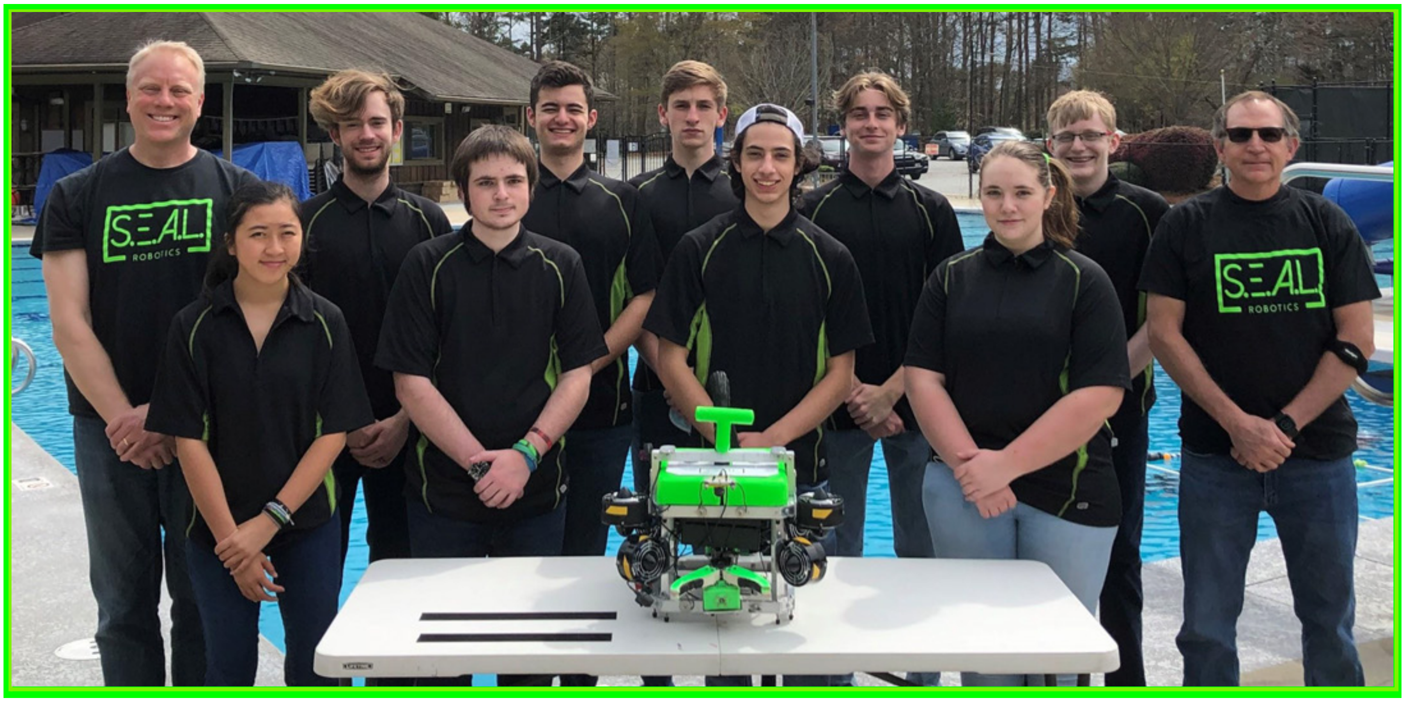
SEAL Robotics Team

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



2021 Team Member	**Primary Roles**
Michael Scutari	co-C.E.O, Programmer, Tech Writer
Jonathan Bacon	co-C.E.O., Project Manager, Tech Writer, ROV Pilot
Nathan Ruppel	Challenge Design Expert, Mechanical Engineer
Ben Liebkemann	Lead Team Programmer
Owen Voorhees	Mechanical and Lead Electrical Engineer, Programmer
Quinn Welch	CAD Designer, Fabrication Expert, Mechanical Engineer
Li Yan Snyder	Marketing Director, Mechanical Engineer
Phillip Szypulski	Video Expert, Electrical Engineer
Caroline Ruppel	Tech Writer, Mechanical Engineer, and Prop Specialist
Clay Austin	Mechanical Engineer and Tech Writer

Team Mentors: Ned Voorhees, Kurt Ruppel, Walt Liebkemann, Robert Welch

Table of Contents

ABSTRACT

The 2020-2021 SEAL Robotics season activities have included team-building, leadership training, community outreach, advanced original software design, fabrication, safety culture promotion, and adult and peer mentorship. This process centered around the creation of a Remote Operated Vehicle (ROV) system "Hammerhead" (Fig. 1). This ROV system is ideal for the tasks of addressing the ubiquitous problem of plastic pollution, the catastrophic impact of climate change on coral reefs, and maintaining healthy waterways.

Major new mission-specific original designs and fabrications for 2020-2021 include dual easily replaceable worm gear grippers, original custom written software for drive control utilizing Proportional Integral Derivative (PID) methodology to enhance vehicle stability in the water, a user-friendly Graphical User Interface (GUI) with built-in camera output, software for generating a coral reef identification simulation using image recognition, thruster reconfiguration for enhanced maneuverability, and custom mission-specific attachments. The ROV and drive system was built methodically, consistent with the stated goals of sustainability and resource conservation.

Organizationally, pre-meeting goal lists were employed to ensure that we maximized our working time. Documentation was maintained by subteams and archived as produced on a shared, cloud-based team archive, with an editorial subteam merging the information into one document.

Since our founding in 2017, no injuries or safety incidents have occurred.

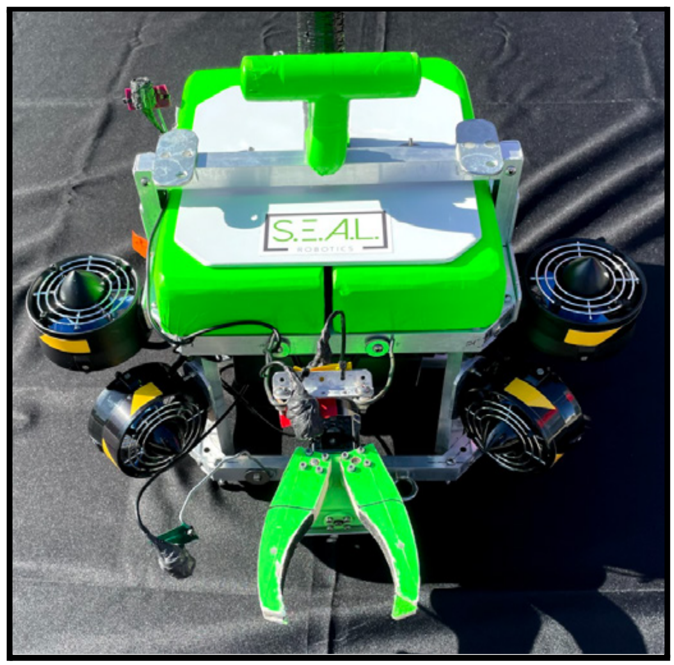


Figure 1 (Right). The 2021 SEAL Robotics ROV, "**Hammerhead**".

