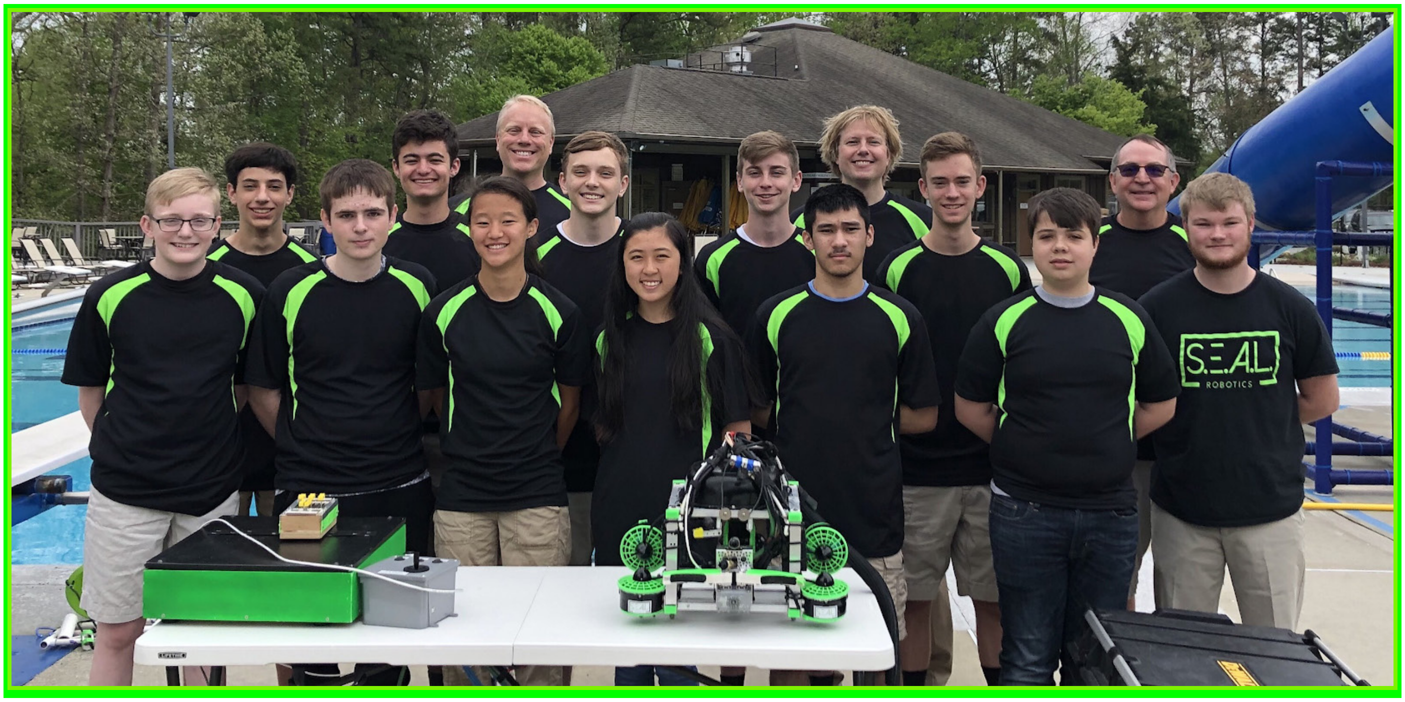
SEAL Robotics Team

Greensboro, NC



2019 Team Member	Primary Roles
Oliver Voorhees	C.E.O., Lead Engineer and Programmer
Logan Smith	Chief Safety Officer
Nathan Ruppel	Challenge Design Expert
Ben Liebkemann	Lead Team Programmer
Owen Voorhees	Programmer and Fabrication and Electrical Expert
Marissa Maynard	Tether Manager and Construction Expert
Jonathan Bacon	Challenge Expert and Team Lead
Michael Scutari	Programmer, specializing in Image Recognition
Clay Austin	Programmer and Fabrication Expert
Quinn Welch	Mechanical Engineer, CAD Designer, Fabrication Expert
Li Yan Snyder	Fabrication and Construction Expert
Phillip Szypulski	Electrical and Fabrication and Construction Expert

Team Mentors: Ned Voorhees, Kurt Ruppel, Walt Liebkemann, Robert Welch, Austin Ramey, Brock Longley, Stephen Austin

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Abstract

(248 words)

The 2019 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 creation of a Remote Operated Vehicle (ROV) system (Fig. 1) ideal for the tasks of ensuring public safety, maintaining healthy inland waterways, and historical preservation as specified in the Request for Proposal (RFP).

Team-building exercises to kick off the season included a team egg drop challenge in August, along with workshops on safe tool use and electronics design as part of our safety culture. In that timeframe, budget and timeline of tasks were developed and later refined as the RFP details emerged.

Major new mission-specific original designs and fabrications for 2019 include a worm gear end effector, original software for drive control utilizing Proportional Integral Derivative methodology to enhance inspection control, a Graphical User Interface, software for benthic species identification simulation using image recognition, a remotely deployable Micro-ROV for pipe inspection, thruster reconfiguration for enhanced maneuverability, and custom mission-specific attachments. Consistent with Eastman's stated goals of sustainability and resource conservation, the ROV frame and on-land system board were reconfigured or revised rather than replaced unnecessarily with new materials.

Organizationally, pre-meeting goal lists and post-meeting reporting of subteams to the full team were employed. Documentation was maintained by subteams and archived as produced on a shared team cloud-based archive, with an editorial subteam collating the accumulated assets.

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

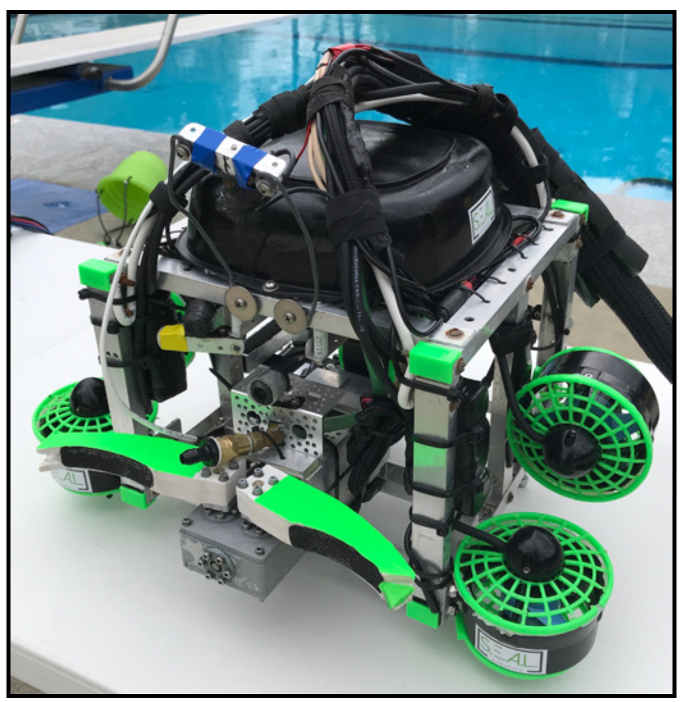

Figure 1. The 2019 SEAL Robotics ROV, "Mako," with gripper widely opened.

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 potentiate 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 with meeting organization. Team members produce and critique designs, fabricate and construct the robot, write every line of code, and 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.

Eastman Science/Industry Mission:

SEAL Robotics Mako ROV system incorporates exceptional and original components for 2019 to optimally address the science and industry mission of the Eastman RFP.

