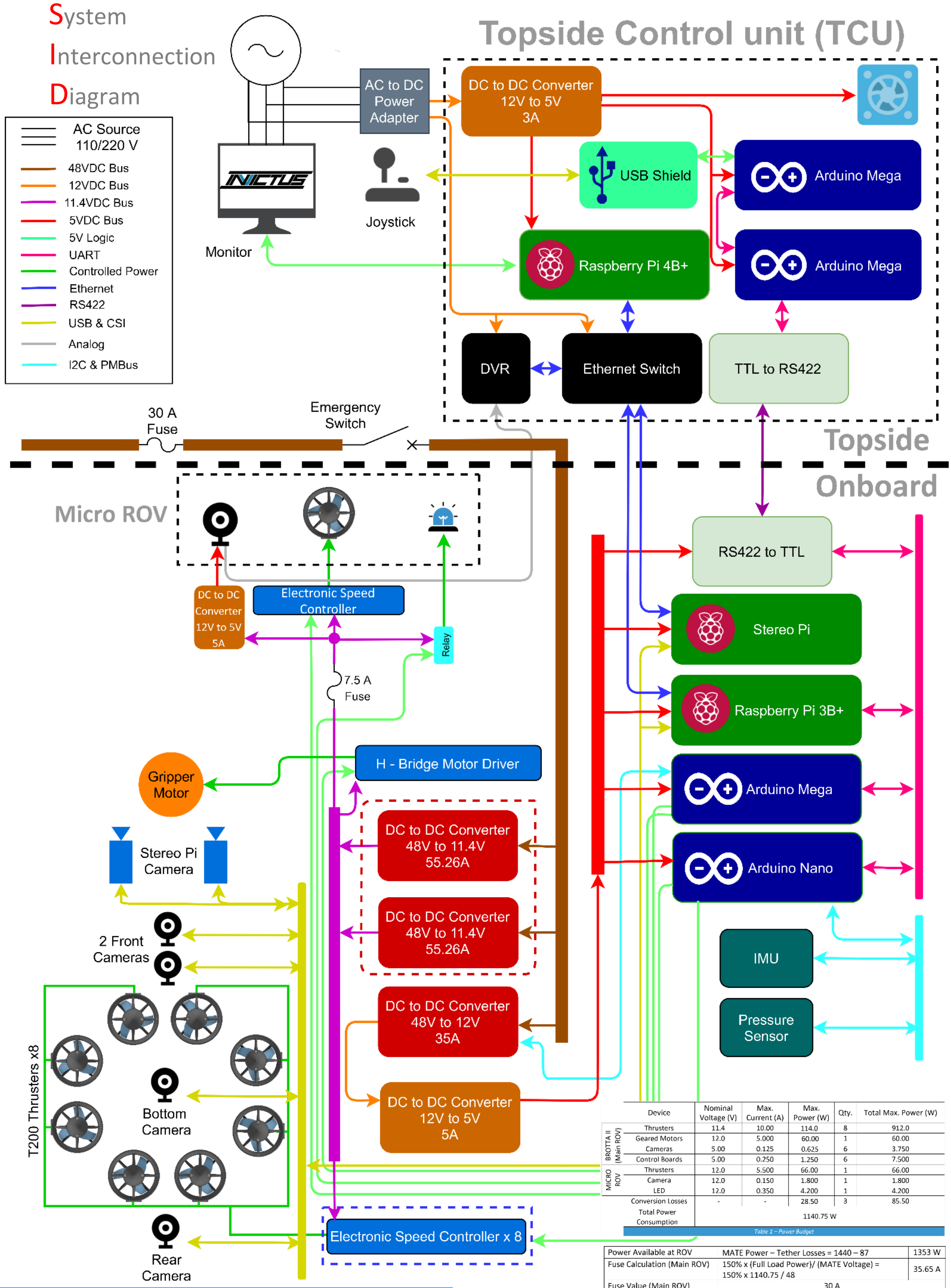
Appendix A:

