SEAL Robotics Team

An Independent Community-based Organization
Greensboro, NC, U.S.A.

2022 Team Member	**Primary Roles**
Michael Scutari	C.E.O., Programmer, Tech Writer
Jonathan Bacon	Project Manager, Tech Writer, ROV Pilot
Ben Liebkemann	Lead Team Programmer
Owen Voorhees	Mechanical, Lead Electrical Engineer, Programmer
Quinn Welch	CAD Designer, Fabrication Expert, Mechanical Engineer
Phillip Szypulski	Mechanical Engineer, Prop Designer
Clay Austin	Mechanical Engineer, Prop Designer
Marissa Maynard	Mechanical Engineer

Team Mentors: Ned Voorhees, Kurt Ruppel

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ABSTRACT

During 2021-2022 SEAL Robotics season, our team has focused team-building, leadership training, community outreach, advanced original software design, unique fabrication solutions, safety culture promotion, and adult and peer mentorship. This process was centered around the development of the Remotely Operated Vehicle (ROV) system SEALbot (Fig. 1). Specifically, this ROV system is ideal for the tasks of addressing the real-world challenges involved with: the responsible consumption and production of affordable and clean energy; maintaining a healthy environment for fish and the surrounding ocean community to promote food security; and the effects of climate change on the ocean environment.

Major new mission-specific original designs and fabrications for the 2021-2022 season include modified and enhanced thruster configuration for increased stability and maneuverability in the water, original custom written software for drive control utilizing Proportional Integral Derivative (PID) methodology to enhance vehicle stability in the water, the addition of a drybox to the ROV resulting in significantly decreased tether size and therefore enhanced maneuverability, servo-mounted adjustable camera systems, and various other mission-specific software and hardware solutions. This ROV and drive system were built methodically, consistent with the stated goals of sustainability and resource conservation.

"SEALbot" is a testament to over 4+ years of experience in the development of ROV systems. This report examines why our team's design rationale, organizational strategies, and ROV construction philosophy has made this system the most stable, maneuverable, and reliable that SEAL Robotics has ever constructed.

Figure 1 (Right). The 2022 SEAL Robotics ROV, "**SEALbot**".

COMPANY OVERVIEW

SEAL Robotics is a community robotics team based in Greensboro, North Carolina without any school affiliation.

Mission: We leverage team approaches and peer mentorship to develop original, customized, industry-leading robotics platforms that address environmental and sustainability concerns of the marine community.

Vision: We are enabling and nurturing our team members into leaders with mindsets focused on innovation and collaboration who are prepared to make responsible decisions and to address the environmental and social problems of the future.

Role of Mentors: Mentors at SEAL Robotics act as guides to pass on concepts and skills, ensure a safe environment, maintain the financial accounts, and assist team member leaders in organizing meetings. Our team members produce and critique designs, fabricate and construct the ROV, write every line of code, as well as produce the electrical, technical, and presentation materials. Every team member also considers themselves a peer-mentor, ready to share knowledge with the rest of the team.

PROJECT MANAGEMENT

SEAL Robotics adopts an organized but flexible approach to project management. Among the defining characteristics are:

- **Development of an overall timeline and budget** and revision as necessary - performed by member leaders in conjunction with mentors. An example organizational chart follows in Table 1.
- **Divide and Conquer: Use of flexible subteams for individual project components**. Accommodate team member interests, skills, and learning opportunities to further our vision and mission.
- **Meeting planning and objective determination**: A leadership group of members and mentors used the GroupMe app to develop an agenda and specific task assignments for members and sub-teams prior to each meeting. That agenda was sent out on the full team GroupMe the night before each weekly meeting.

Team Roles and Assignments

Member seniority was taken into account in deciding initial leaders for the team. Prior to publication of specifications about exact mission goals, SEAL Robotics performed skill-building workshops and seminars in meetings, including an egg-drop engineering competition between 5 subteams (including a mentor team), and refurbishment of components of our prior ROV design. Every member rotated through different sub-teams to participate in hardware, software, electronics, documentation, project management, and execution teams. Members gravitated to certain areas, and every attempt was made to accommodate preferences. The most challenging area to introduce beginners was in the software development side, as we have multiple advanced coders and others who are interested, but novices. We produced small side projects for the new members and had them shadow and learn from the advanced coders.

Target Date	SubTeam Lead	Task
1-Oct-2021	Michael	Create Timeline, make Assignments, study MATE docs
9-Dec-2021	Everyone	Read MATE Competition documentation released so far before the next meeting.
15-Jan-2022	Jonathan	Begin building "Props"
31-Jan-2022	Ben	New Drive System Programming Complete and Tested on the ROV
28-Feb-2022	Owen	GUI Programming Complete and Integrated and Tested with ROV Drive System
1-Mar-2022	-	Register for Regional Competition
2-Mar-2022	-	First trial at pool with props, single gripper, and Micro ROV
16-Mar-2022	-	Additional manipulators/tooling complete and installed on ROV
31-Mar-2022	Jonathan	"Props" build 100% complete
1-Apr-2022	Michael	First Draft of Technical Report Complete
7-Apr-2022	Quinn	Final draft of ROV SID, Float SID, and other CADs completed.
15-Apr-2022	Michael	Final Draft of Technical Docs Complete and submitted to Regional
15-Apr-2022	Clay	First generation of Self-Profiling Float completed and ready for initial testing.
30-Apr-2022	Marissa	Second generation of Self-Profiling Float completed and read for testing.
30-Apr-2022	Ben	Video Recognition Software Complete (if team decides to pursue)
14-May-2022	-	Regional Competition in Johnson City, TN
20-Jun-2022	-	World Championship Competition, if we advance

Table 1. Timeline developed for the 2021-2022 SEAL Robotics build season.

Member leaders made every **effort to balance the tasks** across all members. For example, every team member was assigned at least two major parts of the documentation. All members were rotated through poolside drive team assignments. Recordings and time trials were used for a data driven approach to assess individual performance and also determine task order and priority. Competition conditions were simulated. **Final poolside drive team membership** was based on availability, member preference and commitment, and a consensus vote of the members and mentors after a series of time trials.

Eventual non-pool teams roles are listed in Table 2 below.

Subteam Specialty	Team Members (Team lead in **bold**)
Programming - Drive System	**Ben,** Owen, Michael
Programming - GUI	**Owen,** Ben, Michael
Programming - Video Recognition	**Michael,** Ben
Programming - Manipulators, Challenge Specific	**Owen,** Michael
Props - Research and Building	**Jonathan**, Phillip
CAD, Chassis Fabrication - Design and Build	**Quinn**, Clay
Vertical Profiling Float Design and Build	**Clay,** Marissa
Challenge-specific Designs and Builds	**Marissa**, Quinn

Table 2. Subteams and team member roles 2022.

Overcoming Day-to-Day Challenges

Since SEAL Robotics inception, the team's size has diminished to roughly 50% of what it was initially as members moved on to success in other areas. One of the biggest challenges that we faced this season was associated with the limitations of working with a smaller development team. Our traditional strategy of divide and conquer often required significant alterations, and team members were often expected to fill several different roles. While subteams were still critical to our project management strategy, increased flexibility proved essential to maintaining a similar level of productivity to our traditional style.

