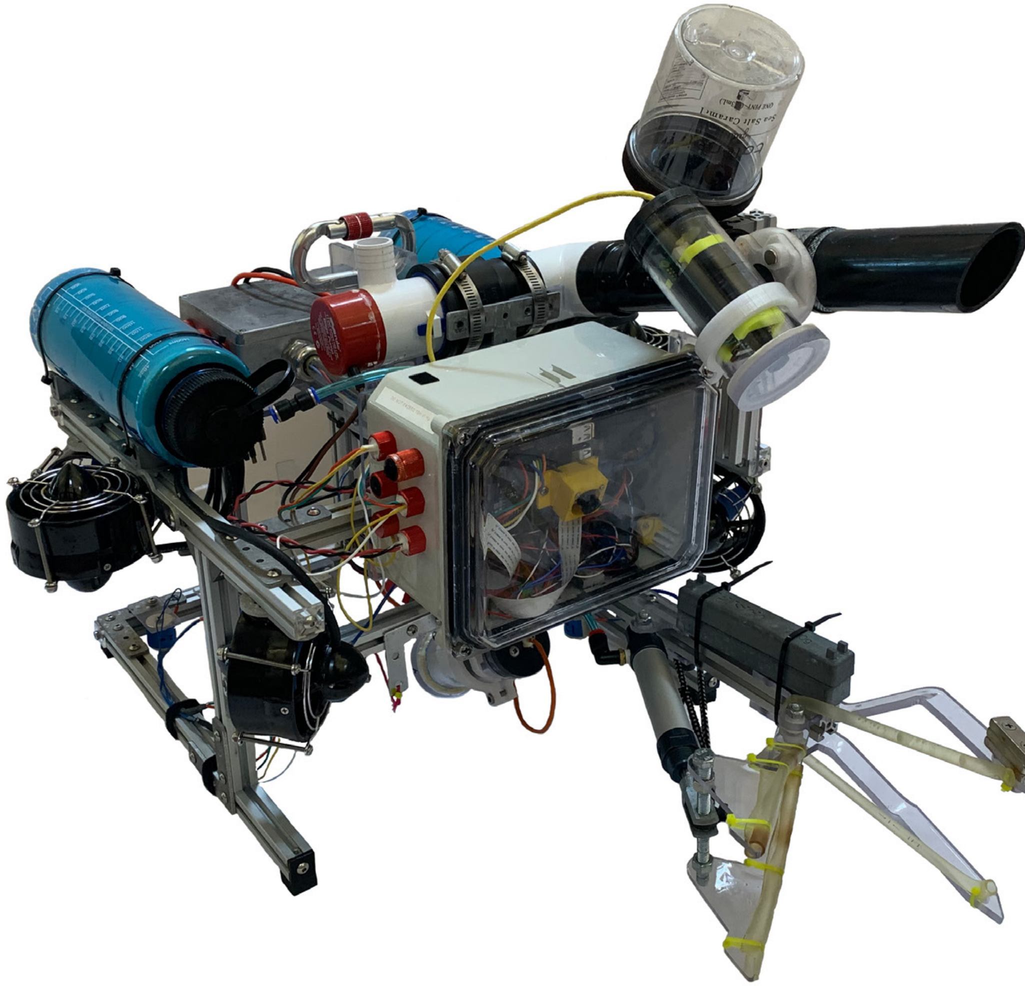


ROVOTICS

JESUIT HIGH SCHOOL ROBOTICS

JESUIT HIGH SCHOOL

CARMICHAEL, CA

MATE 2021

TEAM MEMBERS

Freshmen
- '24 Dylan Olsen*, Software
- '24 James Randall*, Electronics
- '24 Jonah Reynolds*, Safety Officer
- '24 Adon Sharp*, Software

Sophomores
- '23 Daniel Kriefels*, Software
- '23 Timothy Monroe, Mechanical
- '23 Michael Solis, Mechanical

Juniors
- '22 Charlie Diaz, CEO
- '22 Nick Venegas, Electronics
- '22 Taylor Vicente, COO

Seniors
- '21 Alden Parker, Software
- '21 Andrew Grindstaff, Software
- '21 Luke Rosellini, Mechanical
- '21 Joe Watanabe, Mechanical

*New Members

Head Coach: Jay Isaacs

Assistant: Steve Kiyama

Cheryl Kiyama

Marcus Grindstaff

Michael Sharp

INTRODUCTION

ABSTRACT

Nautilus is Rovotics' newest and most advanced Remotely Operated Vehicle (ROV) and is designed to operate in underwater environments around the world. Nautilus is fully equipped with tools to remove trash from the water, restore and remediate aquatic habitats, and survey subsea features.

Nautilus is the product of months of planning, prototyping, and testing to meet quality and safety standards. With features such as a modular frame, expandable electronics, and an extensible software platform, Nautilus is built to adapt to emerging global environmental challenges. This technical document describes the design and development process of our ROV and how Nautilus addresses the ubiquitous problem of plastic pollution, the catastrophic impact of climate change on coral reefs, and the maintenance of healthy waterways.

Rovotics is a fourteen-person company with years of collective experience designing, manufacturing, and operating robotic solutions to ecological problems in aquatic settings.

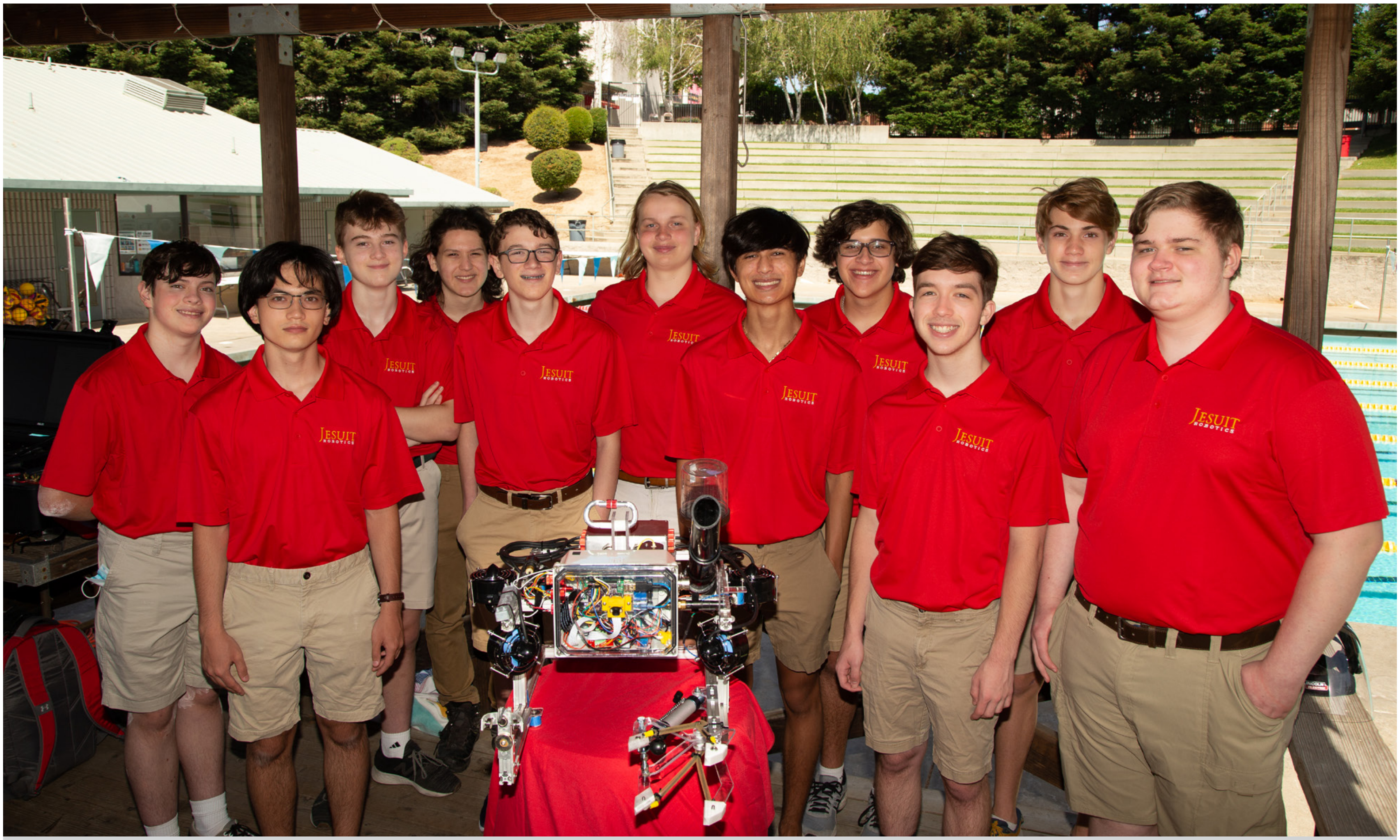


Figure 1. Rovotics Team Members

TABLE OF CONTENTS

DESIGN RATIONALE

DESIGN EVOLUTION

Nautilus is Rovotics' second generation of our core ROV system, based on our 2018 - 2019 ROV, Boxfish. The reuse of core systems meant that Rovotics was able to rapidly design and build Nautilus' mechanical frame, electronics, and operating system during the beginning of the 2019 season.

Throughout 2020, Rovotics continued to innovate, adapting to virtual ways of working. In keeping with CDC guidelines, Rovotics made the switch to an entirely virtual workspace. While working from home, Rovotics' software department made strides in increasing the modularity of our custom Robot Operating System (ROS) software architecture. More time at home meant that the team had more time to spend planning, prototyping, and revising Nautilus' custom tool suite. This extended early tool development phase meant that once lab activities restarted in early 2021, Rovotics was able to rapidly integrate refined tools onto a robust core ROV (Figure 2).

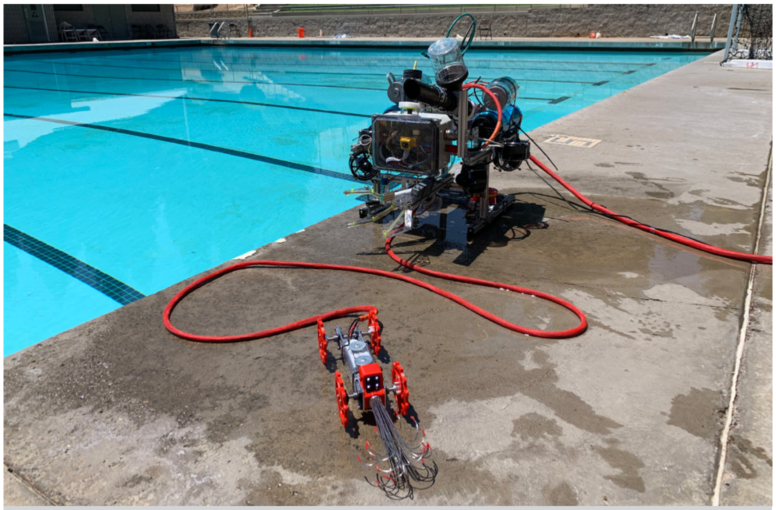


Figure 2. Nautilus with Tools

While older ROV designs made use of analog cameras, Rovotics created an all-new waterproof economical real-time streaming digital video system for this year's ROV, replacing the prior connection-switched analog camera system. The goals included very low latency, expandability, multi-stream video, off-the-shelf components, adjustable mounting, and the ability to use the video stream for additional image processing. The magic of the new digital camera system is brought to life through strong collaboration between the electronics, software and mechanical departments.

Safety continues to be Rovotics' top priority. Rovotics' standardization of ROV systems meant that proven safety systems from previous ROVs have been maintained in Nautilus. Software monitoring of Nautilus' sensor readings allow operators to quickly detect and address abnormalities in the event of system failure. In addition to software and electronics safety features, Nautilus' mechanical design continues to implement safety elements such as thruster guards, which protect the ROV and limit the risk of injury for deck crew.

MECHANICAL DESIGN AND MANUFACTURING PROCESS

Rovotics decided to design a new ROV that would leverage most of Boxfish's core ROV systems. Mechanical designs of the frame and electronics housings would therefore be largely based on Boxfish's original designs.

Boxfish's modular frame and rectangular electronics housings proved to be improvements over previous cylindrical housing designs.

Nautilus' design process began with an interdepartmental team of mechanical, electrical, and software engineers to discuss which aspects of the new ROV should remain the same as the previous design, and which aspects could be improved. A decision matrix was applied to the design process. Factors such as current usability , product or material availability, cost and suitability for future use were evaluated. It was found that the existing Main

Figure 3. Nautilus' MEH and Electronics

Electronics Housing (MEH) was undersized for the planned electronics expansion, which included a large ethernet multiplexer for our new digital vision system. The mechanical department analyzed commercial-off-the-shelf waterproof housing solutions to meet the requirements. The result was the purchase and modification of a rectangular waterproof housing (Figure 3). The housing chosen is a variation on Boxfish's MEH, but is larger so as to accommodate the electronics expansion.

The ease of design, manufacturing, and modification of Boxfish's aluminum extrusion frame proved to be useful during development and operation. Application of the design matrix verified use of an extrusion frame design remains a significant advantage. As a result, Nautilus' aluminum extrusion frame is an optimized version of the Boxfish frame. Initial frame design work was done on Fusion 360, Rovotics' Computer-Aided Design (CAD) platform of choice (Figure 4). After the initial design was complete, revisions were made during meetings in which the optimization of costs, tool placement, and the reduction of size and weight were discussed. Upon the completion of design revisions, parts for the frame were purchased and the final product was fabricated.