Ensuring Public Safety: Sinkholes and cracking can lead to catastrophic dam failure if mitigation is not instituted. Boone dam inspection and repair is understood to require exceptional nimble ROV in constrained area adjacent to the dam including strafe capability for grid-based mapping and crack measurement capability. Pipeline inspection and fine control manipulation for trash rack replacement are also necessary elements. SEAL Robotics solutions: thruster reconfiguration; a completely new drive system was written in the highly stable Rust language; a new GUI was created also in Rust and optimized for fine navigation; video frame grab and image-based measuring was implemented; power to individual thrusters is now software limited allowing for lighter and less stiff wires in the tether, helping maneuverability. A 7-camera approach allows broad visualization for task efficiency; and a new SEAL Robotics end-effector has been designed and fabricated for better control and reliability. Finally, a new Micro-ROV vehicle has been designed for deployment for lighted pipeline inspection.

Maintaining Healthy Waterways: Maintenance of water quality, aquatic ecology, and habitat restoration are critical elements to help the Boone reservoir serve the eastern Tennessee community. For example, while adequate levels of organic and man-influenced water phosphate are critical for plant and animal growth in Boone Lake due to being a growth limiting nutrient, too much phosphate can lead to eutrophication, which causes ecosystem instability, cyanobacteria blooms, plant overgrowth, and eventual death of animal species from hypoxia (1). SEAL Robotics team members are trained in water collection and analysis. Our end-effector and debris removal hook are purpose built to be effective for debris removal and rock movement tasks, and to also function for deployment purposes. A robust deployment container to introduce trout fry into ideal locations was developed. Finally, SEAL software designers created original image recognition systems modelling the underwater automated identification and counting of benthic species.

Preserving History: Civil War artifact identification and recovery has been prioritized by SEAL Robotics. New image acquisition and analysis tools allow for accurate measurement and analysis of artifacts for recovery, and lift bag and tagging systems for ferromagnetic identification and tagging are included.

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-2018	-	Create Timeline, make Assignments, study MATE docs
9-Dec-2018	Everyone	Read MATE 2018 Competition documentation released so far before the next meeting.
16-Dec-2018	Nathan	Begin building "Props"
16-Dec-2018	Oliver	New Drive System Programming Complete and Tested on the ROV
30-Dec-2018	Phillip	1st Gen *Micro* ROV build complete
30-Dec-2018	Ben	GUI Programming Complete and Integrated and Tested with ROV Drive System
6-Jan-2019	Nathan	"Props" build 100% complete
13-Jan-2019	Quinn	New Gripper complete and installed
3-Feb-2019	-	First trial at pool with props, single gripper, and Micro ROV
15-Feb-2019	-	Register for Regional Competition (either Norfolk or Atlantic Beach - TBD)
17-Feb-2019	-	Additional manipulators complete and installed on ROV
24-Feb-2019	-	Video Recognition Software Complete (if team decides to pursue)
17-Mar-2019	-	First Draft of Technical Report Complete
7-Apr-2019	-	Final Draft of Technical Docs Complete and submitted to Regional
26-Apr-2019		Regional in Kingsport - not sure where we will end up going at this point though...
20-Apr-2019	-	Approx date for Regional Competition (either Norfolk or Atlantic Beach - TBD)
20-Jun-2019	-	International Competition

Table 1. Initial timeline developed for the 2018-2019 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 subteams to participate in hardware, software, electronics, documentation, project management, and execution teams. Members gravitated to certain areas and every attempt was made to accomodate preferences. The most challenging area to introduce beginners was in the software development side, as we have multiple advanced coders and some who are interested but beginners. We produced small side projects for the beginners 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 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 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** is responsible to set up a GroupMe with subteam members and mentors, get together if needed, and ensure they make the target date)	Mentor
Programming - Drive System	**Oliver**, Owen, Michael, Ben	Walt / Brock / Ned
Programming - GUI	**Ben**, Michael	Walt
Programming - Video Recognition (later)	**Ben**, Clay	Walt
Programming - Micro ROV	**Jonathan**, Owen, Clay	Ned
Programming - Manipulators, Temp, Calculations, Challenge Specific	**Owen**, Clay, Jonathan, Quinn	Austin / Ned
Props - Research and Building	**Nathan**, LiYan, Phillip, Jonathan, Quinn, Logan	Brock / Austin / Kurt/ Stephen
Gripper - Design and Build	**Quinn**, Logan	Robert / Brock
Micro ROV Design and Build	**Phillip**, LiYan, Nathan, Jonathan	Ned / Stephen / Kurt
Challenge-specific Designs and Builds (grout, measuring, fish transport, etc.)	Marissa, Oliver, Michael, Quinn, LiYan, Nathan, Loga	Austin / Brock / Kurt / Walt
Grout	**Marissa**	
Measuring	**Michael**	
Fish Transport	**Logan**	

Table 2. Team member roles.

Overcoming Day-to-Day Challenges:
These were escalated as necessary to involve the team and seek creative solutions. For example, the drive team complained that the strafe thruster (originally intended for fine motion control rather than true locomotion) was exceedingly difficult to use for dam inspection with a forward facing camera - slow and unreliable due to ROV rotation, taking well over 3 minutes per inspection run on average. After escalating the issue to the entire team, one of our programmers suggested making one of our 7 cameras a lateral-facing camera and performing dam inspection using a side view from the ROV. At time trials, the dam inspection dropped to 1 minute using this technique.

ROV System Design - SEAL Robotics "Mako"

Overview: The SEAL Robotics Mako is a lightweight, flexible ROV system utilising a cube-shaped frame of aluminum C-channel, six thrusters, and seven cameras with a custom fabricated worm gear based gripper and depth and temperature probes. Two Arduino processors are programmed to perform sensory and motor functions, controlled by a new 100% custom-written drive program with Proportional Integral Derivative (PID) vertical control. A newly written, multi-threaded Graphical User Interface, written within the Rust programming language, feeds information to pilots and gives troubleshooting information. Even while keeping major electronic components on shore, SEAL Robotics has been able to significantly reduce tether size and weight this year through wire optimization. Operator safety has been incorporated into all parts of the Mako design and operations. One feature that makes the Mako system unique is that all major electronic components are on-shore, allowing for quick repair and/or replacement should one fail. Although this requires a more bulky tether, SEAL engineers have been able to solve the problem with the aforementioned tether improvements.

Hardware Components:

Technical Drawing of vehicle demonstrates the extruded aluminum C-channel chassis without (Fig 2) and with (Fig. 3) thruster placement. Cameras, gripper, and other hardware removed for illustration purposes.

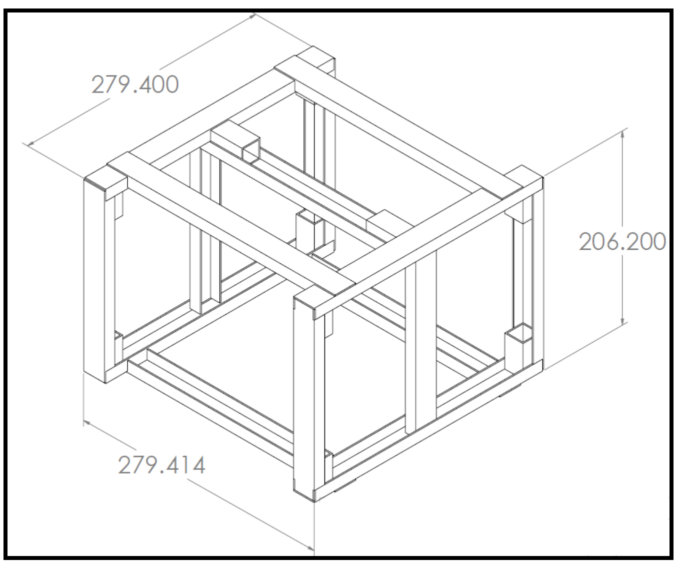

Figure 2. Technical drawing of SEAL Robotics "Mako" vehicle chassis. Dimensions are in millimeters.