ROV DESIGN RATIONALE

Engineering Design Rationale

Several months were spent planning the design of various onboard and poolside systems; our team took into account our failures from previous seasons, the successes of our previous systems, and the expert opinion of SEAL's veteran team. The design of SEAL Robotics' previous system, "Hammerhead," centered around both maneuverability and precision. We found, however, that our maneuverability was somewhat hindered in the water by our large tether. For the 2022 competition, we therefore designed a system that could incorporate both high levels of precision and lightning fast speed through the water. In addition, given its resounding success in last year's competition, we wanted a system that expanded upon Hammerhead's modular tooling system to provide increased flexibility for mission specific tasks. SEAL Robotics is happy to present "SEALbot" for competition 2022.

Innovation

SEALbot features numerous innovations that improve upon system reliability, usability, and performance when compared to SEAL's previous system, Hammerhead. The addition of a drybox featuring a small, single-board computer (SBC) in the form of a Raspberry Pi has paved the way for several improvements including: (a) the dramatic reduction in tether thickness meaning that SEALbot has the thinnest tether that SEAL has made yet; (b) the addition of additional on-board electronics such a gyroscope, servos, water intrusion detectors, and more which enhance overall vehicle functionality; and (c) the ability to control all vehicle systems from a single laptop computer on the surface of the water, with no control box.

As opposed to previous systems three vertical thruster triangular design, SEALbot now incorporates four vertical thrusters in a rectangular configuration, enhancing the precision of our depth adjustment. This change has also allowed for the relocation of our tether to the rear of the system. This change, while seemingly minor, has proven crucial in maintaining vehicle stability in the water.

A simple innovative feature of SEALbot is the further incorporation of armature wire into the placement of camera systems on the ROV, giving us a significant edge when it comes to sensor adjustment.

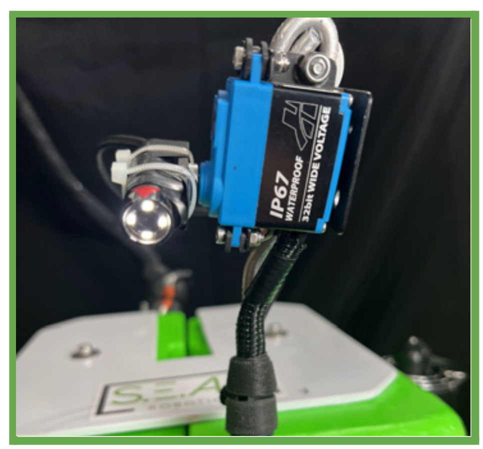


Figure 2. SEALbot Camera mounted on ¼" Aluminum Armature Wire.

Problem Solving

Effective problem-solving is at the core of SEALbot's design. As flaws were identified in the system, groups of team members experienced with the problem area began a discussion of possible solutions and their potential benefits. After examining the benefits and drawbacks of current solutions, decisions could be made using data that had been gathered and ideas that had been proposed. SEAL's open communication and a collaborative ethos result in accessible help and efficient problem solving natural consequences of our environment.
For example, the addition of a drybox in this year's system—a feature that SEAL has never included before on one of its systems—has resulted in numerous problems. From finding cable penetration solutions, to working to fit electronics within a limited dry space, to communicating with SEALbot's SBC, the Raspberry Pi, this new constraint required methodical and deliberate problem solving strategies for implementation to go as planned.

One example of where we had to use creative problem solving this year was when working with the Raspberry Pi computer. Troubleshooting is much more difficult when the drive computer is sealed inside the drybox. One cannot just disassemble the ROV and plug in a keyboard, mouse, and monitor during a practice at the pool. In order to solve problems effectively we had to think outside of the box and plan ahead. We instituted historical log files on the Raspberry Pi, to enable us to do forensic analysis on those logs to determine after the fact, what had happened. Similarly, we had to be creative by checking voltages and amperages *outside* of the drybox, to make educated guesses as to what was going on *inside* the drybox. Finally, we had to make use of terminal emulation programs and ssh utilities to access the Pi while it was physically inaccessible.

Systems Approach

All of the systems on SEALbot are tightly integrated and designed to be simple but effective. We have four cameras on the ROV. We used articulating cameras to give our drivers a clear look at their surroundings as well as a depth sensor in order to give our drivers an indication of where they are in the pool. These sensors then feed back into our control system, which shows our drivers vital system information through our GUI and receives inputs through two Xbox controllers. The drive system then takes information from the control system and powers our thrusters to give us fine-grain control in the water. No one system is more important than the others, and none was focused on more than the others. We made sure when designing each of our systems that they not only worked quickly but also worked to make SEALbot as effective as it could be on tasks this year.

Vehicle Structure

When discussing the possible structure of SEALbot, as a team, we wanted to focus on smooth, fast movement and maximum thruster efficiency. To ensure smooth movement and meet ideal size guidelines, we decided to keep SEALbot under 15 kg, at 10.2 kg, and under 60cm max diameter, at 41.9 cm. One of the key components of our ROV when it comes to reducing the weight is the material out of which the chassis is constructed: extruded aluminum C-channel. This material is not only lightweight, but we have found that it is also extremely durable. This aluminum C-channel is also easy to drill into, which allows us to mount grippers and thrusters directly onto the chassis. Our structural design, which is a cube with notched corners, was chosen in order to allow us to mount our thrusters in a vectored configuration, free of interference.

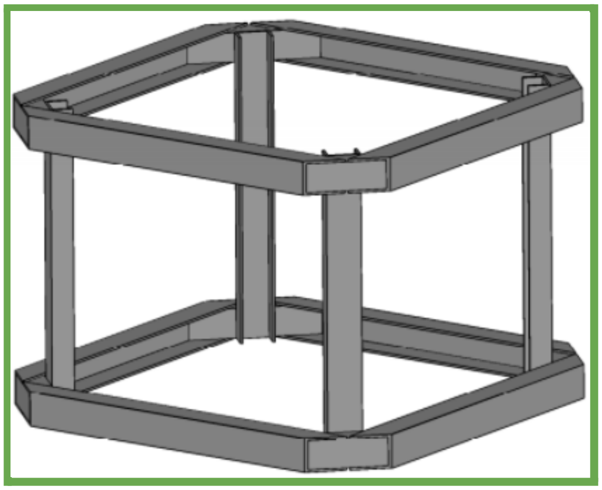


Figure 3. 3D model of SEAL Robotics "SEALbot" vehicle chassis.

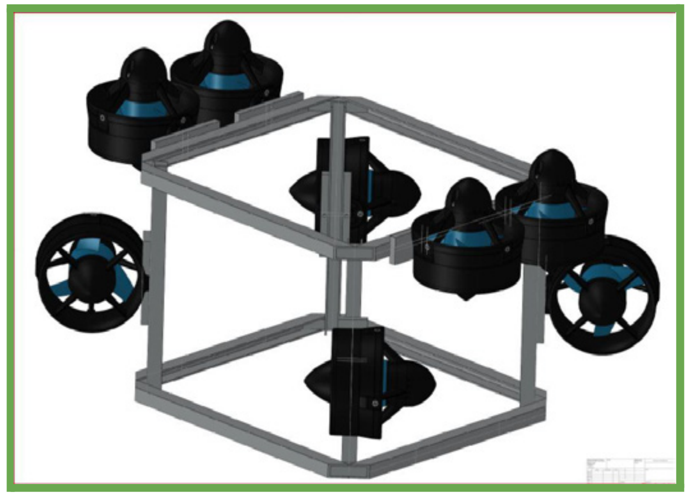


Figure 4. System chassis rendered with planned thrusters.