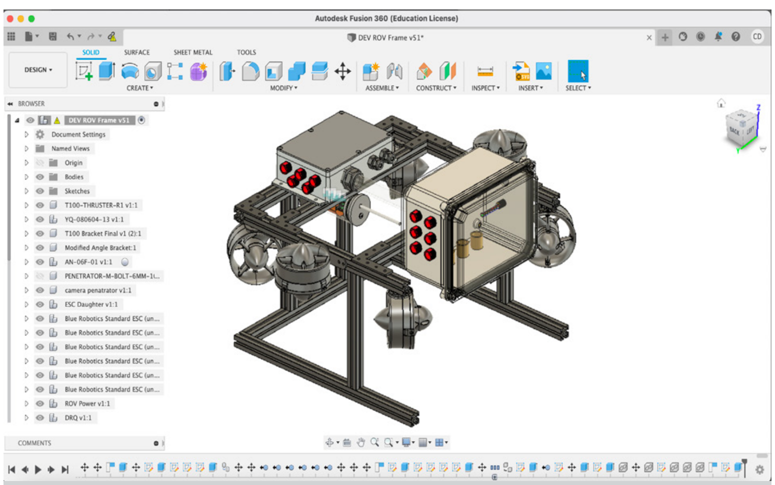


Figure 4. Nautilus' CAD in Fusion 360

MECHANICAL COMPONENTS

Frame

Nautilus' frame is the latest evolution of our modular frame system (Figure 5). Rovotics' modular frame system is made out of beams of 20mmx20mm extruded aluminium with T slots.

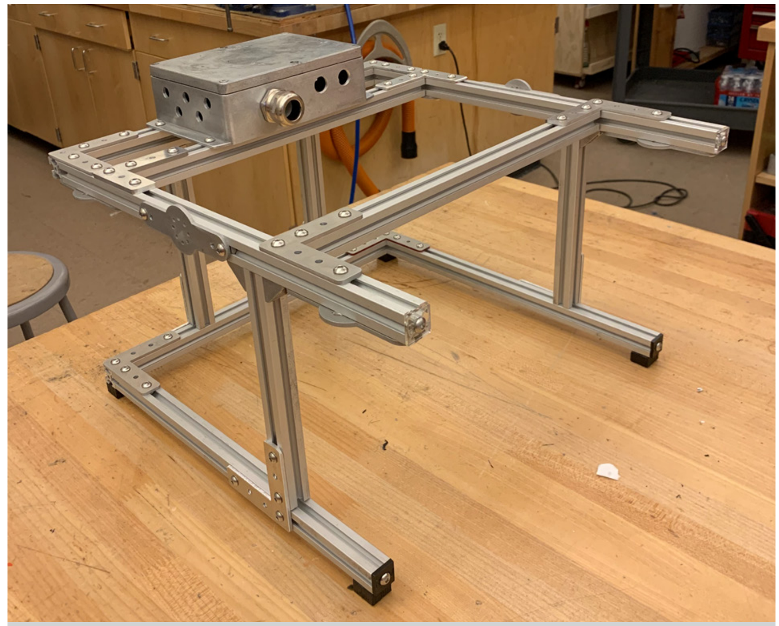


Figure 5. Nautilus' Frame

Previous ROVs used custom frames whose manufacturing had higher costs, required more custom manufacturing and lacked the flexibility afforded by a modular frame. Rovotics moved to using aluminum extrusion because of its low cost, ease of manufacturing, and ability to be rapidly modified. Extrusion is readily available from many online suppliers along with a wide assortment of fastening solutions. Manufacturing of extrusion frames consists of cutting the extrusion to length and fastening segments of extrusion together using brackets, screws, and sliding nuts. Modification of the frame is identical to the manufacturing process, and is therefore just as quick and easy. During our design revision discussions, it was decided that Nautilus' frame would take the shape of a large rectangular prism providing ample interior space for tools. The frame's revised design used less extrusion than our previous ROV design, which further decreased the cost and weight while providing increased area for tool mounting.

The MEH and Power Systems Enclosure (PSE) are mounted to the top frame which account for a majority of the buoyant force. Placing this buoyancy at the top of the ROV contributes to its stability. The MEH and PSE were chosen because of their off-the-shelf availability and short lead time. These housings also utilize more secure face seals as opposed to the bayonet seals used on previous tube-style housings. The PSE is a cast aluminum box chosen for its high thermal conductivity. This thermal conductivity is used to cool both the Electronic Speed Controllers (ESC) and voltage converters.

Horizontal thrusters are mounted on the corners of the frame at 45° for vector drive, and two vertical thrusters are mounted on either side of the ROV. The center of mass is aligned with the center of thrust to maximize ROV stability.

Electronics Housing

Both Nautilus' MEH and PSE are rectangular, off -the-shelf housings (Figure 6). In previous years, Rovotics used cylindrical housings to contain our ROV's core electronics. Through design reviews performed in previous years, it was determined that commercially available rectangular housings are waterproofed to a higher degree, cheaper, and had more surface area for submersible connectors than our custom in-house built cylindrical housings. As our electronics suite expanded to accommodate new features such as digital cameras, it was deemed necessary that our housings expand as well.

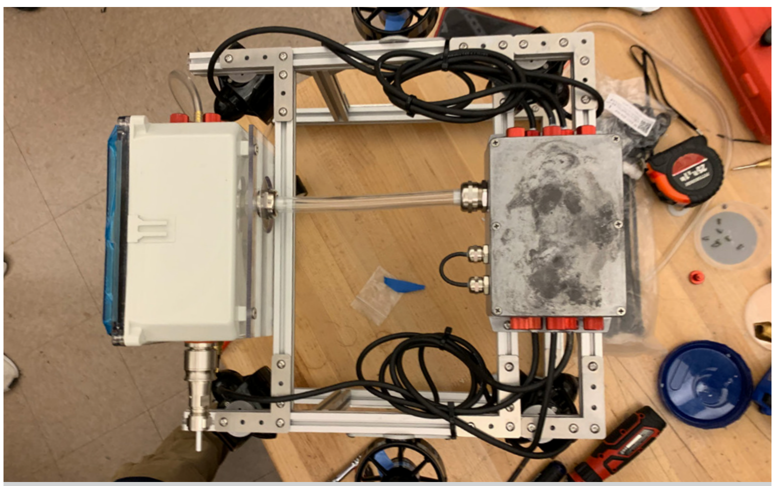


Figure 6. Top View of Nautilus' Electronics Housings

Through dividing the electronics architecture into two waterproof housings, the PSE and the MEH, Nautilus is able to retain the operating and servicing advantages of utilizing a clear plastic housing while simultaneously reducing housing thermal expansion caused by high energy components.

The PSE houses Nautilus' ESCs and voltage converters. To dissipate heat generated by the ESCs and the voltage converters, the PSE is manufactured out of aluminum which, when submerged in water, doubles as a heat sink. The voltage converters, which are responsible for generating the majority of heat in the system, were aligned on the aluminum walls of the PSE to maximize thermal transfer to the water. The utilization of an aluminum housing has brought average voltage converter operating temperatures down from 80° C in our prior plastic cylindrical housings to 35° C out current aluminum PSE.

The cast plastic MEH contains the core ROV computational systems. The MEH has a clear lid to allow for a 110° Field of View (FOV) digital camera which is used as our primary navigation camera. The clear lid also allows for visual inspection of the interior of the housing, which is valuable for operations and servicing. A modular sliding shelf system provides easy access to service internal components.

The clear and flexible Power and Communications Tube joins the PSE and MEH. This tube allows the PSE to provide power to the MEH electronics, and the MEH to provide the ESCs information from Topside. This tube is especially beneficial for maintenance as it allows vacuum testing both housings simultaneously which reduces the complexity and improves the reliability of the test.

Thrusters

Nautilus is equipped with six T100 Blue Robotics thrusters. The T100 thrusters were chosen for their low weight, affordability, and proven reliability on previous Rovotics' designs. A previous ROV design, Mako, used four T100 thrusters and two T200 thrusters; however, the additional cost of the T200 thrusterswas not justified by the little benefit provided. Additionally, the standardization in thrusters eliminates the costs of having two different types of backup thrusters.

To achieve stable vector control, four T100 thrusters are mounted at 45° angles at the corners, allowing all thrusters to contribute to the total propulsion in the cardinal directions and minimize flow interference with accessories in the center of the vehicle. The T100 thrusters operate at a

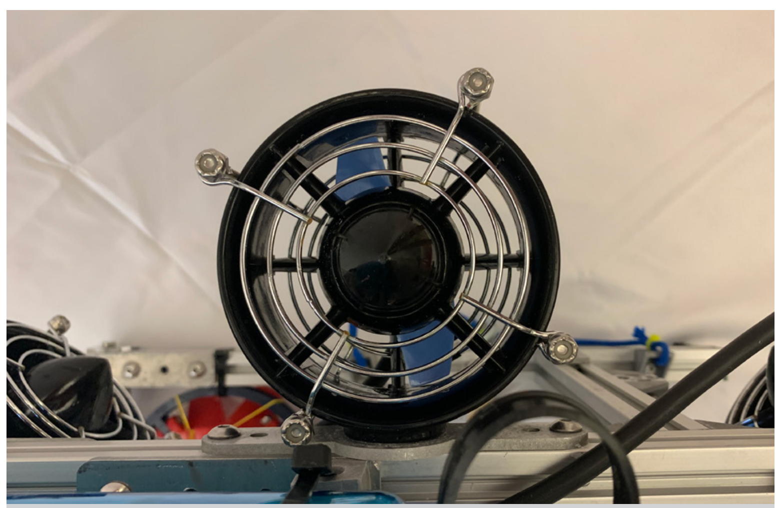


Figure 7. Nautilus' Thruster Guards

Item	Quantity	Mass (Kilogram)	Volume (Cubic Meters)	Density (kg/m^3)	Total Buoyant Force (Newtons)
20x20 Frame	1	2	0.00074	2710	-12.42
PSE	1	0.925	0.00179	516.76	8.42
MEH	1	1.285	0.00474	271.1	33.72
T100 Thrusters	6	NA	NA	NA	-6.93
Frame Brackets	16	0.02155	0.000008	2693.75	1.04
Tether	1	3.6	0.00362	994.48	0.09
Tools	1	4.5	0.00103	4368.93	-34.04
MABS	10	0.022	0.0001	220	9.56
Total Buoyancy				Slight Negative Buoyancy >	-0.56

Figure 8. Nautilus' Buoyancy Calculation Spreadsheet

maximum power of 150W each, manageable within Nautilus' power budget. For the safety of personnel and equipment, low resistance thruster guards are mounted on both sides of the thrusters to prevent foreign objects from entering the thrusters (Figure 7).

Buoyancy

Nautilus, along with its components and tether, has a maximum displacement of $1.5 \times 10^4 cm^3$. Nautilus has three main buoyancy components: electronics housings, syntactic foam, and our Manually Adjustable Buoyancy System (MABS). At over $6.5 \times 10^3 cm^3$, the two electronics housings are Nautilus' largest displacement component and serve as the main buoyancy devices. Our MABS utilizes syntactic foam disks which will remain buoyant for depths up to 300 meters, allowing Nautilus to reach the target depth of any MATE mission with ease. Our MABS allows for buoyancy to be adjusted by inserting or removing foam disks, allowing deck crew to quickly adapt to mission's needs.

A spreadsheet was made to record the displacements and densities of each part of the ROV (Figure 8). Using Archimedes' Principle, this data was used to calculate Nautilus' weight in water. Once the majority of the ROV was manufactured and assembled, the actual and calculated values were compared to allow for fine-tuning using our MABS.

Nautilus' tether achieves a slight positive buoyancy by using rigid, lightweight aluminum water bottles interspaced along its length. The tether's positive buoyancy ensures that it does not interfere with the ROV during operations while not being so buoyant that it impedes ROV movement.

ELECTRICAL SYSTEMS

Topside Control Unit (TCU)

One of Rovotics' major investments in the 2019 season was a TCU that integrated all of the on-deck devices to increase portability and reduce setup time (Figure 9). Because of the similar requirements, Rovotics has opted to continue using our TCU to reduce the amount of work and budget needed. The TCU has been maturing over the past three years, and because of our design strategy, it has been tailored to meet this year's mission goals with appropriate software and hardware updates.

The TCU was designed to fit in a Pelican iM3220 case that allows for easy transportation, setup, and protection due to its durable and mobile design. Two 60 cm monitors are mounted on the top of the case and are plugged directly into the Intel NUC, a powerful Single-Board Computer (SBC),

Figure 9. The TCU

housed in the bottom compartment. This is an upgrade from the previous UDOO X86, which had insufficient computational power. The Intel NUC has more processing power and RAM allowing it to drive both monitors and run the pilot and co-pilot systems effectively. A highly visible main shut-off power switch has also been implemented as a safety feature to enable the quick shut down of the ROV.

The TCU's bottom compartment was designed with a liftable lid to easily service the most critical components, such as the NUC. Wiring channels also ensure an organized and modular construction. The internal Intel NUC serves as the main computer for the Topside control system. It communicates to all subsystems through a routed Transmission Control Protocol (TCP) / User Datagram Protocol (UDP) IP communication. Both the router and an ethernet switch are contained within the TCU. The keyboard, mouse, joystick, and throttle connect to the Intel NUC through a USB hub integrated into the TCU.

The back of the TCU contains USB and Ethernet connections and bulkhead connectors for pneumatics. To prevent connection errors, two different format high-current Anderson Powerpole (Figure 10) connectors are used as

Figure 10. TCU Connections

separate connection points for both the 48V MATE supplied power and the 48V power feed to the ROV. A TCU SID is located in Figure 11.