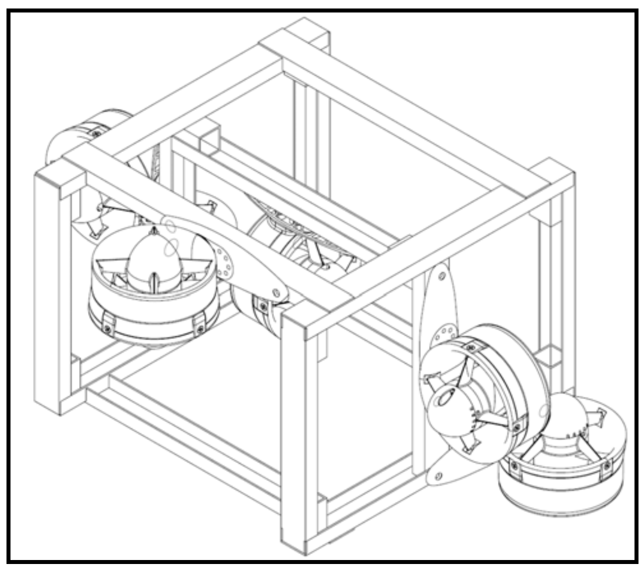

Figure 3. Vehicle depicted with thrusters.

Chassis: Re-used and Refined.
The chassis is a 30 cm per side cube-shaped frame made out of light-weight extruded aluminum C-channel (Fig. 4). We re-used this item because the design was felt to align well with current mission tasks, and replacement would be wasteful of resources. Other materials and geometries were considered to offer no advantage to offset cost. The frame is lightweight, resists underwater degradation, has a low drag, is easily drilled and modified to

allow air and water escape channels, and is rigid and stable. The chassis also features two horizontal aluminum members housing the longitudinal thrusters and one across the top to accommodate flotation, cameras, and a depth sensor.

On top of the chassis is a flotation housing with foam that creates near neutral buoyancy. Testing was mostly empirical; for example, marine grade floatation was added along the front channels to achieve near-neutral buoyancy and offset the front gripper weight. The frame was refactored to accommodate the new gripper and alternate thruster placement, and some hardware, including screws, were replaced with stainless steel screws to resist corrosion.

Figure 4. Aluminum C-channel section.

Gripper: Custom Built.

Custom fabricated worm gear driven end-effector driving two identical gears on either side.

After a malfunction of our Vex gripper in 2018, SEAL Robotics members were keenly aware of the need for a robust, custom fabricated gripper; this design and fabrication was a major focus of the entire team.

In a non-watertight box, the worm gear drives two identical gears which rotate shafts holding the claws. The worm gear is connected to a motor via two shafts held together by couplings of varying sizes (Fig. 5). In Figure 6 below, the gripper is shown from a cross-section view from the left side. It reveals the worm gear, shafts, and couplers all connected, but excluding the motor.

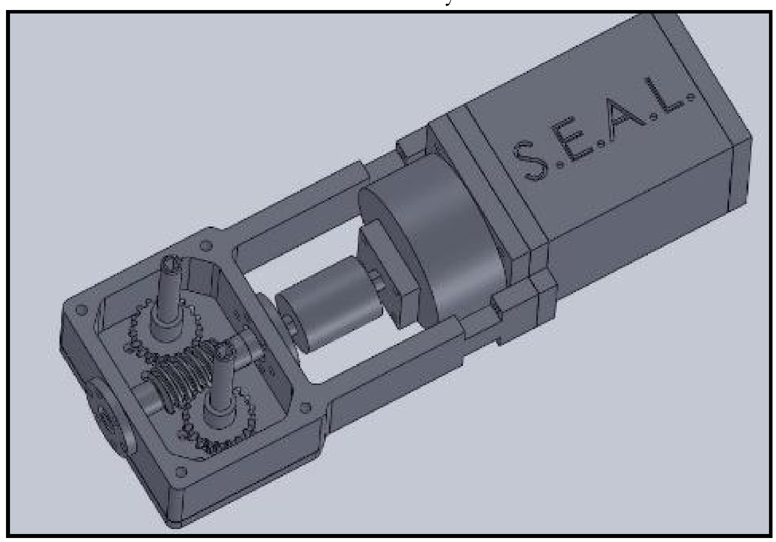

Figure. 5. Gearbox open view of SEAL Robotics gripper.

Hardware and non-fabricated parts were purchased from McMaster-Carr for its large selection of parts, reasonable prices, and quick delivery. Waterjet and CNC milled aluminum components designed in SolidWorks (©2002-2019 Dassault Systèmes SolidWorks Corporation) and produced by the Guilford College fabrication shop. Some housing parts were 3D printed from PLA and coated with epoxy resin for water tightness using a Robo 3D R1+ printer with 1.75mm PLA. O-ring watertight seals are present where the shaft penetrated the motor housing, and silicone was used to fill the housing. A uxcell 12V DC 120 RPM gear motor drives the gear.

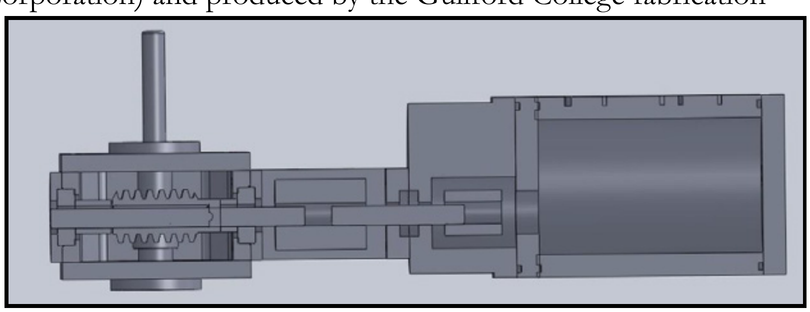

Figure 6. Side view of gripper assembly, claws removed.

Advantages of this design: Can handle extremely large reductions; simple in operation and easy to maintain; huge torque capability; added benefit of braking when the worm is not turning; good torque and noise properties.
Disadvantages: Low efficiency (energy loss through the worm and gear), not suitable for high speed rotation; and weight.
Planning and design, Teamwork: The entire team was divided into four sub-teams that each participated in a gripper design challenge over 1 month.

Each sub-team went from paper design through two sets of prototypes until the entire team voted this design as the best suited for our team's needs. Quinn W. was the primary designer and coordinated fabrication. Nathan R. and Logan S. helped with end-effector design, while Philip S. gave 3D printer advice. Primary mentors guiding team members in the fabrication and testing were Robert W. and Kurt R.
Testing: The gripper has numerous hours of bench testing and water testing. Current limiting and set screw tightness on the claws are used to ensure operator safety from harmful level of pinch.
Scientific and Engineering Principles: Worm gears work well in small spaces and provide high ratio speed reduction. Friction maintains a moderate grip even when power is off (self-locking feature), unlike some other types of gears, which is helpful when performing tasks requiring transport - a brief power blip does not result in a dropped object from the gripper.

Micro-ROV: Custom Built.

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.

Lighting, Camera, and Propulsion:
For inspection in low light areas, there is an **integrated 12V LED light** mounted on the very front. There waterproofed Chuanganzhuo Universal High Definition CMOS 308B-FT **camera** is mounted on the front just behind the LED light. **Propulsion** is provided by a bilge pump motor fitted with an RC boat propeller.