Vehicle Systems

We designed SEALbot from the ground up for this competition to meet the unique challenges this year. We decided to use Blue Robotics T200 thrusters, as opposed to previous systems T100s, vectored on the edges of our ROV to allow for maximum maneuverability in the water. We also have four DiamondDynamics vertical thrusters that work in conjunction with our depth sensor for quick deployment and stability. The two Blue Robotics grippers we have mounted to the front and back of SEALbot are robust and can be rotated or extended to suit the task we are currently executing. For vision underwater, we have four Teslong waterproof endoscope cameras mounted on servos for pan and tilt functions. SEALbot is still very much a living ROV and has evolved during practice to address challenges that have arisen.

Throughout the design process, SEALbot evolved to match up well with mission tasks and specifications. New software functionality was added such as inverse mode, which gives the pilot the ability to invert all control output for tasks such as deploying and retrieving the hydrophone; precision mode, which allows more refined movement control to aid in precision reliant tasks like replacing the buoyancy module on the inter-array cable; and the implementation of camera output visible from our GUI, which centralizes all import sensor output into one place.

Figure 5: SEALbot overhead view showing the 4 small DiamondDynamics Vertical Thrusters.

On the ROV itself, the addition of mounting points for mission-specific hardware allows for quick mounting and removal, shortening time out of the water. Also, servo mounts allow for even more advanced challenge specific solutions. While none of this is exactly what was planned from the start, the evolution of SEALbot has resulted in a product that meets and exceeds mission specifications.

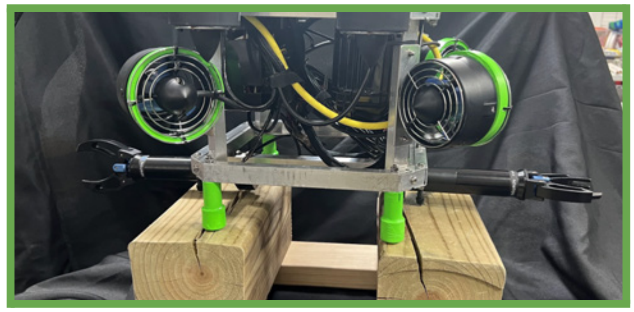


Figure 6: SEALbot's Dual Grippers can both extend and rotate to efficiently tackle the mission task at hand..

Tether:

SEALbot's tether contains only 3 cables in total, one of which is a Blue Robotics Fathom ROV Tether (Cat5) cable as described in Table 3 (below). The tether is bundled and covered with F6 split loom to protect against chafe and to keep everything together. In addition, velcro ties are used to hold the split loom closed. A tether length of 20.1 m was adopted to readily accomplish mission objectives even in deeper water when required. We tested to ensure that voltage drop in this longer tether was within the necessary parameters. One of our primary objectives for this year was to have a thin 3 wire tether.

Multiplexing all Video, Sensor data, and all ROV controls over a single cat5 wire was not easy, but the payoff is huge in a small, nimble tether.

Table 3. Wires that make up the SEALbot ROV tether.

Wire Type	Usage
Primary - 8 gauge power	12V Power
Primary - 8 gauge ground	Common Ground
One - Cat 5	(Everything) Multiplexed Video, Sensors, and all ROV Controls.

Control/Electric System:

Whereas previous systems developed by SEAL featured Aruinos on the surface, SEALbot uses a Raspberry Pi 4.0 in an on-board drybox housing. This means that for Competition 2022, SEAL's system **does not feature any control box**, just a single laptop on land. The laptop runs the GUI, written in python, and communicates with on-board systems through the tether. The Raspberry Pi in the ROV's drybox runs a Python program as well, that functions as a servant to the program being run on the laptop. They are connected via custom-written serial communication software. The Raspberry Pi supplies data from our sensors and sends it to the GUI program for analysis. The GUI program then makes calculations and sends instructions back to the Raspberry Pi. The Raspberry Pi uses those values to change the thruster speed and gripper positions. The analogy is similar to a central nervous system calling the shots (the GUI program) and a peripheral nervous system accepting instructions and sending back sensor values (the Raspberry Pi). This approach allowed us to update only the GUI Program frequently, rather than both programs.

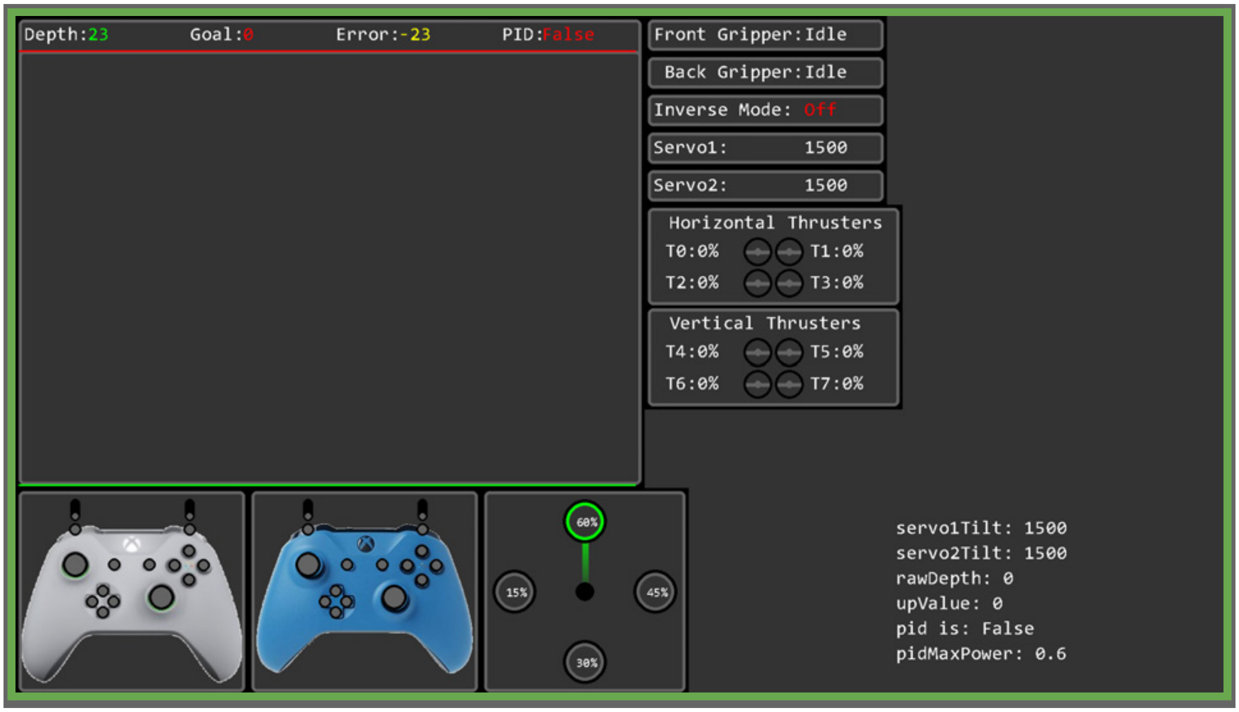


Figure 7: Screenshot of GUI drive control. Camera feed displayed on secondary monitor.

The SEALbot system has a variety of waterproofed components. For our cameras, we selected four Teslong 3rd Generation USB Borescope cameras. In order to articulate our cameras, we used Hitec D956WP digital waterproof servos. These servos have performed well even at deeper water levels. In order to power these servos, we used adjustable DROK DC buck transformers. We waterproofed these transformers using West Marine epoxy. In order to control the eight thrusters on SEALbot, we have on board Blue Robotics Electronic Speed Controllers (ESCs), waterproofed by potting in West System Epoxy. Since the Diamond Thrusters come with waterproofed ESCs, we only waterproofed four ESCS for our four T200 Blue Robotics Thrusters. Having on-board ESCs makes our tether far lighter than "home running" high power wires for each thruster, and thus improves our maneuverability. The SEALbot system uses two Subconn connectors, a Blue Robotics Wire Penetrator, and some custom Thru-Hull solutions to transfer signals into our Otterbox drybox.

