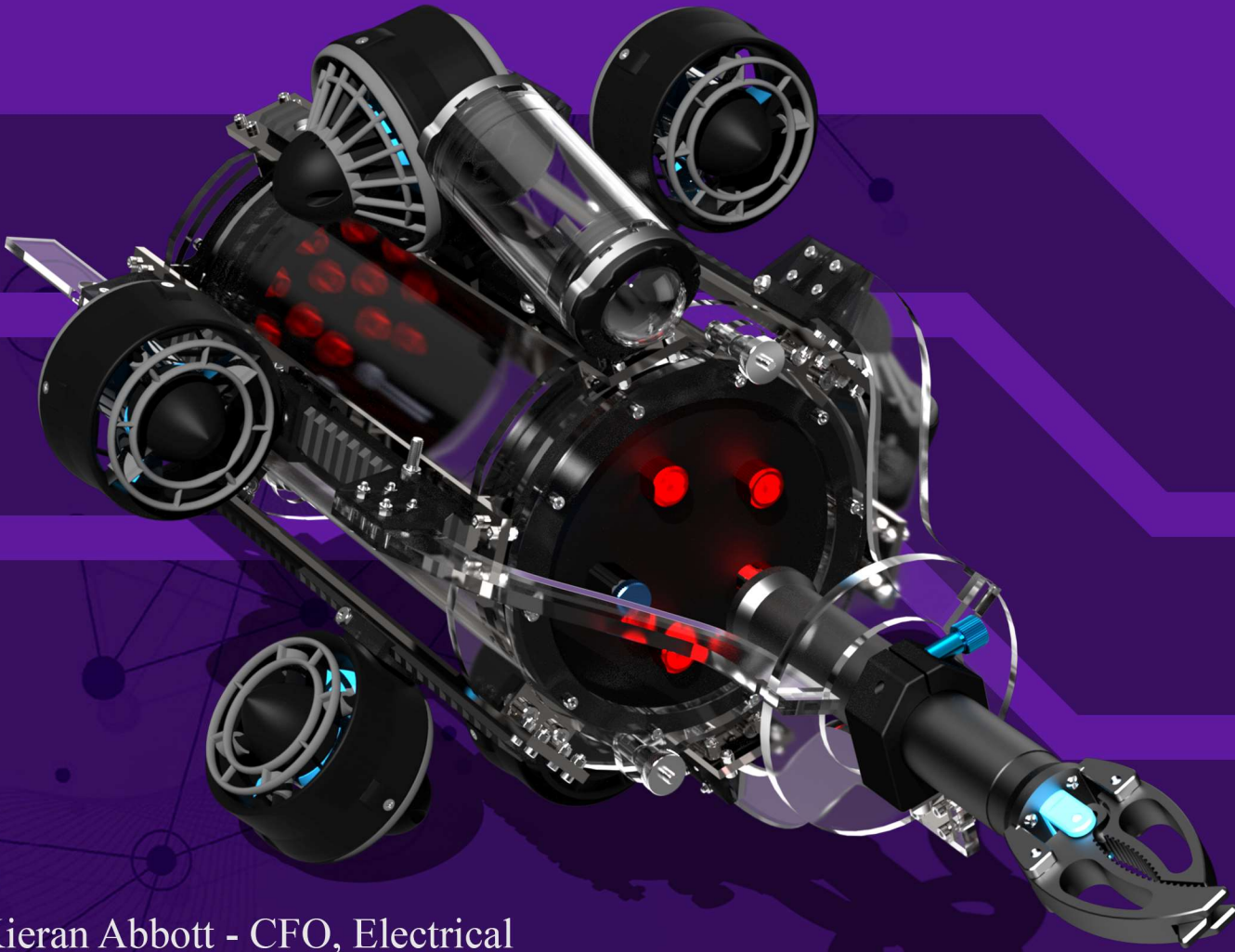


Robosharks

Technical Documentation



Kieran Abbott - CFO, Electrical
Zhenren Miller Meng - CEO, Pilot, Mechanical
Julian Snyder - Software, Electrical
Ian Graves - Mechanical
Mackenzie Olsen - Mechanical, Safety
Mattison Konczak - Mechanical
Ada Tessar - Electrical
Jack Wysong - Mechanical
Deven Mak - Software
Eli Diamond - Software, Electrical
Karissa Murra - Mechanical
Jaqueline Martinez - Software
Liam Goodman - Software

Jessica Klauzer-Zimmerman - Mentor
Geo Tam - Mentor
Sera Vogel - Mentor



Abstract

The Robosharks, from Boulder, CO, was founded to create innovative solutions to various underwater problems. We're composed of 13 members, six returning and seven who are new to the Ranger class. Additionally, our company has three Navigator subteams to train and mentor newer members. For this year's RFP, the Robosharks are proud to present Mako.

Mako was designed to be simple, serviceable, and versatile. To pursue these goals, we opted to forgo a traditional frame, instead installing rails to mount our thrusters, camera, and manipulator to. These rails allow for easy adjustment of the thrusters, which gives us freedom to compensate for changes in our center of mass. The frontal nose cone offers us a stable, central mount for our off-the-shelf manipulator. This manipulator allows us to easily interact with objects underwater, and its location puts it perfectly into our camera's FOV, giving the pilot excellent knowledge of the task at hand. Our serviceability is also emphasized through the use of a removable tether, which allows Mako to be easily transported and serviced.

