TECH REPORT

JESUIT ROBOTICS

MATE 2022

Explorer Class

MANATEE

TEAM MEMBERS

Freshmen:
‘25 Mark Weden*, Mechanical
‘25 Ethan Bullard*, Mechanical
'25 Douglas Crone*, Electronics

Sophomores:
‘24 James Randall, Software
‘24 Jonah Reynolds, Safety Officer
‘24 Adon Sharp, Software
‘24 Alex Bertran*, Software
‘24 Nathan Peterson*, Software

Juniors:
‘23 Daniel Kriefels, Mechanical
‘23 Timothy Monroe, Mechanical
‘23 Michael Solis, Electronics

Seniors:
'22 Charlie Diaz, CEO
‘22 Nick Venegas, Electronics
‘22 Taylor Vicente, Compliance Officer

*New Members

COACHES AND MENTORS

Jay Isaacs
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Steve Kiyama
Marcus Grindstaff
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ROVOTICS

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INTRODUCTION

ABSTRACT

Rovotics is a fourteen-person company with years of collective experience designing, manufacturing, and operating robotic solutions to ecological problems in aquatic settings. *Manatee* is Rovotics' newest and most advanced Remotely Operated Vehicle (ROV) and is designed to operate in a multitude of underwater environments. The ROV is fully equipped with tools to maintain offshore wind farms, inspect aquaculture pens, monitor the health of the ocean, and ensure a healthy environment for sea life.

Manatee 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, *Manatee* is built to adapt to emerging global environmental challenges. This technical document describes the design and development process of our ROV and how *Manatee* addresses the myriad of challenges and tasks it will face.

JESUIT HIGH SCHOOL

Figure 1. Rovotics team members

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ACKNOWLEDGEMENTS

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- National Science Foundation - Their funding of the MATE competition
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- Jay Isaacs, Head Coach - His time, creativity, knowledge, and guidance for the past seventeen 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
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- 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, Andrew Grindstaff
- Adobe Systems - for providing student discounted software license
- Our Families - Their continued support and encouragement

DESIGN RATIONALE

DESIGN EVOLUTION

Manatee is Rovotics' third generation of our core ROV system, based on a previous ROV design. The reuse of core systems provided the means for Rovotics to rapidly design, prototype, and manufacture *Manatee's* mechanical frame, electronics, and control software in a predictable amount of time, allowing for an earlier development schedule with a more reliable ROV platform earlier in the season.

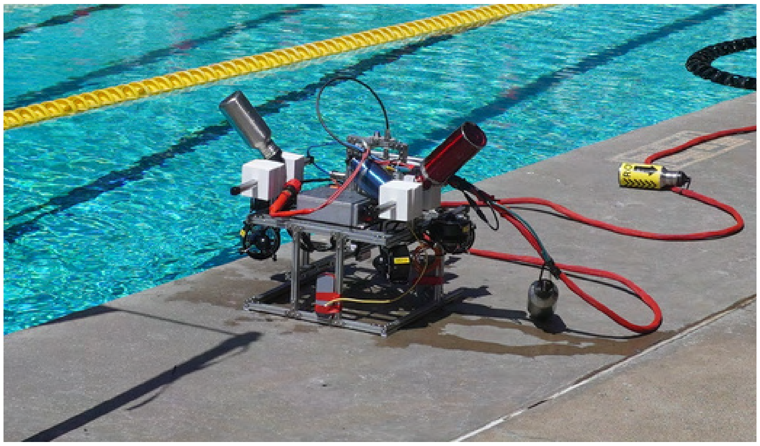


Figure 2. Manatee ROV on Deck

This early standardized platform allowed Rovotics to iterate quickly and efficiently on tools in the design process.

Rovotics first made the switch to commercial off-the-shelf (COTS) components in our 2018 first generation ROV design. A strong focus on standardization allowed Rovotics to quickly replace damaged components with reduced lead times. Use of commercially available parts allowed Rovotics to train newer members more easily, because custom parts require specialized knowledge to create and maintain, and frequently this knowledge was lost with graduating members. Standardization permitted Rovotics to allocate more resources towards developing new functionality which necessitated custom hardware and software innovation, like with our digital cameras, which are now more leak resistant due to improvements in housing construction. *Manatee's* frame design allows for standardized parts to be detached and replaced quickly.

The decision on the standardization tradeoff was made to ensure that both customers and Rovotics employees can be confident that our technology will be forwards compatible with future Rovotics innovations. Advancements used in previous ROVs are able to be reused this year, which provides cost benefits. Rovotics' introduced several innovations with standardization in mind, including a new Raspberry Pi Hat designed with standard I^2C support to easily upgrade ROV functionality; a standard tool mounting interface to quickly swap different tools to service many different tasks; a standard SW test bench to quickly optimize SW updates with limited ROV downtime.

With safety as a top priority, Rovotics' standardization ensures that proven safety systems from previous ROVs have been maintained in Manatee. Its mechanical design implements safety elements such as thruster guards and a smaller, lighter Topside Control Unit to protect the deck crew from injury.

DESIGN AND MANUFACTURING PROCESS

Rovotics decided to design a new ROV that would leverage much of its previous core ROV system. Mechanical designs of the frame and electronics housings were to be largely based on proven designs.

Rovotics' modular frame and rectangular electronics housings proved to be improvements over previous cylindrical housing designs. The *Manatee's* 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 Electronics Housing (MEH) was too large to manage the buoyancy of our ROV, and the extra space that was allocated for electronics was not needed. The mechanical department analyzed commercial, off-the-shelf, and waterproof housing solutions to meet the requirements. The result was the purchase and modification of a smaller rectangular waterproof housing. The housing chosen is a variation on a prior MEH design, but is smaller so it will allow for the easier distribution of buoyancy on the ROV.

Figure 3. Tool Integration to Modular Frame

The ease of design, manufacturing, and modification of previous ROVs' aluminum extrusion frame proved to be useful during development and operation. Application of the design matrix verified the use of an extrusion frame design which remains a significant advantage. As a result, the *Manatee's* aluminum extrusion frame is an optimized version from a prior design. Initial frame design work was done on Fusion 360, Rovotics's Computer-Aided Design (CAD) platform of choice. 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.

TROUBLESHOOTING AND TESTING TECHNIQUES

For the past several ROV iterations, Rovotics has implemented multiple dedicated test environments utilized to test and troubleshoot problems using a Root Cause Analysis, or RCA method. Parallel test environments allow each department to complete software and electronics tools or field testing before integrating with the *Manatee* Production ROV. Rovotics' testing approach serves to reduce the downtime of *Manatee*, as well as diminish the risks posed when integrating new features.

The electronics and software departments use a simulation test environment to test new components and code respectively. These test environments are designed to simulate the functionality and conditions faced by the production ROV, *Manatee*. For example, thruster test code used on the test platform allowed the crew to verify motor control and operation prior to integration of the code onto the production ROV.

Before Rovotics implements a new software feature onto the ROV, it is tested on one of Rovotics' three software test benches (Figure 4). These test benches are outfitted with adequate hardware to simulate both the environments of topside and bottomside, ensuring that untested code doesn't make it into the Rovotics GitHub or the ROV. During the 2021-2022 season, Rovotics used these test benches to ensure the safety of all of its software, including new programs like its depth hold.

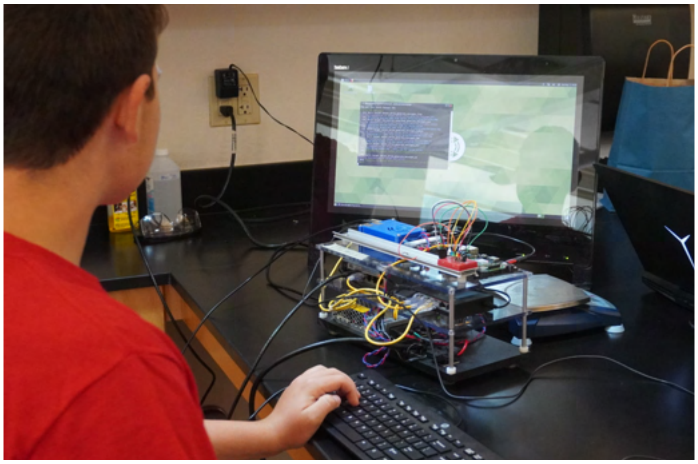


Figure 4. Software Engineer at Testbench

Rovotics was able to test depth hold on a test bench by creating a simulation environment for rapidly changing the pressure using a pump. This allowed Rovotics to see how the software responded to rapid changes in pressure. The software test benches each contain a drop-in replica of both ROV's core electronics control system, which allows for testing MEH electronics components in the software test environments.

The electronics team's test environment is a repurposed production robot from a previous competition, allowing the electronics and mechanical departments to test new designs and components in a similar environment to that of *Manatee*. This ROV test environment contains the same electronics as the *Manatee* production ROV and is similar in construction and design, allowing this test system to be used for water trial runs.

For testing of tools, the repurposed old ROV allowed testing to occur with minimized risk to the production ROV. The mechanical department developed and tested prototypes of tool designs using the integration test environment. Each tool undergoes an extensive design review process that ensures each tool is ready for testing. Once necessary tool modifications and software and electronics testing were completed, the team integrated the mission tool onto *Manatee*.