Tether

Nautilus' reliable, manageable, and lightweight (3.6 kg) tether is designed to transport necessary signals, power, and pneumatics 14 meters from the TCU to the ROV, and

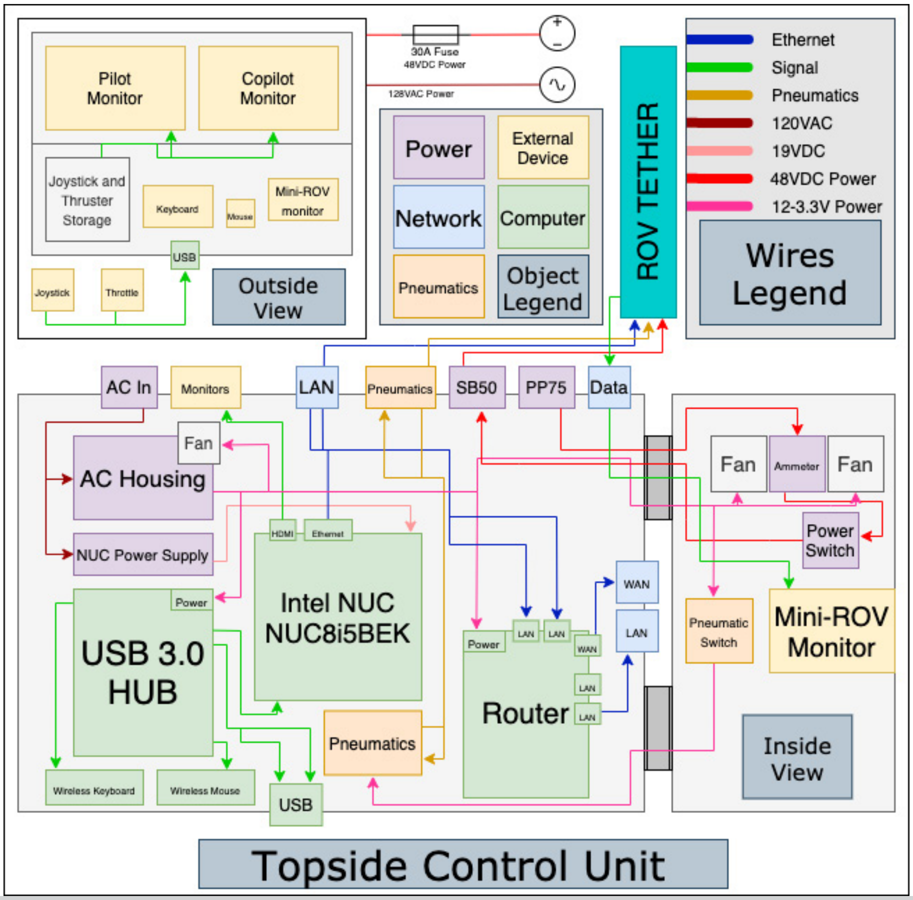


Figure 11. TCU SID

retains many key characteristics from Rovotics' previous designs. The tether is wrapped in a high-visibility, durable and flexible, braided polyester sheathing. This sheathing protects the lines housed within. The braided polyester allows for stretch or controlled "give" on the pull of the tether, helping to ease sudden jerks or sharp motions. This prevents unwanted stress on connections. Pressure-resistant stainless steel flotation devices are used to keep the tether slightly positively buoyant. This helps prevent the tether from becoming an obstacle to the ROV, allowing for easier and unobstructed movement, keeping the tether and ROV safe from interference damage. Nautilus' tether has sturdy strain relief sheathing at both its ends, coming from the TCU and going into the ROV (Figure 12). The ROV can be lifted by its tether without damaging connections.

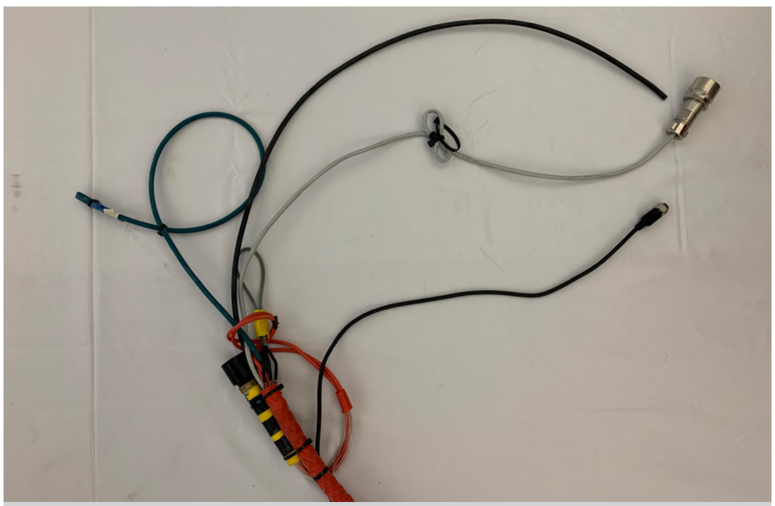


Figure 12. Tether Connections - ROV Side

Two high-performance insulated silicone DC power lines are used to supply 48V power to the ROV. The 12 American Wire Gauge (AWG) silicone insulated wire was chosen for its low weight, compact size, excellent flexibility, and low resistance to minimize the voltage drop and power loss across the tether. The calculated resistance of the power cable is 0.3 ohms, meaning that at the expected 23.2 A current draw, the voltage will drop 7V across the tether (23.2 A * 0.3 ohms = 7V). This gives our ROV a minimum operating voltage of approximately 39V, which is above the programmable 34V input cut-off voltage of the DC-DC voltage converters. A gigabit Category 6a Ethernet (CAT6a) cable is used as a network line to Nautilus' Raspberry Pi computer due to its superior signal propagation characteristics compared to the CAT5e. The CAT6a cable is terminated into a T-568B compliant connector. A 4 pin M12 coax is used to carry the mini-ROV's analog video signal from the mini-tether to the TCU. In order to accommodate Nautilus' pneumatic systems, one 1/4" OD, 1/8" ID (6.35mm OD, 3.175mm ID) polyurethane pneumatic tube is used to create an open-loop system. The tubing diameter was chosen to balance weight and airflow based on the pressure drop at the expected depth of 6 meters and the requirements of the tools developed for the RFP. The tubing chosen exceeds the safety requirement of 3 times the operating pressure of 40 psi (Topside) at 145 psi (25° C). However, the relative pressure drop of the ROV at the maximum operating depth of 10m is 14.6 psi (100 kPa). So the expected relative pressure of the pneumatic lines at the ROV is at least 25 psi (172 kPa). All pneumatic tools are designed to operate safely and effectively at the minimum and maximum pressure.

Tether management is handled by the tether manager, who is responsible for the proper deployment, tensioning, and stowing of the ROV's tether. At the beginning of a mission, the tether manager calls for all non-essential personnel to leave the deck (side of the pool). The tether manager then removes the tether from its carry bag, uncoils the tether, and lays it out on the deck with one end facing the TCU and the other end facing the ROV. The tether is connected to the TCU first, beginning with the strain relief connection, followed by the power, ethernet, mini-ROV video signal, and finally, the pneumatics line. The tether is then connected to the ROV, proceeding in the same order as the TCU connection. When the ROV is deployed, two deck crew members lower the ROV into the water using strain relief and hardpoints on the ROV. While in maneuvers, the tether manager has constant contact with the tether and ensures a proper amount of slack is provided so as not to inhibit ROV movement. Upon completion of the mission and the shut down of the ROV, the tether manager disconnects the tether from the ROV, disconnecting the strain relief last, and then disconnects the tether from the TCU, again, disconnecting the strain relief last. Once the tether has been completely disconnected, the tether manager coils the tether and places it back in the carry bag. The tether manager coils the tether by alternating the winding of every other loop, which prevents damage to the tether seen in continuous winding and helps with storage.

Bottomside Electronics

The electronics system was designed around the principles of serviceability, low build times and component lead times, and operational stability. Bottomside electronics

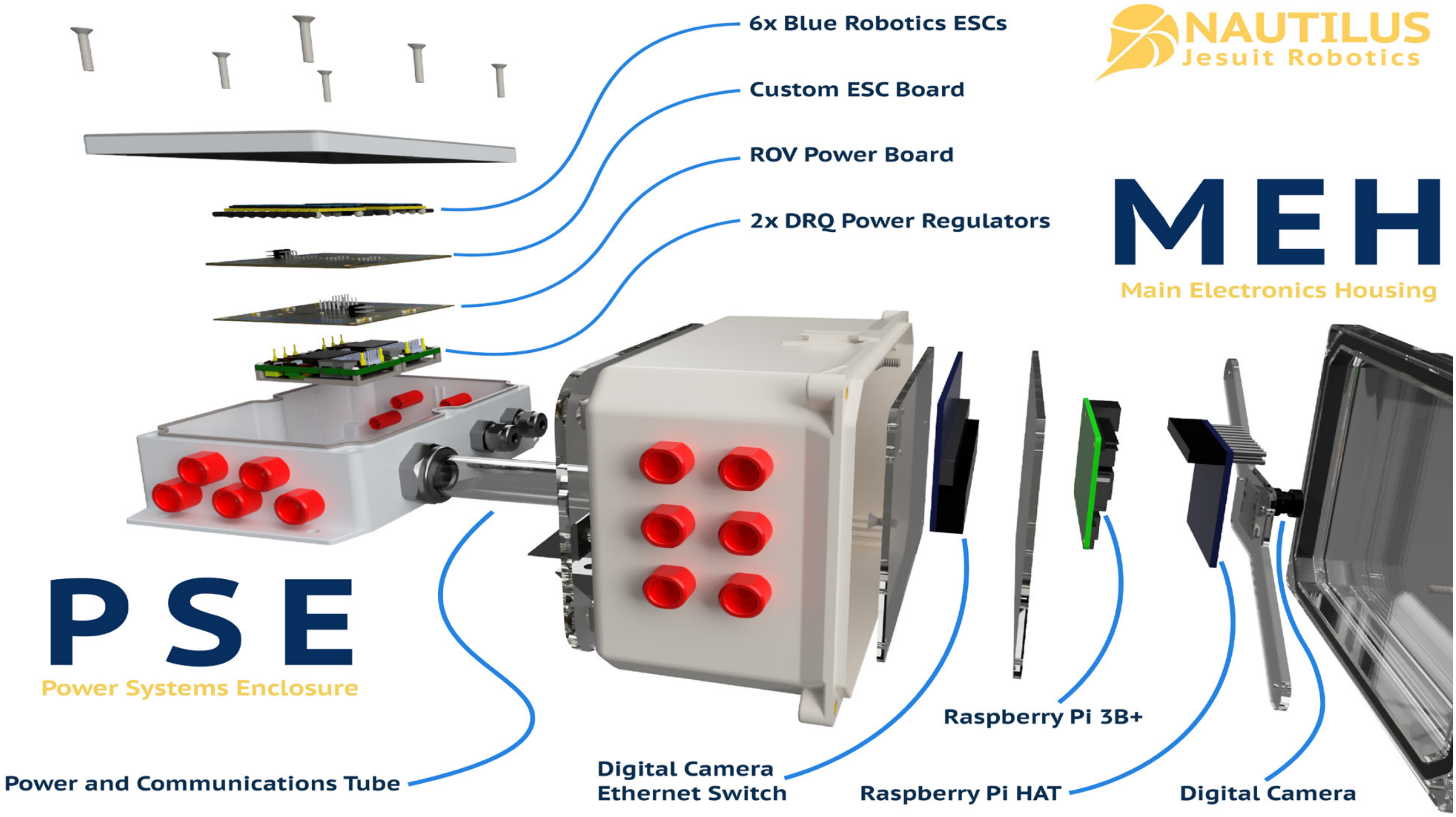


Figure 13. Bottomside Electronics Architecture

consists of two primary parts, the PSE and MEH (Figure 13).

The PSE contains two DRQ1250 48V to 12V voltage converters, a custom power Printed Circuit Board Assembly (PCBA), six Electronic Speed Controllers (ESC), and an Arduino Nano (Figure 14). The control signals for the thrusters are sent to the PSE using a simple USB connection between the Arduino Nano in the PSE and the main Raspberry Pi computer in the MEH. The serial communication received by the Arduino is then converted to Pulse Width Modulation (PWM) signals used by the ESCs. The Arduino Nano is programmed with a watchdog timer to default the thrusters to zero thrust in the event that the main Raspberry Pi crashes or communication is lost. The six T100 thrusters are connected directly to the PSE with six Blue Robotics 6mm penetrators.