COMPANY OVERVIEW

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

Mission: We leverage team approaches and peer mentorship to develop original, customized, industry-leading robotics platforms.

Vision: We are enabling and nurturing the problem solvers 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. 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 is to also consider herself or himself a peer-mentor in order to share knowledge and help on-board new members.

PROJECT MANAGEMENT

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

- **Develop an overall timeline and budget** and revise as necessary - performed by member leaders in conjunction with mentors. Timeline follows in Table 1.
- **Divide and Conquer: Use 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.

Target Date	SubTeam Lead	Task
2-Dec-2020	-	Create Timeline, make Assignments, study MATE docs
9-Dec-2020	Everyone	Read MATE Competition documentation released so far before the next meeting.
16-Dec-2020	Nathan	Begin building "Props"
16-Dec-2020	Oliver	New Drive System Programming Complete and Tested on the ROV
30-Dec-2020	Phillip	2nd Gen *Micro* ROV build complete
30-Dec-2020	Ben	GUI Programming Complete and Integrated and Tested with ROV Drive System
6-Jan-2021	Nathan	"Props" build 100% complete
13-Jan-2021	Quinn	First redesigned Gripper complete and installed
3-Feb-2021	-	First trial at pool with props, single gripper, and Micro ROV
1-Mar-2021	-	Register for Regional Competition
16-Mar-2021	-	Additional manipulators/tooling complete and installed on ROV
16-Mar-2021	-	Video Recognition Software Complete (if team decides to pursue)
20-Mar-2021	-	First Draft of Technical Report Complete
1-Apr-2021	-	Final Draft of Technical Docs Complete and submitted to Regional
1-May-2021		Regional in Kingsport
1-Aug-2021	-	International Competition?

Table 1. Timeline developed for the 2020-2021 SEAL Robotics build season.

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.

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	**Owen,** Michael, Ben
Programming - GUI	**Ben,** Owen, Michael
Programming - Video Recognition	**Michael**, Ben
Programming - Manipulators, Challenge Specific	**Owen,** Michael
Props - Research and Building	**Nathan**, LiYan, Phillip, Jonathan, Quinn
Gripper - Design and Build	**Quinn**
Micro ROV Design and Build	**Nathan**, Caroline
Challenge-specific Designs and Builds	**Nathan**, Caroline, Clay, Phillip, Jonathan

Table 2. Subteams and team member roles 2021.

Overcoming Day-to-Day Challenges

One of the biggest challenges that we faced this season was the COVID-19 pandemic and its effects on the team's productivity, morale, and ability to meet in person. Even though the team could not meet in person for several months, each team member continued to do their part from home, working to the best of their capabilities to ensure that all projects could be smoothly resumed once meetings resumed. Though not ideal, we made the best of it and met via Zoom for many months, and recorded the meetings for reference. Each of our meetings used a standard structure with goal-setting at the beginning of the meeting, and then a summary at the end.

ROV DESIGN RATIONALE

Engineering Design Rationale

For the 2021 competition, SEAL Robotics has developed Hammerhead. As opposed to our previous system, Mako, Hammerhead was designed to promote increased mobility both in and out of the water. 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 both the Mako and other systems at the 2019 competition, and the expert opinion of knowledgeable mentors as well as our diverse group of experienced team members. This year, we are happy to present Hammerhead for competition.

Innovation

Hammerhead features numerous innovations that improve upon system reliability, usability, and performance when compared to SEAL's previous system, the Mako. The transition from poolside ESCs to waterproof ESCs onboard the ROV has drastically reduced the size of the tether, resulting in a more nimble system. In addition, this change has allowed us to make our tether detachable, making system transport much more convenient. Performance of the gripper system has also been significantly improved. Hammerhead features grippers powered by waterproof BlueRobotics brushless motors.

We created an innovative modular design, so that Hammerhead's grippers or cameras are now easily replaceable: a job that took a tremendous amount of time with Mako can now be accomplished by one person in under 10 minutes.

Other simple innovative features such as this year's addition of a strong, prominent handle (Fig. 2) help with poolside handling and ROV transport.

Figure 2: ROV Handle Pictured.

Problem Solving

Effective problem-solving is at the core of Hammerhead'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. As an example, one major problem we encountered was the amplification of a 5V signal being sent over our 50ft tether. While we were only sending 5V down the tether, the ESCs mounted on the ROV received a significantly greater peak voltage of up to 18V. After one of our ESCs was burned up, the problem became urgent and a group was assigned to work on the problem. After investigation and discussion, we decided to invest in an oscilloscope in order to examine the peak voltage of the PWM signals. With the new oscilloscope, we were able to identify the problem and fix it with the addition of 100 OHM resistors on each signal wire. By working together to address problems, we were able to brainstorm new ideas and quickly find solutions that would have taken individual members a significant amount of time.

Systems Approach

All of the systems on Hammerhead are tightly integrated and designed to be simple but effective. We have multiple cameras on the ROV 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 gets their inputs through two Xbox controllers and a few switches. The drive system then takes information from the control system and powers our thrusters to give us fine 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 Hammerhead as effective as it could be on tasks this year.

Vehicle Structure

When discussing the possible structure of Hammerhead, 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 Hammerhead under 15 kg, at 12.4 kg, and under 60cm max diameter, at 50.8 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.

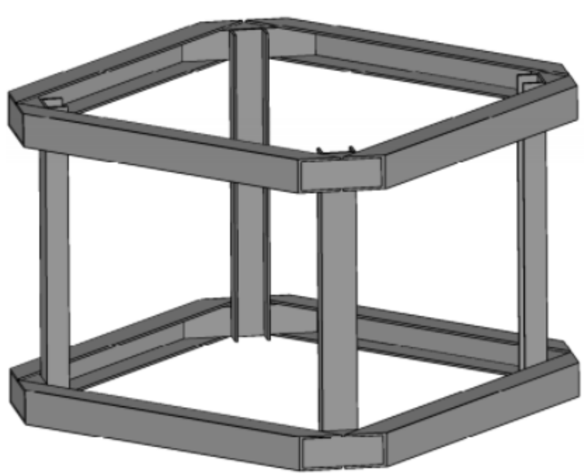


Figure 3: 3D model of SEAL Robotics "Hammerhead" vehicle chassis.

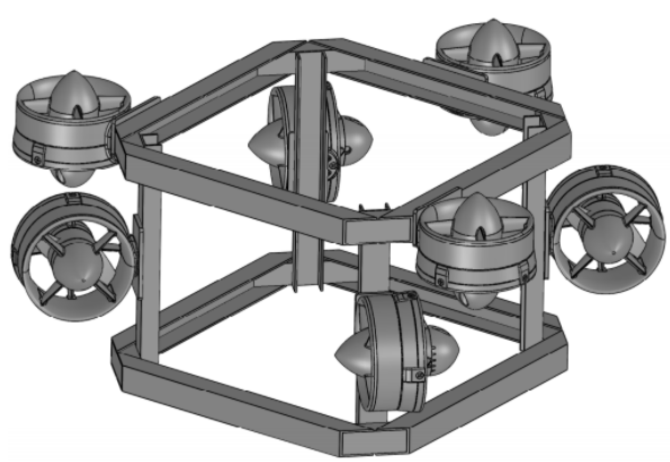


Figure 4: System chassis rendered with planned thrusters.