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 practice saved the company many hours of troubleshooting time while enabling more time for parallel tool development.

MECHANICAL SYSTEMS

FRAME

Rovotics' modular frame system is made out of beams of 15 x 15 mm extruded aluminum with T slots. Previous ROVs used custom frames with higher manufacturing costs and lacked the flexibility afforded by a modular frame. Rovotics originally moved to use aluminum extrusion because of its low cost, ease of manufacturing, and ability to be rapidly modified. Still, the 20 x 20 mm aluminum extrusion used on a prior ROV's design proved to be very heavy. Rovotics switched to 15 x15 mm aluminum extrusion, (Figure 6) providing a lighter frame build and more responsive ROV. Extrusion and a wide assortment of fastening solutions are readily available from many online suppliers, supporting easy standardization.

Manufacturing extrusion frames consists of cutting the extrusion to length and fastening extrusion segments 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.

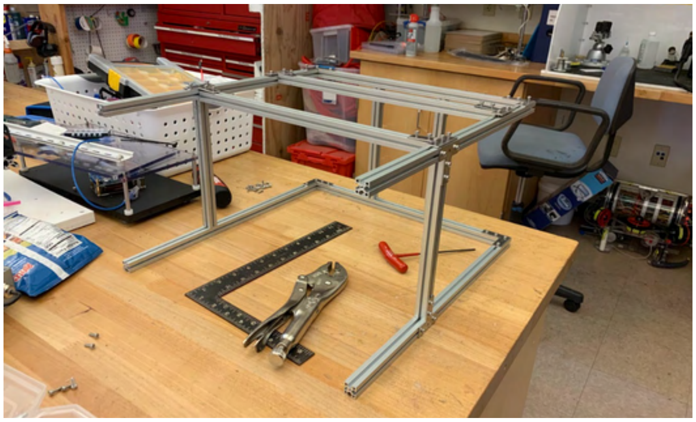


Figure 5. Manatee Extruded Aluminum Frame

During our design revision discussions, the design requirement for *Manatee's* frame specified a sizable 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 increasing the tool mounting area.

The MEH and Power Systems Enclosure (PSE) are mounted to the top frame (Figure 6), which accounts for most of the buoyant force. Placing this buoyancy source at the top of the ROV contributes to its stability. The mechanical design team chose the MEH and PSE 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.

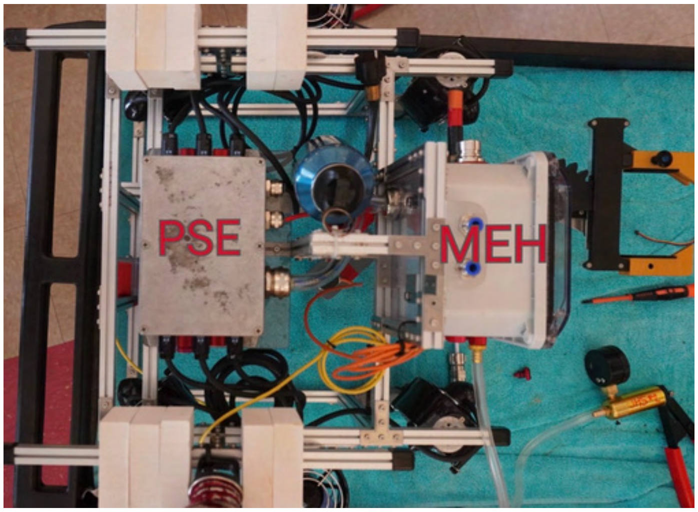


Figure 6. Manatee Top View

TOPSIDE CONTROL UNIT

One of Rovotics' significant investments in the *Manatee* ROV is a new TCU that integrates all on-deck devices to improve portability and reduce setup time (Figure 7).

The large size and significant weight of the previous TCU made it cumbersome to use and was a potential safety hazard. The new design is smaller and lighter allowing one person to safely handle it. The new TCU includes all of the previous capabilities of the last TCU as well as some new features such as multiple pneumatic switches and an internal pneumatic regulator to simplify the setup process.

Figure 7. TCU with Joystick and Peripherals

The TCU was designed to fit in a Pelican iM2700 Storm case that allows easy transportation, setup, and protection due to its durable and mobile design. 6.35 mm (1/4 inch) piece of ABS plastic is mounted to the TCU to serve as the control panel for the TCU. The control panel has an ammeter, pressure gauge, two voltmeters, and two pneumatic switches. Consolidating all meters and controllers allows for a more simplistic use of the TCU.

ELECTRONICS HOUSINGS

Both *Manatee's* Main Electronics Housing (MEH) and Power Supply Enclosure (PSE) are rectangular, off-the-shelf housings. In previous years, Rovotics used cylindrical housings to contain our ROV's core electronics. Though these designs performed well, Rovotics determined that commercially available parts were easier to replace, quicker to obtain, and more aligned with our standardization goals. As our electronics suite expanded to accommodate new features such as digital cameras, it was deemed necessary that our housings expand as well.

By dividing the electronics architecture into two waterproof housings, the PSE and the MEH, *Manatee* can retain the operating and servicing advantages of utilizing a clear plastic housing while simultaneously reducing thermal expansion caused by high energy components.

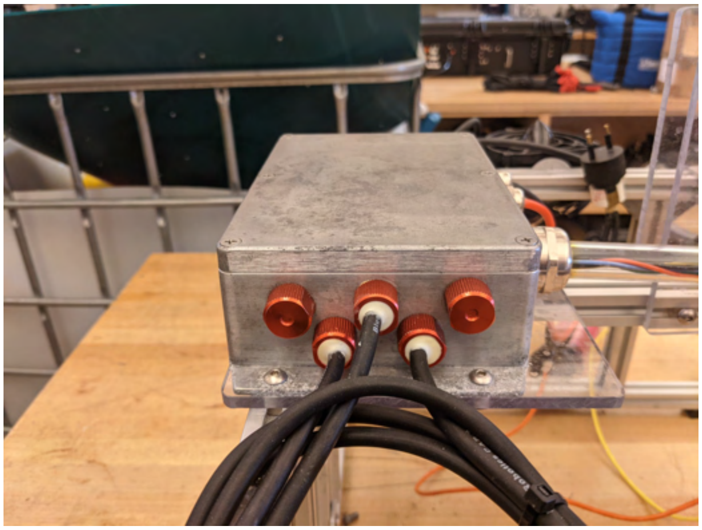


Figure 9. Power Supply Enclosure (PSE)

The PSE houses *Manatee's* 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 PSE has brought average voltage converter operating temperatures down from 80° C in our cylindrical housings to 35° C.

The polycarbonate 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.

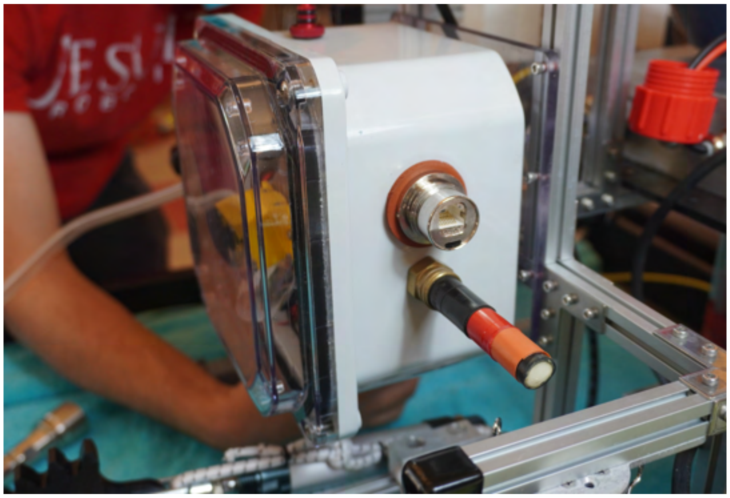


Figure 8. Main Electronics Housing (MEH)

PROPULSION

Manatee 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 used four T100 thrusters and two T200 thrusters; however, the additional cost was 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 of the ROV, 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 maximum power of 150W each, manageable within *Manatee's* power budget. For the safety of personnel and equipment, low resistance thruster guards (Figure 10) are mounted on both sides of the thrusters to prevent foreign objects from entering the thrusters, increasing safety for the deck crew and reliability of the thrusters.