System Interconnection Diagram



	Device	Nominal Voltage (V)	Max. Current (A)	Max. Power (W)	Qty.	Total Max. Power (W)
BROTTA II (Main ROV)	Thrusters	11.4	10.00	114.0	8	912.0
	Geared Motors	12.0	5.000	60.00	1	60.00
	Cameras	5.00	0.125	0.625	6	3.750
	Control Boards	5.00	0.250	1.250	6	7.500
MICRO ROV	Thrusters	12.0	5.500	66.00	1	66.00
	Camera	12.0	0.150	1.800	1	1.800
	LED	12.0	0.350	4.200	1	4.200
	Conversion Losses	-	-	28.50	3	85.50
	Total Power Consumption	1140.75 W				

Table 1 – Power Budget

Power Available at ROV	MATE Power – Tether Losses = 1440 – 87	1353 W
Fuse Calculation (Main ROV)	150% x (Full Load Power)/ (MATE Voltage) = 150% x 1140.75 / 48	35.65 A
Fuse Value (Main ROV)	30 A	
Fuse Calculation (Micro-ROV)	150% x (Full Load Power)/ (MATE Voltage) = 150% x 72 / 12	9 A
Fuse Value (Micro-ROV)	7.5 A	

Table 2 – Fuse Calculations

Appendix B: Budget Sheet

	Category	Description/Example	Amount (USD)
INCOME	University Funding	Arab Academy for Science, Technology and Maritime Transport	$1,000.00
	Blue Robotics	Prize	$500.00

	Description	Type	Value	Category Total	Budge
Mechanical Body	HDPE Sheet (Sides and Supports)	Purchased	$20.00	$143.00	$88.000
	PVC A4 size (Gripper Members)	Purchased	$3.000		
	Acrylic Parts (Used in minor parts)	Purchased	$16.00		
	CNC Router Cutting (Done by AAST Workshops)	Donated	$40.00		
	Assembling Components	Purchased	$15.00		
	Geared Motors (To actuate grippers)	Purchased	$14.00		
	Aluminum Material (Gripper Sealing)	Re-used	$15.00		
	O-Rings (To seal enclosures)	Purchased	$20.00		
Thrusters	Blue Robotics T200 Thruster	Purchased	$850.0	$1620.0	$1066.0
	Blue Robotics T200 Thruster	Donated	$510.0		
	Blue Robotics 30A Electronic Speed Controller (ESC)	Purchased	$216.0		
	3D Printed Guards (Done by AAST Workshops)	Donated	$44.00		
Tether	VideoRay Neutrally Buoyant Tether 50 feet	Re-used	$150.0	$187.00	$00.000
	Tether Nylon Sleeve	Re-used	$25.00		
	Ethernet Cable (Connecting RS485 to station)	Re-used	$12.00		
Control Box	Acrylic Tube (Containing all electronics)	Purchased	$22.00	$168.00	$148.00
	Aluminum Flanges (Seals radially with the tube)	Purchased	$36.00		
	Aluminum Penetrators (Seals the cables)	Purchased	$50.00		
	Acrylic Caps (Carries the penetrators)	Purchased	$10.00		
	Flanges Machining (Done by AAST Workshops)	Donated	$20.00		
	Stainless Steel Strain Relief Mechanism	Purchased	$30.00		
Onboard Electronics	DC/DC Converters (600W Converters Murata)	Purchased	$180.0	$350.35	$306.85
	Arduino MEGA 2560	Re-used	$23.00		
	Arduino Nano	Re-used	$9.000		
	IMU (Gets vehicle's orientation)	Re-used	$11.50		
	Pressure Sensor (Gets vehicle's depth)	Purchased	$21.50		
	PCBs (The main board and power board)	Purchased	$17.00		
	Acrylic Parts and 3D Printed Tray	Purchased	$34.35		
	Raspberry pi 3B+ & Logic Level Converter	Purchased	$44.00		
	Wires and Connectors	Purchased	$10.00		
Cameras	Polyamide-6 (PA6) Enclosures	Purchased	$9.000	$233.00	$223
	Acrylic Transparent Caps	Purchased	$6.000		
	Housing Machining (Done by AAST Workshops)	Donated	$10.00		
	Laser Cutting for Caps	Purchased	$2.000		
	Full HD USB Camera	Purchased	$90.00		
	Raspberry Pi Camera	Purchased	$26.00		
	Stereo Pi Kit	Purchased	$90.00		
Piloting Station	Raspberry pi 4	Purchased	$70.00	$186.40	$70
	Logitech Extreme 3D Pro (To control the vehicle)	Re-used	$28.90		
	Arduino MEGA 2560	Re-used	$46.00		
	Arduino Nano	Re-used	$9.000		
	Monitor (Displays video and data)	Re-used	$32.50		
	Total Cost	**$2887.75**			
	Total Reused and Donated items	**$985.900**			
	Total Budget Allocated	**$1901.85**			
	Cash Income	**$1500.00**			
	Funds Needed	**$401.850**			
	Travel and Transport	**Telepresence**			

