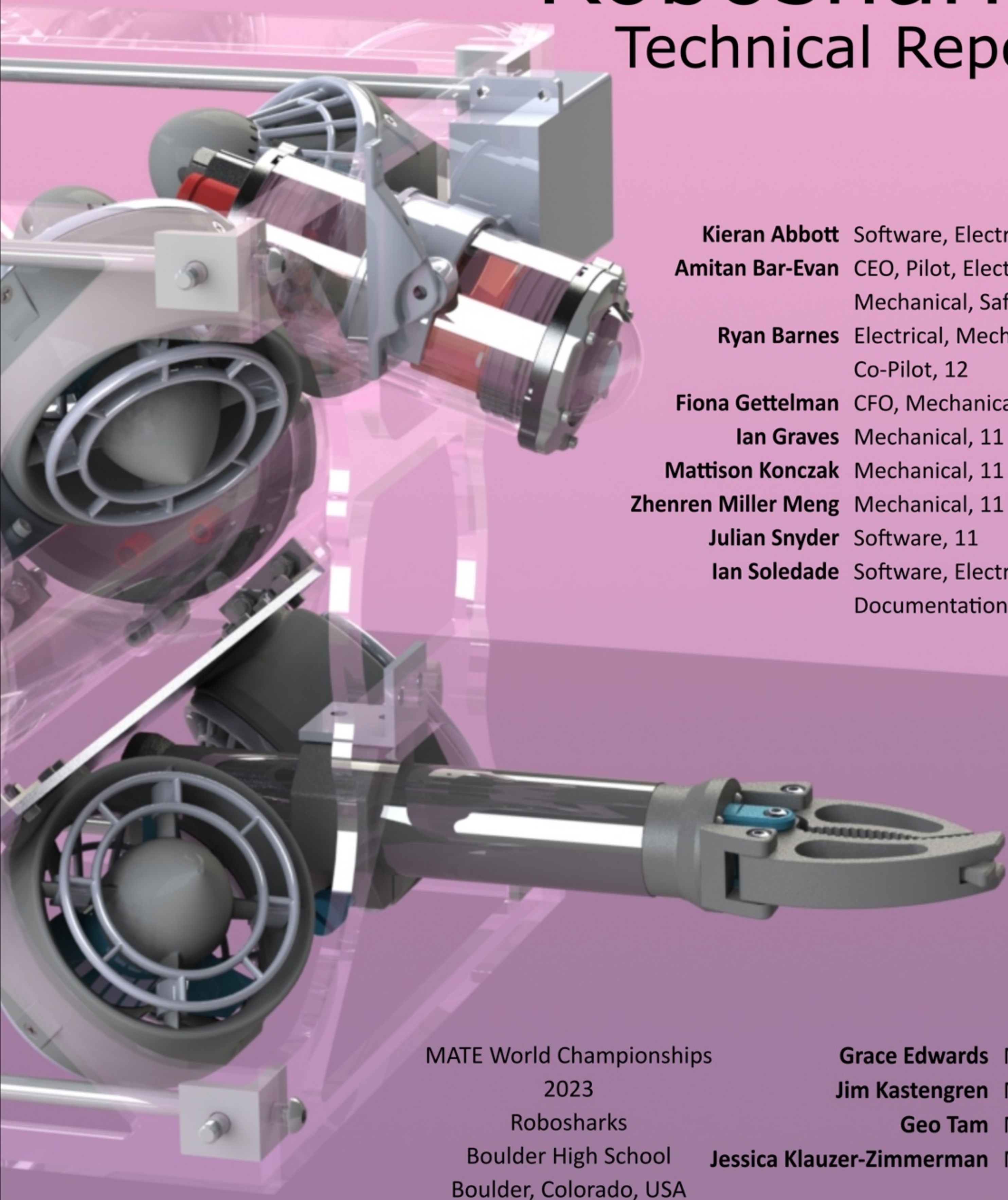
Robosharks

Technical Report



Kieran Abbott	Software, Electrical, 10
Amitan Bar-Evan	CEO, Pilot, Electrical, Mechanical, Safety, 12
Ryan Barnes	Electrical, Mechanical, Co-Pilot, 12
Fiona Gettelman	CFO, Mechanical, 12
Ian Graves	Mechanical, 11
Mattison Konczak	Mechanical, 11
Zhenren Miller Meng	Mechanical, 11
Julian Snyder	Software, 11
Ian Soledade	Software, Electrical, Documentation, 12