Mako's software was similarly designed with a focus on simplicity. Using an Arduino Minima to send PWM signals to the thrusters, Mako is able to move in all six degrees of freedom using a simple game controller.

Despite the simplicity of the tasks we are performing, we hope that Mako will nevertheless be able to inspire efforts to reach the UN's Sustainable Development Goals.



Left to right, top to bottom: Kieran Abbott, Zhenren Miller Meng, Julian Snyder, Ian Graves, Mackenzie Olsen, Mattison Konczak



Left to right, top to bottom: Ada Tessar, Jack Wysong, Deven Mak, Eli Diamond, Karissa Murra, Jaqueline Martinez
Not pictured: Liam Goodman



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Design Philosophy

The Robosharks have always been about reinvention rather than iteration. Our last robot—Bubbles—pursued the idea of symmetry. Nearly cubic, it sported equal thrust power in every direction. This year we pursued simplicity and streamlining. Our radially symmetrical, forward-biased thruster layout enables powerful forward movement and roll at the expense of stability, strafe, and climb. This instability informed our other major design feature, using picatinny rails to mount our thrusters, allowing us to adjust them to sit as close to our center of mass as possible, mitigating the instability.

Mako was designed as a response to some of the challenges we faced in previous years. Its drybox is significantly larger than our previous designs, while the frame is simpler, allowing us to easily service our thrusters and internal components. The front nose cone gives our manipulator a stable mounting place and its placement puts it in a central view of our camera, which allows us to easily see what we're holding. The picatinny rails on the side were purchased to allow us to alter the position of our thrusters quickly and easily in response to changes in the center of mass.

Teamwork and Scheduling

Project Management

Each member of our team has worked on a team in the past, which has granted us an understanding of each other's and our own skill sets. This allowed us to assign tasks to the person most suited to perform them. However, most tasks are interdisciplinary, and require the expertise of more than one member, so we often have multiple people working on one task. This cooperation ensures high-quality work on all aspects of the project, and streamlines the design process as multiple people can contribute ideas and suggestions. We also elected our CEO based on who we believed would be able to keep things running smoothly and on schedule. To keep tasks organized, we created a team notebook where we wrote down what we accomplished during our meetings, and what we still had to complete.

Scheduling

We began the school year by developing a meeting schedule that focused on accessibility. We scheduled our weekly meetings around our schedules, as well as by surveying other members of



the club. Once this was done, we decided to meet once a week to train new members and do preliminary design work on our robot in the fall and early winter.

Once the competition manual was released, we started meeting twice a week on Mondays and Wednesdays for an hour after school. We chose an end date for our Mako's completion, but due to issues in procuring parts, as well as time management issues, it soon became clear that this time was insufficient. In order to remedy this and catch up, we decided to extend Wednesday meetings another hour, and after our spring break was over, we did the same with our Monday meetings as well.

Communication

Our primary platform for communication and planning was Discord, where we created channels for different categories to expedite communication and had space for people to discuss timelines and challenges as we worked. In addition, we also used email to send out important information to the company, since while Discord works well for discussion, it is not as effective for important company-wide announcements.

Additionally, we utilized GitHub for our code repository. This program allowed for easier and more efficient collaboration between team members while working on code. Finally, we used a company-wide Google Drive to easily share pdfs, spreadsheets, and text documents.



Figure 2: Mako



Design Rational

Mechanical

Overview

The goals of speed, simplicity, and versatility drove our design. Mako's thruster rails allow for highly configurable torque and thrust vectors, while being simple to assemble and easy to transport. Mako was designed to be quick because we wanted to limit time spent in transit between tasks, to optimize our ability to perform well in a timely manner.

Main Enclosure and Penetrators

Mako is built around a single 6" Blue Robotics watertight enclosure (Figure 2). We opted to buy a bigger drybox instead of reusing a smaller one due to spatial difficulties we experienced last year. With a larger drybox, we ensured easy access to electrical components, as well as better organization and clearer wiring. For our penetrators, we chose Blue Robotics potted penetrators for the majority of our wires as they have proven themselves to be reliable and easy to use. One important exception to this is our tether penetrators, which are purchased from Blue Trail Engineering, and allow us to fully detach our tether during storage and transit.