GUI and Drive System:

Every year, we try to challenge ourselves by updating and refactoring our GUI in a new Programming language. This year is no exception. We have a Raspberry Pi 4 in a drybox of our ROV that controls all of our electronics. Our custom drive software is connected to our GUI (written in Python) on land through Ethernet and a TCP connection. We receive input from two Xbox controllers, which makes it simple for anyone to pick one up and pilot SEALbot. Our two-way communication facilitates the transfer of sensor and camera input from the ROV, and thruster and servo outputs from our GUI.

An example of this being important is with our Proportional-Integral-Derivative (PID) controller, which brings the ROV to a user-selected depth with the help of a depth sensor. We decided to use a TCP connection to the Raspberry PI since it could handle all of the data we wanted to send back and forth–including video–quickly and securely. Requiring only a CAT5 cable down to the ROV has reduced our tether size greatly and improves our movement through the water. Due to this design, both programs are tightly integrated, so redundancy in case something goes wrong has been a big priority for us in this competition.

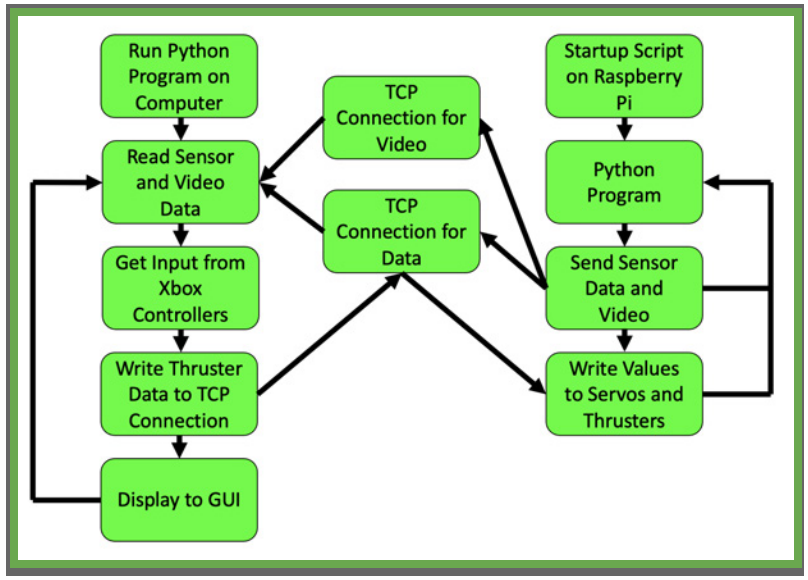


Figure 8: Flow Diagram of SEALbot Raspberry Pi and Laptop Python software stack.

Xbox Drive Controllers:

SEALbot is controlled using two wireless Xbox controllers. These controllers communicate with the GUI program which makes all necessary calculations and displays desired input on the GUI. The Raspberry Pi program then receives data and instructions via a serial interface. The Arduino reads the data (ie, thruster values, gripper values, etc) and writes to the thrusters, gripper ESC, and servos.

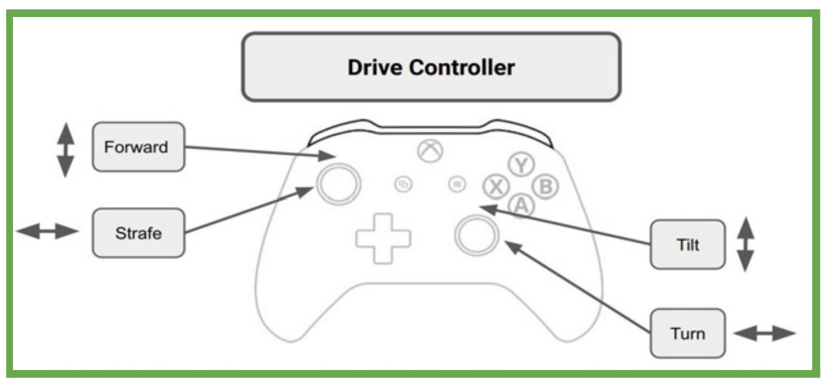


Figure 9: Xbox Drive Controller control scheme.

Tether Management Protocol:

Below is our tether Management Protocol, which is also listed in our team's Job Safety Analysis (JSA) document.

4.b. **Tether Management Protocol**

i. Ensure that tether is coiled in a small area away from the deck crew (apart from the appointed tether manager).
ii. No person is to step over the tether unless absolutely necessary.
iii. When putting the ROV into the pool, kneel to avoid falling in .
iv. Stay away from the edge of the pool whenever possible.

Propulsion

For propulsion, SEALbot utilizes a total of 8 thrusters, comprised of four Blue Robotics T200 Thrusters and four Diamond Thrusters. This year, our main goal regarding propulsion was to improve our ROV's overall speed and maneuverability in the water. For this reason, four T200 thrusters are attached along the horizontal plane of the ROV in order to boost SEALbot's horizontal velocity. In the vertical plane, we decided to use four Diamond thrusters, which draw less power and were much cheaper, without compromising significantly on speed and lift power. These Diamond thrusters are mounted on top of each of the four corners of the ROV. Additionally, we considered many options and ultimately decided to vector SEALbot's horizontal thrusters. Vectored thrusters are crucial to meeting our goal of increased maneuverability, as they significantly help the ROV turn faster and more precisely.

Figure 10: Blue Robotics T200 Thruster

Figure 11: Diamond Dynamics 1.2kg Thruster

Buoyancy and Ballast

In planning, we set out to create an ROV system that is neutrally buoyant at the surface of the water. This would provide SEALbot with increased stability in the water, while minimizing the amount of power required by our PID stability system, which maintains a certain depth. To create neutral buoyancy, SEALbot is equipped with polystyrene high density foam located at the very top of the system. After testing various configurations for buoyancy, we settled on the top as the best location. Locating the flotation at the top and most of the weight (gripper gearboxes and motors) at the very bottom led to a very stable ROV in testing. Through trial and error, we optimized the amount and position of the polystyrene foam, as well as foam inside the tether sheathing to optimize the buoyancy of the entire ROV system.

Payload and Tools

Servo Motors and Cameras:

SEALbot uses four 3rd Generation Teslong Auto Focus endoscope inspection cameras. These cameras are lightweight, for the most part come pre-waterproofed, give us clear images, and are extremely economical. As opposed to previous years, these cameras use a USB connection, which is hooked directly into our drybox to the Raspberry Pi. We had concerns that the field of vision (FOV) of these cameras would be too limited for them to be practical underwater; however we found that, when combined with our new servo driven camera aiming system, their FOV proved more than adequate.

On previous systems, we have focused on using many different adjustable cameras in order to gain a larger viewing range in the pool. This, however, resulted in significant increases to ROV weight and required electronics infrastructure. Thanks to the addition of a Raspberry Pi, which can control servo motors, this year we have decided to take a different approach and instead have four cameras that can tilt up and down on the y-axis. This change has allowed us to have one camera do the job that 2 or 3 cameras would do in the past. For example, while flying the transect line on the wall we need a more forward facing view for the best accuracy and vision. However, for the power array cable placement, we need a camera that faces down in order to have extreme accuracy. Thanks to our servo motor system, we only need one camera to complete both of these tasks. This contributed to the smaller size of this system's tether and other improvements as we were able to divert our manpower to other areas on the ROV because of how much time this simple system saved us in the build.