MATE World Championships
2023
Robosharks
Boulder High School
Boulder, Colorado, USA

Grace Edwards	Mentor
Jim Kastengren	Mentor
Geo Tam	Mentor
Jessica Klauzer-Zimmerman	Mentor

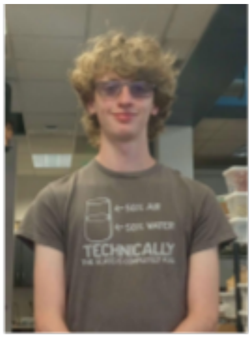
Abstract

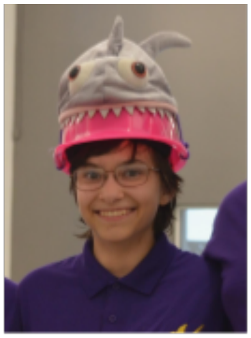
The Robosharks, a company from Boulder High School in Boulder, CO, was founded to develop outside-the-box solutions to various underwater problems. We are composed of four returning members and five new members, each with a passion for robotics and design. Additionally, our company houses two Navigator sub-teams, where we train our new members. The Robosharks are presenting Bubbles for this year's RFP.

Bubbles is designed to be easily serviceable and modular, and we developed each of the ROV's components to fit these criteria. The frame allows for customizable configurations of our off-the-shelf manipulator, while two industrial cameras provide high-quality, low-latency video that assists in piloted ROV operation and autonomous computer vision tasks. Finally, we have a custom float using a buoyancy engine to complete vertical profiles while monitoring ocean conditions.

Bubbles uses optimized software to give the pilot precise control over all six degrees of motion. Additionally, Bubbles has an intuitive graphical user interface to assist in ROV operation.

While we are still picking up pieces of PVC off the pool floor, we hope that Bubbles will further inspire the global effort to reach the UN's Sustainable Development Goals.


Kieran
Abbott


Amitan
Bar-Evan


Ryan
Barnes


Fiona
Gettelman


Ian
Graves


Mattison
Konczak


Zhenren
Miller Meng


Julian
Snyder


Ian
Soledade

Contents

Teamwork

Project Management

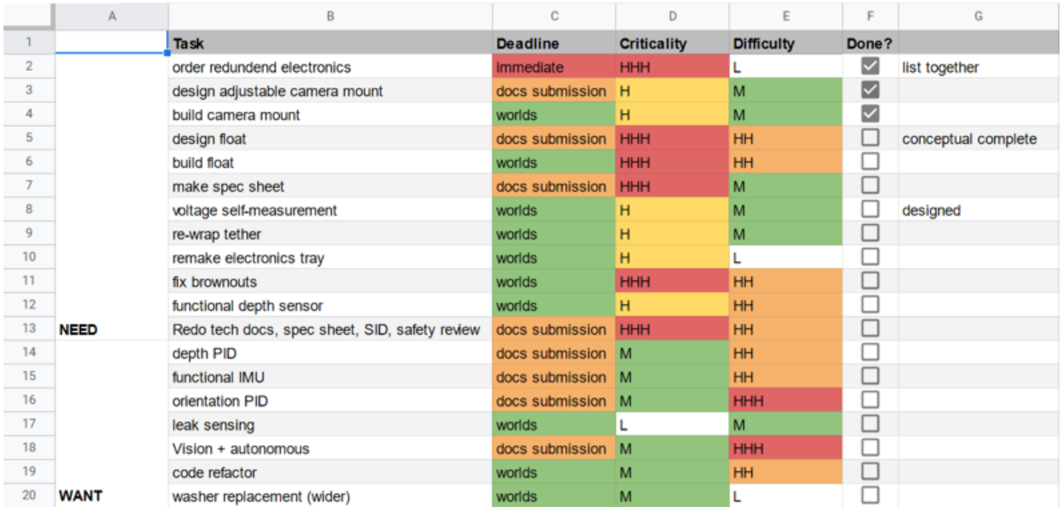
Each member of the Robosharks have worked together in the past, and each of us has a good understanding of everyone else's skill sets. This allows us to structure our company based on who is best suited for the job at hand. With this, we are able to assign tasks tailored to each member's expertise. Most tasks, however, are interdisciplinary, and require the expertise of more than one member. As a result, we generally have multiple members working on each task. This helps members learn from each other and improves the design process.