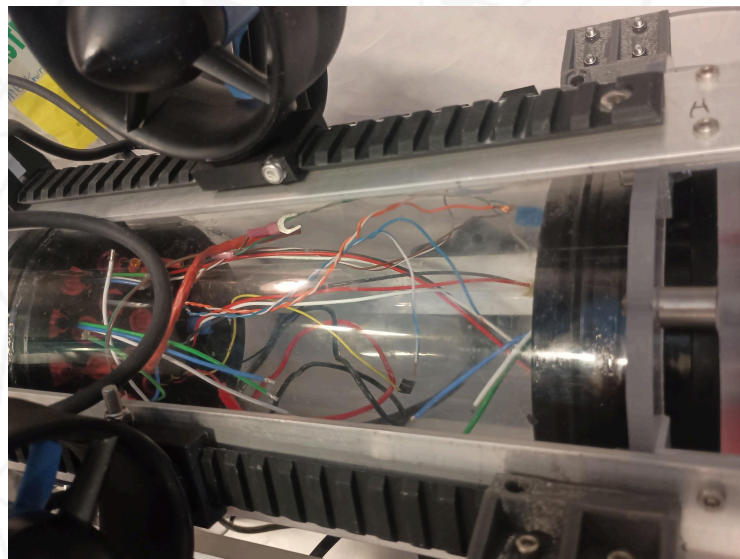


Figure 2: Mako's main enclosure



Thrusters

Our main considerations when deciding on a thruster layout were simplicity and strong forward power. We had the choice to use eight thrusters, but opted for six because it would be less crowded and simpler to build than eight, although it slightly increased the work needed for our software to properly divide vectors among the thrusters. In order to ensure that we would have access to all six degrees of freedom, we used a program called TAU (thruster arrangement utility) to graph the thrust and torque forces that our bot would be able to produce (Figure 3).

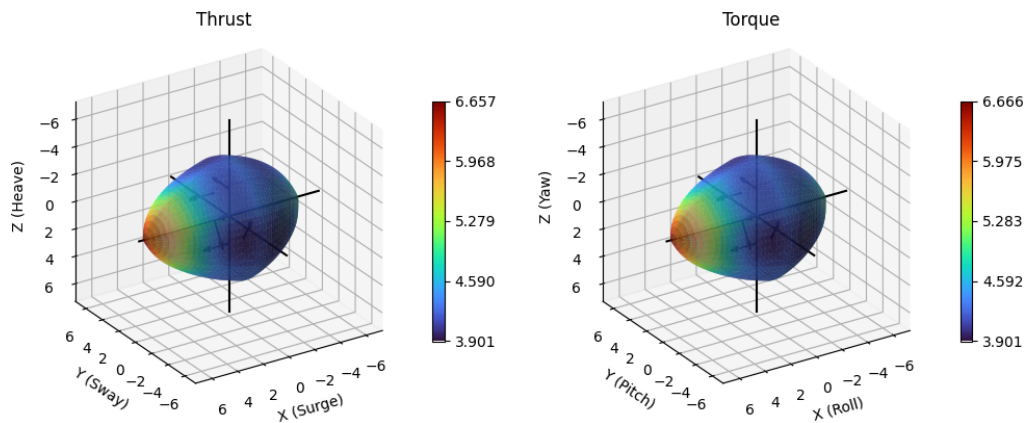


Figure 3: TAU graphs of Mako's thrust and torque

Outboard Camera

The camera included is mounted on a static mount that is connected to the bot via our picatinny rail system. This placement combined with the location of our manipulator allows us to look much further forward while keeping the manipulator within view compared to previous years, where our cameras faced downward at a 45° angle, limiting forward visibility.

The camera itself is a FLIR Blackfly IP camera module. It communicates over Ethernet, and is powered off of 12v. The camera is housed in an external enclosure (figure 4), and gives us low-latency, high quality video. The camera is pointed through a domed port on the front of the enclosure to prevent image distortion and we chose a wide-angle lens for a large field of view. The camera module emits a significant amount of heat so in order to keep our thermals in check, the camera mounting bracket is made of high thermal conductivity copper. This copper is mounted to the metal endcaps of the enclosure, allowing heat to conduct and dissipate easily into the surrounding water.

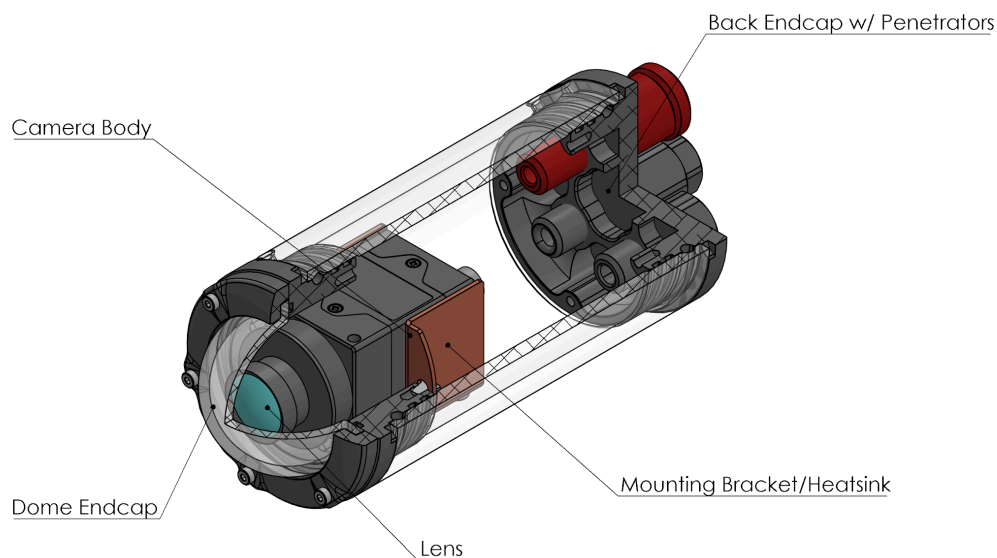


Figure 4: Camera assembly

The ROV has one main drybox and one separate camera enclosure. The main electronics enclosure is made of a new 6-inch acrylic tube, two O-ring flanges, two cable penetrator plates, and cable penetrators, all of which are manufactured by Blue Robotics. We bought everything new this year to reduce difficulty modifying and maintaining the electronics once they are hooked up. The separate 2 inch camera enclosure, penetrator plate, and penetrators are also manufactured by blue robotics.