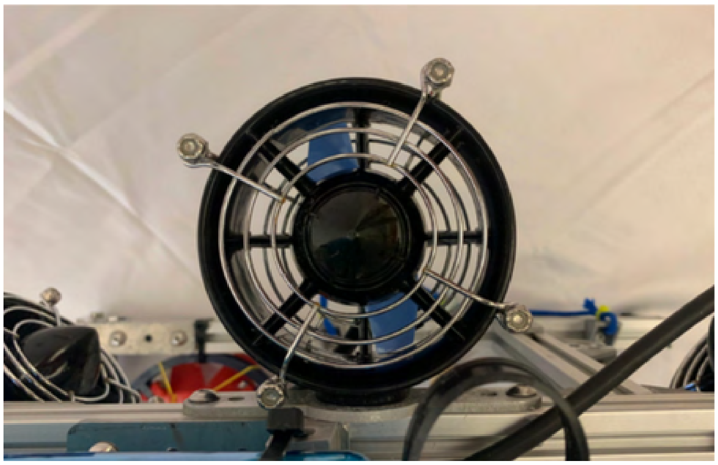


Figure 10. Manatee's T100 Thruster Guards

BUOYANCY

Manatee, along with its components and tether, has a maximum displacement of 7650 cm3. It possesses three main buoyancy components: *Manatee's* Main Electronics Housing (MEH), Power Systems Enclosure (PSE), and Manually Adjustable Buoyancy System (MABS), seen in Figure 12.

Figure 11. Rovotics Employees in Lab

At over 4360 cm3, the two electronics housings are *Manatee's* largest displacement components and serve as the primary driver for the ROV's buoyancy. These two electronic housings are joined with a single piece of aluminum extrusion allowing for adjustment of the ROV's center of buoyancy. Our MABS utilizes syntactic foam disks which will remain buoyant for depths up to 300 meters, allowing *Manatee* to reach the target depth of any MATE mission with ease. The MABS allows for buoyancy to be adjusted by inserting or removing foam disks, allowing the deck crew to quickly adapt to any mission's needs.

Rovotics maintains a spreadsheet to record the displacements and densities of each part of the ROV. Using Archimedes' Principle, this data was used to calculate *Manatee's* weight in both air and 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.

Manatee's 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.

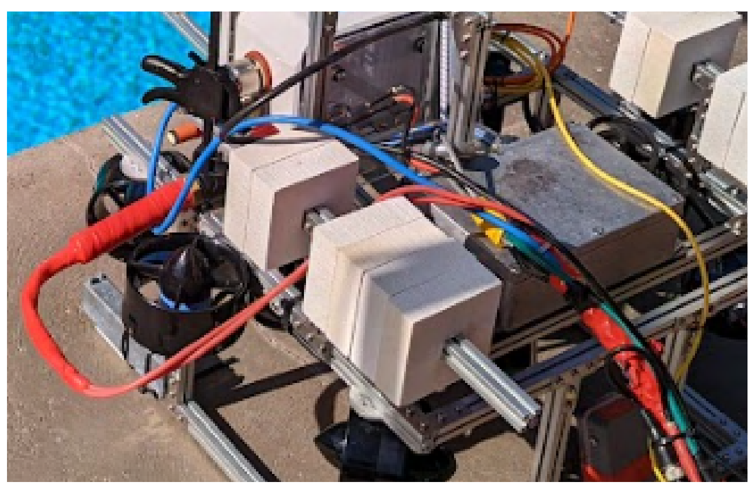


Figure 12. Manually Adjustable Buoyancy (MABS)

PNEUMATICS

Manatee's 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 adjustable pressure regulator. *Manatee* has two pneumatic grippers, each controlled by two-way, three position solenoid valves which are located in the TCU and are activated by co-pilot controlled switches.

Manatee's dual grippers are the only pneumatic tools in the ROV system. Each gripper is extended by the activation of a pneumatic piston and returns to the retracted position by an elastic cord. By utilizing an elastic return, Rovotics eliminated the need for a return air line on the tether, improving tether flexibility and reducing weight. Components in the system are rated for 8.5 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.

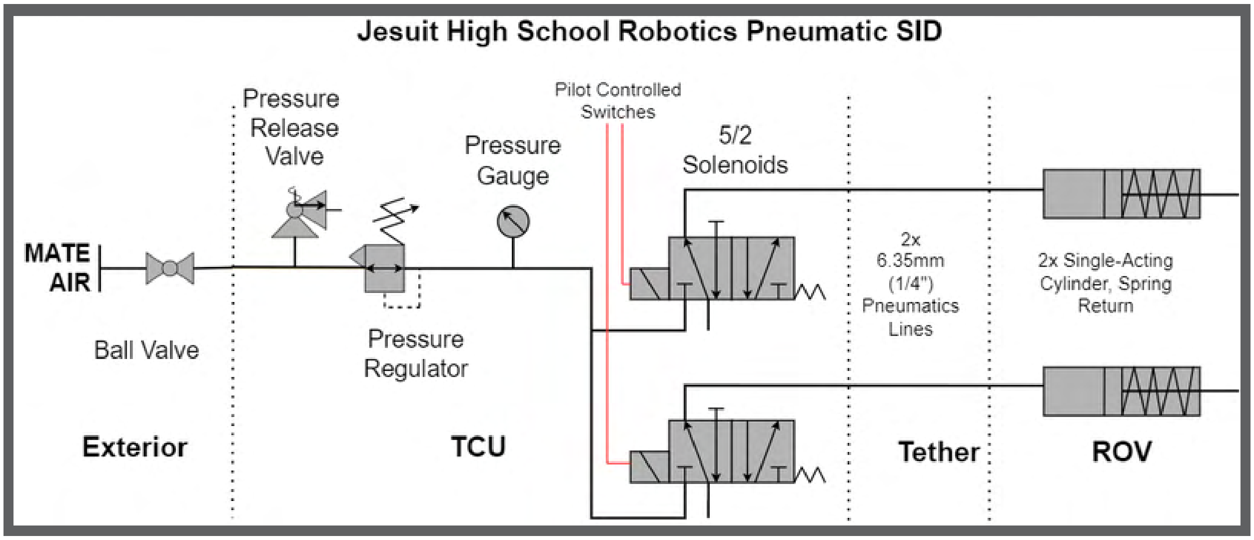


Figure 13. Pneumatics SID

ELECTRICAL SYSTEMS

TOPSIDE ELECTRONICS

The TCU's bottom compartment (Figure 15) was designed with a liftable lid to easily service the most critical components, such as the powerful Intel NUC, a single board computer (SBC), housed in the bottom compartment. Wiring channels also ensure an organized and modular construction. The internal Intel NUC serves as the main computer for the topside control system.

The Intel NUC 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. A single 533 mm (21 inch)monitor is mounted on to the lid of the case and is connected directly to the TCU. The Intel NUC has more processing power and RAM allowing it to drive the monitors and run the pilot and co-pilot systems effectively.

A second monitor is also connected to the TCU to assist the co-pilot. 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 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 connectors are used as separate connection points for both the 48V MATE supplied power and the 48V power feed to the ROV.