The two Murata DRQ1250s convert 48V from the tether to 12V at up to 100A depending on power consumption. The DRQ1250s were chosen for their nominal power, efficiency, reliability, and performance characteristics along with their array of safety features including overcurrent, overvoltage, undervoltage shutdown, and short circuit protection. The DRQs are housed on a power board that Rovotics manufactured to include a custom power-sharing bridge that allows for supply redundancy to the Main Electronics Housing (MEH). The custom bridge allowed Rovotics to save on cost and avoid using hard-to-find power-sharing DRQ1250 components. In addition, the DRQs' small

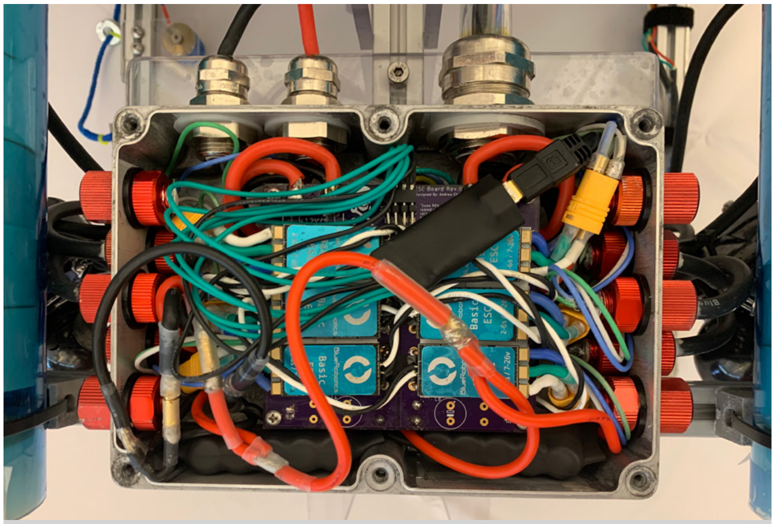


Figure 14. PSE Interior

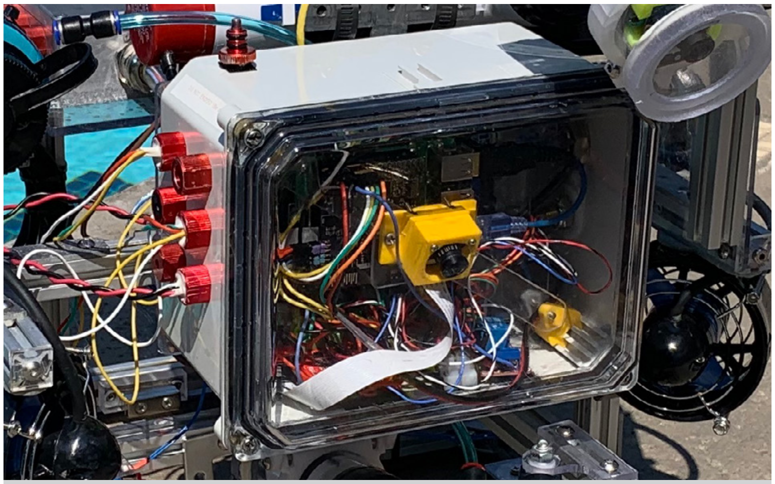


Figure 15. The MEH

size allows for a custom-mounted solution in an aluminum enclosure to disperse heat and minimize thermal issues.

The MEH contains Nautilus' main computer, a Raspberry Pi 3B+, and a custom built peripheral and sensor PCB referred to as the ROV Hat (Figure 15). The ROV Hat streamlines the wiring, improves system reliability while containing a temperature sensor, humidity sensor, pressure sensor, and a 9-axis Inertial Measurement Unit (IMU) that provides control data to the Raspberry Pi. This sensor data is monitored by safety algorithms and the ROV operators. The digital video system utilizes custom Raspberry Pi cameras connected over ethernet. A modified ethernet switch in the MEH allows for power over the ethernet cable by using unused pins on the RJ-45 connector. In addition to the independent navigation camera, the six available tool cameras contain an off-the-shelf Raspberry Pi Zero, a USB

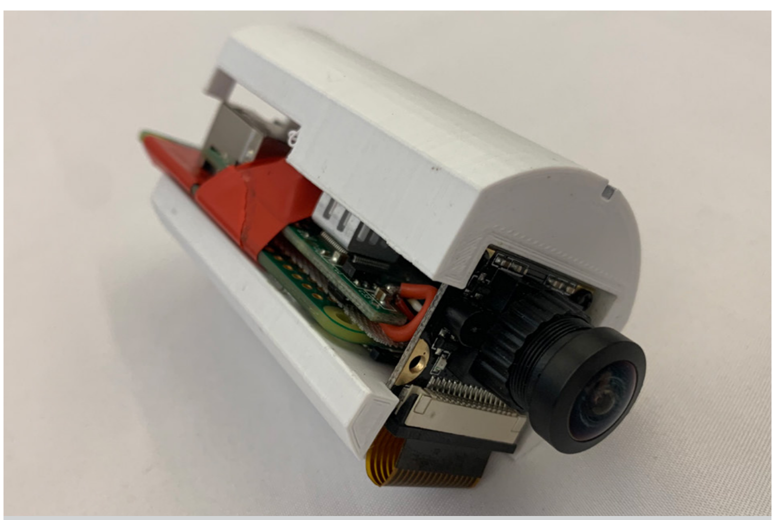


Figure 16. Digital Tool Camera

to 100 Mb ethernet adapter modified to power the Pi, and a wide-angle fish-eye lens that allows for maximum field of view (Figure 16). In tandem with the custom software solution, this architecture provides for lens-to-screen latency of less than 90ms. The ethernet connection allows for each camera to be completely independent and field-replaceable in a few minutes. See Figure 19 for the electronics SID, and Figure 20 for the power budget.

Submersible Connectors

Nautilus uses a combination of Blue Robotics cable penetrators, SubConn wet-mateable electrical connectors, McMaster-Carr cable glands, and a Bulgin 6000 series ethernet connector (Figures 17 - 18). Blue Robotics cable penetrators are used for the connections between PSE and the thrusters and are epoxied for permanent water-proof connections to reduce costs. Connections between the MEH and PSE make use of the Power and Communications Tube. The Power and Communications Tube is a waterproof conduit enabling multiple wires to pass through it. The Tube also allows for connection flexibility as additional wiring can be passed through the tube without changing the design. The tether's power connection utilizes SubConn connectors for their durability and reliability. With the new MEH design, Rovotics can use more reliable Blue Robotics connectors for tools. The balance of modularity and reliability helped minimize ROV downtime while maintaining low costs.

Figure 17. MEH Blue Robotics Penetrators

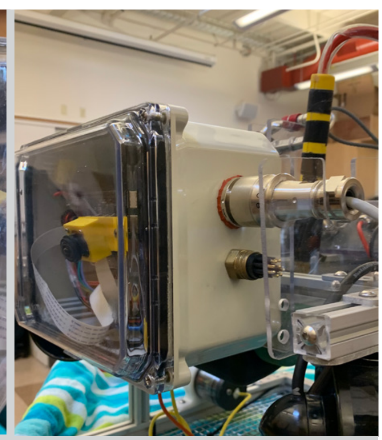


Figure 18. MEH Subconn and Bulgin Penetrators

PNEUMATICS

Nautilus' pneumatic system is a simple, lightweight single-line system that receives air from the MATE supplied connection and is regulated to 2.76 bar (40 psi) by an

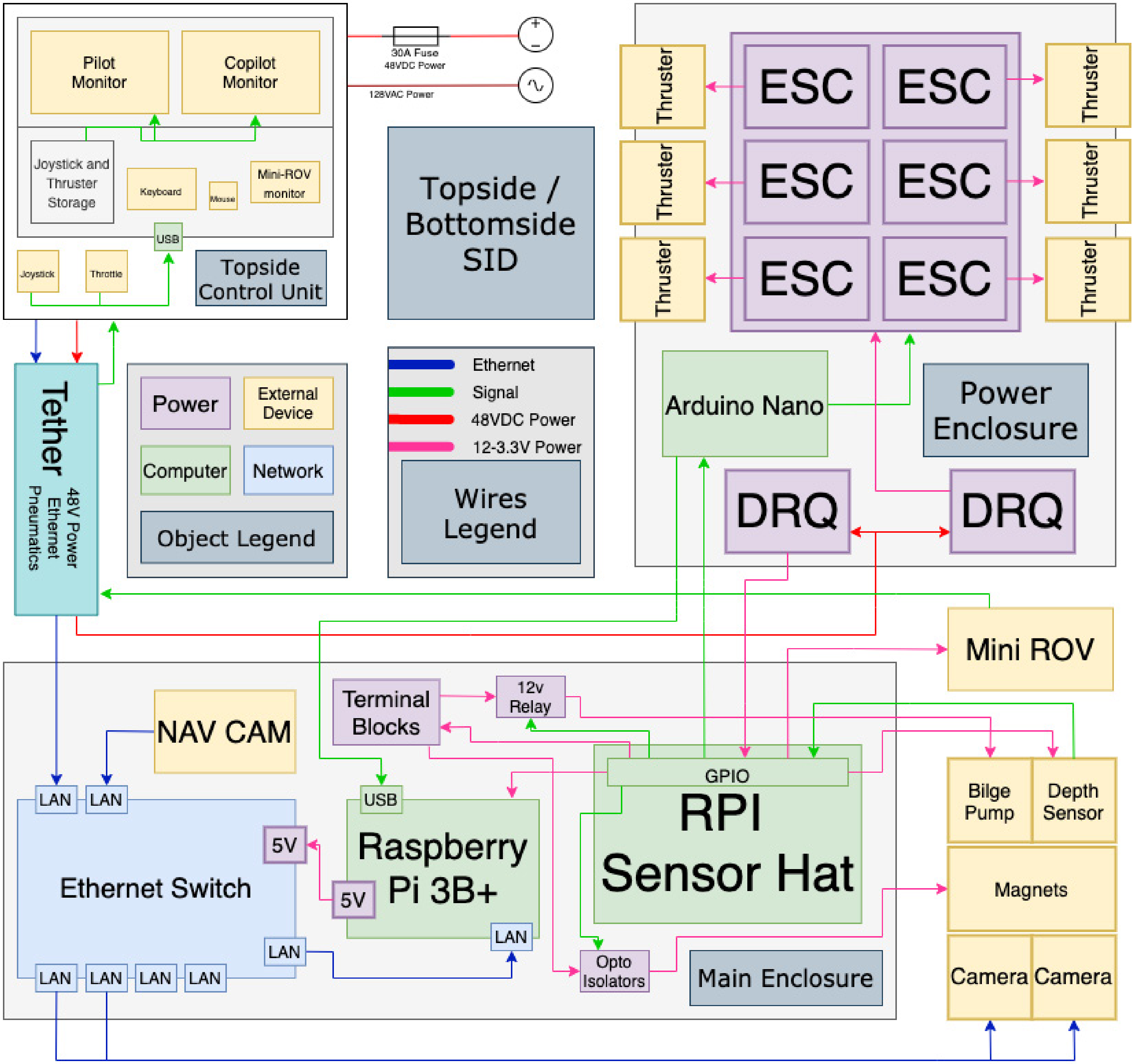


Figure 19. The Electronics SID

Device	Quantity	Voltage	Max Power Each (W)	Total (W)
T100 Thruster	6	12	130	780
Blue Robotics ESC	6	12	6	36
ROV Hat and Raspberry Pi	1	12	7	7
Cameras	2	3.3	2	4
Electromagnet	4	12	10	40
Bilge Pump	1	12	44.4	44.4
Ethernet Switch	1	12	13	13
Brushed DC Motor	1	12	6	6
DRQ1250 Voltage Converter	1	48	21.84	21.84
Tether Max Power Loss	1	7	162	162
Total Power Consumption				1,114.24

Figure 20. The Power Budget

adjustable pressure regulator. The gripper is controlled by a two-way, three position solenoid valve located in the TCU and is activated by a co-pilot controlled switch. Nautilus' gripper is the only pneumatic tool in the ROV system. The gripper's cylinder is configured to return to the retracted position by an elastic cord. This eliminates the need for a second air line on the tether, improves tether flexibility, and reduces weight. Components in the system are rated for 8.27 bar (120 psi) or greater to meet the MATE safety requirement. The entire system is also protected by a pressure relief valve located ahead of the pressure regulator. See pneumatics SID, Figure 21.

SOFTWARE

Nautilus' ROV software system integrates the functions of command and control, ROV telemetry, digital imaging, graphical interface (GUI) displays, and managing input from keyboard and joysticks. The software consists of two primary subsystems: Topside and Bottomside. The Topside provides the user interface and pilot controls, and communicates to the Bottomside through the TCU. Bottomside receives the command and control data for ROV thrusters and tools from Topside and sends back sensor and camera information.

Rovotics architecture is based on the open-source

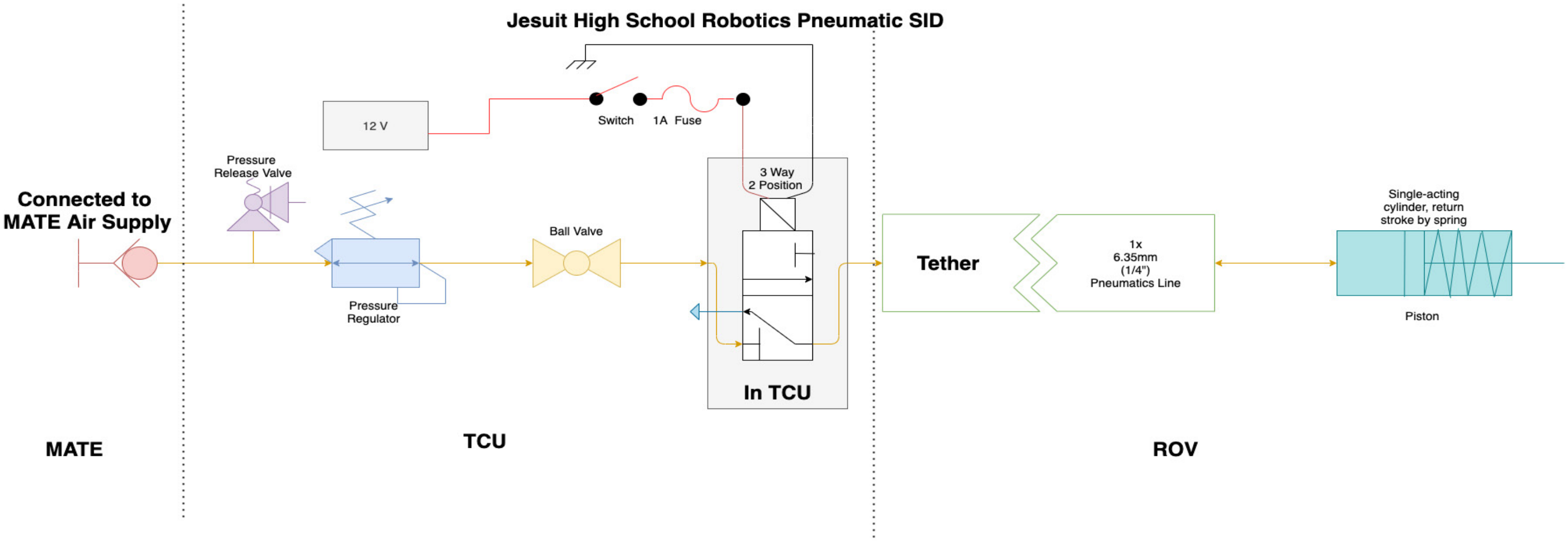


Figure 21. Pneumatics SID

Robot Operating System (ROS) framework. We chose this software architecture because it has a modular system organized around easily maintained nodes, or subsystem programs, that control core features such as thrusters, input, sensors, or individual tools. Each node is connected over a network, which means new features and subsystems can be quickly added without risk to critical ROV infrastructure. Control signals such as joystick and pilot features are broadcast through the network and received by nodes or devices in the ROS framework requesting the information, such as our original vector drive algorithm, which handles the translation of joystick input to thruster data. Reference Appendix 2 for Software Flowchart.