Buoyancy

Buoyancy is something that we struggled with. Due to our thruster layout, our bot needs to have the center of buoyancy located almost exactly in the center of the drybox to prevent torque on the bot during motion. In order to solve this problem, we tested our robot with different amounts of foam, until we finally found a layout that was only barely positively buoyant. We decided to be positively buoyant, so if we have a critical failure while in operation, the ROV floats to the surface and can be easily recovered.



Systems Design

Electrical

The single biggest impact on our electrical system was the decision to communicate with the vehicle over a single Ethernet cable. Due to this design decision, we only need one connection point to our topside computer. It also makes our tether more flexible and lightweight, and it eliminates points of failure.

Tether

Mako's tether is incredibly simple. It consists of two 8-gauge power conductors and a single Ethernet cable. The cables are wrapped in a sheath to protect them and keep them bundled together. Blocks of foam are placed intermittently around that sheath in order to keep the tether neutrally buoyant. Due to our use of Blue Trail Engineering Cobalt penetrators, our tether is also fully removable, allowing for ease of transit and storage.

Onboard electronics

The second-biggest influence on our electrical systems was to make communication between our top and bottom end computers easier. Last year only had an Arduino with an ethernet shield on a custom PCB, which made control of the robot fairly easy. This year we are similarly having an Arduino Minima with an Ethernet Shield, however we decided to forgo the custom PCB to keep things simple. The Arduino, which is used to control six Blue Robotics Basic ESCs (Electronic Speed Controllers) and one Blue Robotics Newton Subsea Gripper. We have two ethernet devices onboard, one camera, and the ethernet shield, requiring us to use an ethernet switch. Our thrusters, camera, Arduino, and manipulator are powered via the 12v on our tether, while our ethernet switch and thermometer require a 12V to 5V step down converter.

Topside electronics

Our topside electronics consist of a Custom Built PC and Xbox controller that communicate with the onboard electronics via ethernet, as well as a mounted monitor to give our pilot additional information. All of the heavy computing is done by the PC.



Control System

Control Box

Our control box is a high-performance desktop PC built inside of a Pelican 1600 waterproof case. It's made with a custom cut acrylic top sheet, custom CNC'd bottom plate, and many custom 3-printed mounting pieces. The PC contains a RTX 3070 graphics card, a Srock mini-ITX motherboard with an Intel i7 13700k. It also has a built-in monitor, keyboard and mouse in the case, turning it into an all-in-one, high performance PC. An Xbox controller stored in the box is used to control the ROV itself. Our design prioritized a very efficient internal airflow. Fans draw in air from the left wall of the case, move them across every device using the CPU and GPU fans, and expel it from the case through the right wall of fans.



Figure 5: Internal components of PC



Figure 6: PC Monitor, keyboard and mouse

Control Software

Our topside control software has two purposes: communication between topside and bottom side, and displaying our robots video feed. Our topside program will take inputs from an Xbox controller and maximize which thrusters should be firing for the best speed in a given direction. This data is then converted from a normalized -1 to 1 value into microsecond PWM timings and combined into a list which is sent to the Arduino Mimina, which then sends the signal to the requisite thrusters, while also controlling our Gripper.

Graphical User Interface (GUI)

Our camera's feed is displayed by using Flir Teledyne's software provided with the camera as this gives us the best support for all functions we may need to use the camera for, such as taking pictures for computer vision tasks which will run with a press of a button on the Xbox Controller. We otherwise use a terminal interface to read live data from our sensors on board the robot.

Payload and Tools

Manipulator

In order to interact with props, we have a Blue Robotics Newton Subsea Gripper mounted on the front of our robot. The gripper's position, centered on the front of our robot, allows us to



rotate the gripper to satisfy any orientation need, and its distance from the bot means the ROV will not interfere with surrounding objects. It can also be removed and stored alongside the ROV for ease of transportation.

Thermometer

In order to accurately survey the temperature of the water, Mako is equipped with a DS18B20 temperature sensor in a waterproof housing. We chose this thermometer because it's fully compatible with our Arduino controller, while offering an accurate temperature report.

Float

For one of the tasks, we deploy a float we constructed to complete vertical profiles of the area. The float operates through the use of a buoyancy engine powered by a linear actuator, which changes the volume of the float by moving a machined plug within a tube open to the water. This causes the float's density to change, letting it complete its vertical profiles without any outside assistance. It also includes an Arduino Minima R4 with a 240 MHz wifi transmitter, depth sensor, and real time clock to keep time of day. The transmitter enables the float to transmit this data to a surface device. The one major revision from last year is the use of an aluminum pipe instead of PVC as our main enclosure. We had thermal management issues with our previous design, so we chose aluminum to facilitate heat transfer from the interior out to the surrounding water, acting as a heatsink for our electronics.