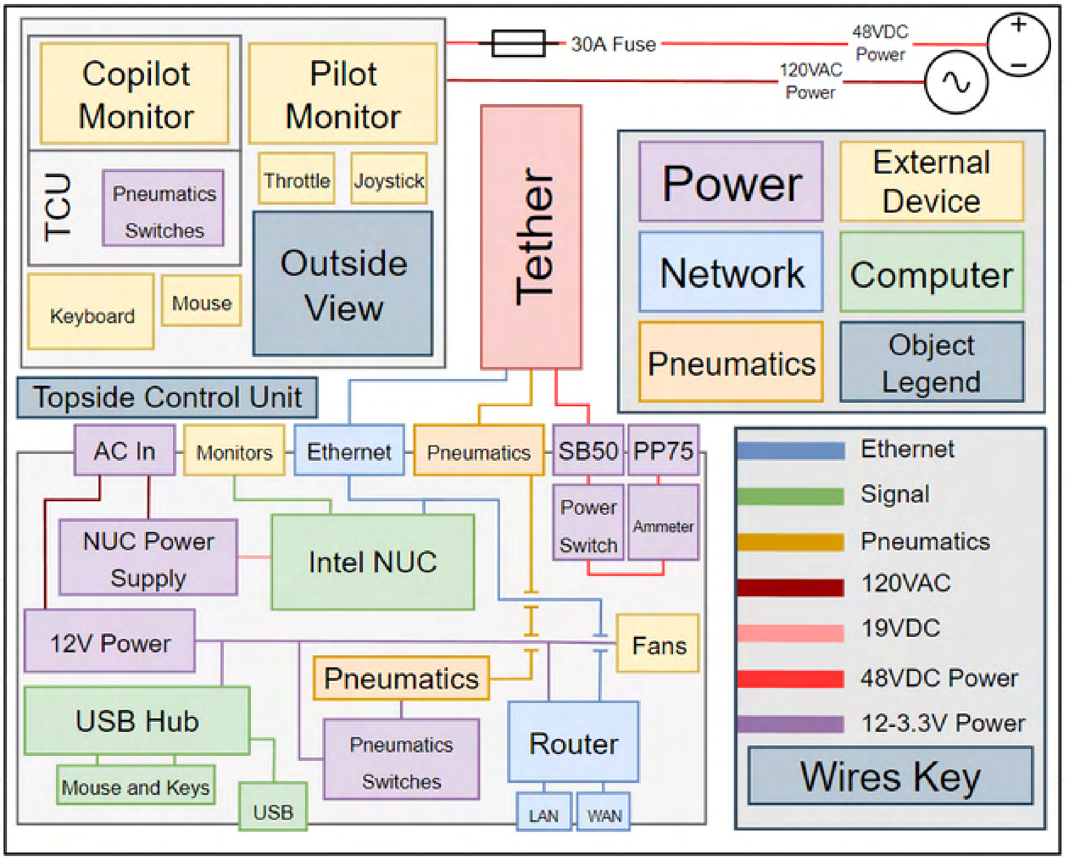


Figure 14. TCU SID

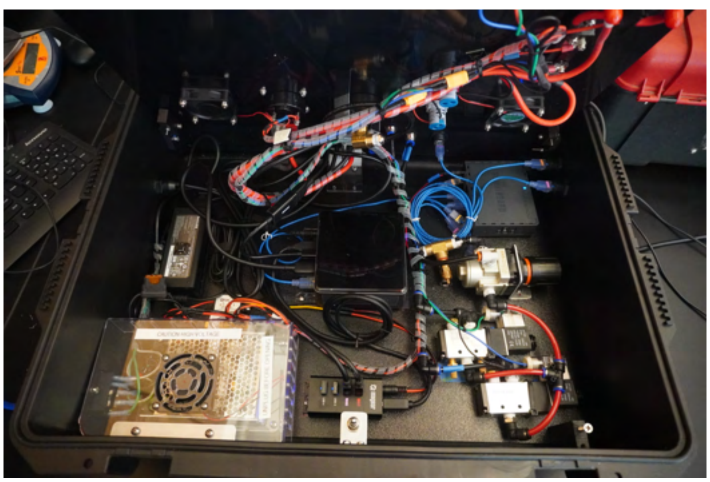


Figure 15. TCU Interior

BOTTOMSIDE ELECTRONICS

The bottomside (ROV) electronics system was designed around the principles of serviceability and standardization. The ROV electronics are contained in the Power Systems Enclosure (Figure 16) and the Main Electronics Housing. The PSE contains two 600W DSQ0150 48V to 12V voltage converters, a custom power Printed Circuit Board Assembly (PCBA), six Blue Robotics Electronic Speed Controllers (ESC), and an Arduino Nano. 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 sent to the Blue Robotics 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 (RPi) crashes or communication is lost. Each thruster is connected directly to the PSE with a Blue Robotics 6mm penetrator. The two Murata DSQ0150s convert 48V from the tether to 12V for a total of 1200 watts available for ROV power.

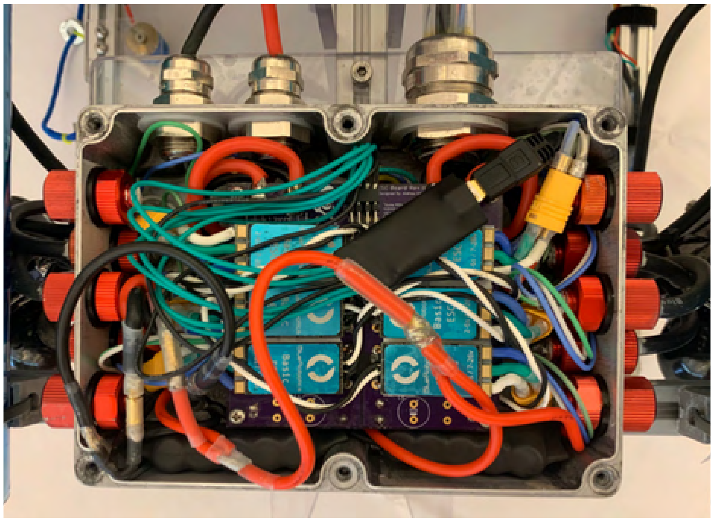


Figure 16. Interior of Power Supply Enclosure

The DSQ0150's 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 DSQs are placed on a power board that Rovotics designed to tightly integrate all high power components into a small aluminum enclosure. With this power conversion board comes a secondary "sister" board, which carries all Blue Robotics ESC's. These are supplied with 12v from the DSQ's and control the Blue Robotics T100 thrusters. Both boards are interconnected to allow sharing of power and communications signals, effectively creating a power distribution and control stack. This power stack is isolated in an off the shelf all aluminum housing. All high current electronics are connected directly to the aluminum enclosure with thermally conductive tape. This keeps all high power electronics cool by transferring all heat generated through the enclosure into the aquatic environment.

The Main Electronics Housing (Figure 17) contains Manatee ' main computer, a Raspberry Pi 3B+, a custom Raspberry Pi HAT, and a 5 port ethernet switch.

The RPi 3B+ is outfitted with a custom RPi HAT (Figure 18) to streamline environmental sensing, device control, and to provide power. Off the shelf RPi HATs were initially considered, but a lack of basic functionality and high costs led to the development of Rovotics custom solution. To reduce costs and build times, off the shelf I^2C breakout boards are used to expand its sensing capabilities. Breakout boards can be placed on the RPi HAT where they are provided with power and a connection to the I^2C bus. This eases serviceability of the electronics system by allowing vital components to be replaced or removed if needed.

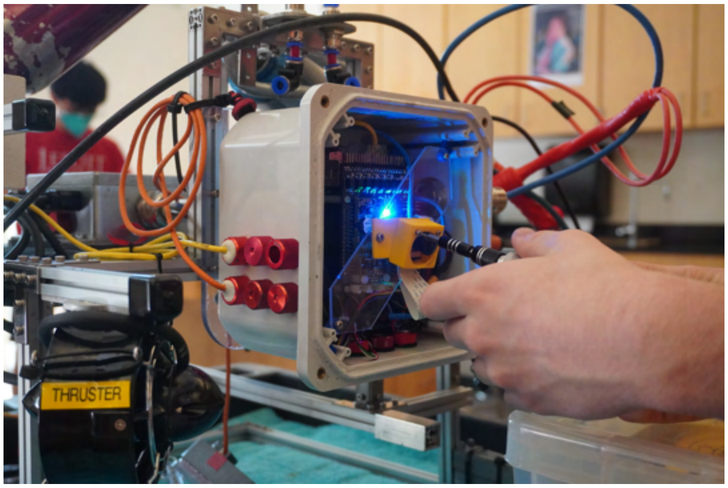


Figure 17. Interior of Main Electronics Housing

The RPi HAT contains a 9-axis inertial measurement unit (IMU) (1) and a humidity, pressure, and temperature sensor (2). A I^2C isolator is included to allow safe communication with the DSQ (3). To expand the pi's limited control capabilities, a ATSAMD09 breakout board provides additional PWM control, analog to digital (ADC) converters, and the ability to drive NeoPixels (4). Many I^2C Grove connectors are present on the HAT to allow for simple expansion to new capabilities (5). Six 2A relays (6) and two 4.5A relays (7), as well as two 1.7A (2.5A peak) directional motor drivers (8) are included to allow for electromagnet, laser, and motor control among other things. Power connections and individual indicator LED's for the relays and drivers, as well as the ability to switch them between 5v and 12v, are built into the HAT significantly simplifying wiring and use.

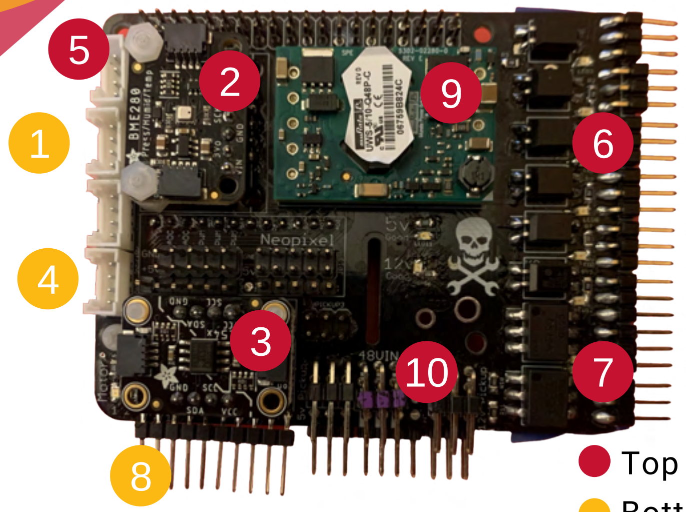


Figure 18. ROV HAT

A five port ethernet switch connects the Raspberry Pi 3B+ and any additional cameras or equipment to the TCU and each other. The switch was chosen for its incredible balance of performance, compact size, and low cost. In the event that more cameras or ports are needed to connect to the TCU, a secondary ethernet switch can be added to expand capabilities without changing the electronics system's size.

To provide 5V for the control electronics, a Murata UWS-5/10-Q48 voltage converter (9) located on the RPi HAT takes 18V-75V and converts it to 5V for use by the electronics. This wide voltage input range allows the core control electronics to remain powered in the event of large drops in voltage. The UWS regulator has additional safety features, including input undervoltage lockout and over temperature shutdown. In the case of a short circuit, onboard indicator lights will pulse to show current limiting via the "hiccup" auto restart technique. Converted 5V power is connected to power pickups to allow 5V power to be easily accessed. 12V is additionally brought in from the DSQ converters and distributed amongst power pickups (10). All power inputs to the HAT and power pickups are designed to be reversible or polarized. 12V and 5V pickups are separated and clearly labeled to further prevent incorrect connections.