Figure 12: Camera mounted on flexible armature wire above the front gripper, which we refer to as a "birds eye" camera. The servo allows the camera to tilt or pan, greatly increasing the field of view.

Figure 13: Teslong 3rd Generation Auto Focus endoscope inspection camera with integrated light and USB plug..

Grippers:[1]

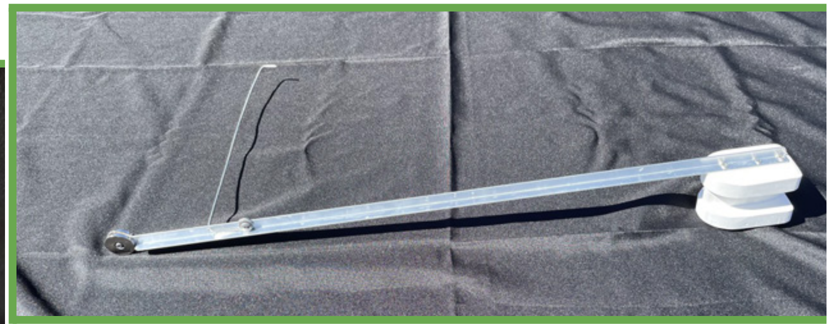
A staple of SEAL Robotics pool runs has been multitasking. To that effect, we've put Blue Robotics grippers on both the front and back of our ROV. We have cameras mounted in both of these positions as well as a dedicated "inverse mode" in our program to allow either end of SEALbot to function as the "front." This allows for easy use of our grippers which can be rotated and extended according to the task at hand for optimal efficiency. The grippers we have chosen are strong and robust, allowing for precision handling of light and heavy objects alike.

Custom Tooling:

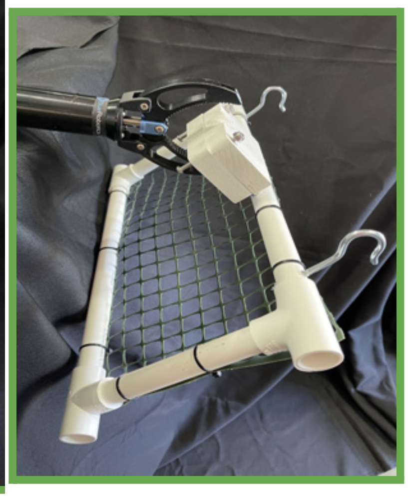
SEALbot utilizes several custom-built, mission-specific tools that can be attached and removed from the ROV quickly. In Figure 17 below, we show several examples of the custom tooling created to improve efficiency.

[1] https://www.youtube.com/watch?v=gzDhCUafj9w

Second iteration of tooling to capture the GO-BGC Float. At the top is a catch made from an Ikea hook that is actuated by a rubber band to capture the float.



Combo tool for ghost net pin removal and retrieval of the net.



Custom PVC gripper jaw insert tool holds the fish pen patch at the optimal angle for placement.

Gripper claw insert with neodymium magnets for removing tent stakes that simulate cutting the undersea cable.

Figure 14. Mission-Specific Tools **c**ustom designed to execute mission tasks efficiently.

Buoyancy Engine Powered Vertical Profiling Float:
We created a Vertical Profiling Float following the MATE non-ROV Device (NRD) specifications, specifically engineered to utilize a buoyancy engine to execute two vertical profiles during the competition demonstration period. After several design and test iterations, we settled on a simplistic solution.

General Construction:
The SEAL Robotics Vertical Profiling Float contains an integrated buoyancy engine. The housing of the float is constructed from 4" PVC pipe with a syringe potted in epoxy on one end, and a rubber cap on the other end. Inside is a 500ml syringe, a linear servo and an Arduino Mega microprocessor. The separate battery housing is constructed from 3" PVC pipe. The battery housing has an integrated 7.5A fuse, as well as a pressure relief valve in the form of a 30cm rubber stopper. The vertical profiling float's **dimensions** are 97 cm in length and 12.7 cm in diameter, which falls within the MATE specifications.

Propulsion:
Propulsion is provided by a buoyancy engine. An Arduino Mega controller governs the linear servo action to change buoyancy of the float once every 4 minutes. This causes the float to iteratively dive and surface.

Figure 15. SEAL Robotics Vertical Profiling Float with battery compartment on top.

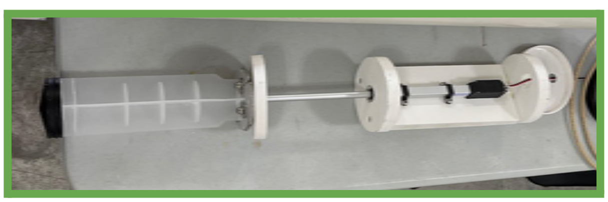


Figure 16. SEAL Robotics Vertical Profiling Float internals - linear servo and syringe plunger.

Float (NRD) Fuse Calculations	
Device	**Current Draw (Amps)**
Arduino	0.2
Linear Servo	4.7
Total Calculated Current (Amps)	**4.9**
Overcurrent Protection Factor	**150%**
Fuse Calculation (Amps)	**7.35**
Round to Fuse Size (Amps)	**7.5**

Table 4. Fuse calculations for the Vertical Profiling Float.

Build vs. Buy, New vs. Used

Since we designed and built an ROV system from scratch, we were able to reevaluate every component from previous years, and determine whether to reuse them or go in a different direction. We decided early on reliability was of utmost importance, and that we would let cost and time savings also drive build vs. buy decisions. We also decided that certain components that had performed flawlessly would be reused. We made a conscious decision this year to shy away from building our own components to instead focus on the integration of more advanced commercial components. As a team of MATE veterans and high school seniors, we recognize that future employers will charge us with buying off the shelf hardware and seamlessly integrating them to work well together, rather than building individual components from scratch. As a result, many of our Build vs. Buy decisions this year were based on compatibility and the creation of the best possible system without as much design effort.

Drybox Housing (Buy instead of Build):

This year, we decided to modify a prebuilt Evergreen 56 Waterproof Drybox, by adding custom cable penetrators and subconn connectors to suit our needs. We decided to do this rather than buying a standard drybox using built-in cable penetrators because we do not need our cameras to be in our drybox and we had issues with commercial dry boxes with cable penetrators in the past. We made a significant number of modifications to the drybox to improve reliability including: (a) the addition of marine-grade grease to the box's seal and (b) the presence of hyper-absorbent fiber within the box as a last defense against a water-intrusion event. Our custom-made dry box also comes with multiple practical advantages like the ability to add extra penetrations if needed. Another advantage to our drybox is that it allows us to customize the size the cable penetrators come into the box which leads to high space efficiency. On the other side of the tether, but we decided this year we would only have a laptop and monitor on shore instead of a pelican case. Instead of buying a prebuilt dry box, we decided it was more advantageous to create our own using commercial parts.

Gripper [2](Buy instead of Build):

Last year's custom-built gripper system required a significant investment of both time and resources. While it performed admirably in the water, it was clear that fully refurbishing and successfully integrating that system into SEALbot would require more of an investment than we could handle with our reduced team size. As a result, we decided to purchase a pre-built gripper system from Blue Robotics. This decision has allowed us to divert resources to other vehicle systems without compromising overall system performance by cutting corners on this crucial component.