Topside

The Topside Control Unit (TCU) contains an Intel NUC which communicates to the Bottomside. The TCU prints telemetry data to the display screens, uses OpenCV to display live camera views (Figure 22), controls the ROV through two joysticks and a keyboard, makes changes and adjustments to settings through a ROS GUI, and displays our Mini ROV's camera feed through a built-in analog monitor. This year, many software tools have been moved away from external computers and integrated into the TCU, such as the mussel bed calculator and the photomosaic tool to decrease failure points and consolidate the Topside controls.

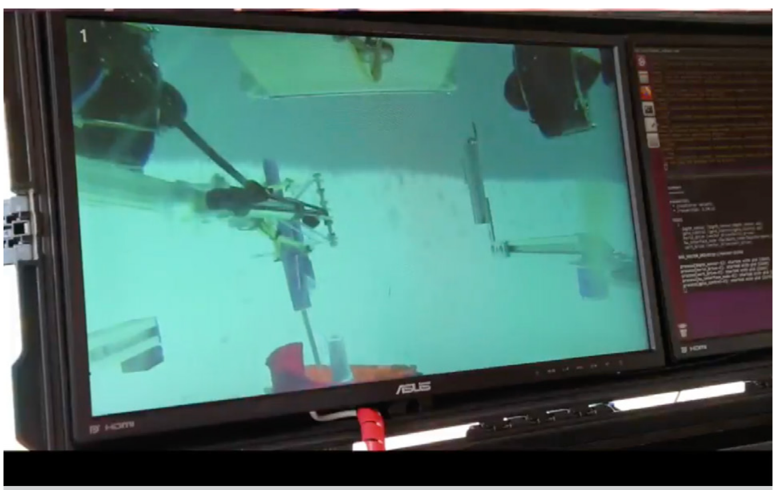


Figure 22. Digital Camera Pilot View

Bottomside

Nautilus' Bottomside main subsystem is a Raspberry Pi 3B+ which receives command and control instruction from the Topside. The Raspberry Pi manages hardware interfaces for ROV functions, such as thruster control, and communicates vital sensor and telemetry data through ROS to the TCU for display. For thruster control, the Raspberry Pi communicates serially to an Arduino Nano that generates PWM signals to control six electronic speed controllers (ESC). The Nano was chosen for its hardware timers dedicated to PWM and communication processes, ensuring fail-safe operation disabling all thrusters in the event of a communications failure.

Vision System

Nautilus' digital vision system is equipped with up to 6 external digital ethernet cameras in addition to the navigation camera. The cameras each have a Raspberry Pi Zero powered through a custom Ethernet switch designed to provide power to the camera modules using unused wires in the ethernet cable. The cameras are custom made from commercial-off-the-shelf (COTS) and in-house manufactured parts with the software, electronics, and housing all designed, built, and tested in-house.

Nautilus' digital cameras are housed in a clear polycarbonate tube, epoxied on one end with a clear lens and compression sealed with a bayonet seal on the other. Cameras are mounted to the ROV's frame with magnetically locked mounts, allowing the camera to be rapidly repositioned during tool exchanges. There are three main cameras, the navigation camera in the MEH, and two tool cameras.

TOOLS

Subway Car Photomosaic

Nautilus' light-based edge detection algorithm and automatic cropping and stitching functions are used to

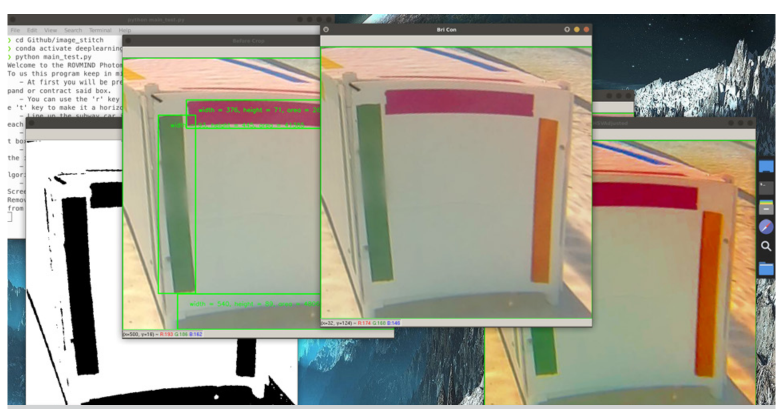


Figure 23. OpenCV Image Processing

quickly and accurately take photos of each side of the subway car and create a mosaic version. The program uses OpenCV, an open source computer vision library, to process the picture, making adjustments to contrast and lighting, and then using the contour function to determine where the subway car ends and the pool begins. It then crops the image to this contour and uses light levels and grayscaling to match the colored pieces of tape together (Figure 23). It is then stitched and outputted as a final, flat image of the subway.

Multi-Purpose Gripper

Nautilus' multi-purpose pneumatic gripper is used to replace eel traps, propagate corals onto reefs, and assist in the retrieval of Nautilus' mini ROV (Figure 24). The gripper is built around a 0.6 meter length of 20mm x 20mm aluminum extrusion. The jaws of the gripper are made out of 3mm thick polycarbonate. The polycarbonate stock was heated and bent at 35-degree angles to achieve a wide jaw, resulting in a jaw width of 82mm. The fixed jaw is fastened to the aluminum extrusion. The movable jaw is actuated by a pneumatic piston and can open the jaw 50 degrees relative to the fixed jaw. Silicone tubing lines the jaw surfaces to allow gripping smooth objects such as the coral samples while under water.

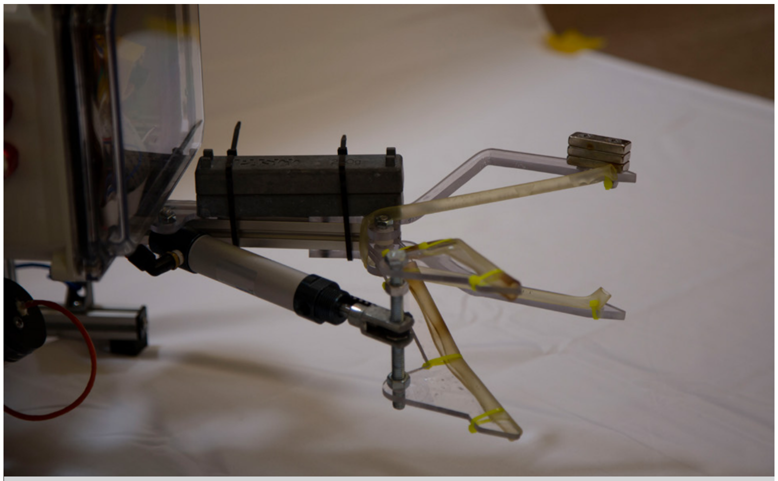


Figure 24. Multi-Purpose Gripper

Surface Debris Pump

The surface debris pump uses the suction force generated by an onboard pump to remove surface debris from the water and store it in a secure holding tank (Figure 25). The surface debris pump consists of a bilge pump, an ABS pipe coupler, a 90-degree connector, a Y connector, a 300mm length of ABS pipe, and a detachable debris holding tank. The tool attaches to the ROV at a positive twenty-degree angle

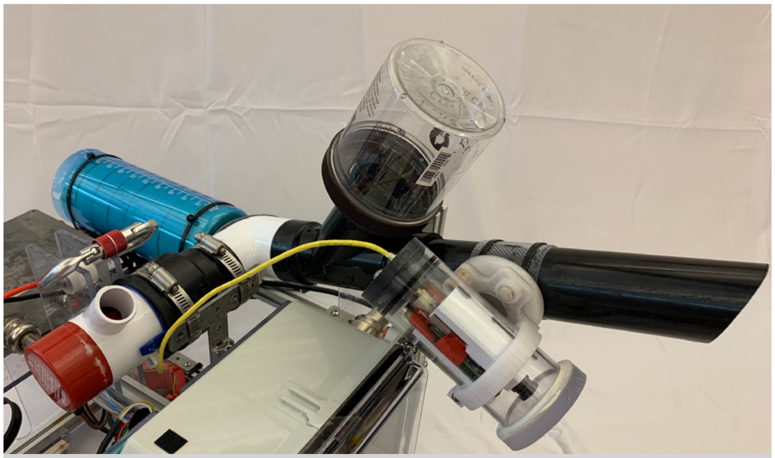


Figure 25. Surface Debris Pump

relative to the surface of the water.
To operate the tool, the upwards-facing end of the tool is positioned at the surface of the water. Next, the pump is activated, drawing the surface debris down the PVC pipe and into the Y connector. Once inside the Y connector, the pump is shut off, and the debris floats into the debris holding chamber. This process is repeated until all surface debris is removed and stored in the holding chamber.

Sea Sponge Gripper

The sea sponge gripper uses four circular friction pads to grab a single sea sponge sample (Figure 26). The gripper is made of six primary parts: the pad hinge ring, four friction pads, and a rubber band, which constricts the friction pads. When the sea sponge gripper is maneuvered over and onto the sea sponge sample, the four friction pads are forced

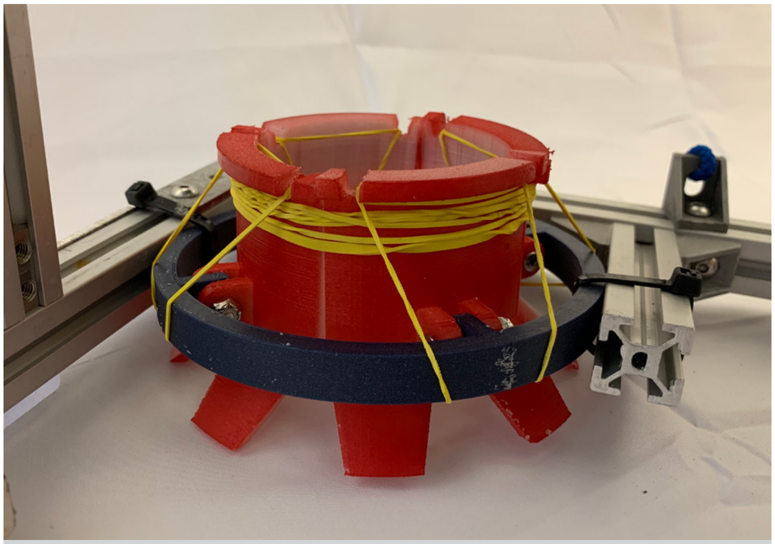


Figure 26. Sea Sponge Gripper

apart by the circular body of the sea sponge. A frictional force is created between the sea sponge and the constricted pads. This frictional force is strong enough that Nautilus can securely remove a single sea sponge sample.

Angled Fork

One of the simplest yet most versatile tools on our ROV, the angled fork, gives Nautilus the ability to retrieve objects such as the Sea Bin's power puck and mesh catch bag. The angled fork, consisting of only one component, is easy to manufacture and easier to operate. The angled fork is made of a single 3mm thick polycarbonate sheet with a V-shaped gap in the center, forming two prongs (Figure 27). The V-shaped opening allows the angled fork to engage the vertical neck of the Sea Bin's power puck, while the angled fork's 150mm width gives it the ability to grab the Sea Bin's mesh catch bag with both prongs, ensuring the catch bag's stability. The angled fork's prongs are inclined at 45 degrees above the horizontal, which adds to the stability of captured objects and improves pilot usability.

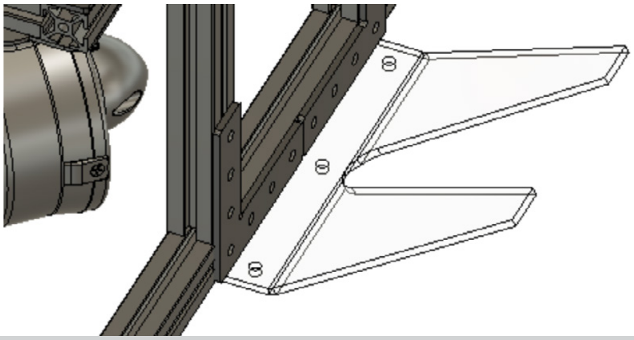


Figure 27. Angled Fork

Magnetic Eel Trap & Ghost Bin Removal Tools

Nautilus provides two neodymium magnet-based tools. Both tools use the same type of neodymium magnet, so their construction and operation are very similar. Each tool includes a set of magnet blocks used to pull the ghost net or retrieve the full eel trap. Both magnetic removal tools utilize strong neodymium magnets with a pull force of greater than 110 newtons, ensuring a secure grip on the steel components of the objects retrieved by the ROV. The eel trap magnet block is positioned at the bottom of the modular 2020 aluminum frame, which gives the magnet block unrestricted access to the bottom of the pool where the full eel trap will be located (Figure 28). The ghost net magnet block is attached to the tip of the multi-purpose gripper, which is the furthest forward position on Nautilus and provides unobstructed access to the ghost net pin (Figure 29).