TETHER

Manatees' reliable, manageable, and lightweight (3.6 kg) tether (Figure 19) is designed to transport necessary signals, power, and pneumatics 15.5 meters from the TCU to the ROV. A high-visibility, durable and flexible, braided polyester sheathing that protects the lines housed within. The braided polyester allows for stretch or controlled "give" of the tether, helping to ease sudden jerks or sharp motions, and preventing unwanted stress on connections. Adjustable flotation devices are used to keep the tether held in the optimal position for operations, preventing the tether from becoming an obstacle to the ROV, preventing interference damage. *Manatee's* tether has sturdy strain relief at both the TCU and at the ROV. The ROV can be lifted by its tether without damaging connections.

Two 12 AWG (American Wire Gauge) insulated silicon power lines supply 48V to the ROV. They were chosen for the excellent balance of flexibility and low resistance. The calculated resistance of the power cable is 0.3 ohms, meaning that at the maximum possible 30 A current draw, the voltage will drop 9V across the tether (30 A * 0.3 ohms = 9V). 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 6 Ethernet (CAT6) cable (T-568B termination) is used as a network line to *Manatee's* Raspberry Pi computer. In order to accommodate *Manatee's* pneumatic systems, two 98 durometer ¼" OD, ⅛" ID (6.35 mm od, 3.175 mm id) polyurethane pneumatic tubes are used to create two open-loop systems. The tubing diameter was chosen to balance safety and airflow based on the pressure drop at the expected depth of 6 meters and 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 180 psi (23° C). The relative pressure drop of the ROV at the maximum operating depth of 7m is 10.0 psi (0.687 bar).

Given this, the expected relative pressure of the pneumatic lines at the ROV is at least 30 psi (207 kPa). All pneumatic tools are designed to operate safely and effectively at the minimum and maximum pressure.

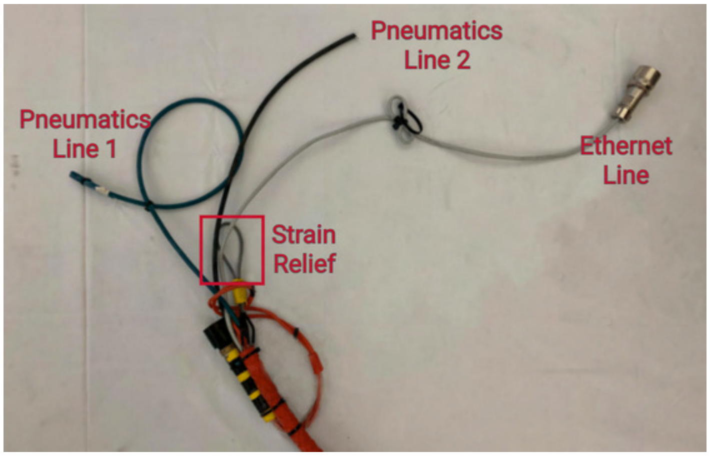


Figure 19. Tether Connections to ROV

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, 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 the 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 in an over-hand under-hand manner, which prevents damage to the tether seen in continuous winding and helps with storage.

SUBMERSIBLE CONNECTORS

Manatee uses a Bulgin 6000 series ethernet connector, Blue Robotics cable penetrators (Figure 20), SubConn wet-mateable electrical connectors, and McMaster-Carr cable glands. Blue Robotics WetLink cable penetrators are used for the connections between PSE and the thrusters, making a waterproof and modular seal without the using epoxy pitted penetrators.

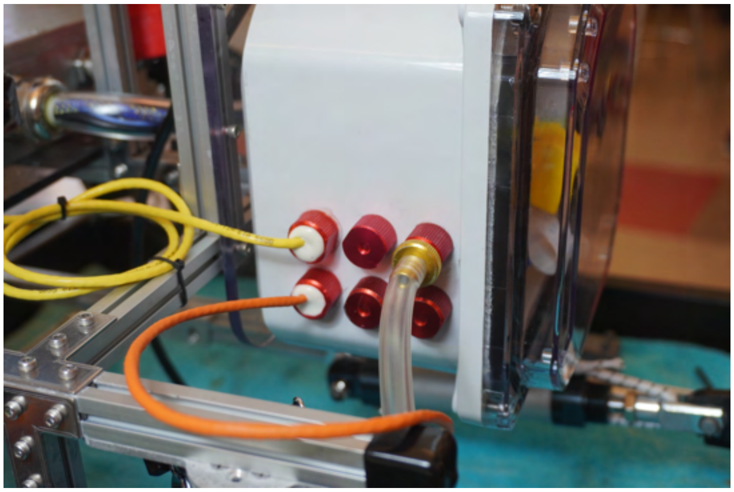


Figure 20. Blue Robotics Penetrators

Connections between the MEH and PSE make use of a custom connector named "the Tube". The 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, chosen 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 helps to minimize ROV downtime.

Device	Quantity	Voltage	Max Power Each	Total Power
T100 Thruster	6	12V	150W	900W
Blue Robotics ESC	6	12V	6W	36W
Raspberry Pi and Pi Hat	1	5V	8W	8W
Cameras	3	5V	3W	9W
Ethernet Switch	1	5V	4W	4W
DSQ0150 Voltage Converter	2	48V	18W	36W
Lasers	2	5V	0.25W	0.5W
Tether Max Power Loss	1	7.3V	170.5W	179W
Total Power Consumption				1172.5W

Figure 21. Rovotics Power Budget

SOFTWARE SYSTEMS

SOFTWARE INFRASTRUCTURE

Manatee' 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 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 on 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.

TOPSIDE

The Topside Control Unit (TCU) contains an Intel NUC which communicates to the Bottomside. The TCU software 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, and makes changes and adjustments to settings through a ROS GUI. Topside is manned by a pilot, and a co-pilot. The co-pilot uses Rovotics' custom GUI to enable or disable thrusters, initiate software tasks, and switch camera feeds for the pilot. Topside also includes a laptop for operational calculations such as the GO-BGC surface calculator, and the fish biomass calculator, allowing for a more streamlined Topside operation where tasks can be done in parallel, alongside operation of the ROV.

Figure 22. Topside Camera Feed

BOTTOMSIDE

Manatee' 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.

CODE MANAGEMENT

To ensure efficient development across multiple software developers, Rovotics utilizes GitHub (Figure 23), a Version Control System (VCS), to manage parallel software development. Using a VCS, Rovotics monitors the changes to software and manages multiple software versions. GitHub is a well-supported and highly-adopted distributed VCS

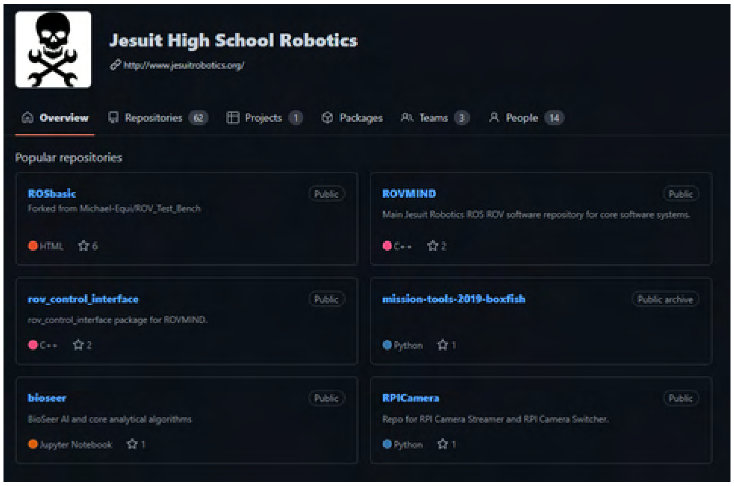


Figure 23. Rovotics GitHub

that provides each developer with a remote and local copy of the code repository.

GitHub also enables software branching and merging, which is of paramount importance when multiple team members work on different areas of the software environment. In the event that problems arise, GitHub allows for rollback of previous, functioning versions. Rovotics has readily available documentation for the process of pushing to GitHub, including instructions for creating new releases of software and use of our cloning shell scripts. This documentation is available to all team members, as is all of the Rovotics code, so that future Rovotics members will be able to quickly understand and maintain the software environment.

TOOLS

FLOAT

Rovotics' float, Vampire Squid (Figure 24), is used in task 3.1 to complete two vertical profiles of the underwater environment. Vampire Squid is driven by an electric motor-powered buoyancy engine powered by four AA batteries. Vampire Squid's buoyancy engine consists of an electric motor attached to a lead screw which actuates the plunger of a 150 ml syringe. The syringe's tip is open to the environment, allowing it to intake or eject sea water to alter the float's displacement. Vampire Squid has an overall length of 76.5 cm and a diameter of 13 cm.

Vampire Squid is activated when placed within the jaws of *Manatee's* front-facing horizontal gripper. An internal Hall-effect sensor detects magnets embedded in *Manatee's* gripper, priming the float for deployment. Once released from *Manatee*, Vampire Squid intakes seawater and begins its descent.