Appendix C: Project Costing

Type	Expenses	Description	Amount	Project Cost	Running Balance
Cash donated	Prize Money from BlueRobotics	-	$500.0	-	$500.00
Cash donated	Funds from AASTMT University	-	$1000	-	$1500.0
Cash donated	Funds from Banque Misr	-	$400	-	$1900.00
Purchased	HDPE Sheet	Frame Material	$20.00	$20.0000	$1880.0
Purchased	PVC Sheet	Gripper Material	$3.000	$23.0000	$1877.0
Purchased	Acrylic parts	For Sealing	$16.00	$39.0000	$1861.0
Donated	CNC Routing	Donated by AASTMT Workshops	$40.00	$79.0000	$1861.0
Purchased	Assembling Components	For Assembling Frame & Gripper	$15.00	$94.0000	$1846.0
Purchased	Geared Motors	For Gripper	$14.00	$108.000	$1832.0
Re-used	Aluminum Material	For Power unit Sealing	$15.00	$123.000	$1832.0
Purchased	O-rings	For Sealing	$20.00	$143.000	$1812.0
Purchased	T200 Thrusters	For ROV	$850.0	$993.000	$962.00
Donated	T200 Thrusters	Discount from BlueRobotics	$510.0	$1503.00	$962.00
Purchased	30A Electronic Speed controllers	For Thrusters Control	$216.0	$1719.00	$746.00
Donated	3D Printed Guards	Donated by AASTMT Workshops	$44.00	$1763.00	$746.00
Re-used	Videoray Tether 50 feet	ROV Tether	$150.0	$1913.00	$746.00
Re-used	Nylon Sleeve	Tether Protection	$25.00	$1938.00	$746.00
Re-used	Ethernet Cable (Connecting RS485 to station)	Communication	$12.00	$1950.00	$746.00
Purchased	Acrylic Tube (Containing all electronics)	For Control unit Sealing	$22.00	$1972.00	$724.00
Purchased	Aluminum Flanges (Seals radially with the tube)	For Control unit Sealing	$36.00	$2008.00	$688.00
Purchased	Aluminum Penetrators (Seals the cables)	For Control unit Sealing	$50.00	$2058.00	$638.00
Purchased	Acrylic Caps (Carries the penetrators)	For Control unit Sealing	$10.00	$2068.00	$628.00
Donated	Flanges Machining	Donated by AASTMT Workshops	$20.00	$2088.00	$628.00
Purchased	Stainless Steel Strain Relief Mechanism	For ROV Tether	$30.00	$2118.00	$598.00
Purchased	DC/DC Converters (600W Converters Murata)	For Power Conversion	$180.0	$2298.00	$418.00
Raised	Self-Funds from Team Members	-	$200.0	-	$618.00
Re-used	Arduino MEGA 2560	For Control unit	$23.00	$2321.00	$618.00
Re-used	Arduino Nano	For Control unit	$9.000	$2330.00	$618.00
Re-used	IMU (Gets vehicle’s orientation)	For Control unit	$11.50	$2341.50	$618.00
Purchased	Pressure Sensor (Gets vehicle’s depth)	For Control unit	$21.50	$2363.00	$596.50
Purchased	PCBs (The main board and power board)	For Control unit	$17.00	$2380.00	$579.50
Purchased	Acrylic Parts and 3D Printed Tray	For Control unit	$34.35	$2414.35	$545.15
Purchased	Raspberry pi 3B+ & Logic Level Converter	For Control unit	$44.00	$2458.35	$501.15
Purchased	Wires and Connectors	For Control unit	$10.00	$2468.35	$491.15
Purchased	Polyamide-6 (PA6) Enclosures	For Cameras	$9.000	$2477.35	$482.15
Purchased	Acrylic Transparent Caps	For Cameras	$6.000	$2483.35	$476.15
Donated	Housing Machining	Donated by AASTMT Workshops	$10.00	$2493.35	$476.15
Purchased	Laser Cutting for Caps	For Cameras	$2.000	$2495.35	$474.15
Purchased	Full HD USB Camera	For Cameras	$90.00	$2585.35	$384.15
Purchased	Raspberry Pi Camera	For Cameras	$26.00	$2611.35	$358.15
Purchased	Stereo Pi Kit	For Cameras	$90.00	$2701.35	$268.15
Purchased	Raspberry pi 4	For Cameras	$70.00	$2771.35	$198.15
Re-used	Logitech Extreme 3D Pro (To control the vehicle)	For Station	$28.90	$2800.25	$198.15
Re-used	Arduino MEGA 2560	For Station	$46.00	$2846.25	$198.15
Re-used	Arduino Nano	For Station	$9.000	$2855.25	$198.15
Re-used	Monitor (Displays video and data)	For Station	$32.50	$2887.25	$198.15
Purchased	DC/DC Converters (600W Converters Murata)	Re-Purchased after failure of first batch	$180.0	$3067.75	$18.150