Figure 17. Gripper

Drive Controllers (Buy instead of Build):

The Drive Controllers are an area where we ultimately chose to **buy** instead of **build**. In previous years we had built controllers out of switches, joysticks, and potentiometers, but when we weighed the cost and the reliability against a relatively inexpensive wireless Xbox One controller ($62), we decided to buy them this year.
This turned out to be a good decision, as use of these ergonomic controllers has allowed the pilots to focus more on the status of the ROV and the task at hand, rather than accessing several different devices for control.

[2] https://www.youtube.com/watch?v=h4pMCnDv_eE

Figure 18. Xbox Drive Controller.

Thrusters (Buy instead of Build, and Reused this Year):

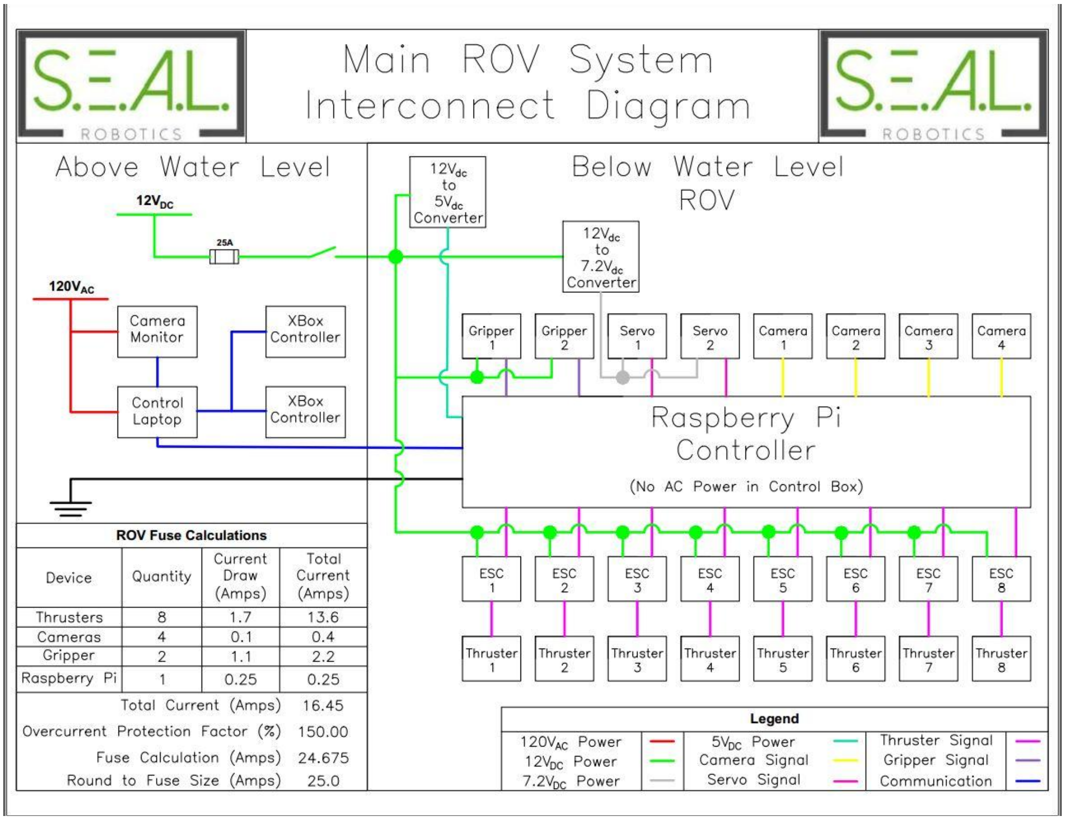
SEALbot utilizes commercial Blue Robotics T200[3] thrusters (Fig. 21). The thruster is made out of polycarbonate plastic, and the motor is sealed with an epoxy covering and uses all corrosion-resistant components. The only disadvantage of using these thrusters is the high price. Each T200 thruster costs about $200, while a typical bilge pump thruster costs around $30. At the original purchase, we decided that the thrusters' robust and dynamic design justified the price of this mission-critical hardware. Compared to our previous systems, which used several thrusters for forward and reverse and strafe, SEALbot uses a vectored thruster configuration. This allows the ROV to move in any direction with great precision, improving upon mission performance.

Figure 19. Purchased for the ROV this year - Blue Robotics T200 Thrusters

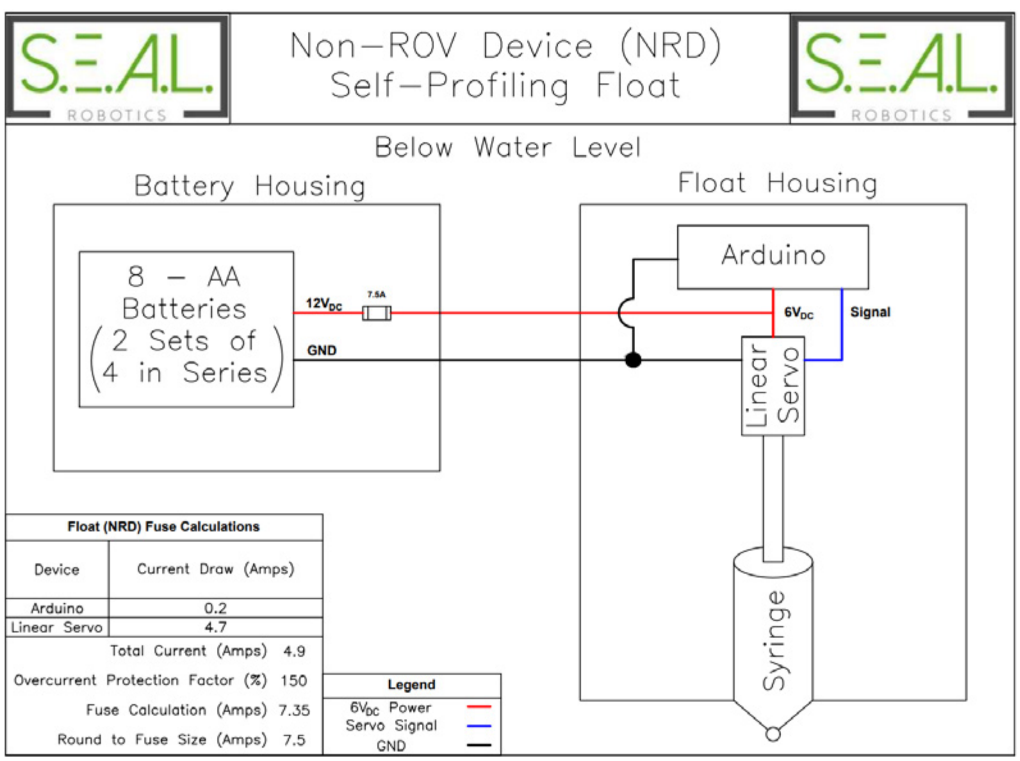
[3] https://www.bluerobotics.com/store/thrusters/t100-t200-thrusters/t100-thruster/

SYSTEM INTEGRATION DIAGRAMS (SID)

Main ROV SID



Vertical Profiling Float SID



SAFETY

Safety Rationale and Philosophy

Safety of team members and the safety of our products is of primary importance to SEAL Robotics. We work not only to address safety issues and concerns, but to proactively prevent them before they occur. Inspired by OSHA (Occupational Safety and Health Administration) suggestions from their OSHA10 program, "near miss" safety incidents are carefully reviewed by all team members in order to develop protocols that minimize risk from human error. We use safety glasses, ear protection, proper clothing and closed shoes, and other safety equipment when working with hazardous equipment, and our mentors provide safety training on each tool. We carefully insulate all exposed electrical connections, and we use GFCIs when working with 120 VAC power sources, regardless of whether we are near water. In light of the COVID-19 pandemic, we took extensive precautions to socially distance, utilize video meetings when possible, use outdoor work locations whenever possible, clean surfaces, wash/sanitize hands regularly, wear masks at all times when sharing a room or workspace, and comply with US Center for Disease Control guidelines.