Vehicle Systems

While designing Hammerhead, we made an important point of making cost effective choices that still give our system a competitive edge. We focused on maintaining high-quality, essential components as well as making sure that possible failure points were easily replaceable. For example, the gripper system relies on an extremely reliable ESC and waterproof brushless motor; however, the gripper itself is easily replaceable. In addition, we also made a point of making our ROV extremely modular, allowing for the addition of low-cost tools that can improve our performance in individual tasks, without compromising on cost or performance. Our modular gripper attachments system is a perfect example of this. Depending on the needs of the challenge at hand, attachments can be added to our gripper system to change the profile of the jaws when they are closed. In addition, magnetic mounting points on the top of Hammerhead allow for easy addition of other tools, such as our plastic collection net.

Throughout the design process, Hammerhead 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 removing plastic debris; precision mode, which allows more refined movement control to aid in precision reliant tasks like the replanting of coral; and the implementation of camera output visible from our GUI, which centralizes all import sensor output into one place. 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. While none of this is exactly what was planned from the start, the evolution of Hammerhead has resulted in a product that meets and exceeds mission specifications.

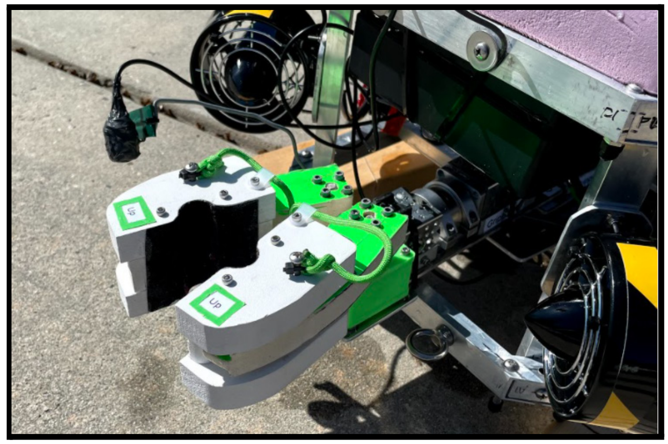


Figure 5:"Hammerhead" Gripper system depicted with specialized coral grabbing manipulator

Figure 6: Stand-alone manipulator on "Hammerhead." This system is featured on both the front and rear of the system.

Control/Electric System

In order to control the seven thrusters on Hammerhead, we have on board Blue Robotics Electronic Speed Controllers (ESCs), waterproofed by potting in West System Epoxy. We actually included eight ESCs - the extra is a planned spare in case of a failure. Having on-board ESCs makes our tether far lighter than "home running" high power wires for each thruster, and thus improves our maneuverability. This was one of our design goals as a team after the 2019 competition. The Hammerhead system uses two Subconn connectors and two ethernet ports that enable the tether to be detached from the control box for easy transport.

Tether:

Hammerhead's tether contains 6 cables in total, some of which are structured cables 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 15.2 m was adopted to readily accomplish mission objectives and minimize voltage drop and signal decay.

Wire Type	Usage
Primary - 8 gauge power	12V Shared Power
Primary - 8 gauge ground	Common Ground
Two - Cat 7	Video - 8 cameras
One - Cat 5	Thruster and Gripper Signals
Triplex - 18 gauge	MicroROV Thruster
Keller America Submersible Level Sensor (includes integrated power, ground, signal, and air pressure reference)	Depth Sensor

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

Control Box:

For the Control Box, SEAL Robotics chose the Arduino MEGA 2560 REV3 for sensory connectivity and motor control. We chose this board because of its easy control of the T100 thrusters and standard motors. Along with that, many members on our team had past experience with Arduinos. Moreover, this Arduino was known to function well with our controller choices discussed below. At $38 retail, the board is inexpensive.

We used the Arduino as a servant to the Java program, executing on our connected laptop through a serial communication protocol that we custom developed. The Arduino supplies data from our sensors and sends it to the Java program for analysis. The Java program makes calculations and sends instructions back to the Arduino. Then the Arduino uses those values to change the thrusters and gripper positions. The analogy is similar to a central nervous system calling the shots (the Java program) and a peripheral nervous system accepting instructions and sending back sensor values (the Arduino). This approach allowed us to overcome the code length and processing speed limitations of the Arduino.

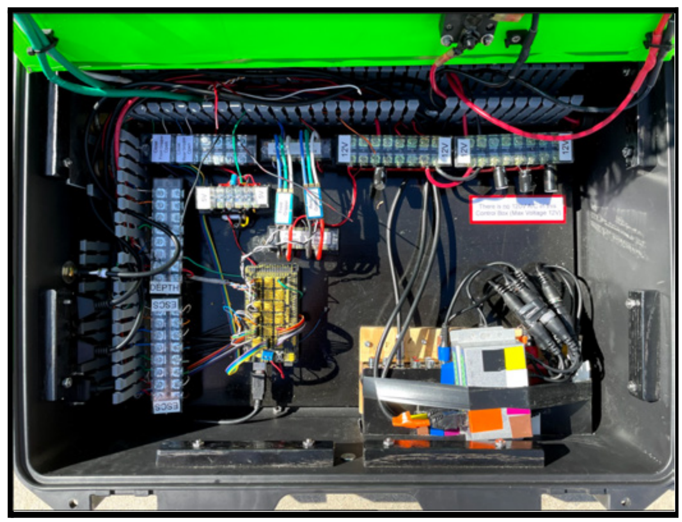


Figure 7: Inside of Hammerhead's control systems box.

As an example of the modular and easily repairable design philosophy employed by SEAL Robotics, the Arduino is located on-shore, mounted to an Arduino shield (KEYESTUDIO MEGA Sensor Shield V1). Should a malfunction occur, the Arduino can be released from the shield and replaced in minutes, without rewiring or complex operations on the vehicle.

GUI and Drive System:

The GUI and drive system is written in Java due to member experience, execution speed, and reduced latency between driver input and ROV execution based on comparison conducted with other drive languages we have used in the past. A basic flow diagram of the overall program is presented (Fig. 8), showing distribution of tasks between the drive thread and the GUI thread.

The drive program implements a Proportion Integral Derivative (PID) controller in order to bring the ROV to the user selected depth and maintain that depth. The drive program receives "sensory" input from the Arduino using a custom built bit stream serial interface. This includes data from the controllers as well as depth and thruster information. The drive program performs a set of calculations based on these parameters and the desired depth to pass thruster values back to the Arduino to write to the thrusters. The GUI itself was designed with the goal of achieving a simple user-friendly interface that still provides all necessary information to our driver.