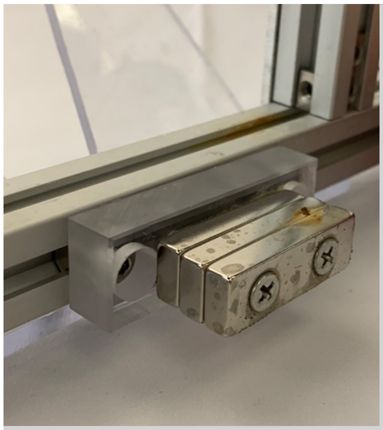


Figure 28. Eel Trap Magnets

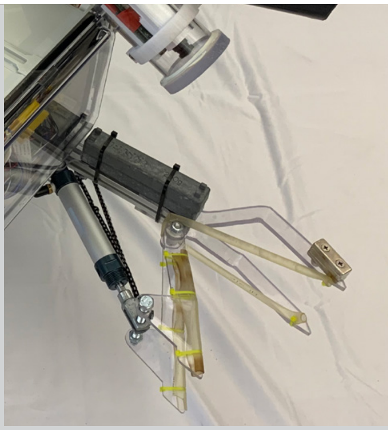


Figure 29. Ghost Net Magnets

Sea Star Injection Device

Seastar culling is performed by Nautilus' electromagnetically deployed custom injection devices. While maneuvering to sea stars, on-board electromagnets keep our injection devices secured to Nautilus' frame (Figure 30). Nautilus subsequently attaches an injection device onto sea stars and disengages from the sea stars and injection device by turning off the corresponding electromagnet. Nautilus' injection devices are made of small, transparent 6 cm by 6 cm polycarbonate squares (Figure 31). The pads are perforated to increase deployment accuracy by reducing hydrodynamic drag and allow Nautilus' pilot to easily confirm that the injection devices have attached to the sea stars properly. The bottoms of the injection devices are covered in velcro hook material. Upon contact with the sea star, these velcro pads secure our injection device for sea

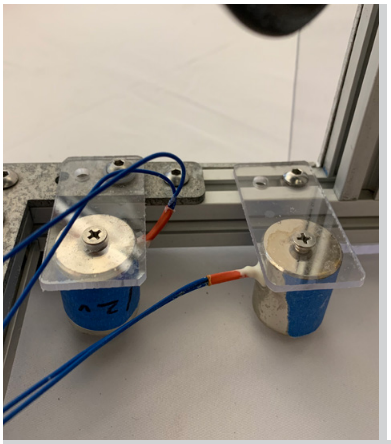


Figure 30. Retaining Electromagnets

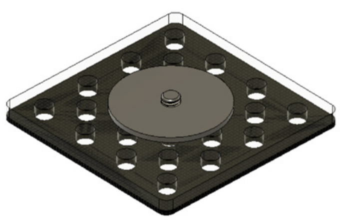


Figure 31. Perforated Sea Star Injection Device

star culling. Mounted at the center of the squares are steel washers, which allow our injection devices to interact with the electromagnets. Nautilus' sea star injection devices weigh less than 5 newtons in water.

Mini ROV - Axolotl

Nautilus' Mini ROV, named Axolotl, is used in task 3.1 to retrieve a sediment sample from within a drainage pipe (Figure 32). Axolotl is powered and controlled by Nautilus through a 3.6-meter tether and does not require any onboard batteries (Figure 33).

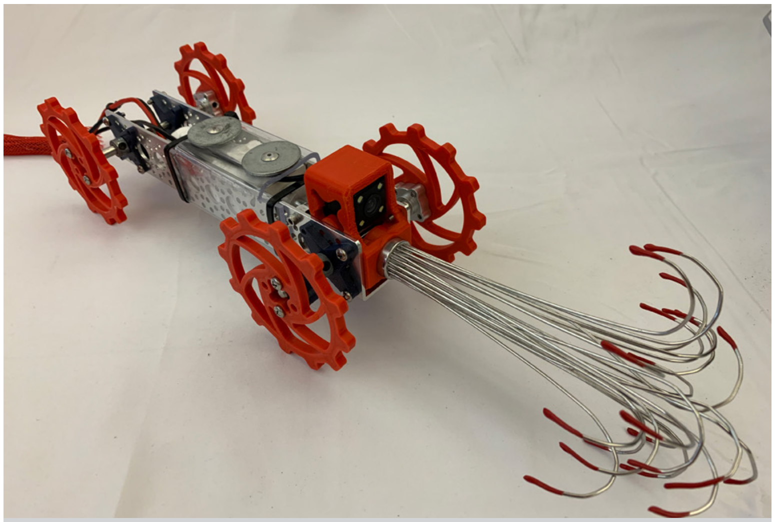


Figure 32. Mini ROV, Axolotl

An onboard camera and array of LEDs provide the pilot with a well-illuminated forward-facing view for navigation in low-light environments. A series of steel hooks, coated with red rubber for safety. are attached to the front of Axolotl and is used to engage the nylon loop of the sediment sample.

Axolotl sits on four sprocket wheels. Two of Axolotl's

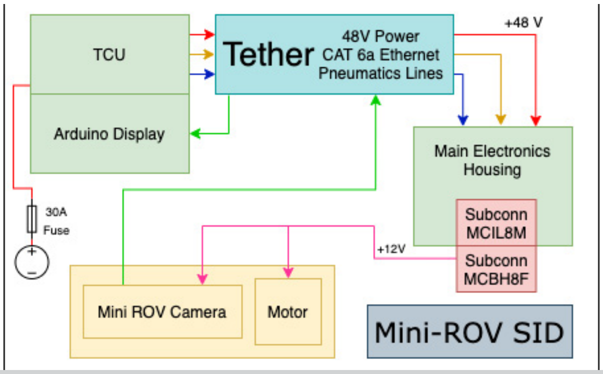


Figure 33. Mini ROV SID

wheels are powered by an onboard motor housed in a water-tight magnetically coupled housing that allows Axolotl to propel itself through the drainage pipe.

Axolotl's onboard motor uses an internal and external magnet array to transmit rotational motion through the solid wall of the motor housing. This design eliminates the shaft and shaft seal so there is no possibility of water leaking into the motor housing. The magnetic coupling also acts as a clutch and protects the motor and driven parts from damage in the event there is a stall condition.

Quadrat

As part of our mussel estimation, Nautilus deploys a half-meter by half-meter quadrat onto a mussel bed. In order to fit the 64 centimeter size restrictions, Nautilus' quadrat had to be able to collapse into a smaller form factor (Figure 34). To meet this requirement, the quadrat consists of four brass folding ribs, joined at the center of the quadrat by an elastically actuated hub. The ends of the brass spokes are joined by a high visibility nylon cord, attached to the brass spokes every half-meter. The quadrat is stowed on Nautilus using an electromagnetically actuated retainer. When the quadrat's retaining electromagnet disengages, the quadrat falls away from the ROV. Once free, the elastically actuated hub extends the spokes from the stowed position to the open position, which forms a square quadrat measuring half a meter by half a meter.

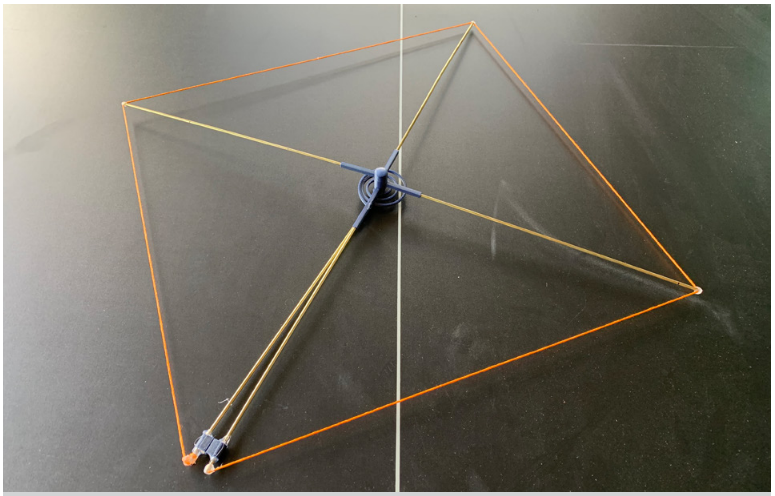


Figure 34. Quadrat

Bottom Debris Gripper

Nautilus is equipped with a vertical Debris Gripper (Figure 35). The debris gripper is designed to pick up the

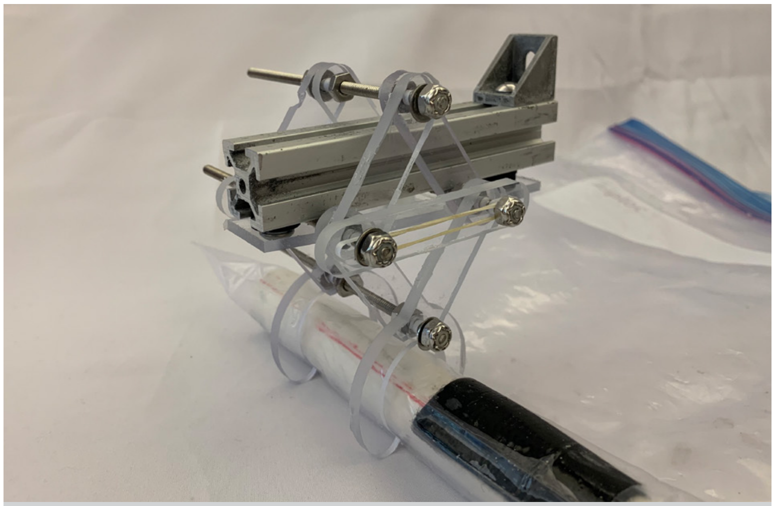


Figure 35. Bottom Debris Gripper

bottom debris from the mariana trench by positioning over the PVC inside a ziploc bag. The gripper then grabs onto this PVC and pulls it to the surface.

The debris gripper is fully mechanical, using a rubber band tightly wound around two pins. Rubber bands were chosen because they are inexpensive, highly elastic, and easily replaceable. The clamp is open just enough to snap over and secure the debris. When the clamp is lifted, its gripping tongs apply pressure against each other - the heavier the object, the greater the clamping pressure. This is a proven tool design that has been used in previous seasons to accomplish similar tasks.

TROUBLESHOOTING AND TESTING TECHNIQUES

This season, Rovotics began developing and implementing multiple dedicated test environments to test and troubleshoot problems following a Root Cause Analysis (RCA) method. A dedicated test environment allowed each department to complete software and electronics tool testing or field testing of mission tools before integrating them into the Nautilus Production ROV.

The electronics and software departments use a simulation test environment to test new code and electrical components before integration to the Production ROV (Figure 36). The simulation test environment is used to simulate the behavior of the ROV and was developed to include all of the electronics present on the Production ROV, a verified ROS system software release, along with a minimal frame. This allowed both the software and electronics departments the freedom to test new features before integration to Nautilus' Production ROV. Without the simulation environment, software and electronics testing on the Production ROV would often cause the ROV to stop working and result in schedule delays that reduced pilot practice time in the pool. For field testing of tools, an integration test environment was established using an initial developmental version of Nautilus. The integration test environment contained the same electronics as Nautilus' final ROV and was almost identical in construction and design. The mechanical department developed and tested prototypes of tool designs using the integration test environment. When necessary tool modifications and successful software and electronics testing were completed, the team approved the final mission tool and appropriate modifications for Nautilus. Over time, the integration environment transformed into the final Nautilus ROV design.

Using dedicated test environments made it easier to troubleshoot issues encountered with the Production ROV and allowed each department to continuously develop in parallel with minimal downtime, unlike prior years of sharing a single test and development environment across the teams. This improvement saved the company many hours of troubleshooting time. It also resulted in an operational ROV several weeks in advance, allowing for additional days of mission practice time in the pool.

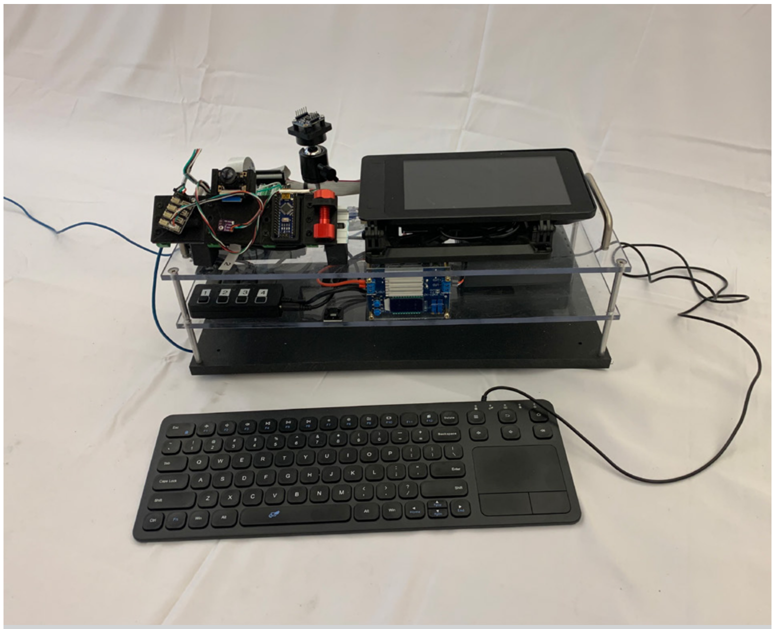


Figure 36. Software Test Environment

SAFETY

COMPANY SAFETY PHILOSOPHY

Employee safety is the company's highest priority. Rovotics' employees are committed to meeting or exceeding all safety guidelines published by MATE and have a proven track record, consistently meeting MATE's safety requirements. Adherence to the company's safety policies and training procedures allows employees to avoid accidents and injuries. As a result of the COVID-19 pandemic, Rovotics adopted the necessary safety procedures required by state and county health agencies. Each employee worked in a safe and remote workplace to complete the design and development of the ROV. When a shelter-in-place policy was needed, the team met virtually using collaboration and conferencing tools such as Discord and Zoom. Once it was safe and meetings could resume in person, employees practiced social distancing. They were required to wear masks, complete weekly COVID testing, and record health checks on the school's tracking application before attending meetings.