Build vs. Buy, New vs. Used

The ROV uses a mix of custom built and COTS parts tailored for a low cost with high reliability and efficiency. COTS parts, while generally more expensive, also offer a higher degree of reliability, making them ideal for critical components such as the enclosures responsible for keeping the electronics dry. For components such as the ROV's frame, manufacturing them ourselves allows for the components to be better suited to our specific needs for a lower price.

As this is our fourth year competing with MATE, we had the option of reusing several major components from previous years. However, our mentor encouraged us to keep last year's ROV intact because we all felt like it was a beautiful second generation design with little improvement possibilities. As a result, almost every part of the ROV was bought new, with the exception of our manipulator, tether, camera, and camera enclosure.



Accounting

We began the year by deciding what we wanted to accomplish with our ROV. We were unsure on whether we wanted to deconstruct last year's robot, but we knew we didn't want to iterate on it again. At the urging of our mentor, we decided to construct a completely separate bot, with new components, and leave last year's bot intact for community outreach and education.

We created three budgets with this goal in mind: the lowest one would not have allowed us to buy a new set of parts, but would've let the company run. The median budget, which was what we were aiming for as it granted us a lot of freedom to do what we wanted while still reusing some components, and a moonshot budget, which would've allowed us to fully commit to creating a new design. We sent these budgets to the Bartlett Foundation, from which we received a generous donation of \$12,000, which included funds for our Navigator subteams, our company, and club-wide materials. We went for a much more conservative design than we were originally planning on, which resulted in us having an excess of funds. These have been extremely useful for modernizing our shop tools, as well as giving us a large safety net for component failures.

Throughout the year we attempted to keep a good track of our expenses and ensure that we were sticking to the budget. See appendix D for a detailed breakdown.



Safety

Safety Checklists

Operations

TEAM: _____

Task to be checked	Y/N
No internal wires/ electronics with exposed metal	
Flange O'Rings in place and greased	
All penetrators O'Rings greased and in place	
Penetrators tightened down to full degree	
Flange/ drybox bolt tightened down	
All vents and blanks are in and tight.	
Below begins tasks to be completed pool side during setup time provided at competition.	
Robot responds to power on the surface.	
Briefly test robot systems on surface	
Ranger specific PLUG IN TETHER	
Power On topside computer and prep programs.	
Check all connections to robot one final time	
Boot Code	
Place robot in pool and wait to start comp	
Good Luck?	

Construction

1. Always have teacher mentor present when operating power tools
2. Wear proper PPE (ear, eye, and hand protection) and closed toed shoes when operating power tools.
3. Turn ventilation on for power tools that require it.
4. Remove or secure loose clothing.
5. Never leave CNC or laser cutter unattended



Safety Feature

Strain Relief

Our tether is looped around a carabiner attached to the “feet” before going into the main body of the ROV. This ensures that there is no tension on the cable penetrators and allows us to pull the ROV out by the tether if the need arises.

Propeller Guards

Our propeller guards are 3D printed guards designed for use with the T200 thrusters we’re using. They are sturdy enough to resist breaking during use and are rated at IP-20 (finger-proof). The rear guard is also easily removable to allow maintenance on the thrusters when powered off.

Fuse

The ROV uses a 25 Amp fuse, located within 30 cm of the power supply for overcurrent protection.

Critical Analysis

Challenges

Mechanical: At and leading up to the regional, we had several parts fail, including our ethernet penetrator and camera. These failures required us to work together to quickly devise a stop-gap solution which would allow us to compete.

Interpersonal: We struggled a lot with having differing visions for what we wanted the bot to be built for and with the challenge of running a club while building an ROV. We managed to overcome these through working incredibly hard to find compromises for our differing designs.

Electrical: We had a lot of difficulty in organizing our wires, both inside and out of the drybox, while also keeping components easy to access and maintain.

Software: We had difficulty in selecting what components we wanted to run our bot’s software on, as we moved between planning for a custom PCB like last year’s bot, a Raspberry Pi, and our current Arduino Minima.



Lessons Learned

We learned a lot about the process of designing a robot as a team, and how to multitask by also providing mentorship to our newer members. The Robosharks took on the challenge of mentoring three navigator teams while also designing our own advanced ROV. This proved to be a heavy time and financial commitment which taxed our organizational abilities. Keeping track of scheduling and money in a neat and detailed manner was of the utmost importance, and a skill we developed over the course of the year.

Testing and Troubleshooting

Our company performs many tests of the ROV to determine functionality. Frequent tests are leak tests, buoyancy tests, software tests, and full systems tests.

To ensure that the electronics and camera enclosures are sealed, we submerged each enclosure underwater at depth for an extended period of time. This test allows us to detect if any cable penetrators are improperly sealed, or a leak occurs anywhere else in the enclosure.