Figure 7. Completed SEAL Robotics Micro-ROV.

Figure 8. Micro-ROV Control Box.

Micro-ROV Power Source, Control Box, and Tether:

There are **no batteries** used by the Micro-ROV as it is powered by a 12V shore-side power supply. There is a dedicated 3 amp fuse within 12 cm of the power supply connection. The Micro-ROV control box (Fig. 8) and tether are completely independent from the main ROV systems. The control box has a joystick for controlling forward and reverse thrust, and three switches for Main Power, Light, and Camera. The control box contains an Arduino Mini and a Motor Controller. The Micro-ROV **tether contains only copper wire (no fiber optic cable)**, and is completely independent from the main ROV tether. **Fuse calculations** are shown below in Figure 9.

Micro-ROV Fuse Calculations		
Device	**Current Draw (Amps)**	**Total Current**
Thruster	1.25	1.25
Camera	0.1	0
Light	0.3	0
Total Calculated Current (Amps)		**1.25**
Overcurrent Protection Factor		**150%**
Fuse Calculation (Amps)		**1.875**
Round to Fuse Size (Amps)		**3**

Figure 9. Micro-ROV fuse calculations.

Cameras: Purchased and Waterproofed.

Chuanganzhuo Universal High Definition CMOS Non-Mirror Image Waterproof Front View cameras, model 308B-FT (Figure 10).

The 308B-FT 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. We have seven cameras located on Mako because we believe that a multi-camera setup permits a wide range of vision which will assist us in completing several different tasks at different angles; for example the dam inspection using a left facing camera. A gripper-mounted camera is useful in retrieving props such as the water sample.

Figure 10. CMOS cameras used on Mako.

Trout Fry Deployment Device: Custom Built.

2.54 cm (1 inch) diameter PVC pipe with foam and a trapdoor with weights on opposing ends (Fig. 11). Connecting the device to the ROV is a tether that runs from the foam end of the PVC pipe to a carabiner which is located on the ROV enabling it to be detached. With the foam end inverted, the PVC pipe with the trout fry inside, will be secured in the jaws of our gripper. When released, the device inverts due to weighting of the trapdoor and opens over the orange zone, allowing the trout fry to escape. This apparatus is uniquely designed to help us safely deploy the trout fry.

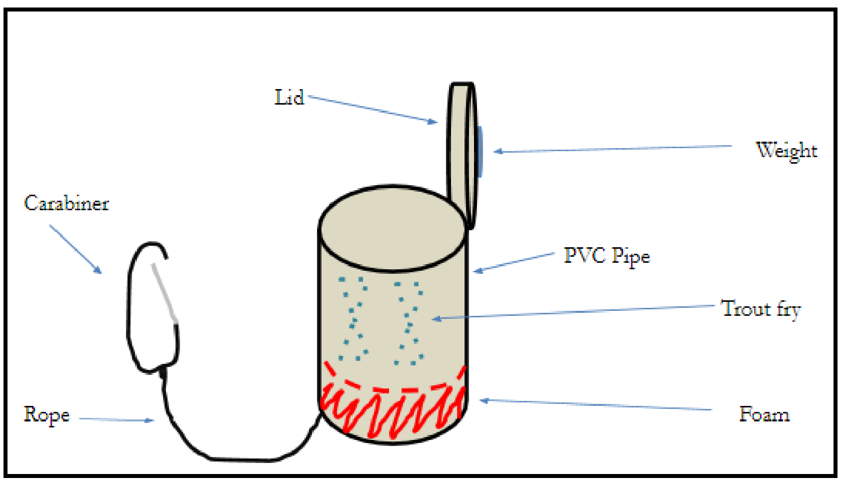

Figure 11. Simple drawing of deployment device.

It was devised to allow the gripper the freedom to retrieve a prop that needs to be returned to the surface after releasing the trout fry. To test the deployment device, the trout fry was placed inside the PVC device, which was then collected by the gripper. After plunging Mako beneath the surface of the water, the ROV was allowed to release the trout fry by releasing the PVC device. Our prop expert, Nathan R., with the help of other team members, built this device using his knowledge of physics and ideas from prototypes built by other team members.

Temperature Sensor: Purchased.
Waterproof Maxim Integrated DS18B20 sensor.
This small oblong sensor is mounted onto the chassis. Advantages: low expense ($10 retail), waterproofed, digital pre-calibration, requires only 1 wire and ground. These characteristics make it a superior choice to other models such as analog devices or a team-built thermistor system that require frequent calibration. Initial dry testing was performed to ensure accuracy through the length of tether. Once this produced accurate values, the sensor was incorporated into the ROV and appropriate Arduino and GUI subroutines written to obtain and display temperature data.

Depth Sensor: Re-used.
Keller America Submersible Level Sensor (Fig. 12).
Using an atmospheric reference that runs through the tether, the depth sensor allows accurate water depth of the ROV to be read and acted upon by the drive program in order to set ROV depth to a user selected setting. We considered the option of eliminating constant vertical level control in the drive system and relying solely on manual control, but in the end, elected to retain depth stability to assist with dam inspection, which might be especially challenging if the ROV is drifting up or down during the grid-based inspection process. The sensor is a level gauge which uses level transducers to generate an output signal of 0-5V, translated by our drive program and GUI to scalable depth.

Figure 12. Depth level sensor.

Sensory and Motor Microcomputer: Re-used.
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 Rust program, executing on our connected laptop through a serial communication mechanism that we custom developed. The Arduino supplies data from our sensors and sends it to the Rust program for analysis. The Rust program makes calculations and sends instructions back to the

Arduino. Then the Arduino would uses those values and changes the thrusters and gripper positions. The analogy is similar to a central nervous system (the Rust program) and a peripheral nervous system (the Arduino accepting sensory and transmitting motor instructions). This allows us to overcome the code length and complexity limitations of the Arduino.

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 seconds, without rewiring or complex operations on the vehicle.

Controllers: Custom Built and Re-used.
PS/2 wireless controller for locomotion (re-used), Axis-rotation and gripper controller (re-used), Thruster precision adjuster (built).

A PS/2 wireless controller ($21) was re-used for the main thruster control by the pilot because of the ergonomics, price, flexibility, array of buttons, pressure sensitivity, and reliability, which are difficult to match in a handbuilt controller.
The Axis-rotation and gripper controller (Fig. 13, left) uses mounted potentiometers to pass a signal to the main drive program, which in turn sends values out to the Arduino and finally thrusters or gripper motor. For example, during the tire removal challenge, pitch is used to secure the tire on the hook capture device during ascent.
The Precision Mode dial (Fig. 13, right) is a potentiometer whose value is used to attenuate the current to the thrusters, to allow for fast motion or fine control. This allows for much finer control than our 2018 solution, which only toggled between 25% intervals in power and provided no visual or tactile representation of mode.