Safety Features

Our ROV system includes a number of safety features:

- Shrouded thrusters (Fig. 22), with high visibility caution stickers
- Single Main Power Switch cuts all power to the ROV.
- Software failsafe: Software only activates once the driver presses "enter", once all members of the drive team are in "ready drive position" (Fig. 23).

Figure 20. Safety shrouds installed on all thrusters.

Pre-Run Safety Checklist

- All nuts and bolts and attachments are secured.
- Thruster shrouds are secured and tight.
- Thrusters unobstructed - no foreign objects inside thruster shrouds.
- All wires are secure and in good condition.
- There are no sharp edges and/or corners on the ROV.
- Drive table set up is clean and organized.
- All members of the drive team are in "ready drive position" (Fig. 23).

Produce Demonstration Safety Checklist

- Tether manager is the only person handling the tether (other team members cannot step over the tether).
- Power connection is secure and not near water.
- GFCI (Ground Fault Circuit Interrupter) is used for monitors, laptops, and power supplies.

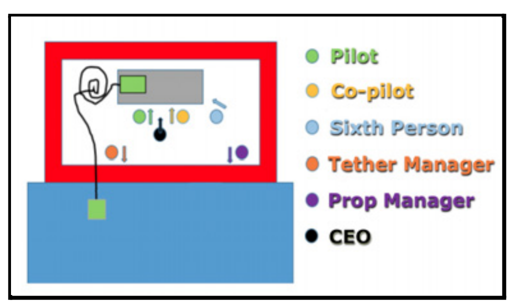


Figure 21. Poolside ready positions for safety and efficiency.

- Control station equipment is securely placed on the table (away from edges of table surface) in a clean and organized fashion.
- Team members must walk at all times (running/jogging is not allowed during demonstration).

Post-Run Safety Checklist

- Make sure all equipment is safely removed from the product demonstration area.
- All nuts, bolts, and attachments are secured.
- Thruster shrouds are secure and tight.
- Thrusters unobstructed - no foreign objects inside thruster shrouds.
- All wires are secure and in excellent condition.
- Ensure there are no water leaks or damage.
- Members thank and coordinate with judges and staff.

ROV Construction Safety Checklist

- Personal Protection Equipment (PPE): Eye and hearing protection, close-toed shoes, and proper clothing must be worn in workspaces.
- Proper Training: Team Members must be trained on a given tool before using it.
- Hazards: Loose clothing and hair is tied back before using tools.
- Power: Power is off to any components that are being worked on or soldered.
- For a comprehensive list of our ROV Construction Safety Checklists, see our separate Job Safety Analysis (JSA) document.

CRITICAL ANALYSIS

Testing Methodology

Our **testing strategy for the complete vehicle** was based around performing mission tasks in the pool, which revealed weaknesses in our system that needed refinement. This often allowed us to identify critical flaws in the system that would impact its performance where it really matters: in the field. Implementation of system changes and in-pool testing went hand-in-hand to assess the performance and reliability of SEALbot.

Strategies and Techniques for Troubleshooting

Our troubleshooting strategy was based on a systematic isolation of problem areas by outlining all components of a faulty system and then methodically testing each component. Examinations of individual components were documented until the problem could be isolated and solutions could be proposed. In such a complex system, it is important that team members consider all possible points of failure, both to address current problems as well as prevent those that may arise in the future.

Prototyping and Testing

Prototyping was an essential part of SEALbot's design process. The aimable camera system on SEALbot was extensively prototyped and tested before it was chosen. Testing for water intrusion included tests in a trash can filled with water, as well as a 5 hour torture test at the bottom of a 4 meter pool. Camera field of view, focus, and signal degradation were also measured in order to choose the best camera solution. Three other camera types were rejected due to water intrusion, inadequate field of view, or lack of auto focus. Only after extensive testing and evaluation did we accept the approach and invest in additional cameras and servos of the chosen models. Another example where we did extensive testing was with our IP67 rated Evergreen 56 Drybox. We knew that true IP67 resistance to water intrusion would not be adequate for our purposes. We initially performed an overnight test with this box tied to bricks in the bottom of a 4 meter pool. After several such tests we determined that this box was built beyond spec, and we felt comfortable integrating it into our system. Other systems such as SEALbot's custom tooling also went through numerous prototyping iterations to arrive where they currently are. After testing in the pool, tooling was refined and tested again and again until performance was fully optimized.

Dedicated Testing Rigs and Trash Cans

Countless hours of testing are required in order to build a reliable ROV. We created multiple dedicated testing rigs to simulate the environment and tune our hardware and software. Pictured below (Fig 24) is one such testing jig that we used to measure power consumption and voltage drop, and analyze the effects of different precision mode settings. This dedicated testing rig matches actual conditions (e.g. 15.2 meters of tether, the same software, ESCs, firmware, power, gripper components, etc.).

As crazy as it sounds, for us a 90 gallon trash can filled with water (Fig 25) may be our most indispensable testing tool! We constantly used a trash can, testing everything: thrusters, cameras, sensors, mission tooling, ROV PID software, depth sensors, Profiling Float, etc.. For accurately measuring buoyancy, we use a suitcase scale while suspending the item in the water.

We spent many hours testing and tuning the hardware and software. We built a dedicated testing rig (Fig. 24) that matched actual conditions (e.g. 15.2 meters of tether, the same software, ESCs, firmware, power, gripper components, etc.). Similarly, we needed to objectively measure and tune grip strength. We made a measurement device using a kitchen scale to accomplish this (Fig. 25).

Figure 22. Thruster testing jig used to measure power consumption and to analyze the effects of different precision mode settings.

Figure 23. SEALbot has undergone over 40 hours of in-water testing to date.

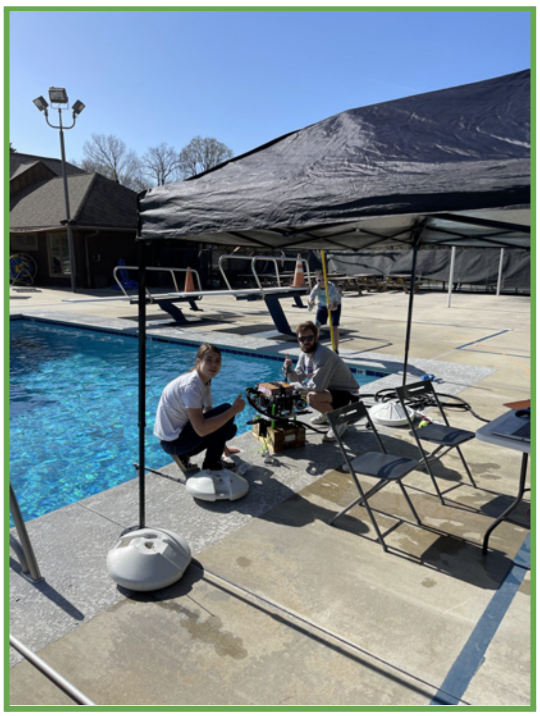


Figure 24. The time that we invest in testing systems for reliability, and the hours that we practice execution of the MATE mission are key to our team's success.

Figure 25. A 90 gallon trash can filled with water may be our most indispensable testing tool, testing everything: thruster power, cameras, sensors, mission tooling, PID software, depth sensors, Profiling Float.