Project Cost	**$3067.75**
Project Cost – Reused and Donated Items	**$2081.85 (More than Allocated budget by $180)**
Total Income	**$1500.00**
Total Raised	**$600.000**
Final Balance	**$18.1500**

Appendix D: Operation and Construction Safety Checklists

Procedure	**Check Mark**
Pre-Power Checks	
All crewmembers are wearing safety gear.	
Power is disconnected before conducting safety check.	
Check fuse is not blown.	
Propellers, shafts, and manipulators clear of obstructions.	
Cables are tied down and electrical connections are waterproofed.	
Check operating environment is clear of obstacles.	
Call out “Safe”.	
Pre-Water Checks	
Connect tether to control station and power the system.	
Check video system.	
Pressurize the electronics enclosure for the rated depth for the called dive.	
Check internal pressure reading at control station is correct for the dive.	
Power down the system and call out “Water Ready”.	
Two crewmembers and the tether man lower the ROV in the water.	
Call out “In Water”.	
In-Water Checks	
Power up the system and check warning lights.	
Check internal pressure is stable at surface.	
Call out “Pilot in Command”.	
Recovery Checks	
Check ROV is at surface, facing away from pool wall.	
Power down the system and call out “Crew in Command”.	
Two crewmembers and tether man lift the ROV from the water onto land.	
Safety officer signature:	

Entering the Lab or Workshop	
Sign and timestamp Employee Sign Sheet.	
Wear Company Issued facemask and PPE.	
Operating Power tools	
Wear all required PPE per tool.	
Always keep hands away from tool head.	
Tie back long hair and keep rotating parts clear of strings, ropes, and flexible fabrics/materials.	
Working with Electrical Components and Soldering	
Use a soldering fumes extractor.	
Make sure soldering iron or hot air hand tool is in its holder when not in use.	
Check all electrical connection and make sure they are distant from Liquids.	
Employee Signature:	