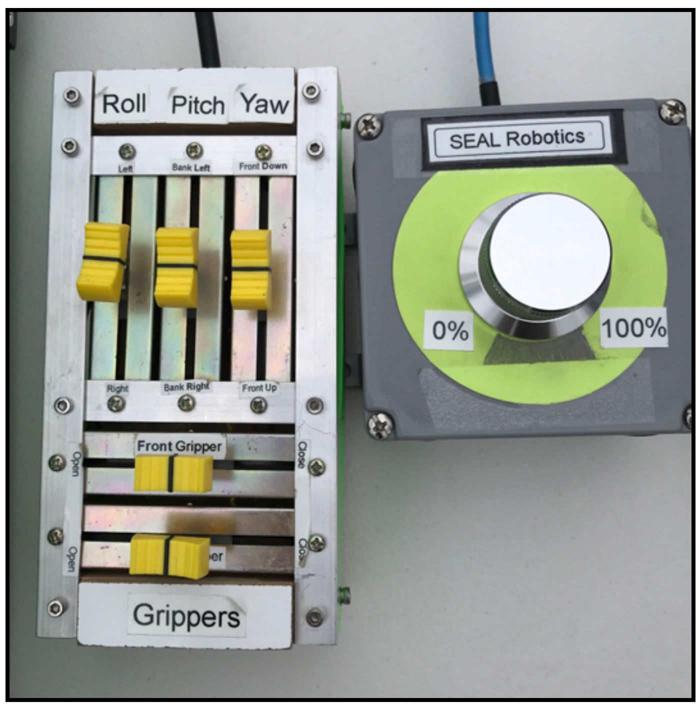

Figure 13. Precision Mode and Slide Potentiometers

Thrusters: Re-used.
Blue Robotics T100 thrusters (Fig. 14), $119 if purchased new. Configuration: vertical tripod, two forward/reverse, single strafe for a total of 6 thrusters.

The T100 thruster (2) is a brushless motor designed for underwater robotics. 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 original purchase, we decided the robustness of the thruster and support from Blue Robotics justified the price of this mission-critical hardware. Testing of the thrusters for drive program calibration was performed by mounting them on rods in a bucket; on the assembled ROV in a large fluid filled container; and in pools.

Figure 14. Blue Robotics T100 thruster

Air System: Re-used.

Airhead AHSUP-AO23 Sup Hand Pump and Hitachi 19412QP polyurethane air hose.

Our ROV has an air system that includes an air hose and pump specifically used for the recovery of historically important underwater objects such as Civil War cannons. The air hose (Fig. 15) is a green, flexible but spiral reinforced polyurethane hose measuring 15.2 meters in length and 0.635 cm diameter. It runs through our tether and to the gripper. It has bend restrictors to prevent breaking and leaks. We re-used this air hose from last year because it is robust and effective. Retail cost $28.98. Other air hoses are cheaper, but as a team we selected the Hitachi because of its durability and flexibility under the water. Upon testing, excellent airflow was achieved through this hose at a 3.6 meter depth. The Airhead hand pump, rated to 15 PSI, has a large reservoir for high volume air movement to quickly fill our lift bag device, even at depth. This air pump originally cost $46.14, comparable to other pumps rated to this PSI.

Figure 15. Hitachi Air Hose.

Lift Bags: Custom Built.

Polymer bucket with carabiner attachment (Fig. 16).

The Request for Proposal indicated a need for a lift bag to lift and release or recover heavy objects of historical significance underwater. We designed a lift device to lift and recover heavy objects underwater using the Archimedes principle. Based on our design from 2018, but with more lift capacity, the system will lift an object up to the surface where the Mako ROV can pull it to shore. Foam buoyancy on the top of the device helps it retain orientation underwater for easy filling. SEAL Robotics team originally prototyped and tested many lift bag systems before settling on this one. In testing, the bucket-based design was effective in accomplishing the task quickly. Volume capacity of approximately 1.5 gallons was determined empirically to readily lift the cannon.

Figure 16. Polymer lift device.

ROV Modular Accessories: Custom Built.

Attachable Tire Capture Device

Even with the extreme opening capacity of the new SEAL Mako gripper, removing heavy and unwieldy debris, such as submerged tires, warranted a custom fabricated modular accessory. SEAL Robotics members designed and fabricated an aluminum hook (Fig. 17) which attaches, using a slotted design and single pin, to the bottom of the Mako ROV. This hook is ideally suited for capturing submerged tires and can even be adapted to fit a modified lift bag rather than attaching rigidly to the vehicle. Aluminum does not degrade in water and has sufficient rigidity to lift these objects.

Figure 17. Tire Capture Device.

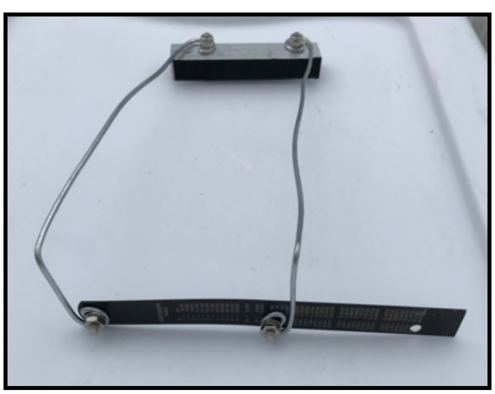

Figure 18. Ruler Extension Device.

Attachable Reference Ruler: Built.

An attachable reference ruler was designed to attach to the ROV using rigid spacer wires (Fig. 18). This ruler, when held in very close proximity to dam cracks or submerged items of historical value, provides a reference length used to calibrate the IC Measure software during the image acquisition process. Once the image is calibrated, measurements can be made. IC Measure also includes software corrections to camera lens distortion.

Dual-Purpose Sensor-Marker: Custom Built.

SEAL Robotics designed a dual purpose detector and marker for underwater items of historical significance known to be of ferromagnetic material. The sensor-marker (Fig. 19) incorporates an inexpensive ferrite magnet into a PVC marker appropriately colored to indicate ferromagnetic underwater items. A clip is used as a tensioning device to secure the marker to the ROV. When the magnet attaches to the item of interest, the force of attraction overcomes the tension of the clip and the marker is released. Mako is capable of carrying two of such markers in a single pass, making frequent return trips to the surface to obtain new markers less necessary. Should an object of interest be shown to not attract the sensor-marker, Mako can use its claw to deploy a different marker appropriate for non-metallic items.

Figure 19. SEAL sensor - marker.

Frame Grabber: Purchased.

DFG/USB2pro frame grabber (The Imaging Source, Charlotte, NC).

The DFG/USB2pro is a small, black, rectangular box with two inputs—one Composite video and one S-VHS—and one output—a USB type B port that connects to the computer via a USB cord (Fig. 20). Cost is usually $200, but we were able to get it at a discount for $100. Advantages of this device over other frame grabbers are: 1) Uses composite video format which matches our cameras; 2) Industrial quality; 3) The Imaging Source is a semi-local company to SEAL Robotics with excellent engineering support; and 4) the device is known compatible with IC Measure, an industry standard measuring software for frame grabbed images also published by The Imaging Source (2). We compared it to similar devices as inexpensive as $20 designed for digitizing VCR output to a computer, but based on reviews those devices are extremely unreliable, have little or no support, and often have driver or other incompatibilities. Testing primarily by team members Ben L. and Michael S. with on-land, through the tether, and underwater cameras and proportional measurement for benthic species identification and cannon and crack measurement demonstrated.

Figure 20. DFG/USB2pro frame grabber.

Main Tether: Custom Built.

Two Cat6 wires carry power and signals to and from the depth sensor, temperature sensor, and the gripper. Two new 10-conductor 22 gauge structured cables carry signals to the six T100 thrusters. There are also seven video wires, atmospheric reference tube for the depth gage (re-used), and air hose as described above (re-used). Foam weatherstripping is used to keep the tether close to neutral buoyancy. SEAL Robotics was able to replace previous 18 gauge triplex wires for thrusters with 22 gauge wires, resulting in significant weight and size reduction, without significant loss of thruster performance. The tether is still substantial in size and weight due to our safety and reliability design priority to place all sensitive electronics on-shore rather than on the vehicle itself. Cat6 wire was used as standard due to being lightweight, flexible, and inexpensive. Voltage drop and other factors over the 14 meter tether was measured for each component and taken into account.