At the pool, we need to get the ROV as close to neutral buoyancy as possible, so we gradually add and remove ceramic weights until the ROV is stable. Any time a change is made to the ROV, we reevaluate the ROV's buoyancy to see if any changes are necessary.

There are many different components of software that go into the final code; we break down the code into individual sections, such as cameras, controller, and movement, and test each individually to make sure that section works before adding them to the final program, allowing us to pinpoint errors and bugs in the code.

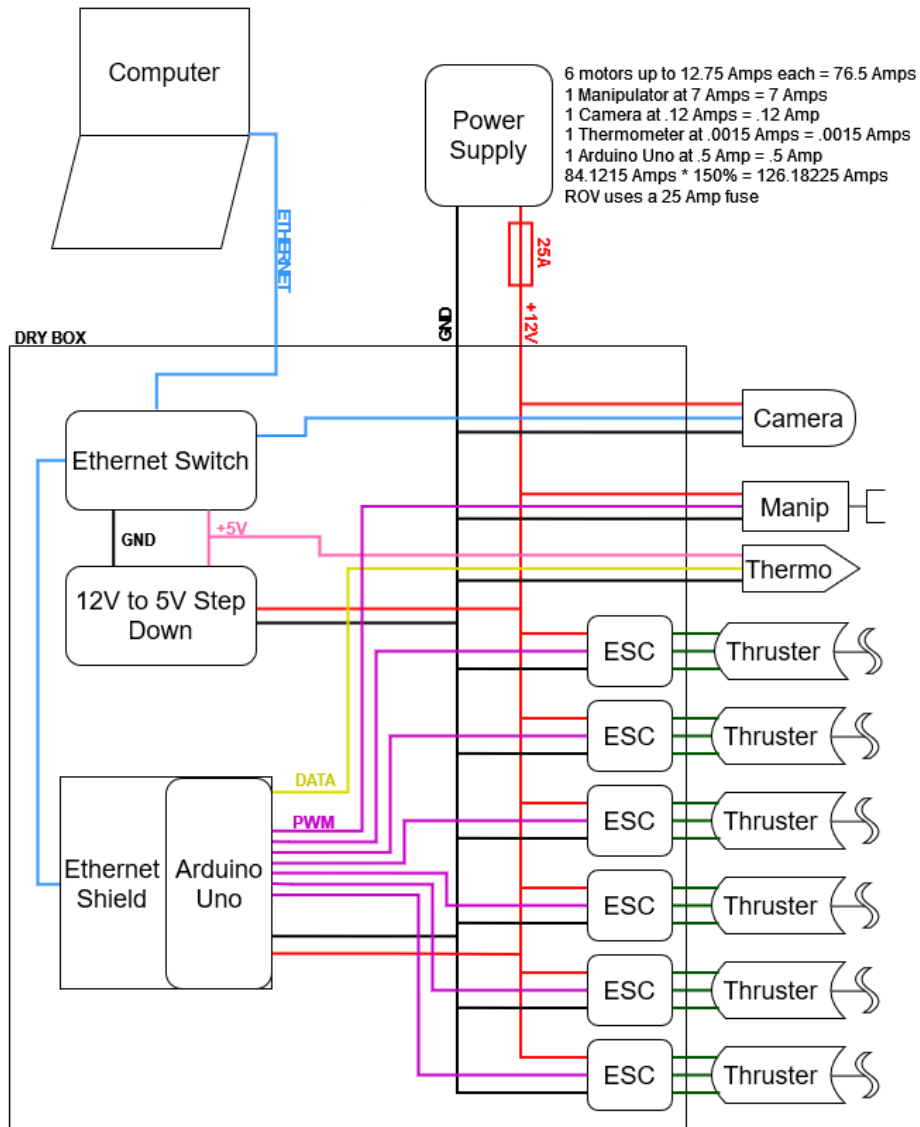
Future Improvements

- Add a quick release mechanism to the thruster mounts to improve adjustability
- Add a depth sensor, gyroscope, and accelerometer to provide real-time telemetry
- Improve structure to reduce risk of tangling
- Better time management and communication