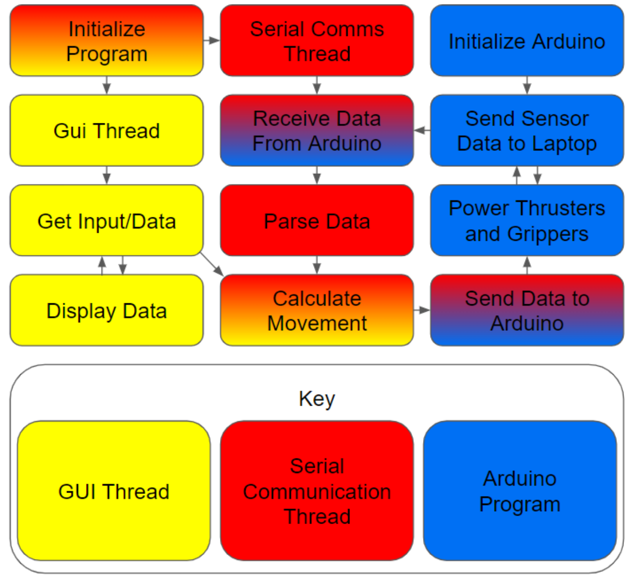


Figure 8 (right):. Flow Diagram of Hammerhead Java and Arduino software stack

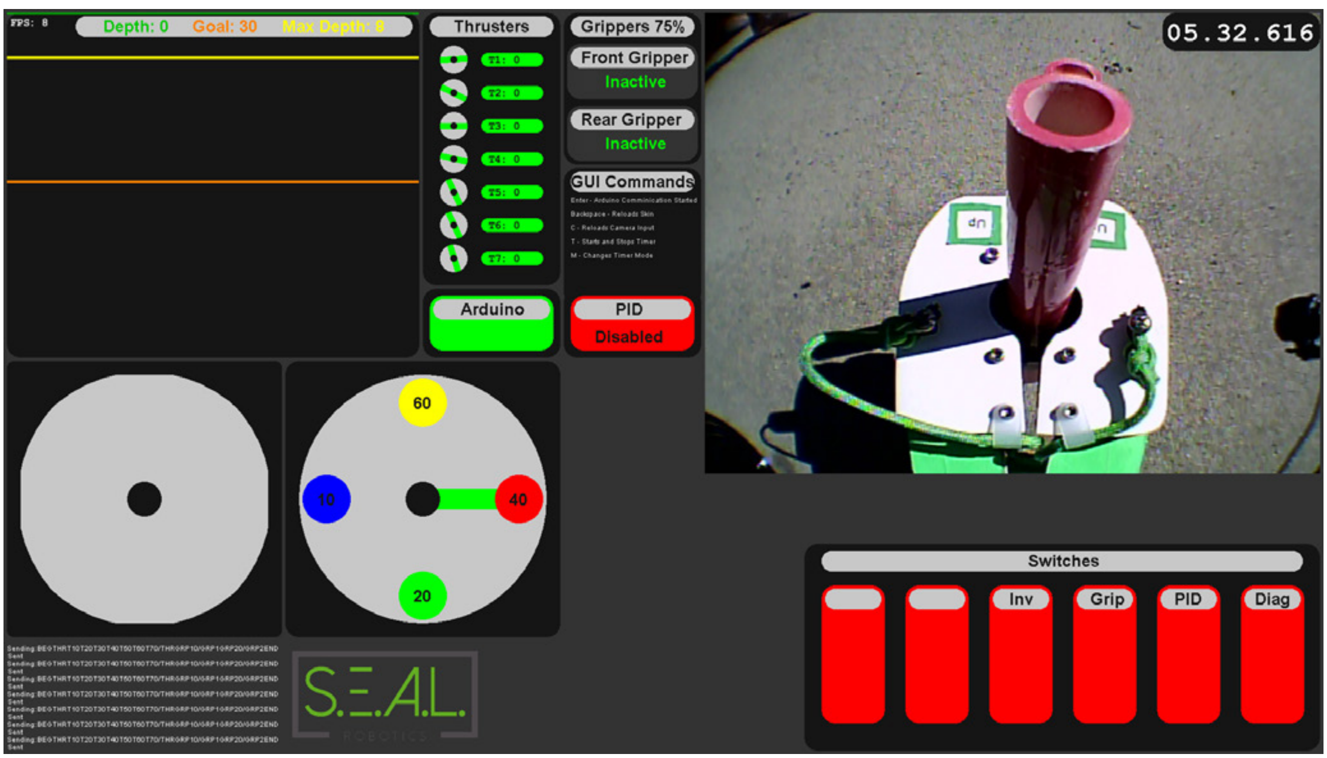


Figure 8. Screenshot of GUI drive console with integrated camera feed.

Xbox Drive Controllers:

Hammerhead is controlled using two wireless Xbox controllers. These controllers communicate with the Java program. The Java program then displays the data on the GUI after making calculations, and it sends data and instructions to the arduino via a serial interface. The Arduino reads the data (ie, thruster values, gripper values, etc) and writes to the thrusters and gripper ESCs.

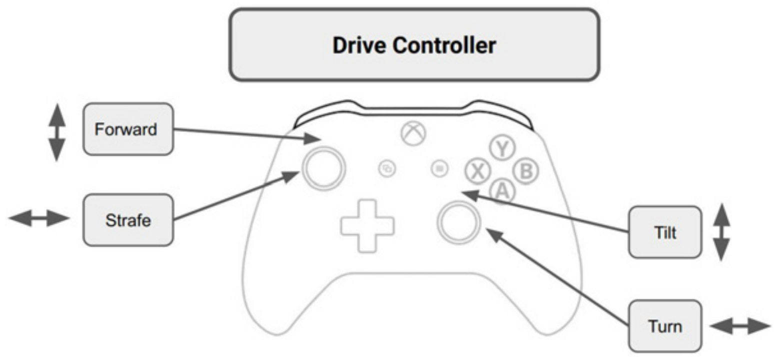


Figure 9: Xbox Drive Controller control scheme.

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 edge of pool whenever possible

Propulsion

For propulsion, Hammerhead utilizes seven Blue Robotics T100 Thrusters. In order to provide the ability to lift heavy objects with our front grippers, we placed two vertical thrusters near the front, and one at the rear, in a triangular formation. From what we learned in previous years, we needed to refactor horizontal thrusters in order to provide more effective and more precise strafing. As a team, we considered many options and ultimately decided to vector Hammerhead's thrusters on the four corners of Hammerhead. Since we positioned four thrusters at 45 degrees, Hammerhead can provide 35 N (about 8 pounds-force) in any horizontal direction.

Figure 10: Blue Robotics T100 Thruster

Buoyancy and Ballast

In the beginning, we set out to create a neutrally buoyant ROV system. This would provide Hammerhead 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, Hammerhead is equipped with polystyrene high density foam located at the very top of the system. After testing various configurations for the 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.

Gripper Analogs for Tuning Buoyancy and Ballast:

During construction, we needed to test and tune ROV buoyancy, however, our grippers (the heaviest component in the system) were still being built and would not be ready for several months. In order to move forward, we built two "gripper analogs" Fig. 11 (right). We weighed all of the components of each gripper, and then built these out of plywood filled with pieces of rebar to match the actual gripper weight. We mounted these gripper analogs to the ROV in the exact locations where the grippers would be in order to move forward with buoyancy testing.