Control Box: Re-used.

With modifications since last year, our land-based control box (Fig. 21) is used to securely and safely organize our electronics, including the Arduino.

- No AC power is present in the Control Box.
- No fluid power is used on this ROV System.
- No Lasers are used on this ROV System.

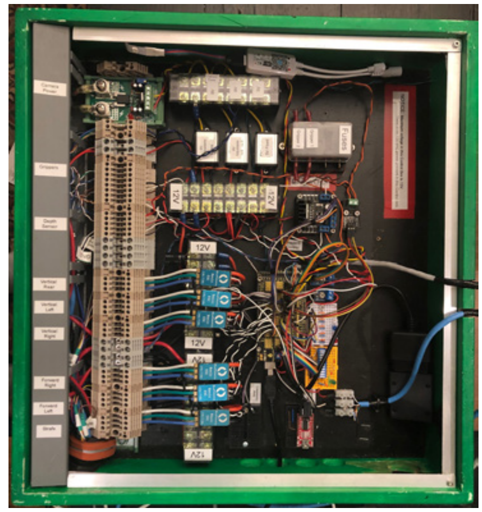

Figure 21. Electronics control box, lid removed.

Main Fuse: ROV Overcurrent Protection Fuse Calculations:

Fuse Calculations			
Device	**How Many**	**Current Draw Each (Amps)**	**Total Current**
Thrusters	6	2.25	13.5
Cameras	7	0.1	0.7
Gripper	1	1.2	1.2
Arduino	1	0.25	0.25
	Total Calculated Current (Amps)		**15.65**
	Overcurrent Protection Factor		**150%**
	Fuse Calculation (Amps)		**23.475**
	Round to Fuse Size (Amps)		**25**

Table 3: Fuse calculations for overcurrent protection.

Based on these fuse calculations and the MATE limits, the Mako ROV system uses a 25 amp slow-blow fuse (Table 3). The fuse is positioned well within 30 cm of the Anderson Power Pole connection, as per the specification.

Ancillary Supplies:

Laptops (re-used and purchased), video screen(re-used), video selector (re-used), and powered video splitter (purchase).

One Dell Inspiron laptop is re-used to execute the main drive and GUI programs. A second ASUS laptop is used for the frame grabber in order to allow the sixth drive team member to perform tasks without interfering with the drivers. The video selector allows us to quickly and manually select between all 7 cameras for task completion. A RadioShack 1500320 video splitter is used to split off composite video to the frame grabber in order to preserve the 1 volt peak-to-peak signal and terminate both split signals with the appropriate 75 ohm load. We chose Sceptre video monitors because they were inexpensive and exceeded the resolution of our composite video cameras. All of these purchases were chosen to balance functionality, weight, and low cost.

Software:

Drive System: Custom Built.

Rust programming language (3).

The overarching program at the heart of the Mako ROV makes use of the safe multithreading capabilities of the Rust programming language (The Rust Project, open-source under the M.I.T. license and the Apache 2.0 license) in order to handle serial communication with Arduino boards, calculations, and the GUI simultaneously. In Fig. 22 a basic flow diagram of the overall program is presented, 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.

Rust was chosen as the development language due to its superior safety and stability with multithreading. Our Rust programmers (Oliver V. and Ben L.) used print and online resources for learning purposes (3).

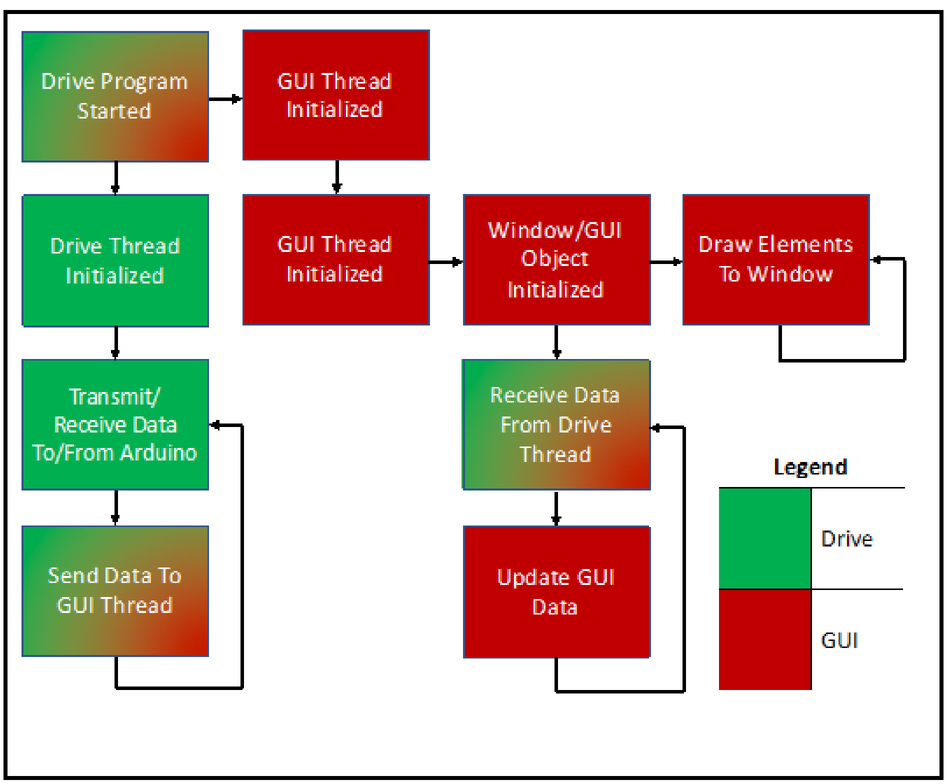

Figure 22. Flow diagram of the Mako Drive system and GUI code.

The drive system was re-written this year to bring order and neatness to the ROV's code, and reach past the limitations of using the Arduino C language. Due to the use of computer science principles in design, the entire programming team was able to divide and conquer each individual section of the program before it was brought together. The custom drive program is a result of our programmers identifying a problem, proposing a solution, and acting upon it to make it reality.

Graphical User Interface: Custom Built.

Rust programming language.

To diagnose any problems with the ROV, as well as to help the driver complete challenges, our team developed a Graphical User Interface (GUI) from scratch using the Rust programming language (Fig 23). Our legacy GUI (written in Java) did not allow for two-way communication between the computer and Arduino. This lack of communication to the Arduino left much of the heavy lifting computation-wise to be done on the Arduino, which limited our performance.

Rust has a graphical library for OpenGL called Piston. We created an element showing our depth, another showing the current inputs on our PS/2 controller, one showing the current water temperature, and more. Each panel was tested in and out of the water, with dummy values, as well as with real sensor values, to ensure that every possible condition was accounted for. The GUI shows the controller input it is sensing; the thrust values reported by the T100 thrusters; the depth level and user-set desired level; temperature; and other diagnostic data.

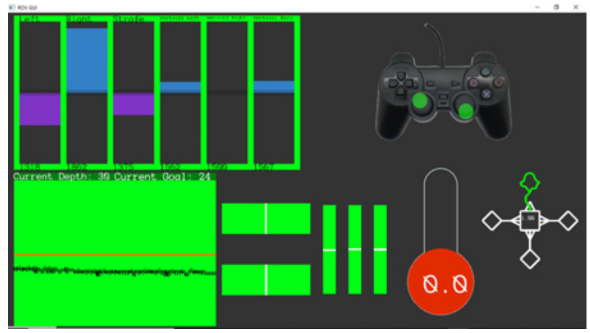

Figure 23. GUI screengrab showing thruster values (top left), controller activity (top right and bottom middle), current depth and target depth (bottom left), and temperature and precision mode feedback.