ACCOUNTING

Budget

BUDGET - SEAL Robotics ROV Build 2022 October 2021 - May 2022				
Income				
Source				Amount
SEAL Robotics Team Membership Dues and monetary donations earmarked for ROV Project				$ 7,350.00
Expenses				
Category	Type	Description	Projected Cost	Budgeted Value
Printing and Imaging	Purchased	Printing and binding MATE documentation, technical reports, pictures, etc.	$ 135.00	$ 135.00
Registrations	Purchased	Competition Registrations	$ 200.00	$ 200.00
ROV - Cameras	Purchased	Cameras, cables, connectors, adapters, multiplexers, screen grab software, etc.	$ 850.00	$ 850.00
ROV - Prop Supplies and Tooling	Purchased	Prop building supplies, supplies for custom tooling for challenges	$ 375.00	$ 375.00
ROV - Grippers	Purchased	Grippers, motors, servos, controllers, etc.	$ 1,550.00	$ 1,550.00
ROV - Thrusters and Electronics	Purchased	Thrusters, ESCs, balluns, boards, waterproof cases, etc.	$ 1,255.00	$ 1,255.00
ROV - Frame and Tether	Purchased	Aluminum, fasteners, strain relief, tether wire, sheath, plugs, waterproofing, etc.	$ 720.00	$ 720.00
Dry Control Box	Purchased	Raspberry Pis, connectors, thru hull, epoxy, waterproof penetrators, wiring, etc.	$ 825.00	$ 825.00
Misc	Purchased	Misc and budget allowance for overruns	$ 950.00	$ 950.00
Travel	Purchased	Travel to Competition *(7 hotel rooms for one night @ $110, $510 for van rental and gas, and $490 total for meals).*	$ 1,770.00	$ 1,820.00
ROV - Video	Reused	32" monitor	$ 297.00	$ -
Main Control Box	Reused	Power supplies, meters, etc.	$ 550.00	$ -
ROV - Thrusters and Electronics	Donation	Subconn Connectors	$ 1,192.30	$ -
			Total Projected Income Available	$ 7,350.00
			Total Projected Expenses	$ 10,669.30
			Total Projected Expenses minus Re-use and Donations	*$ 8,630.00*
			Total Fundraising Needed	*$ (1,280.00)*

Table 5. Project Budget for 2022 season ROV build.

Cost Accounting

PROJECT COSTING - SEAL Robotics ROV Build 2022 October 2021 - May 2022							
Date	Type	Category	Expense	Description	Source / Notes	Amount	Running Balance
Oct-21	Donated	Electronics	Control Box	Two Subconn Ethernet Connectors	Dry Box	$ 1,192.30	$ 1,192.30
Oct-21	Reused	Electronics	Monitor	32" monitor	Monitor	$ 297.95	$ 1,490.25
Oct-21	Reused	Electronics	Control Box	Power supplies, inline power meter, etc.	Control Systems	$ 328.00	$ 1,818.25
Nov-21	Purchased	Electronics	Thrusters	4 Blue Robotics T200 thrusters and 4 Diamond Dynamics thrusters	Thrusters	$ 979.62	$ 2,797.87
Nov-21	Purchased	Hardware	Grippers	Blue Robotics Newton subsea grippers and aluminum stock and stainless fasteners to fabricate gripper mounts.	Grippers	$ 909.61	$ 3,707.48
Nov-21	Purchased	Materials	ROV	Aluminum stock for ROV chassis and tooling.	New chassis	$ 131.94	$ 3,839.42
Dec-21	Purchased	Electronics	Video Components	Camera cables, cameras, video connectors, screen grab software, other video adapters, multiplexer, baluns, cat7.	New video solution	$ 552.36	$ 4,391.78
Dec-21	Purchased	Printing	MATE Docs	Printing and binding of MATE docs, score sheets, etc.	Printing	$ 229.34	$ 4,621.12
Jan-22	Purchased	Electronics	Dry Box and Wet Box	Raspberry Pis, voltage and current sensors, PCB boards and electronic components, pelican case, aluminum, USB plugs, jumper wires, penetrors, anderson bulkhead plugs, 3M vinyl, knob, wire loom, hookup wire, fuse block, ESCs, paint, stainless fasteners, wire management, LEDs, armature wire, velcro, strain relief materials.	Dry Box and Wet Box	$ 827.00	$ 5,448.12
Jan-22	Purchased	Materials	ROV	Waterproofing supplies (Silicone RTV, heat shrink, liquid electrical tape, 3M Ultra Black, epoxy, etc.), terminal ends, fuses, plugs, LED lights, etc.	Waterproofing general	$ 262.49	$ 5,710.61
Feb-22	Purchased	Electronics	Video Components	Additional cameras, plexiglass, epoxy and hardener, aluminum wire, armature wire, stainless washers, waterproof grease, m3 fasteners, camera servos, cameras	Cameras and waterproofing and mounts	$ 872.12	$ 6,582.73
Feb-22	Purchased	Hardware	Tooling	Aluminum stock, PVC stock, epoxy, netting, fasteners, carabiners, zip ties, polystyrene foam, magnets, m3 fasteners, foam, electrical tape.	Tooling for challenges	$ 162.12	$ 6,744.85
Feb-22	Purchased	Materials	ROV	Velcro, additional waterproofing materials, additional wire, fuse holders and fuses, ballast supplies, epoxy, tether wire, sheath.	ROV internal systems	$ 314.97	$ 7,059.82
Mar-22	Purchased	Electronics	Self-Profiling Float	Arduino, waterproof plugs, syringe, linear servo, battery holder, silicone RTV caulk, m3 fasteners, 4" PVC, 3" PVC rubber cap, drain tailpiece and stopper, fuse holder, epoxy	Self-Profiling Float	$ 236.50	$ 7,296.32
Mar-22	Purchased	Electronics	Control Box	Main disconnect switch, toggle switch panel, SPDT switches for gripper control, resistors.	More control box components	$ 191.97	$ 7,488.29
Mar-22	Purchased	Registration	Registration	MATE Regional Competition Registration	Registration	$ 200.00	$ 7,688.29
Apr-22	Purchased	Electronics	Tooling	More aluminum, epoxy, stainless fasteners, brackets	Tooling/Repairs	$ 211.36	$ 7,899.65
						Total Funds Raised	$ 7,350.00
						Total Spent	$ (7,899.65)
						Balance (additional fundraising/donations required)	$ (549.65)

Table 6. Project Cost Accounting Expenditures for the 2022 ROV build.

ACKNOWLEDGMENTS AND SPONSORS

We appreciate the people of the MATE organization for all of the help and resources they provided this year. Similarly, the following companies helped us by donating materials, money, or advice to help us build our ROV (Table 7):

https://www.marinetech.org	http://www.greensbororadiology.com
http://zibster.com	http://www.theimagingsource.com
http://www.macartney.com	http://powermaxconverters.com
http://www.kelleramerica.com	Lake Jeanette Swim and Tennis http://ljclub.com

Table 7. Sponsors.

Special thanks to:

All the MATE volunteers: Dennis Courtney and Taylor Burgess, as well as all of the volunteer judges.

Marine Technology Society, Ocean Encounter, Schmidt Ocean Institute, Ocean Infinity, and Motorola Solutions Foundation: for sponsoring MATE Underwater Robotics Competitions.

Our Parents: Thanks for bringing us to all of our meetings and practices at the pool. Thanks for funding and supporting the team!

Our Team Mentors: Thanks for encouraging us, guiding us, and helping us when we got stuck.

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