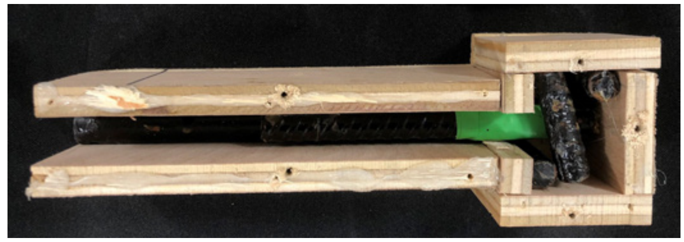


Figure 11: "Gripper Analog" built to match size and weight of gripper, to allow buoyancy testing even while the actual grippers were still under construction.

Payload and Tools

Cameras and Camera Placement:

Hammerhead uses eight Chuanganzhuo Universal High Definition CMOS Non-Mirror Image Waterproof Front View cameras, model 308B-FT. These cameras are lightweight, highly economical, easily replaceable, easily waterproofed and give clear colored pictures allowing color differentiation for green and orange zone differentiation. The camera has a flexible composite (yellow RCA jack) video cable that can work with a wide variety of monitors. There are eight separate cameras on Hammerhead, all mounted on stiff galvanized wire in order to make it easy to fine tune camera position to assist with specific tasks.

We were intentional about positioning cameras for specific mission tasks, for example the mussel bed inspection and the subway car imaging use our down-facing camera. A gripper-mounted camera is useful in retrieving and placing props such as the eel trap and propagating corals onto the reef. Several cameras are placed for maximum efficiency when working with our payload tools. Another example is our upward facing camera, which not only allows the pilot to see the tether in the water, but also allows us to see our fishing net tool that is used to remove plastic debris from the surface of the water.

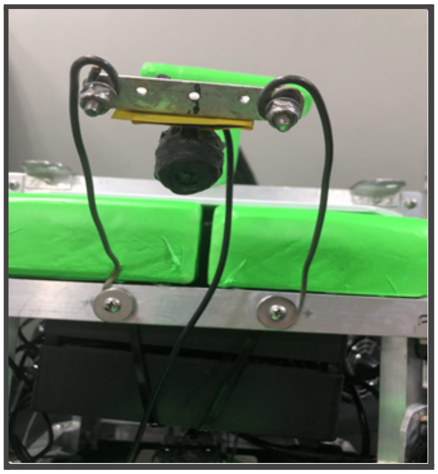


Figure 12: Example of camera mounted on flexible wire above the front gripper, which we refer to as a "birds eye" camera.

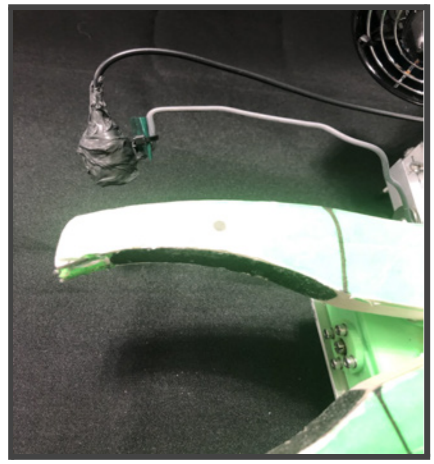


Figure 13: Example of a camera mounted on flexible wire aimed below the gripper, to provide ideal visibility when replanting the coral.

Grippers:
SEAL Robotics team members are keenly aware of the need for a robust gipper design, and this year we wanted to improve on previous designs. Our goals were to have two independent robust grippers to allow for additional speed and efficiency, and to make the grippers easily replaceable if there was some sort of failure.

The resulting gripper design consists of two gearboxes and a waterproof Blue Robotics m100 brushless motor.
3D printed components were designed in SolidWorks (©2002-2019 Dassault Systèmes SolidWorks Corporation). PLA was coated with epoxy resin for water tightness using a Robo 3D R1+ printer with 1.75mm PLA. In a non-watertight box, the worm gear drives two identical gears which rotate shafts holding the claws. The custom designed, 3D- printed worm gearbox is shown in Figure 14 (right).

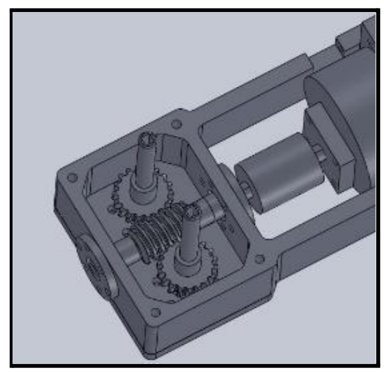


Figure 14: Worm gearbox of SEAL Robotics gripper.

The worm gear is connected to a planetary gearbox with a flex coupler, which is in turn driven by an m100 Blue Robotics brushless motor (Figures 15 and 16 below). The ESCs that drive these grippers have customized firmware flashed on them to help give the motors increased torque at low speed operation. Please see the "Dedicated Testing Rigs" section for more information on how we tested the grippers.

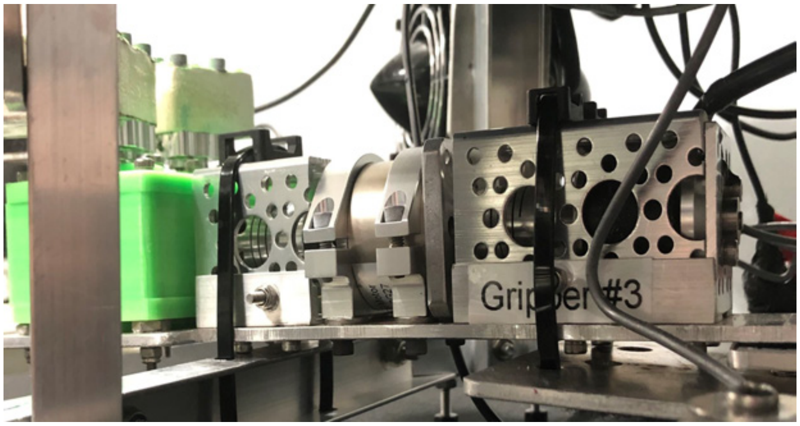
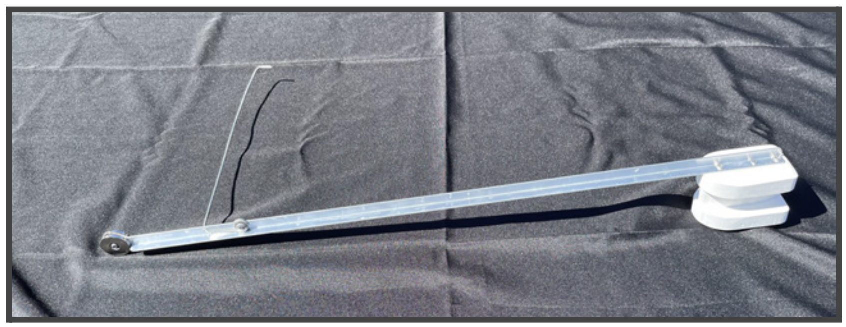


Figure 15: Planetary gearbox and Blue Robotics M100 motor inside of the protective aluminum housing.

Figure 16: Gripper jaws with grip tape glued in place. Green worm gear box and planetary gearbox is visible as well.