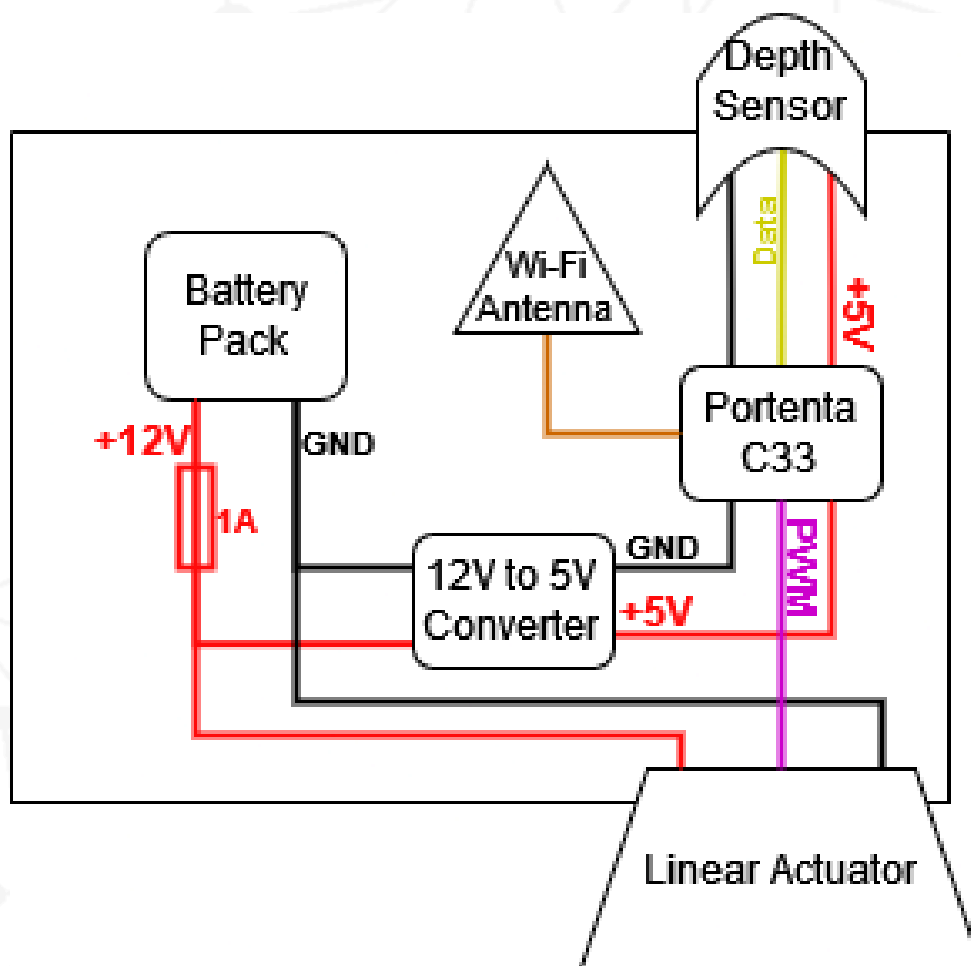
Appendices

Appendix A: ROV SID





Appendix B: Non-ROV Device SID





Appendix C: Job Site Safety Analysis

Job Task	Potential Hazards	Control Measures
Entering / exiting the pool area	<ul style="list-style-type: none"> A. Slipping on pool deck B. Dropping equipment C. Lifting injuries 	<ul style="list-style-type: none"> A. Be aware of surroundings and walk B. Secure all equipment in storage containers C. Have help lifting heavy things
System set up	<ul style="list-style-type: none"> A. Getting water on set up B. Tripping over wires C. Environmental factors 	<ul style="list-style-type: none"> A. Keep power and ethernet cables off the ground B. Take notice of where the tether is and keep it flat on the ground C. Do not operate in electrical storms
Power up checks	<ul style="list-style-type: none"> A. Voltage spikes B. Electrocutation 	<ul style="list-style-type: none"> A. Plug the ROV in the correct order B. Check for loose wires or damaged connections
Pool side operations	<ul style="list-style-type: none"> A. Falling in the pool B. Injury from the ROV 	<ul style="list-style-type: none"> A. Do not reach far into the water A2. Have a lifeguard present B. Wait until the ROV is disabled before reaching into the water
System break down	<ul style="list-style-type: none"> A. Falling in the pool B. Injury from lifting ROV 	<ul style="list-style-type: none"> A. Carefully remove ROV from pool



Appendix D: Bill of Materials

Part Name (Quantity)	Cost (Total)	Quantity	State
T200 Thrusters	\$800.00	4	Purchase
T200 Thrusters	\$400.00	2	Reused
T200 ESC's	\$288.00	8	Purchased
6" Waterproof Enclosure (plus endcaps)	\$425.00	1	Purchased
Potted Penetrators M10 for 6mm cable	\$90.00	15	Purchased
36"x36"x1/4" polycarb	\$97.00	1	Purchased
Blue Trail 3-pin Power Penetrators	\$92.00	2	Purchased
Blue Trail 8-pin Penetrator	\$65.00	1	Purchased
Blue Trail 8-pin Cable Termination Kit	\$25.00	1	Purchased
Blue Trail 8-pin Cable Termination Tool	\$45.00	1	Purchased
Architectural 6063 Aluminum Bar, 1/8" Thick, 1-1/2" Wide (8t)	\$29.93	1	Purchased
Picatinny Rails	\$15.69	6	Purchased
Angle Brackets	\$8.47	12	Purchased
Fuses	\$30.75	2*	Purchased
18-8 Stainless Steel Hex Drive Flat Head Screw M3 x 0.5 mm Thread, 6 mm Long	\$6.23	100 pack Req: 24	Purchased
18-8 Stainless Steel Socket Head Screw M3 x 0.5 mm Thread, 10 mm Long	\$6.00	100 pack Req: 48	Purchased
18-8 Stainless Steel Socket Head Screw M3 x 0.5 mm Thread, 18 mm Long	\$7.63	100 pack Req: 20	Purchased
18-8 Stainless Steel Nylon-Insert Locknut M3 x 0.5 mm Thread, 5.5 mm Wide, 4 mm High	\$6.94	100 pack Req: 48	Purchased
18-8 Stainless Steel Unthreaded Spacer 10 mm OD, 12 mm Long, for M5 Screw Size	\$16.92	4	Purchased
18-8 Stainless Steel Socket Head Screw M5 x 0.8 mm Thread, 14 mm Long	\$15.15	100 pack Req: 24	Purchased
18-8 Stainless Steel Hex Drive Flat Head Screw M5 x 0.8 Thread Size, 15mm Long	\$13.08	100 pack Req: 18	Purchased
Button Head Hex Drive Screw Passivated 18-8 Stainless Steel, M5 x 0.80 mm	\$10.00	25 pack Req: 16	Purchased