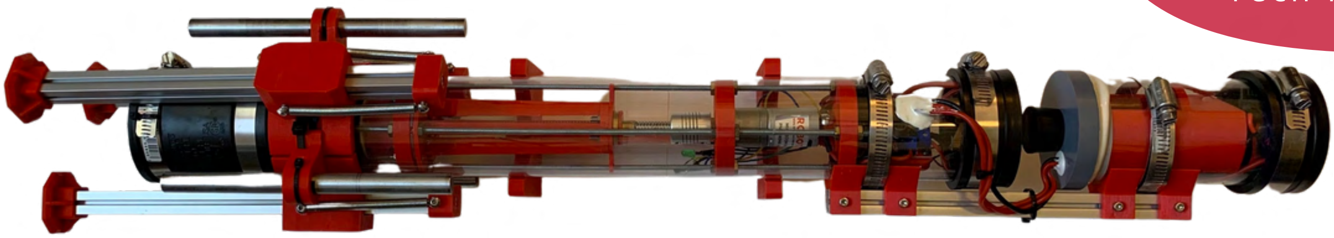


Figure 24. Vampire Squid

GRIPPER

Manatee is equipped with two identical pneumatic parallel grippers (Figure. 24). *Manatee's* parallel grippers allow it to complete a wide variety of tasks from deploying a float to repairing an inter-array cable. *Manatee's* grippers belong to Rovotics' first series of standardized grippers, the Large Parallel Gripper series, or LPG. The LPG series is built around a 50 cm length of 15mm x15mm aluminum extrusion and is attached to *Manatee* with a standardized mounting solution that can be easily attached to any ROV.

Manatee's grippers belong to Rovotics' first series of standardized grippers, the Large Parallel Gripper series, or LPG.

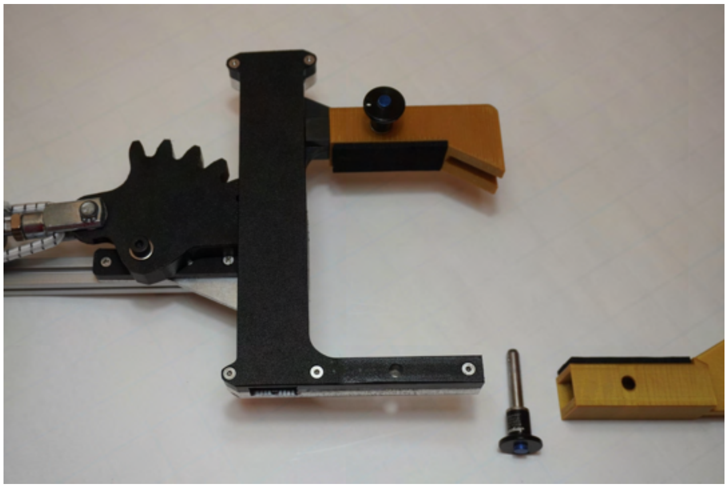


Figure 25. Gripper

The LPG series is built around a [insert length] cm length of 15mm x15mm aluminum extrusion and is attached to *Manatee* with a standardized mounting solution that can be easily attached to any ROV. Each LPG is manufactured out of a combination of milled aluminum, HDPE, and PVC, offering the best balance between cost, weight, and durability. The fingers of the LPG are rectangular and each have a 6.35 mm (1/4 inch) hole drilled through the middle of them for quick release pins, allowing the characteristics of the LPG to be quickly altered, making the LPG Rovotics' most versatile gripper yet.

MEASURING SYSTEM

To measure objects in the water accurately and efficiently, the ROV is supplied with two pairs of laser diodes positioned 5 centimeters apart, with a third laser diode 10 centimeters away.The laser diodes provide a pair of calibrated reference lines for the software tools to calculate the measurement of the object. For objects closer to the camera, the laser diodes 5 centimeters apart are used, while the laser diodes 15 centimeters apart are used for larger objects that may be further away. Using the calibrated reference lines, a team member can plot points on the two lasers and the two ends of the object to calculate the length of the object.

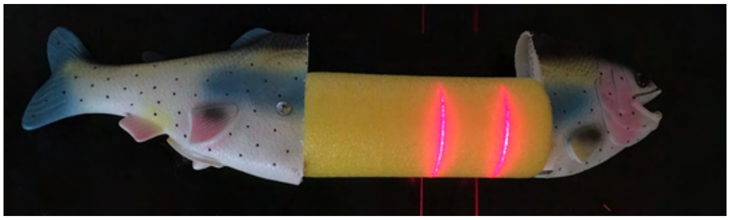


Figure 26. Laser Projected on Fish

DEPTH HOLD

Rovotics implemented its new depth hold feature this year. The purpose of this feature is to maintain *Manatee's* depth autonomously so that the pilot can have better lateral motion control when using a gripper. This allows for tasks that require manipulation of objects to be completed with more precision. The Depth Hold feature takes input from *Manatee's* depth sensor, and runs a PID (Proportional Integral Derivative) loop based on this input. The PID loop provides an effort value for *Manatee's* vertical thrusters, and adjusts this effort value based on the resulting changes in depth, thus allowing the ROV to learn from previous attempts to stabilize depth. The PID loop has been specially tuned to *Manatee*, to ensure that it is as efficient as possible in maintaining depth. To keep simplicity, thruster effort values are interpreted by the same program that interprets joystick signals, so that the ROS infrastructure required for control of the thrusters can be kept as simple as possible.

VISION SYSTEM

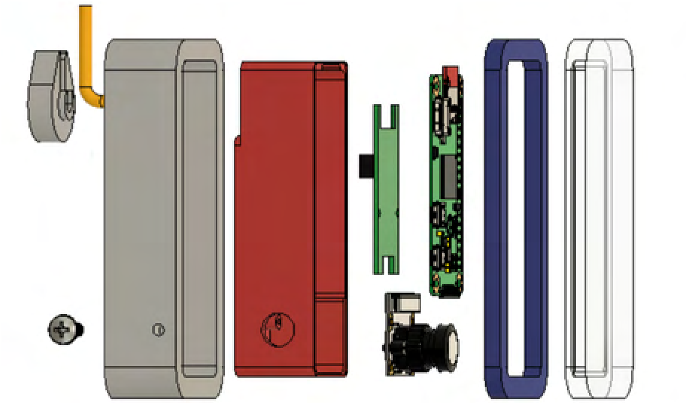


Figure 27. Exploded Camera CAD

Manatee's completely 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 custom manufactured parts with the software, electronics, and housing (Figure 27) all designed, built, and tested in-house.

Figure 28. Digital Camera

Manatee's digital cameras are housed in a PVC housing covered with a polycarbonate lens, which are sealed together with silicone (Figure 28).Cameras are mounted to the ROV's frame fixed or telescoping mounts, the latter of which allows cameras to be rapidly repositioned during tool exchanges. There are three main cameras, the navigation camera in the MEH, and two tool cameras.

SAFETY

COMPANY SAFETY PHILOSOPHY

Employee safety is Rovotics' highest priority. Employees are committed to meeting or exceeding all safety guidelines published by MATE and have a proven track record of consistently meeting MATE's safety requirements.

Adherence to the company's safety policies and training procedures allows employees to prevent accidents and injuries. All employees must take safety training to operate equipment used in the design and manufacture of the ROV. Example equipment includes standard machining tools and soldering stations. Rovotics also requires that all employees wear safety glasses (Figure 29) when working in or near conditions that can result in eye injuries.

Additional safety training for deck crew employees is required to operate the ROV during missions and ensures adherence to the operations and safety checklist.

Figure 29. Employee Observing Safety Protocols

TRAINING

Peer-to-peer training encompasses all aspects of operations at Rovotics, including tool and machinery training, pilot and deck crew training, and sales presentation training.

When learning to operate tools such as soldering irons or mills, new employees first observe experienced employees using the tools. Experienced employees supervise and mentor new employees (Figure 30) as they learn to use the equipment. After new employees consistently demonstrate safe operating practices, they can work independently.

Before competing, Rovotics completes a minimum of forty hours of underwater run practice to ensure safe and efficient ROV product demonstrations. This comprehensive training trains the pilot, co-pilot, and deck crew personnel on routine safety protocols, and allows them to become familiar with the operation and performance of the ROV, so product demonstrations can be completed rapidly and effectively. In preparation for our sales presentation, every team member shares key learnings and compiles facts and details about the ROV and our company.

Figure 30. Senior Member Instructing Trainee

The entire company rehearses for a minimum of fifty hours together, about three weeks before meeting customers. This preparation and training ensures each employee is prepared to communicate all aspects of product information fluently and clearly to our customers.

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. *Manatee* 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 *Manatee* is shut down. After shut down, *Manatee* 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 rubber end caps were added to provide smooth corners on the top frame.

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. CPU temperatures on the Raspberry Pi are also monitored. If values outside of safe operating ranges are detected, a power switch on the TCU (Figure 31) can immediately cut the ROV's power.

Figure 31. ROV Shutoff 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 an operational Job Safety Analysis (JSA) for ROV launch, recovery, and waterside safety. To make this information readily available, Rovotics has attached all relevant checklists to our TCU. This allows the TCU to be operated without a high degree of software knowledge.