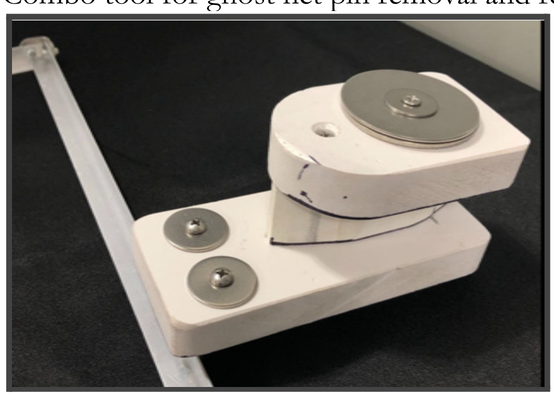
Custom Tooling:

Hammerhead 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.



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

Magnetically mounted surface plastic collection device. Easy debris collection and removal. Other tooling devices use the same magnetic mounts on the ROV.



Custom quadrat mount for positive grip in Hammerhead grippers.

Gripper claw adapters used for coral transplanting.

Figure 17: Mission-Specific Tools custom designed to execute mission tasks efficiently.

MicroROV Created to Remove Sediment Sample from the Drain Pipe:

We created a MicroROV following the MATE non-ROV Device (NRD) specifications, specifically engineered to remove sediment samples from the drain pipe. After several iterations, we settled on a simplistic solution.

General Construction:
The Micro-ROV is constructed from a hard plastic bottle that we sourced from a dental supply (Fig. 7). We prototyped using a plastic 2-liter drink bottle; but for more rigidity in the final design, we used this superior material. The Micro-ROV **dimensions** are 28.25 cm in length and 9.5 cm in diameter. At the top of the Micro-ROV there is a velcro bow to complete the challenge.

Propulsion:
Propulsion is provided by a bilge pump motor fitted with an 4-blade RC boat propeller. In order to achieve increased propulsion to quickly get into and out of the drain pipe, we upgraded both the propeller and the motor from the standard model that MATE uses in their Pufferfish kits.

Figure 18: Completed SEAL Robotics Micro-ROV.

Micro-ROV Power Source, Control, and Tether:
There are **no batteries** used by the Micro-ROV, as it is powered by a 12V shore-side power supply according to the MATE NRD specs. There is a dedicated 3 amp fuse within 12 cm of the power supply connection. The Micro-ROV tether is completely independent from the main ROV system. The control is via a Double Pole Double Throw (DPDT) switch that controls forward and reverse only. **Fuse calculations** are shown below in Figure 9.

Micro-ROV Fuse Calculations	
Device	**Current Draw (Amps)**
Thruster	1.7
Total Calculated Current (Amps)	**1.7**
Overcurrent Protection Factor	**150%**
Fuse Calculation (Amps)	**2.55**
Round to Fuse Size (Amps)	**3**

Table 4: Micro-ROV fuse calculations.

Build vs. Buy, New vs. Used

Since we designed and built a new 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.

Gripper (Build instead of Buy):

In the case of Hammerhead's gripper system, we felt that it was important to build the system ourselves in order to maximize performance and strength while still allowing us the flexibility that we desired. The custom design of this system gives us unique benefits that, combined, could not be found in a cost-effective commercially offered product. Hammerhead's grippers are easily replaceable, while still being strong enough to handle the weight of important mission payloads. In addition, the custom design of the manipulator is important for the stability and reliability of mission specific gripper attachments.

Control Box Housing (Buy instead of Build):

Our previous control box housing was built out of plywood, but we decided that purchasing a Pelican Case would be worth the money this year. The Pelican Case allows the system to be more mobile and more durable during transport.

Depth Sensor (Reuse):

Hammerhead reuses our Keller America Submersible Level Sensor (Fig. 19). A reliable depth sensor is extremely important for the functionality of the PID system on board the ROV. Its reliability, accuracy, and our experience with the system led us to reuse this system. This decision provides Hammerhead with more stability in the water and improves the system's overall reliability in fulfilling all mission requirements.

Figure 19: Depth level sensor

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 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.

Figure 20: Xbox Drive Controller.

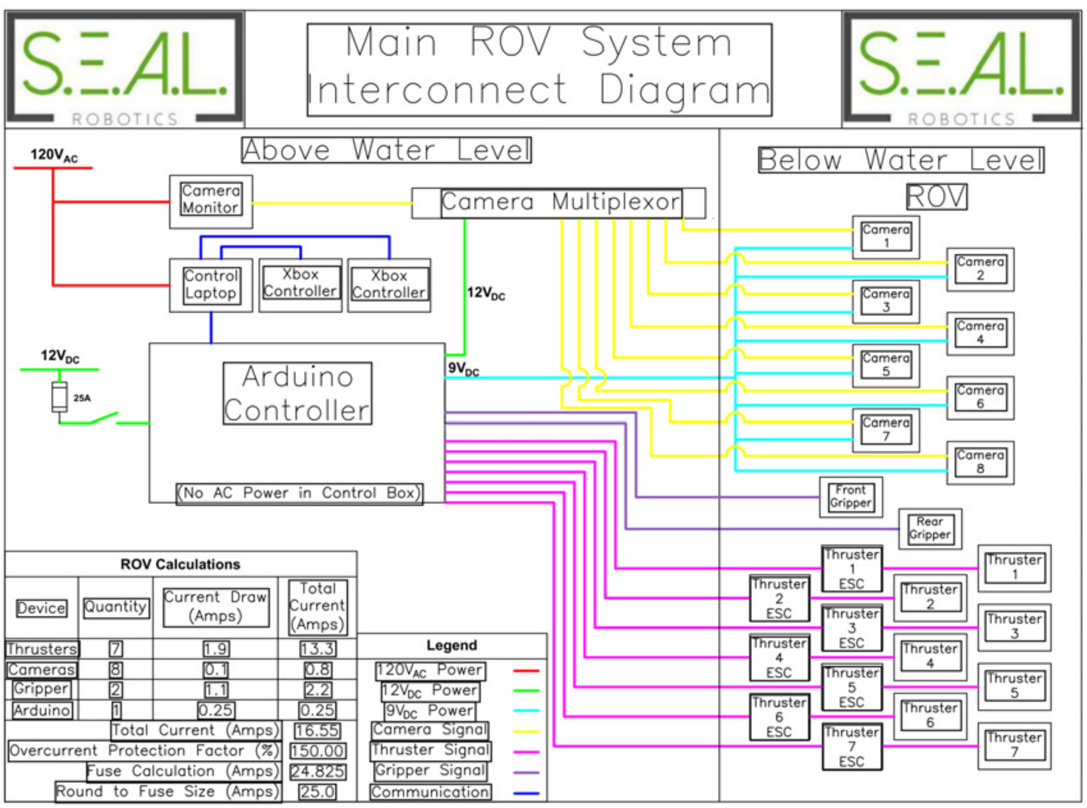
Thrusters (Buy instead of Build, and Reused this Year):

Hammerhead utilizes commercial Blue Robotics T100 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 thruster has an integrated controller which also feeds back status. The major disadvantage is the high price compared to a typical $30 bilge pump thruster conversion, although that price was a sunk cost from last year. At the original purchase, we decided the robustness of the thruster justified the price of this mission-critical hardware. Compared to our previous system, which used several thrusters for forward and reverse and strafe, Hammerhead uses a vectored thruster configuration. This allows the ROV to make more of reused materials, improving upon mission performance while minimizing costs.