Scheduling and Planning

We wanted as much participation from our members as possible, so our meeting schedules were designed with accessibility in mind. We built our schedule around the days that could have the highest attendance, using data we gathered through surveys and observation.

We started with infrequent meetings during the fall and early winter, meeting once a week in order to train our new members and do early design work on the structure of the ROV. Once the competition documentation was released, we shifted to a more active meeting schedule with meetings twice a week on Mondays and Wednesdays, from 16:00 - 17:00, to stay on top of competition deadlines.

Most of our planning was built around an end date where we wanted to have a fully functional ROV, which left us with plenty of room to adapt and respond to issues and problems as they arose.



	A	B	C	D	E	F	G
1		**Task**	**Deadline**	**Criticality**	**Difficulty**	**Done?**	
2		order redundend electronics	immediate	HHH	L	☑	list together
3		design adjustable camera mount	docs submission	H	M	☑	
4		build camera mount	worlds	H	M	☑	
5		design float	docs submission	HHH	HH	☐	conceptual complete
6		build float	worlds	HHH	HH	☐	
7		make spec sheet	docs submission	HHH	M	☐	
8		voltage self-measurement	worlds	H	M	☐	designed
9		re-wrap tether	worlds	H	M	☐	
10		remake electronics tray	worlds	H	L	☐	
11		fix brownouts	worlds	HHH	HH	☐	
12		functional depth sensor	worlds	H	HH	☐	
13	**NEED**	Redo tech docs, spec sheet, SID, safety review	docs submission	HHH	HH	☐	
14		depth PID	docs submission	M	HH	☐	
15		functional IMU	docs submission	M	HH	☐	
16		orientation PID	docs submission	M	HHH	☐	
17		leak sensing	worlds	L	M	☐	
18		Vision + autonomous	docs submission	M	HHH	☐	
19		code refactor	worlds	M	HH	☐	
20	**WANT**	washer replacement (wider)	worlds	M	L	☐	

Figure 1: Prioritized to-do list

Communication

Our primary platform for communication and planning was Discord, where we created channels for different categories in order 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, due to the fact that Discord works well for discussion but is ineffective for important company-wide announcements.

Additionally, we utilized GitHub and GrabCAD for code and CAD version control respectively. These programs allowed for easier and more efficient collaboration between team members. Finally, we used a company shared Google Drive to easily share PDFs, spreadsheets, and text documents.