LAB PROTOCOLS

To ensure a safe work environment, specific safety protocols are implemented while working in the lab. Rovotics uses Job Safety Analysis (JSA) forms for employees to create and review before performing risky operations. New JSA forms are created whenever a new manufacturing process is introduced. The company's handbook is used to train employees on safety practices such as back safety, electrical safety, hazardous materials handling, housekeeping, and tool safety. Readily accessible Material Safety Data Sheets (MSDS) are available for every product used in Rovotics' production process. Rovotics' lab facility features a chemical vent hood so that electronics soldering can be performed without fume exposure (Figure 37). The work area maintains a negative pressure relative to the room, and fumes are carried up to a roof-mounted vent via ducting. To minimize the possibility of spreading COVID-19, employees wore masks, socially distanced, sanitized their work stations, and minimized contact while working collaboratively in the lab.

Figure 37. Chemical Fume Hood

TRAINING

A peer-to-peer system is used for the training of new employees (Figure 38). Newly-hired employees observe experienced employees operating tools and machinery. Experienced employees closely supervise and mentor new employees in one-on-one training sessions as they learn to use equipment. After new employees consistently demonstrate safe and proper operating practices, they can work independently. All employees monitor each other to ensure that everyone follows established safety protocols. Rovotics continued to use a tool safety tracking sheet, visible in the lab, showing who is qualified in using tools. The tool safety tracking sheet is updated as employees learn new skills regarding the safe and efficient use of tools like the band saw and soldering irons.

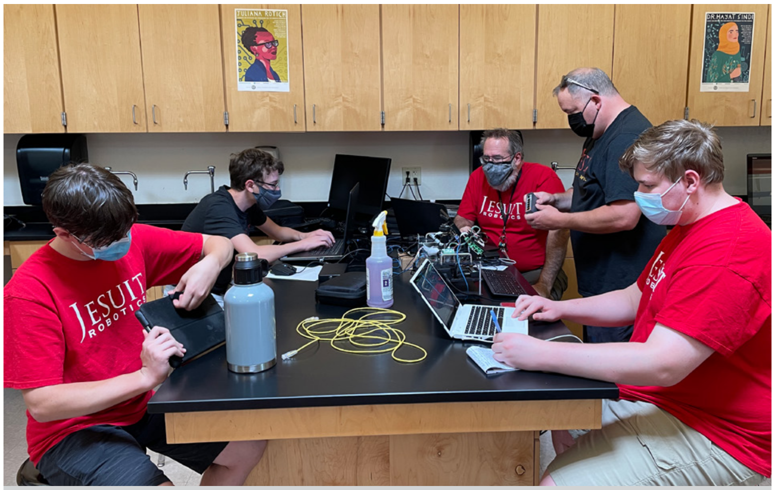


Figure 38. Software Training

VEHICLE SAFETY FEATURES

At the start of each year, Rovotics reviews MATE safety requirements and applies them to the design, manufacture, and operation of our ROV. An operational safety checklist (Appendix 1) ensures that MATE's safety requirements are addressed at all ROV development and operation stages. Nautilus has numerous safety features. O-ring face seals and epoxy potting are waterproofing techniques used to ensure all electronics remain dry, protecting personnel and equipment from electrical hazards.

A leak detector monitored by the software detects moisture and humidity in the electronics housing. If a leak occurs, the ROV status indicator notifies the pilot, and Nautilus is shut down. After shut down, Nautilus can be safely brought back to the surface by the deck crew. The secure strain relief on both the ROV and the TCU ensures the safety of all electrical connectors. For easy visual inspection of the electronics, the MEH enclosure includes a clear lid. Thruster guards were mounted to protect debris from entering the thruster, and frame caps were added to smooth the corners of the top frame. In addition, the mini-ROV's sample retrieval hooks are coated with red rubber to prevent injury.

The TCU incorporates digital displays for the crew to quickly determine if power delivery to the ROV is outside of safe operating values. A microcontroller monitors and displays current and voltage information to the pilot and co-pilot, allowing for quick shut-down in the event of any anomalies. If values outside of safe operating ranges are detected, a large power switch on the TCU can immediately cut power to the ROV (Figure 39).

Figure 39. TCU Safety Switch

OPERATIONAL AND SAFETY CHECKLISTS

Safety protocols documented in Rovotics' Operational and Safety Checklists (Appendix 1) are closely followed throughout ROV operations. Employees also adhere to operational JSAs for ROV launch, recovery, and waterside safety.

LOGISTICS

SCHEDULED PROJECT MANAGEMENT

In 2020, due to COVID-19 shelter-in-place restrictions, Rovotics transitioned to a remote work environment and virtual methods of organizing ROV development, maintaining schedules, and conducting meetings. Rovotics' online meetings were shorter and more frequent, requiring the company to meet multiple times throughout the workweek. One-hour virtual meetings were conducted to discuss company-wide project scheduling and departmental progress updates. While longer four-hour breakout sessions were conducted for each department to focus on expected design and development tasks.

Rovotics' Project Schedules are created in Google Sheets and made accessible to employees to use from a shared Google Drive. The CEO creates schedules for all aspects of the company, from software, electronics, and mechanical ROV development to technical documentation (Figure 40). Department leads assist the CEO in making these schedules, providing knowledge from their respective departments to set realistic goals and deadlines for the team to achieve. Then using interdepartmental feedback, the CEO publishes a year-long master project schedule to track major due dates.

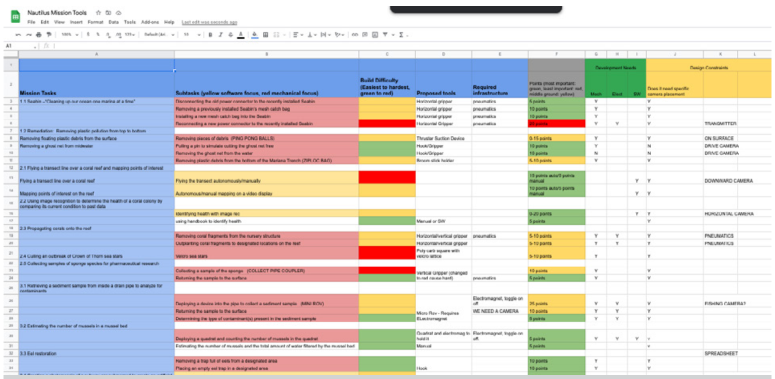


Figure 40. Nautilus Tool Development Schedule

Throughout the development, the CEO is responsible for monitoring company progress, assessing whether ROV development is on track, and collaborating with Department leads to stay on schedule. Departmental updates allow the CEO to adjust project schedules and department assignments based on each Department's progress. After updates are shared, the CEO and Department Leads collaborate on necessary schedule changes to keep the tasks on track and to set goals for the upcoming week.

COMPANY ORGANIZATION AND ASSIGNMENTS

Rovotics is organized into three key departments: Mechanical Design and Manufacturing, Electronics, and Software. Each department has a department lead who manages the assignments and task priorities for employees within their department. The CEO, who is also the Mechanical department lead, works closely with the assigned Software and Electronics department leads to maintain project schedules, discuss feedback on task completion, and ensure collaboration across the departments. Department goals & individual employee work assignments are then determined and assigned by each department lead.

Additionally, throughout the development process, senior employees in each department are tasked with training junior employees. Rovotics encourages cross-training to allow employees to broaden their skills in other departments. By developing knowledge in other areas, employees gain a big-picture perspective, allowing them to provide greater value to the company.

COLLABORATIVE WORKSPACE

To ensure sharing valuable knowledge and many years of corporate memory, Rovotics uses a widely available cloud storage system, Google Drive, to manage company files. Utilizing Google Drive, employees can collaboratively edit files with real-time access to the most current version of a document. In addition, the shared document repository continues to ensure a variety of company information, including training, past design proposals, and company operational processes, are available to all employees.
Like Google Drive's documentation repository, Rovotics' mechanical department uses a cloud-based Autodesk Fusion 360 project to collaborate on designs and assembly drawings. A shared Fusion 360 project ensured design progress and easier collaboration in a remote work environment. Mechanical employees edited designs in a shared project remotely, allowing the employees to review and revise designs collaboratively.

In addition, Rovotics selected Zoom as the video and collaboration platform for our virtual meetings and Discord for instant messaging. Zoom made it easy to calendar video meetings with employees, making it easy to demo tool prototypes, share department updates, and review project schedules. However, for real-time, instant messaging communication, employees communicated using Discord to discuss development problems and share solutions and ideas (Figure 41).

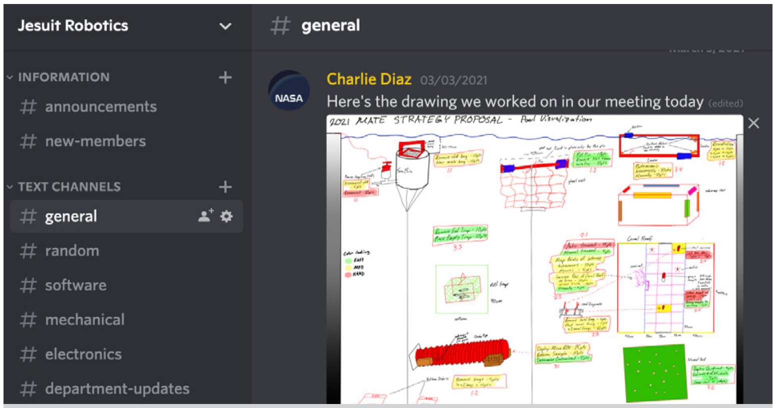


Figure 41. Rovotics' Discord Server

CODE MANAGEMENT

Rovotics utilizes GitHub, a Version Control System (VCS), to manage parallel software development. Using a VCS, Rovotics kept track of overall changes to software and managed multiple software versions. GitHub was selected because it is a well-supported and highly-adopted distributed VCS that provides each developer with a remote and local copy of the code repository. GitHub also enabled software branching and merging, which is essential when multiple people work on interdependent files. Should problems arise, GitHub allows the restoration of previous versions. Additionally, new software updates are tested using the simulation test environment and reviewed using our standardized Github workflow before integration onto the final ROV.

BUDGET AND PROJECT AND COSTING

Rovotics prepares a budget with estimated expenses at the beginning of each season based on the prior year's actual costs. This year, the company's projected budget was much easier to forecast since Nautilus is based on a previous ROV design. Using a standard ROV design allowed the company to focus on cost estimates for ROV enhancements and new tools. In addition, employee transportation and competition meal expenses are estimated but listed separately since Rovotics employees are responsible for these costs.

Income was estimated based on funding from Jesuit

Income	Budget	Type	Production & Operations Budget & Cost Analysis	Project Cost
Jesuit School Funding	$ 14,450.00	Income	Available Income	$ 15,200.00
Student Fund Raising	$ -	Income	Total Budget	
Donations	$ 750.00	Income	Production ROV Costs	$ 4,725.93
MATE Competition Awards	$ -		Research & Development Costs*	$ 488.21
Employee Dues	$ -	Income	Operations Costs*	$ 5,112.97
Total Income	**$ 15,200.00**		* Budget overage due to Lodging	
			Funds available for next season	$ 4,872.89
Production Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Frame & Housing	$ 141.00	Purchased	Polycase Housings, Bottom Deck, aluminum bar	
Thrusters	$ 1,000.00	Purchased	(6) T100 Blue Robotics thrusters & ESCs	$ 990.00
TCU	$ 542.41	Re-used	Case, Monitors, Electronics, Pneumatics	$ 542.41
Tether & Connectors	$ 300.00	Purchased	Tether & Connectors	$ 260.31
Electronics & Connectors	$ 800.00	Purchased	Si wire, CAT5e, coax cable, sheathing, connectors	$ 736.05
Pneumatics	$ 75.00	Purchased	Valves, fittings, tubing	$ 85.16
Mission Tools	$ 500.00	Purchased	Gripper, mini-ROV, ghost net, sea star, debris grabber	$ 468.00
Mission Control Center	$ 1,529.00	Re-used	Laptop, joystick; (re-used from 2018)	$ 1,529.00
Raw materials	$ 575.00	Purchased	Plastics, metals, hardware, 3D filament, consumables	$ 115.00
Production Budget	**$ 5,462.41**		**Total ROV Production Cost**	**$ 4,725.93**
R&D Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Digital Camera System	$ 500.00	Purchased	Digital Camera System	$ 488.21
R&D Budget	**$ 500.00**		**R&D Project Cost**	$ 488.21
Operations Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Lodging	$ 3,500.00	Purchased	7 hotel rooms for team/2 per room	$ 3,815.00
Mission Props	$ 344.18	Purchased	MATE mission props	$ 265.90
MATE Entry Fee	$ 400.00	Purchased	MATE entry fee	$ 400.00
Power Fluid Quiz Fee	$ 25.00	Purchased	MATE power fluid quiz	$ 25.00
Lab Supplies	$ 400.00	Purchased	Lab Supplies: Consumables, plastic, glue, hand tools	$ 373.89
Printing	$ 225.00	Purchased	Report, display, brochure printing	$ 233.18
Operations Budget	**$ 4,894.18**		**Operations Project Cost**	**$ 5,112.97**
Employee Paid Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Competition Meals	$ 2,590.00	Purchased	Cash collected for competition meals;14 people	$ 2,590.00
Transportation & hotel subsidy	$ 2,800.00	Purchased	Cash contribution for car rental, gas, & hotel subsidy	$ 2,929.92
Estimated Employee Fees	**$ 5,390.00**		**Actual Employee Fees**	**$ 5,519.92**

Figure 42. Budget and Project Costing Calculation Report

High School, donations, and employee dues. To ensure adherence to a projected budget, the company submitted purchase requests for review and approval by coaches. And receipts for purchases were tracked in a project costing sheet that was reviewed monthly. The 2020-2021 Budget and Project Costing report is shown in Figure 42.