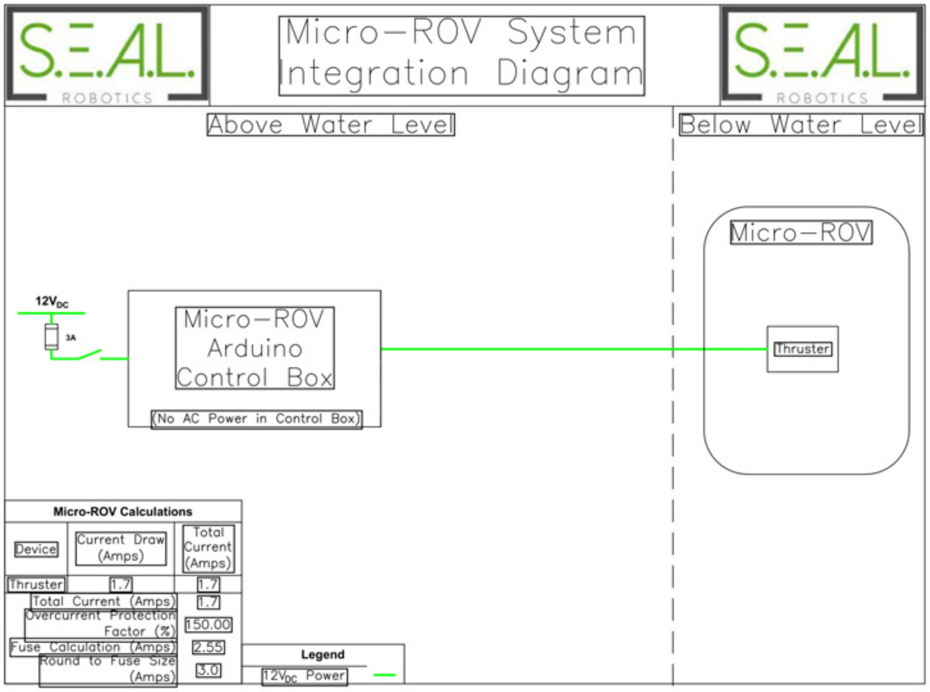
Figure 21: Purchased and Reused on the ROV this year - Blue Robotics T100 Thrusters

SYSTEM INTEGRATION DIAGRAMS (SID)

Main ROV SID



MicroROV SID



SAFETY

Safety Rationale and Philosophy

Safety of team members and the safety of our productsis of primary importance to SEAL Robotics. We work not only to address safety issues and concerns, but to proactively prevent them before they occur. "Near miss" safety incidents are swarmed by team leaders 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. Because 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
- No 120 VAC power in our control box; signage to make this clear.
- Single Main Power Switch cuts all power to the box and 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 22: 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.
- 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).

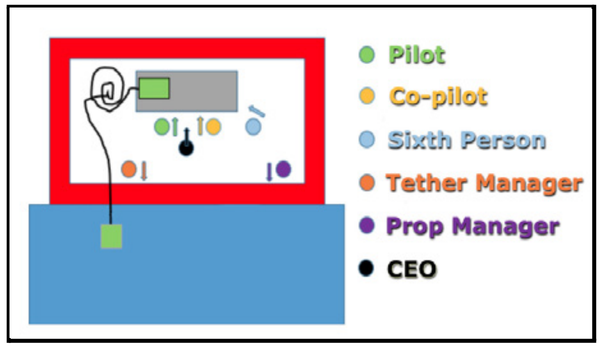


Figure 23: Poolside ready positions for safety and efficiency.

Post-Run Safety Checklist

- Make sure all equipment is safely removed from the product demonstration area.
- All nuts and 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): Both eye and hearing protection 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 in assessing the performance and reliability of Hammerhead.

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 was important that all 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 Hammerhead's design process. The camera system on Hammerhead was extensively deliberated and prototyped before its implementation. After the idea of adding a balun based camera system was proposed, prototypes were made to evaluate every aspect of the system. Team members analyzed signal degradation by testing camera resolution over extremely long lengths of wire, longer than those found in the tether on the system to provide a buffer. In addition, the feasibility of waterproofing the system was assessed by performing water tests on several different sets of waterproofed cameras. Only after these and other aspects were evaluated was the decision made to implement the system over alternatives. Other systems such as Hammerhead's custom tooling also went through numerous prototyping iterations to arrive where they are at currently. After testing in the pool, tooling was refined and tested again until performance was optimized.

Dedicated Testing Rigs

We spent many hours testing and tuning the gripper 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).

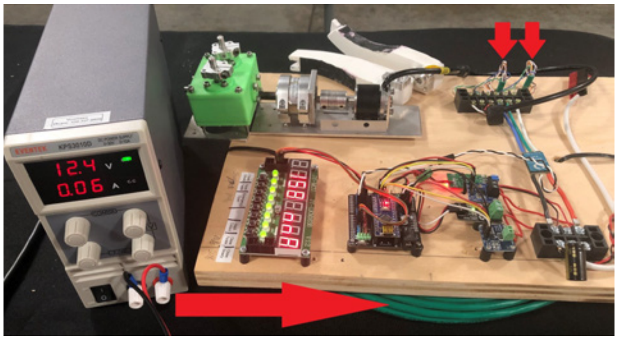
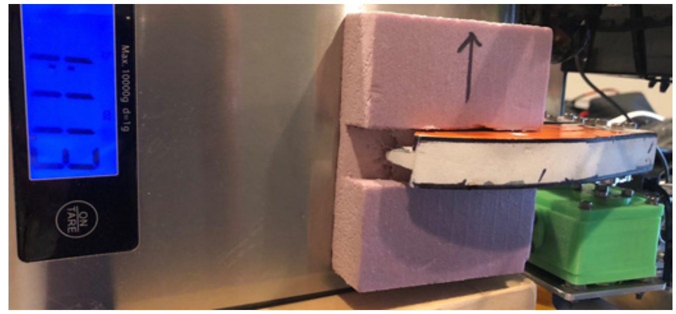
	

Figure 24: Gripper testing. Red arrows note the 15 meters of green cat6 wire through which all signals run to duplicate behavior through tether. The mounted Arduino is used to flash the Blue Robotics ESC with new firmware to improve torque..	Figure 25: Grip strength measurement device. We used foam blocks and a kitchen scale to get consistent measurements of grip strength. We had to carefully limit the maximum grip force in the software so as not to break the gripper, and for operator safety.