Image Recognition, Scripting, and Measurement: Custom Built.

Multiple mission tasks required measurement or identification of certain features of objects underwater. IC Measure (The Imaging Source), along with our frame grabber, allows for measurement using a standard size ruler in proximity to the item being measured. Scripts were written in the Python scripting language and tied to hotkeys in order to allow the Sixth Person to automate two tasks: 1) calibration and measurement for crack and cannon measurement; and 2) image capture with image passed automatically to a custom written Python script that harnesses the OpenCV computer vision library for symbolic benthic species identification. The Python script then returns the number of each benthic species representation to be displayed on-screen without user input. One issue encountered was that the images from the ROV could sometimes appear distorted and could contain noise that would change the output. To prevent this, pilots were trained to obtain proper positioning before image acquisition for ideal angles and orientation.

SID:
(Larger version under separate cover)

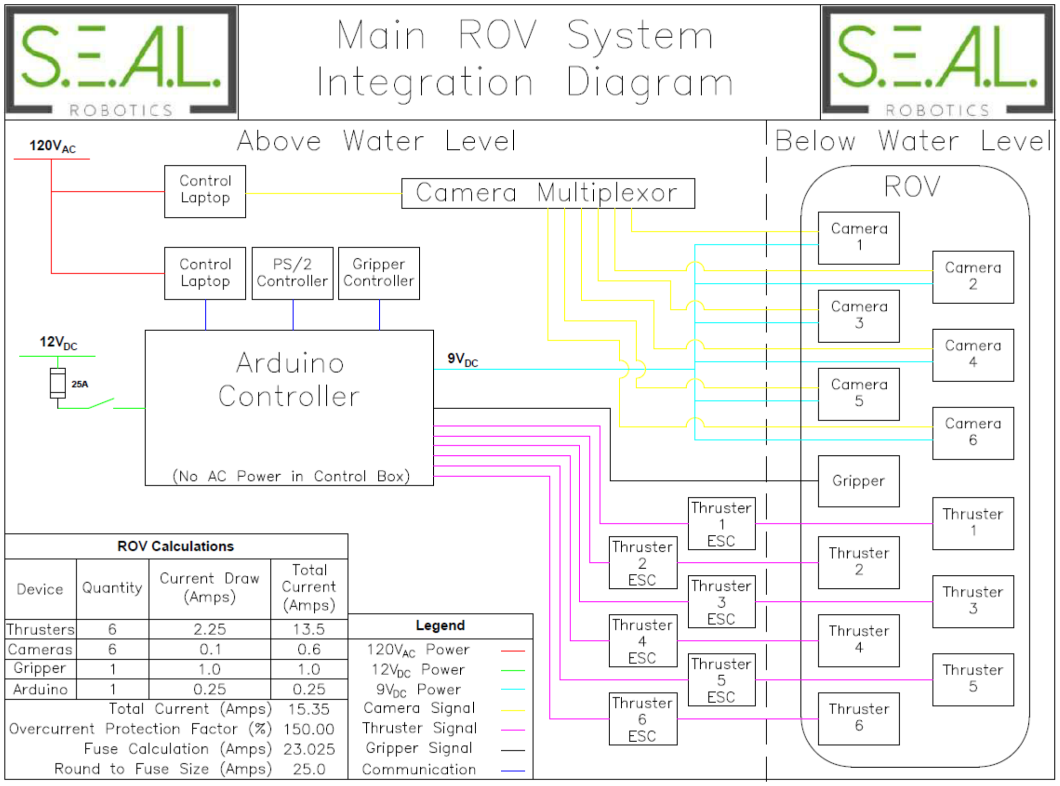

Figure 24. SEAL Robotics systems integration diagram (SID)

Safety

Safety 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. "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, and other safety equipment when working with hazardous equipment, and our mentors provide proper training on each tool. On our ROV system, we do not take shortcuts when it comes to safety. For example, 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.

Safety Features:

Our ROV includes a number of safety features:

- Shrouded thrusters (Fig. 25), bright green in color to draw attention.
- Caution labels inside of our control box for hot heat syncs on the motor controllers.
- No 120 VAC power in our control box; sign to make this clear.
- Green corner protectors on the ROV chassis to protect against sharp edges.

Pre-Run Safety Checklist:

- All nuts and bolts and attachments are secured
- Thruster shrouds are secured and tight

- No foreign objects present inside thruster shrouds
- All wires are secure and in excellent condition
- There are no sharp edges and/or corners on the ROV
- All thrusters are unobstructed
- Drive table set up is clean and organized
- All members of drive team are in "ready drive position" (Fig. 26).

Figure 25. Safety shrouds installed along all thrusters.

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)

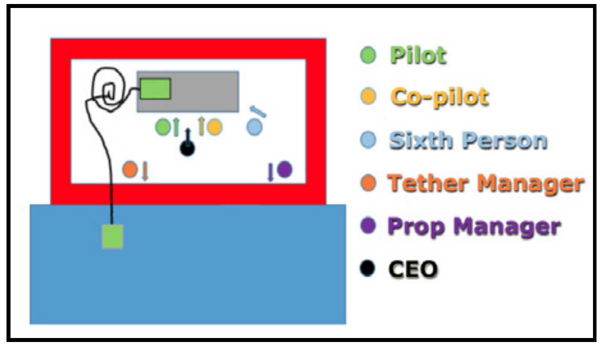

Figure 26. Poolside ready positions for safety and efficiency.

Post-Run Safety Checklist:

- Make sure all equipment is safely removed from product demonstration area
- All nuts and bolts and attachments are secured
- Thruster shrouds are secured and tight
- No foreign objects present inside thruster shrouds
- All wires are secure and in excellent condition
- There are no sharp edges and/or corners on the ROV
- All motors and servos are unobstructed
- Ensure there are no water leaks or damage
- Members thank judges and staff

Critical Analysis

Testing and Troubleshooting:

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. For example, in shallow water our new gripper worked flawlessly; but when first tested performing tasks below three meters depth, water pressure overcame the o-ring seal along the drive shaft separating the wet gear compartment from the dry motor compartment. Despite extensive use of silicone in the motor compartment, the motor was ruined from water penetration. Hence we learned to implement a more robust seal around the shaft.

Strategies and Techniques for Troubleshooting:
These were based on systematic isolation of problem areas by outlining all components of a faulty system and then methodically testing each component in isolation. For example, we experienced a camera problem where our birds-eye camera feed would intermittently cut out. Possible causes included camera failure, connection/waterproofing, wire, or land-based connector problem. After checking the simple things, we were able to replicate the problem by wiggling part of the camera wire that had been cable-tied far too tightly to the chassis by an inexperienced member, partially breaking the wire. We replaced that wire segment and educated all members on proper wire fixation.

Lessons Learned:
Team learning included a specific study of inland waterway ecology, dam maintenance, and preserving history. The project build lessons included technical knowledge we acquired; how to better organize our meetings and share work, and new skills.

Technical Standpoint:
Digital image acquisition, image recognition, underwater weight calculation, end-effector design, and a considerable improvement in software sophistication were tangible benefits. There was substantial information for the team to absorb regarding digitization of video feed and processing the images. We learned about specific gravity and how to use volume and specific gravity to determine the weight of submerged objects. Our end-effector research and internal sub-team gripper prototyping competition taught us design and prototyping of mechanisms of greater complexity; as a team we watched multiple videos on end-effectors prior to our design challenge (5,6). Finally by converting the central "decision making" portion of our software from the Arduino to a PC and using the Arduino programs only for sensory and motor function, our software was able to become much more refined.