LAB PROTOCOLS

To ensure a safe work environment, specific safety protocols are implemented while working in the lab. Rovotics uses JSA forms for employees to create and review before performing risky operations. With *Manatee's* new laser tool, Rovotics' ROV DECK AND WATER SAFETY JSA now includes the proper use of protective eye wear during pre-launch and ROV retrieval.

Experienced employees provide training to new employees on electrical safety, laser safety, hazardous materials handling, housekeeping, tool safety, and injury prevention such as back strain. Material Safety Data Sheets (MSDS) are available for products used in the Rovotics's production process.

Rovotics' lab facility features a chemical vent hood (Figure 32) so that electronics soldering can be performed without fume exposure. The work area maintains a negative pressure relative to the room, and fumes are carried up to a roof-mounted vent.

Figure 32. Chemical Vent Hood

TEAM WORK

PROJECT MANAGEMENT

Rovotics holds weekly virtual meetings to discuss company-wide project scheduling and departmental progress updates. These weekly meetings allow departments to explain progress made during the previous week to the whole team, as well as present plans for the next week.

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 (Figure 33), electronics, and mechanical ROV development to technical documentation. 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 feedback from the team, the CEO manages the team's schedule and discusses due dates and any assistance needed during weekly status and planning meetings.

2021-2022 Software Tasks

Software Mission Tasks and Status	Page #	Points Autonomous	Points Manual	Summary	Assignment	Priority	Difficulty	Status
Fish Calculator	30	5	-	Simple Calculator program used to calculate the mass of the fish. Variables will be provided by MATE.	Adon	High	1	Done
GO-BGC Surface Calculator	32	5	5	The company will be given data about the speed and direction of the current and when the float will surface, and must calculate its surface location.	James	High	1	Done
Potential Software Mission Tasks								
Autonomous Docking	25	15	5	The ROV will need to autonomously move itself into a 1 meter cubed pvc structure, and end the product demo there. At World Championship, the ROV will also need to press a button at the back of the dock.	Adon	Medium	4	-
Photomosaic					Alex		3	
Other Software Tasks								
Ship Mapping					Alex	Medium	3	In Progress
Mort Differentiation					Nathan	Medium	4	In Progress
Laser Measuring Tool	31	15	15	Companies must measure the length of a fish suspended 1M off floor of the pool and the length of a ship	James	Medium	1	In Progress
Depth Hold	-	-	-	Program used to maintain constant depth for ROV. Probably necessary for transect line	James	High	3	
Thermometer	-	-	-	Program used to monitor the temperature of the Raspberry Pi.	Adon	Low	2	Done
Thruster Code	-	-	-	Remap the thrusters to their correct positions and rewrite in Python. Likely involves a GUI	Adon	High	4	Testing
Dead Stick	-	-	-	Used to maintain the flat planar position of the ROV.	James	Low	3	-

Figure 33. Software Project Manager

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

Rovotics is organized into three key departments: Mechanical, Electrical, 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 (reference page 1 to see member roles and responsibilities).

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. Additionally, senior employees in each department are tasked with training junior employees throughout the development process.

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 team-based or even remote work environment. This allows other employees to review and revise designs collaboratively across different devices and locations.

Rovotics selected Zoom as the video and collaboration platform for our virtual meetings and Discord for instant messaging.

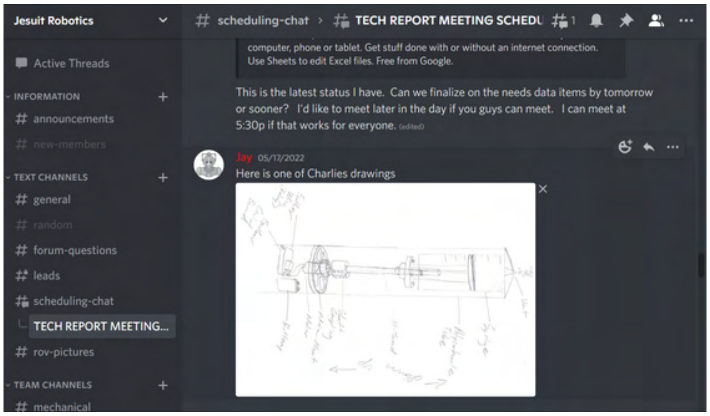


Figure 34. Rovotics Discord

Zoom makes it easy to schedule and hold video meetings with employees, making it easy to demo tool prototypes, share department updates, and review project schedules. In addition, GitHub is also used to maintain Rovotics' code, and software team members regularly use GitHub's suite of software tools to collaborate on software projects. The use of Discord's role functionality makes it easy to send messages to certain teams and keep track of plans. However, for real-time, instant messaging communication, employees communicate using Discord (Figure 34) to discuss development problems and share solutions and ideas.

BUDGET AND PROJECT 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 *Manatee* 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 High School and donations. 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 2021-2022 Budget and Project Costing report is shown in Figure 35.

2021-2022 Project Summary	Item Description	Amount
Income Source		
School Funding	Jesuit School Funding	$ 16,425.00
Donations	MATE Competition Awards	$ 700.00
Available Income		**$ 17,125.00**
Project Cost Summary		
Available Income	School funding & Donations	$ 17,125.00
Actual Project Cost	Production ROV, R&D, Operations Expenses	$ 16,004.13
Project Balance	Budget available for next year	**$ 1,120.87**
Employee Paid Expenses		
Competition Meals	Donations collected for competition meals;14 people	$ 2,590.00
Transporation & hotel subsidy	Donations for car rental, gas, & lodging	$ 4,200.00
Total Employee Paid Expenses		**$ 6,790.00**

	Item Description	Type	Budget	Project Cost	Variance
Production ROV Expenses					
Frame & Housing & Bouyancy	Polycase Housings, 15x15 extrusion, foam	Purchased	$ 475.00	$ 489.38	$ (14.37)
Thrusters	(6) T100 Blue Robotics thrusters & ESCs	Purchased	$ 1,100.00	$ 1,076.63	$ 23.38
TCU	Case, Monitors, Electronics, Pneumatics, NUC	Purchased	$ 2,000.00	$ 1,894.15	$ 105.85
Tether & Connectors	subcon, CAT5e wire, strain relief, sheathing	Purchased	$ 400.00	$ 260.31	$ 139.69
Electronics & Connectors	Si wire, connectors, HAT PCB, DSQs, controllers	Purchased	$ 1,000.00	$ 1,354.36	$ (354.36)
Pneumatics	Valves, fittings, tubing, gauges	Purchased	$ 95.00	$ 85.16	$ 9.84
Mission Tools	gripper, float, ROV cameras, lasers,	Purchased	$ 500.00	$ 468.00	$ 32.00
Pilot Controls	Joystick	Re-used	$ 40.00	$ 32.46	$ 7.54
Raw materials	Plastics, metals, hardware, 3D filament, consumables	Purchased	$ 1,200.00	$ 1,500.00	$ (300.00)
Total Production ROV Expenses			**$ 6,810.00**	**$ 7,160.44**	**$ (350.44)**
R&D Expenses					
3 SW Test Benches	Test Bench materials	Purchased	$ 600.00	$ 815.63	$ (215.63)
Total R&D Expenses			**$ 600.00**	**$ 815.63**	**$ (215.63)**
Operations Expenses					
Lodging	7 hotel rooms for team/2 per room	Purchased	$ 7,000.00	$ 6,615.00	$ 385.00
Mission Props	MATE mission props	Purchased	$ 500.00	$ 324.00	$ 176.00
MATE Entry Fee	MATE entry fee	Purchased	$ 400.00	$ 400.00	$ -
Power Fluid Quiz Fee	MATE power fluid quiz	Purchased	$ 25.00	$ 25.00	$ -
Lab Supplies	Lab Supplies: Consumables, plastic, glue, hand tools	Purchased	$ 400.00	$ 413.39	$ (13.39)
Printing	Report, display, brochure printing	Purchased	$ 300.00	$ 250.67	$ 49.33
Total Operations Expenses			**$ 8,625.00**	**$ 8,028.05**	**$ 596.95**
Total Project Variance			**$ 16,035.00**	**$ 16,004.13**	**$ 30.87**

Figure 35. Budget and Project Costing

CONCLUSION

CHALLENGES

Rovotics faced difficulties with personnel, work environments, supply chain issues and design with manufacture in mind.

Scheduling needed meetings outside of regular LAB hours proved to be a challenge. It became difficult to share and hand off tasks between employees. This issue affected early revisions of the technical report. Rovotics addressed this by creating a tech report task force. A small group of employees integrated and authored the final report with the rest of the employees dedicated to providing feedback.

Work environment challenges impacted Rovotics ability to keep the project on schedule, such as the difficulty of developing software remotely for the ROV to keep SW projects on schedule. Rovotics addressed this by setting up virtual machines that simulated the ROV's Topside and Bottom side. Additionally, supply shortages became particularly difficult this year because of the focus on using COTS parts, especially microcontrollers and electronic components. Materials took significantly longer to arrive, resulting in schedule delays and frequent replanning of build activities. Rovotics took additional steps to plan purchases earlier and purchased extras to minimize the impact of delays and shortages during the season.