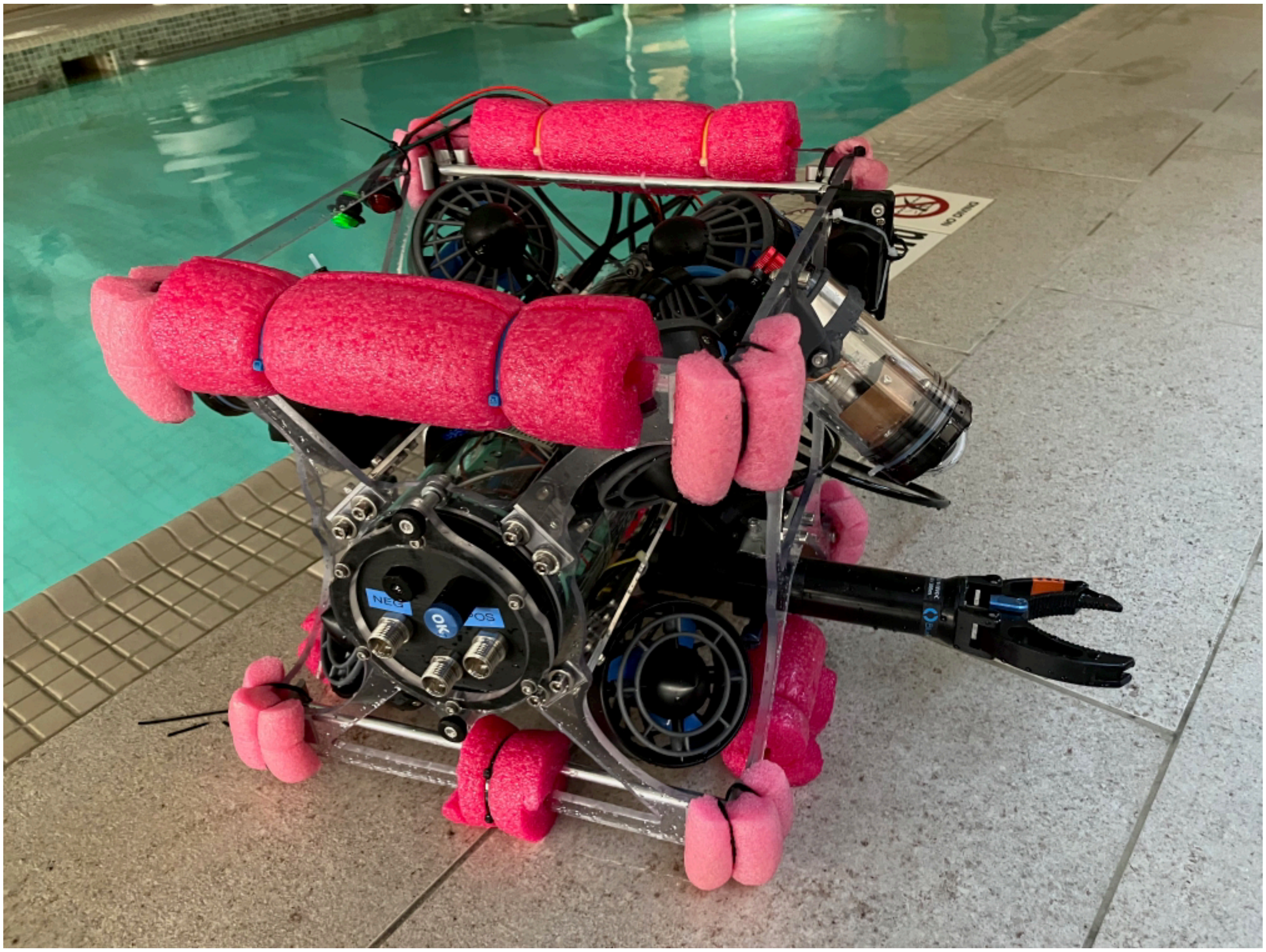


Figure 2: An image of Bubbles during testing.

Design Rationale

Innovation

The first step in our design was to calculate a thruster layout that optimizes our degrees of freedom. We developed a software tool we call TAU (Thruster Arrangement Utility) to quickly prototype and characterize the performance of a variety of thruster layouts. We chose the most effective thruster layout and planned the design of our frame and electronics enclosure with it in mind. From there, we evaluated what other tools the ROV needed, and modified the frame to accommodate the extra payload. Our team researched cameras that would have minimal latency, determined what electronics to use onboard the ROV, and placed them according to the most space-efficient location, all while keeping in mind how our electronics choices would affect our software.

Frame

The ROV frame serves two major purposes: it functions as “connective tissue” between our major functional components (main enclosure, thrusters, etc.) and as a protective box to prevent damage to more delicate components. It also prevents the vehicle from getting caught on any objects in its environment. We constructed the frame out of four polycarbonate panels and aluminum rods. The panels were machined in-house using a CNC router table at Boulder High School. These plates are relatively simple to manufacture and limit ROV damage from unexpected impacts. The plates are secured to each other using aluminum rods and brackets. The aluminum bars that hold the frame and the main enclosure together also serve another purpose: they provide mounting points for our thrusters. When fully constructed, our frame with all attached accessories measures in at 30.48cm x 53.34cm x 30.48cm and weighs approximately 10 kilograms.