Management Lessons:
This year validated our model of having a plan before each meeting with assigned responsibilities and team goals. The 2017-2018 was our first year as a team and we suffered from disorganization. During the 2018-2019 season, work was better distributed across the whole team and a more purposeful and goal-focussed approach prevented the frustration of unproductive and unorganized meetings.

Skills Development:
Skill development included multiple members learning the Rust programming language (chosen both for multithreading safety but also to introduce our coders to a fresh new language); original design and prototyping skills especially in our gripper competition; leadership skills gained from observing more senior team members and mentors; and the ability to digest and fulfill ambitious assignments such as the Micro-ROV and image recognition challenges. Our software designers who worked in Rust wanted a complete rewrite this year to compartmentalize and clean up the code to ease transition to new programmers in future years. For perhaps half of our members, having to successively produce sophisticated prototypes of a complex item like a gripper, capable of being motor driven, was a new level of expectation; we rose to the task by applying the skills we had developed. Our more experienced team leaders modeled responsibility, task ownership, and safe tool use under the guidance of our mentors. Finally, we learned to digest what seemed like ambitious challenges, such as the

Micro-ROV and image recognition missions, break them down into smaller more manageable goals, and put forth a credible solution.

Reflection and Future Improvements:

Not every part of the project went smoothly. For example, the Proportional Integral Derivative (PID) controller of the drive program, which sets the ROV at a given depth chosen by the user, was frustratingly troublesome. Theoretically, as the ROV approaches the correct depth setting, the PID controller routine should slow the thrusters to prevent overshoot and oscillation around the target depth. We experienced a series of frustrations with the PID malfunctioning. Some were due to code bugs, some were due to the difficulty in adapting our system to a "tunable" set of values. Delays in the PID caused delays in the drive system which caused delays in pool practice. Left with few options, we had to use the old software from last year for several pool sessions before the PID issue was fixed. We are considering building an all-new Mako model next year that does not use depth control in its drive mechanism, in order to eliminate the complexity of the PID, and also reduce overall cost.

Accounting

Project Budget:

BUDGET - SEAL Robotics ROV Build 2019				
Category	**Item**	**Projected Cost**	**Budgeted Value**	**Notes**
Competition Display/Report	Display board supplies, technical report, pictures, etc.	$120.00	$120.00	
Registrations	Competition Registrations	$200.00	$200.00	$200 for Regional
ROV - Cameras	Cameras, cables, connectors, adapters, multiplexers, screen grab software, etc.	$400.00	$550.00	
ROV - Lift Bags, Prop Supplies	Lift bag supplies, Prop supplies	$50.00	$75.00	
ROV - Grippers / robotic arms	Grippers, motors, servos, controllers, etc.	$300.00	$300.00	
ROV Sensors / Electronics	Current and Voltage Sensors, temp sensor.	$200.00	$200.00	
ROV - Tether	Tether wire, waterproofing, etc.	$250.00	$275.00	
Control Box	Terminal strips, bus bars, wiring, Arduino, PS/2 Controllers, Paint, etc.	$150.00	$150.00	
Misc	Miscellaneous extra supplies/padding	$250.00	$250.00	
Misc	Other components to be reused including poly air hose, AV switch, etc.	$152.00	$0.00	Reused components
ROV - Frame	Aluminum stock and fasteners	$110.00	$0.00	Reused components
ROV - Cameras	Two 32" monitors	$297.00	$0.00	Reused components
ROV Sensors / Electronics	Depth Sensor	$250.00	$0.00	Reused components
ROV - Thrusters	Blue Robotics T100 with integrated ESC	$777.60	$0.00	Reused components
	Total ROV Projected Expenses	**$3,506.60**	**$2,120.00**	
	Expected Funds/Income for ROV build		**$1,600.00**	*Portion of team income available for ROV*
	Expected shortfall in funding		**$520.00**	*We must raise this much money*

Table 4. Project Budget for ROV build.

Valuation of Reused Materials:

Valuation of Reused Materials and Components			
ROV - Frame	Aluminum stock, fasteners, and ballast.	110.00	
ROV Sensors / Electronics	Depth Sensor Donated - Keller America	250.00	
ROV - Tether	Poly air hose	30.00	
ROV - Thrusters	Blue Robotics T100 with integrated ESC	777.60	
Control Box	Terminal strips, bus bars, wiring, Arduino, Shield, transformers, paint, zip ties and wire management, aluminum stock, sliders.	175.00	
ROV - Cameras and Video	Two 32-inch monitors	297.00	
ROV - Cameras and Video	Analog AV switch box, video adapters and cables	49.00	
	Valuation of Reused Materials and Components	**1,688.60**	
	Total Cost of ROV Project	**3,831.60**	
Incoming Funds and Donations for the ROV Project			
Donation - Funds	Greensboro Radiology	900.00	
Membership Dues	SEAL Robotics Funds from Membership Dues earmarked for the ROV project	1,600.00	
	Total Incoming Funds	**2,500.00**	
	Expected Shortfall in Funding	**(357.00)**	Due to generous donation, slight surplus in available ROV project funds

Table 5. Valuation of Reused Materials and Donations for 2019 ROV build

Project Expenditures:

Category	Item	Expense	Notes
2019 ROV Project Expenditures			
Competition Display/Report	Display board supplies, technical report, pictures, etc.	120.00	
Registrations	Competition Registrations	200.00	$200 for Regional
ROV - Cameras and Video	Camera cables, cameras, video connectors, screen grab software, other video adapters	335.00	
ROV - Gripper / robotic arms	Worm gear, two drive gears, stainless shafts, bearings, epoxy, DC motor, M3 fasteners, lock nuts, roll pins, washers, waterproofing supplies, PVC, aluminum stock, couplers.	320.00	
ROV Sensors / Electronics	Temperature sensor, PCB boards and electronic components.	130.00	
ROV - Tether	Velcro, additional waterproofing materials, additional wire, fuse holders and fuses, ballast supplies, epoxy	94.00	
ROV - Tether	Tether wire	147.00	
Misc Electrical	Waterproofing supplies (Silicone RTV, heat shrink, liquid electrical tape, 3M Ultra Black, etc.), terminal ends, voltage sensor, amperage sensor, fuses, etc.	212.00	
MicroROV Control Box	Potentiometer, knob, switches, Arduino mini, wire, strain relief, box, fuses.	72.00	
MicroROV	Wire for MicroROV tether, MATE bilge pump motor, dental bottle, LED, camera, waterproof plugs, Epoxy, fasteners, waterproofing supplies.	197.00	
Main Control Box	Terminal strips, hookup wire, fuse block, motor controller, paint, stainless fasteners, wire management, LEDs, breadboards, sensors, plugs, strain relief materials.	206.00	
ROV - Custom Lift Bags, Hooks, etc.	Aluminum stock, PVC, Epoxy, Lift bag supplies including buckets, fasteners, carabiners, zip ties.	110.00	
	2019 ROV Project Expenses	**2,143.00**	

Table 6. Project Cost Accounting Expenditures for the 2019 ROV build.

Travel Costs:

Driving from Greensboro, NC to Kingsport, TN:

Gasoline: (210 miles / 25 mpg) * $3/gallon * 12 vehicles = $302

Hotel: $115 per night * 11 member families = $1265

Total travel costs: $1567 for regional and $1567 for international competitions

Acknowledgments and Sponsors

MATE and our Corporate 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://www.forgegreensboro.org	http://www.integraenclosures.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:
Eastman Chemical Company for sponsoring the 2019 MATE Underwater Robotics Competition.
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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