This season Rovotics encountered technical challenges as we worked to improve our digital camera system. The primary concern with our digital cameras was the cameras' waterproof housings, which proved unreliable and difficult to manufacture. Rovotics designed a whole new housing, enabling us to manufacture ten digital cameras reliably, doubling the number of working cameras from last season. Rovotics' approach to the improved camera housing design was the product of several iterations of design reviews, prototyping, and testing in and out of the water that ultimately allowed us to mass produce our final revision of the new housing with a high level of repeatability and precision.

LESSONS LEARNED AND SKILLS GAINED

Rovotics' greatest lesson learned this year came from redesigning its second-generation-digital camera housing. Last season we made the incorrect assumption that the camera housing needed to be disassembled to update the software. Once we confirmed that the camera software could be updated remotely, a difficult to manufacture o-ring sealed housing was replaced with a low-cost permanently sealed housing. The new camera housing is simple to manufacture, reliable, and compact. We learned that a thorough, disciplined review of requirements is needed before starting our design process. This would have allowed us to eliminate the o-ring problem sooner.

Additionally, the second-generation camera housing also taught Rovotics the importance of having well-documented assembly instructions. To effectively manufacture cameras in quantity, critical steps needed to be carefully documented. Once assembly instructions were tested and verified, this also allowed several Rovotics engineers to manufacture cameras at once.

FUTURE IMPROVEMENTS

A primary goal of Rovotics is to create a software environment that allows for easier completion of autonomous tasks that involve piloting the ROV. The software team has elected to name this Autonomous Infrastructure. Rovotics’ goal with this software tool is to allow for autonomous tasks to be completed easily and to lessen the amount of development time. This would streamline the process of completing autonomous tasks and save Rovotics time and resources.

Rovotics aims to have documentation that is accessible to both senior employees and recruits, so a goal next year is to consolidate all documentation into one location. The end result of this process will be a place where documentation pertaining to all departments and marketing will be easily accessible by all employees.

APPENDICES & REFERENCES

APPENDIX 1: OPERATIONS AND SAFETY CHECKLISTS

Pre-Power Procedure (Pilots & 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
- ☐ 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 (Pilots & 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 (Pilots & 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
- ☐ The deck crew calls out "Ready to Launch"
- ☐ Deck crew members handling ROV call out "Hands Off!"
- ☐ Co-pilot calls out "Thrusters Engaged" and pilot begins mission

ROV Retrieval (Pilots & Deck Crew)
- ☐ Pilot calls "ROV Surfacing"
- ☐ The deck crew calls out "ROV Surfaced. 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.

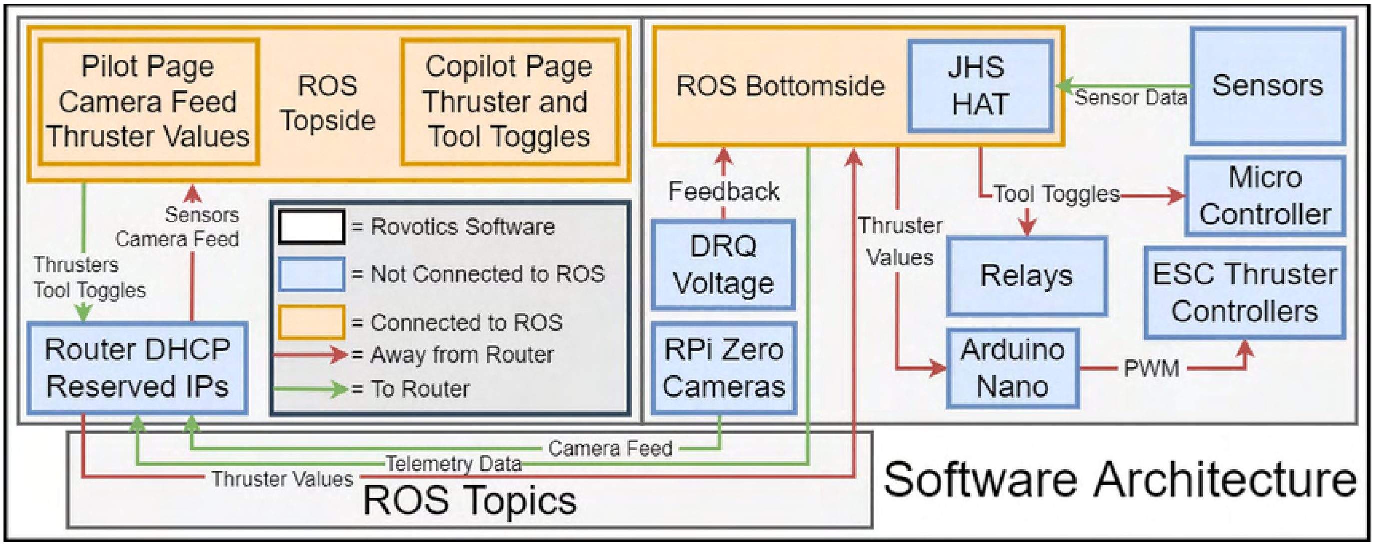
Leak Detection Protocol (Pilots & Deck Crew)
- ☐ Power down system and remove ROV from water if running a mission. Recover ROV by pulling to the surface using the tether if required.
- ☐ Visually Inspect to determine source of leak. Do not disassemble any part of the ROV until the leak is located.
- ☐ 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 (Pilots & 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

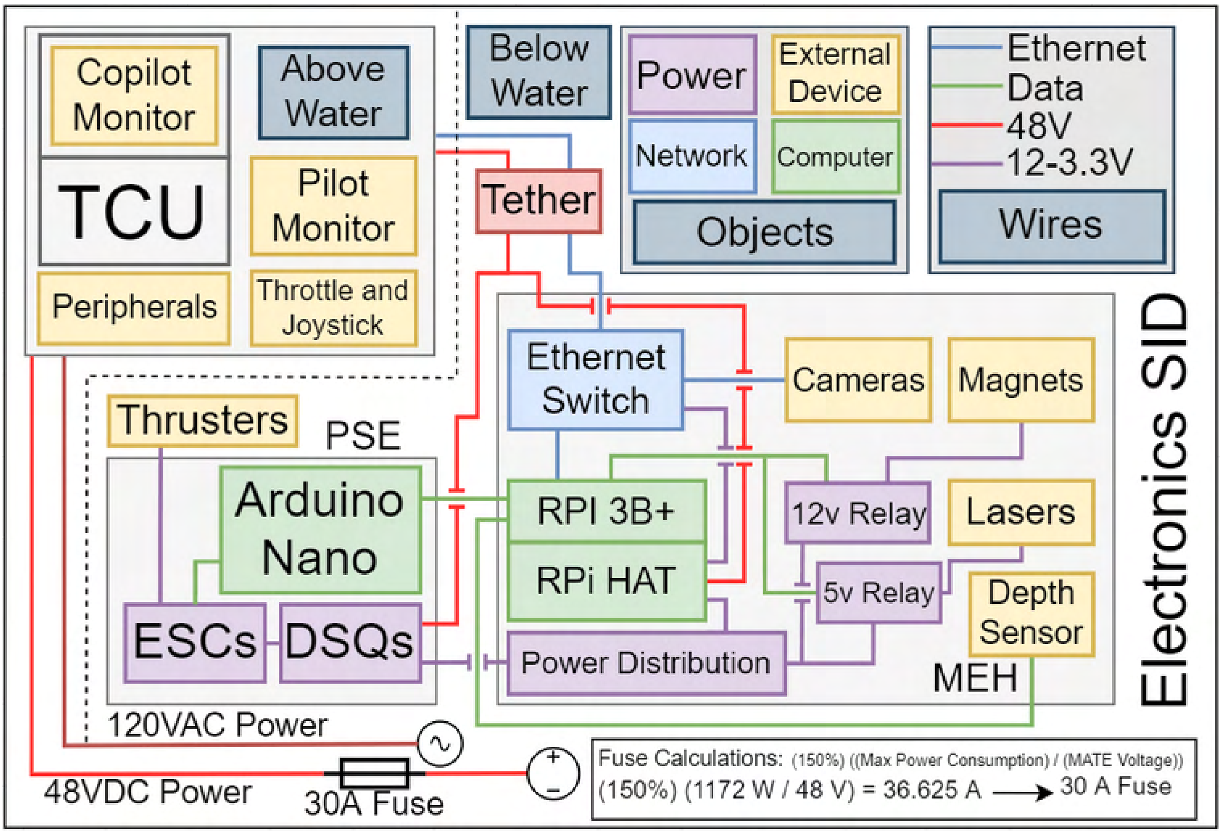
Pit Maintenance (All Team Members)
- ☐ Pit is organized and free of garbage.
- ☐ Verify all tools and cables are neatly stored and there are no trip hazards.
- ☐ Check electrical cords and correct any possible electrical hazards
- ☐ Clean Thrusters with Deionized Water
- ☐ Inspect Tether Power and Network Connectors
- ☐ 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 Pneumatics (Pilots & 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
- ☐ Test tools and adjust pressure regulator to 2.75 Bar (40PSI)

APPENDIX 2: SOFTWARE ARCHITECTURE DIAGRAM



APPENDIX 3: ROV SID



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