ACCOUNTING

Budget

BUDGET - SEAL Robotics ROV Build 2021 October 2019 - May 2021				
Income				
Source				Amount
SEAL Robotics Team Membership Dues earmarked for ROV Project				$ 6,600.00
Expenses				
Category	Type	Description	Projected Cost	Budgeted Value
Printing and Imaging	Purchased	Printing and binding MATE documentation, technical reports, pictures, etc.	$ 120.00	$ 120.00
Registrations	Purchased	Competition Registrations	$ 200.00	$ 200.00
ROV - Cameras	Purchased	Cameras, cables, connectors, adapters, multiplexers, screen grab software, etc.	$ 500.00	$ 500.00
ROV - Prop Supplies and Tooling	Purchased	Prop building supplies, supplies for custom tooling for challenges	$ 400.00	$ 400.00
ROV - Grippers	Purchased	Grippers, motors, servos, controllers, etc.	$ 800.00	$ 800.00
ROV - Thrusters and Electronics	Purchased	Thrusters, ESCs, balluns, boards, waterproof cases, etc.	$ 1,500.00	$ 1,500.00
ROV - Frame and Tether	Purchased	Aluminum, fasteners, strain relief, tether wire, sheath, plugs, waterproofing, etc.	$ 600.00	$ 600.00
Main Control Box	Purchased	Pelican case, terminal strips, bus bars, wiring, Arduinos, Controllers, Paint, etc.	$ 600.00	$ 600.00
Misc	Purchased	Misc and budget allowance for overruns	$ 500.00	$ 500.00
Travel	Purchased	Travel to Competition *(8 hotel rooms for one night @ $110, $490 for van rental and gas, and $450 total for meals).*	$ 1,820.00	$ 1,820.00
ROV - Video	Reused	32" monitor	$ 297.00	-
Main Control Box	Reused	AV switch, power supplies, meters, etc.	$ 550.00	-
ROV - Thrusters	Reused	7 Blue Robotics T100 thrusters	$ 777.60	-
Main Control Box	Donation	Subconn Connectors	$ 750.00	-
			Total Income	$ 6,600.00
			Total Expenses	$ 9,414.60
		Total Expenses minus Re-use/Donations		*$ 7,040.00*
		Total Fundraising Needed		*$ (440.00)*

Table 5. Project Budget for 2021 season ROV build.

Cost Accounting

PROJECT COSTING - SEAL Robotics ROV Build 2021

October 2019 - May 2021

Date	Type	Category	Expense	Description	Source / Notes	Amount	Running Balance
Jan-19	Reused	Electronics	Monitor	32" monitor		$ 297.00	$ 297.00
Oct-19	Donated	Electronics	Control Box	Two Subconn Connectors	Tether to box	$ 750.00	$ 1,047.00
Nov-19	Purchased	Electronics	Video Components	Camera cables, cameras, video connectors, screen grab software, other video adapters, multiplexer, baluns, cat7.	New video solution	$ 550.00	$ 1,597.00
Nov-19	Purchased	Hardware	Gripper Components	Worm gears, drive gears, stainless shafts, bearings, epoxy, m100 brushless motors, ESCs, M3 fasteners, lock nuts, roll pins, washers, clamping hubs, PVC board, waterproofing supplies, PVC, plugs, aluminum stock, couplers, Actobotics cages, aluminum stock, zipties, liquid electrical tape, 3D print media, grease, carbide drill bits.	Gripper building materials	$ 1,120.00	$ 2,717.00
Dec-19	Reused	Electronics	Thrusters	7 Blue Robotics T100 thrusters	Thrusters	$ 777.60	$ 3,494.60
Dec-19	Reused	Electronics	Control Box	AV switch, power supplies, inline power meter, etc.	Control Systems	$ 559.00	$ 4,053.60
Jan-20	Purchased	Electronics	Control Box	Arduinos, voltage and current sensors, PCB boards and electronic components, pelican case, aluminum, USB plugs, jumper wires, bus bars, anderson bulkhead plugs, 3M vinyl, knob, wire loom, hookup wire, fuse blocks, ESCs, paint, stainless fasteners, plywood, wire management, LEDs, breadboards, strain relief materials.	Components for inside new control box	$ 1,249.00	$ 5,302.60
Feb-20	Purchased	Electronics	MicroROV	Wire for MicroROV tether, MATE bilge pump motor, Replacement Prop, dental bottle, LED, camera, waterproof plugs, epoxy, fasteners, waterproofing supplies.	MicroROV components	$ 212.00	$ 5,514.60
Nov-19	Purchased	Materials	ROV	Aluminum stock for ROV chassis and tooling.	New chassis	$ 126.00	$ 5,640.60
Mar-20	Purchased	Electronics	Control Box	Main disconnect switch, toggle switch panel, SPDT switches for gripper control, resistors.	More control box	$ 193.00	$ 5,833.60
Nov-20	Purchased	Materials	ROV	Velcro, additional waterproofing materials, additional wire, fuse holders and fuses, ballast supplies, epoxy, tether wire, sheath.	ROV internal systems	$ 391.00	$ 6,224.60
Dec-20	Purchased	Printing	MATE Docs	Printing and binding of MATE docs for team members	Printing	$ 229.00	$ 6,453.60
Jan-21	Purchased	Materials	ROV	Waterproofing supplies (Silicone RTV, heat shrink, liquid electrical tape, 3M Ultra Black, epoxy, etc.), terminal ends, fuses, plugs, etc.	Waterproofing general	$ 252.00	$ 6,705.60
Feb-21	Purchased	Hardware	Tooling	Aluminum stock, PVC stock, epoxy, netting, fasteners, carabiners, zip ties, polystyrene foam,	Tooling for challenges	$ 190.00	$ 6,895.60
Feb-21	Purchased	Electronics	Video Components	Additional cameras, plexiglass, epoxy, slow hardener, aluminum wire, stainless washers, waterproof grease, m3 fasteners	Better camera waterproofing	$ 147.00	$ 7,042.60
Mar-21	Purchased	Hardware	Laptop	Dedicated Windows 10 ASUS Laptop for Team Drive System	Unlplanned - old laptop broke	$ 679.00	$ 7,721.60
Mar-21	Purchased	Registration	Registration	MATE Regional Competition Registration	Registration	$ 200.00	$ 7,921.60
Apr-21	Purchased	Electronics	Tooling	More aluminum, epoxy, stainless fasteners, brackets	Tooling/Repairs	$ 242.00	$ 8,163.60
Jun-21	Purchased	Registration	Registration	MATE World Championship Competition Registration	Registration	$ 100.00	$ 8,263.60
						Total Raised	$ 6,600.00
						Total Spent	$ 8,263.60
						Balance	$ (1,663.60)

Table 6. Project Cost Accounting Expenditures for the 2021 ROV build.

World Championship Competition Travel Costs

Travel from Greensboro, NC to Johnson City, TN expected total travel costs: $1820 (included in Table 6 above)

Transportation: $490 for a rental van and gas

Food: $450 total for meals for team members and mentors

Hotel: 8 rooms at $110 per night

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):

MATE https://www.marinetech.org	GREENSBORO RADIOLOGY http://www.greensbororadiology.com
zibster http://zibster.com	THE IMAGINGSOURCE TECHNOLOGY BASED ON STANDARDS http://www.theimagingsource.com
MacArtney UNDERWATER TECHNOLOGY http://www.macartney.com	POWERMAX http://powermaxconverters.com
KELLER 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.
Eastman Chemical Company: for sponsoring the 2021 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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