CONCLUSION

CHALLENGES

Due to COVID-19 and shelter-in-place restrictions, Rovotics lost the ability to work in our lab resulting in the cancellation and delay of scheduled work. This provided the most difficult challenge: determining how to work remotely to efficiently and effectively continue design and development work. To address this challenge, Rovotics adopted online methods for meeting and collaborating. We worked remotely with materials shipped directly to employees' homes for prototyping designs and created remote test environments for software development.

LESSONS LEARNED AND SKILLS GAINED

Although difficult at first, the remote work situation required better planning, multiple iterations of prototyping, and design reviews before manufacturing. As a result, when shelter-in-place restrictions were lifted, and access to the LAB was feasible, final ROV fabrication required significantly less time to complete than in past years. To benefit from this efficiency in the future, Rovotics will continue to follow improved planning, iterative prototyping, and thorough design reviews in our future ROV designs.

Additionally, in previous years ROV development was limited to a single development environment platform which made it difficult to use RCA to identify problems quickly without delaying specific department tasks, and ultimately the project schedule. This season, Rovotics learned that having multiple test environments can minimize ROV downtime and increase department productivity by allowing faster issue resolution before integration onto the final ROV. As a result, Rovotics will continue to enable multiple test environments.

FUTURE IMPROVEMENTS

Nautilus' new digital camera system improves on our previous analog camera system reducing cabling and protocols (Figure 43). However, the current digital camera housings are large, and we plan on the continued development of new housings and electronics to reduce size.

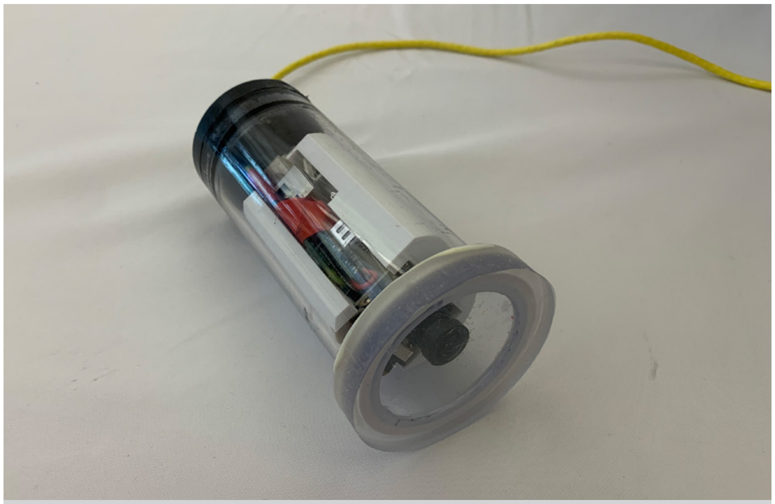


Figure 43. Digital Camera in Waterproof Housing

It is also on our plan to pursue a downsizing of the TCU. Currently, the TCU is sufficient in its tasks, but it is very large, and not easy to handle. A Future TCU may include only one monitor or migrated to a laptop due to our adoption of a digital camera system. Regardless, a more spatially efficient TCU is a high priority.

Magnetically coupled motor housings have proven to be a significant improvement over our previous shaft sealed designs. The low cost and ease of manufacturing, paired with their reliability, make them the perfect solution to providing rotational motion to tools. Rovotics plans to standardize the production of magnetically coupled motors for use in future ROVs.

ACKNOWLEDGMENTS

MATE Center and Marine Technology Society - Sponsoring this year's competition
National Science Foundation - Their funding of the MATE competition
East Tennessee State University - For hosting the 2021 MATE Competition
Oceaneering International - Their support of the MATE competition
Jesuit High School - Generous donation of funding and pool time
Jay Isaacs, Head Coach - His time, creativity, knowledge, and guidance for the past sixteen years
Steve Kiyama, Assistant Coach - His time, experience, and guidance for the team
Cheryl Kiyama, Program Director - Her time, experience, and management of the team
Bulgin - Their generous donation of connectors
MacArtney Connectors - Providing connectors at a reduced rate
GitHub - Providing complimentary private code repositories
Fusion 360 - Providing CAD software
SolidWorks - Providing CAD software
TAP Plastics - Donation of stock plastic
Mentors - Marcus Grindstaff, Michael Sharp
Adobe Systems - for providing student discounted software license
Our Families - Their continued support and encouragement

REFERENCES

Blue Robotics. "T100 Thruster Documentation." Blue Robotics. Blue Robotics, 22 Aug 2015. Web. 9 June 2021.

MATE. "MATE ROV Competition Manual Explorer." MATE. MATE, 3 March. 2019. Web. 15 June 2021.

Murata Power Solutions, Inc. DRQ-12/50-L48 Series. Mansfield: Murata Power Solutions, 2015. Print. 13 June 2021.

Nave, Rod. "Buoyancy." HyperPhysics. Georgia State University, 9 Aug. 2013. Web. 21 June 2021.

Raspberry Pi Foundation. "Official Documentation for the Raspberry Pi". Raspberry Pi. Raspberry Pi, 2019. Web. 13 June 2021.

APPENDIX

1. OPERATIONS AND SAFETY CHECKLIST

Pre-Power Procedure (Pilot, Co-pilot & Deck Crew)

Area clear and safe (no tripping hazards, items in the way)
Verify power switches and circuit breakers on TCU are off
Tether flaked out on the deck and free from damage
Tether connected to TCU and secured

Tether connected and secured to ROV
Tether strain relief connected to ROV
Verify the electronics housing sealed
Visually inspect electronics for damaged wires, loose connections
Fasteners are tight on the electronics housing
Thrusters free from obstructions
Power source connected to TCU
Vacuum test electronics housing (see vacuum test procedure)
Verify vacuum check port is securely capped

Vacuum Test Procedure (Deck Crew)

Verify MEH housing fasteners are secure and visually inspect front cover seal.
Verify PSE screws are secure.
Verify screw caps on all cameras are secure and o-ring seal is properly seated.
Connect vacuum hand pump to ROV electronics housing
Pump electronics housing to -35 kPa (vacuum), this is 10 inches of Hg on the gage.

Verify electronics chamber holds -35 kPa (vacuum) for 5 minutes
Remove vacuum pump and securely cap vacuum check port
Stow vacuum hand pump back in case

Power-Up Procedure (Pilot, Co-pilot & Deck Crew)

Verify TCU receiving 48V nominal
Control computers up and running
Ensure deck crew members are attentive
Call out, "Power On"
Power on TCU
Call out, "performing thruster test"
Perform thruster test/verify thrusters are working properly (joystick movements correspond with thruster activity)
Switch between each camera to verify video feeds and proper camera positioning.
Test any electrical or pneumatic tools that require pilot control

Launch Procedure (Pilot, Co-pilot & Deck Crew)

Place ROV in water
Visually check for bubbles
If there are bubbles from the electronic housings, remove ROV from water immediately and call out "electronics leak". Proceed with Leak Detection Protocol
If no issues are observed, the deck crew calls out "ready to launch"
Co-pilot calls out, "Prepare to launch"
Deck crew members handling ROV call out "hands off!"
Co-pilot calls out "thrusters engaged" and pilot begins mission

ROV Retrieval (Pilot, Co-pilot & Deck Crew)

Pilot calls "ROV surfacing"
The deck crew calls "ROV on the surface. Disable thrusters"
Co-Pilot disables thrusters and calls out "Thrusters disabled"
The deck crew calls "Hands On", and removes ROV from the water
After securing the ROV on deck, the deck crew calls out "ROV secured on deck"
Co-Pilot powers down TCU if the team is demobilizing from deck.

Leak Detection Protocol (Pilot, Co-pilot & Deck Crew)

Power down system and remove ROV from water if running a mission. Recover ROV by pulling to the surface using the tether if required.
Visually Inspect to determine source of leak. Do not disassemble any part of the ROV until the leak is located.
Install pressure testing equipment and use soapy water to verify the leak source.
Create a plan to repair the leak and check all systems for damage and proper operation.
Document the cause of the leak and implement corrective action or design changes as required

Loss of Communication (Pilot, Co-pilot & Deck Crew)

Cycle power on TCU to reboot ROV
If no communications, power down ROV, retrieve via tether
If communication restored, confirm there are no leaks, resume operations
If communication is not restored, begin troubleshooting procedures, Isolate the issue. Is there a hardware or software cause?
Proceed to analyze/ isolate cause
Document the cause of the failure and implement corrective action or repair as required

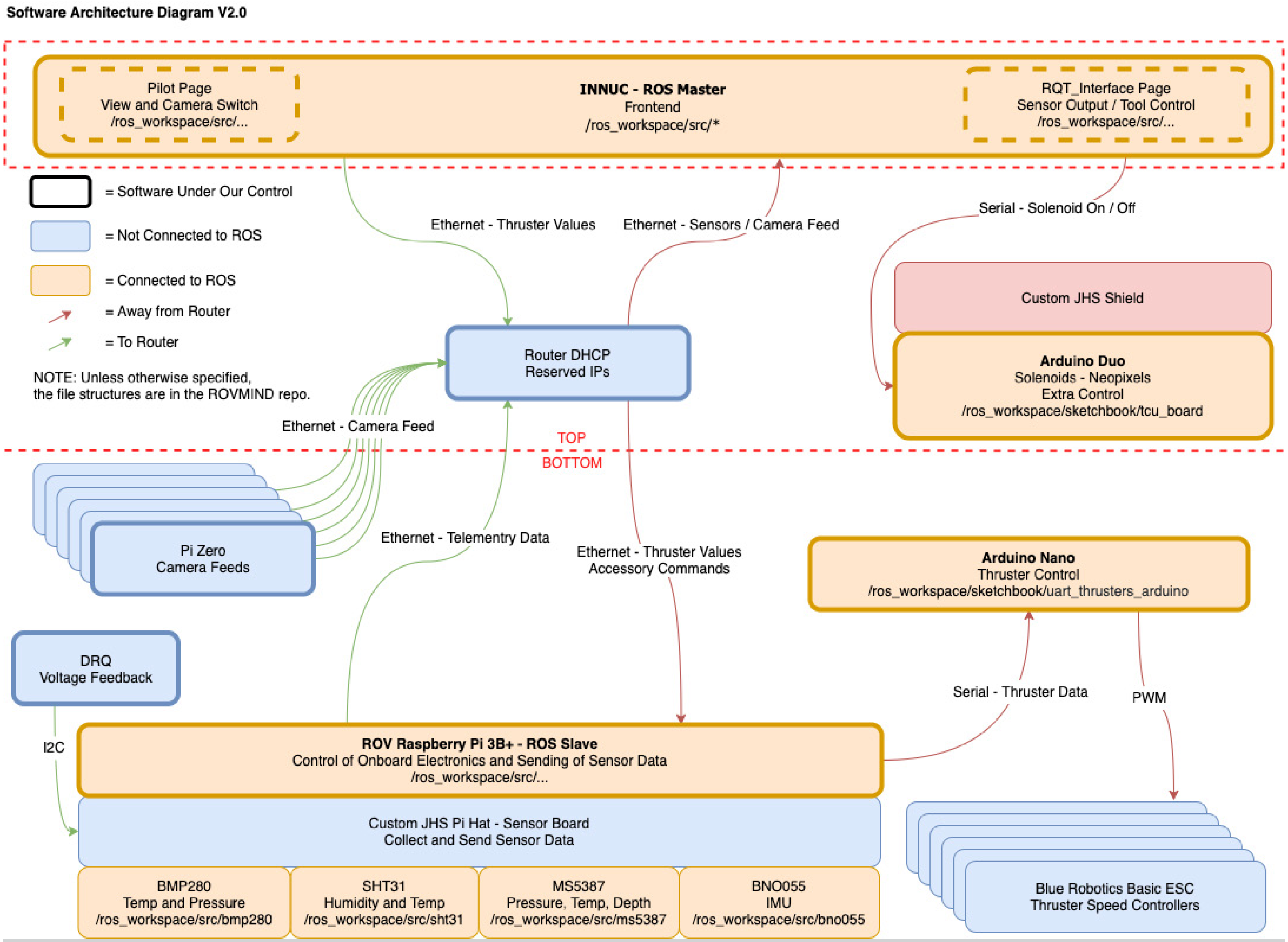
Pit Maintenance (All Team members)

Pit is organized and free of garbage.
Verify all tools and cables are neatly stored and there are no trip hazards.
Check electrical cords and correct any possible electrical hazards
Check supplies and organize a shopping list if anything is needed for repair or upkeep.
Verify TCU, ROV and tether are clean, dry and properly stored.
Protective caps for electrical connectors should be in place
ROV, TCU and tether have been readied for use on the next mission run

Inspect and Test Pneumatic System (Pilot, Co-pilot & Deck Crew)

Verify all pneumatics lines are properly connected to the air source, TCU, and ROV
Verify that the compressor is switched on
Activate pneumatics system and open main valve
Verify there are no leaks and pneumatic lines are securely connected while under pressure
Activate any pneumatic tool and verify the pressure returns to 2.75 Bar (40PSI) after the tool is shut off. Adjust pressure regulator to 2.75 Bar (40PSI) if required and repeat the test until 2.75 Bar (40 psi) is achieved

2. SOFTWARE FLOWCHART



Appendix 2. Software Flowchart