Thread, 45mm Long			
303 Stainless Steel Knurled Knob with M5 x 0.8mm Threaded Through Hole, 19mm Head Diameter	\$48.90	4	Purchased
18-8 Stainless Steel Nylon-Insert Locknut M5 x 0.8 mm Thread, 8 mm Wide, 5 mm High	\$8.77	100 pack Req: 54	Purchased
Blue Robotics Subsea Gripper	\$640	1	Reused
Blue Robotics 2" Enclosure	\$121	1	Reused
FLIR Blackfly Camera	\$670	1	Reused
Ethernet Shield	\$29.80	1	Purchased
Arduino Minima	\$20.00	1	Purchased
Ethernet Switch	\$16.00	1	Purchased
Temperature Sensors	\$12.00	1	Purchased
12V to 5V Step Down Converter	\$24	1	Reused
2" Waterproof Enclosure (plus endcaps)	\$121	1	Reused
WAGO Inline Lever-Nuts	\$24.15	1	Purchased
Total Cost			\$4,229.41

Appendix E: Budget

Naviga tor	Cost (\$)	Ranger	Cost (\$)	Ranger (cont)	Cost (\$)	Club	Cost (\$)
Set Budget, they will design it as they want	\$650 (x3)	Polycarbonate	\$150.00	Newton Gripper x1	\$590.00	Resin	\$200.00
		Depth Sensor	\$72.00	T200 Thruster (x6)	\$1,416.00	Shirts and Hats	\$750.00
		Camera Power Cable (x1)	\$35.00	Blue Robotics Basic ESCs (x8)	\$288.00	Props	\$100.00
		Pressure relief valve (x2)	\$60.00	6 inch tube	\$500.00	Misc Extras (broken)	\$500.00



				(including 2 O-ring flanges		parts, failures, etc)	
		Lens	\$74.00	FLIR Blackfly camera	\$670.00	Printing docs	\$150.00
		Miscellaneous Materials (Tape, Buoyancy Supplies, Silicone Grease, etc	\$500.00	Blue Trail Waterproof Penetrators	\$150.00	Misc Materials (tape, 3D printer filament, etc)	\$500.00
		Electronics (PCB Boards, Microcontroller s, Wires, etc)	\$475.00	2" series enclosures for camera	\$125.00	New tools (drills, screwdrivers, saws, etc)	\$500.00
		Blue Robotics Penetrators	\$180.00	Camera Lens Adapter	\$5.00	Computer Parts (CPU Cooler, PCIE Extender, Power Supply)	\$1,000.00
		Hardware (Screws, Aluminum Bars, Spacers, etc)	\$250.00	Float	\$350.00	Feeding the team	\$500.00
		Maintenance	\$500.00			Monitor	\$350.00
Navigator Total:	\$1950.00	Ranger Total:	\$6,440.00			Club Total	\$4,550.00
		Total Cost	\$12,940.00	Total Expense	\$7,767.89	Remaining Funds	\$5,232.11



Acknowledgments:

The Robosharks would like to acknowledge the following people and organizations:

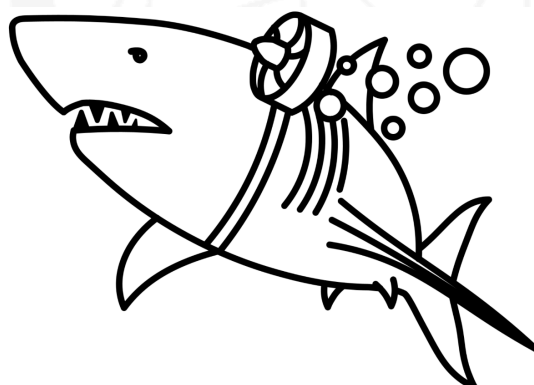
- The Jim and Dede Bartlett Foundation for financial support
- Riana Sartori and Teledyne FLIR for our cameras
- Boulder Parks and Rec for letting us use their pools
- Sara Rove for allowing us to present to her 7th grade classes
- Our mentors and sponsors Ms. Zimmerman, and Ms. Vogel for their time and guidance
- The Wysong family for allowing us to work in their studio
- Blue Trail Engineering for discounted products
- Our friends and family for their support
- Last but not least, MATE for the amazing educational opportunity.

Coding Citations:

<https://docs.arduino.cc>

<https://pyserial.readthedocs.io/en/latest/>

<https://docs.python.org/3/>



"We work in a pool. The water is the ground!" - Mattison Konczak