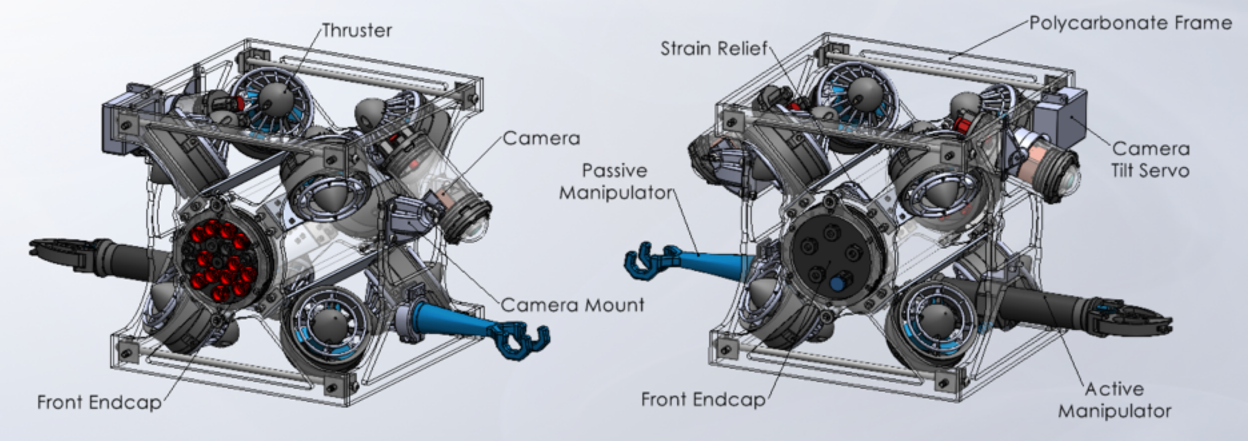


Figure 3: A mechanical overview of Bubbles.

Enclosure

The single largest functional component of our design is our main enclosure. The main enclosure is a 115mm outer diameter, 350mm long tube with end caps on either end from Blue Robotics, and it encloses and waterproofs the bulk of our electronics. The enclosure is the smallest, lightest, and most cost-effective size that can hold all of the onboard electrical systems necessary to power and control the ROV. The enclosure is held together by our custom machined frame. This portion of the frame serves as mounting points for the custom machined aluminum bars that prevent the endcaps of our enclosure from falling off, as well as mount the enclosure sub-assembly to the rest of the frame. Electrical cables enter and leave the enclosure by means of waterproof cable penetrators from Blue Trail Engineering and Blue Robotics.

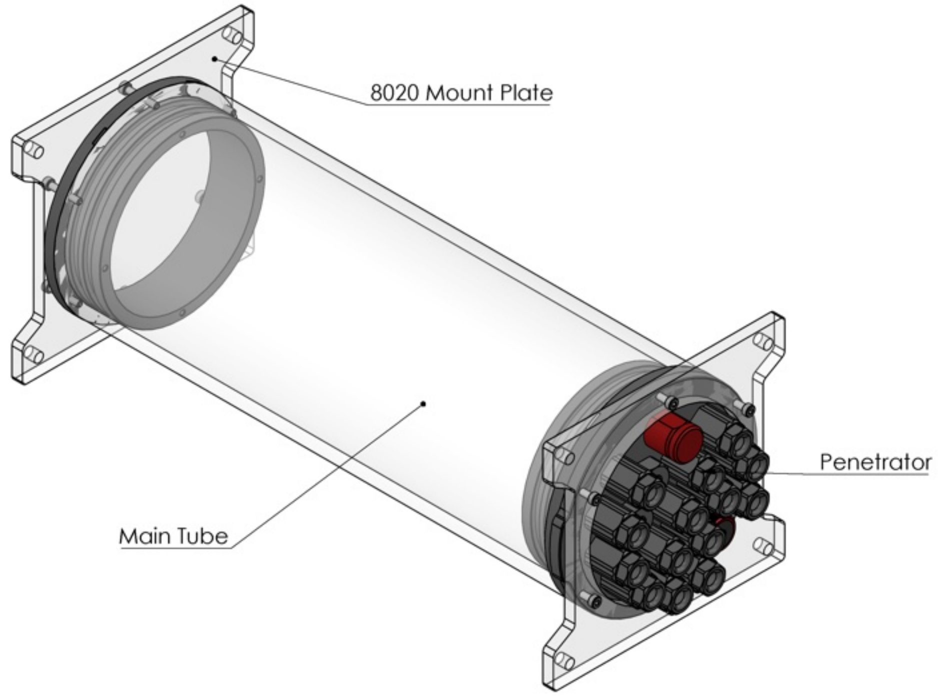


Figure 4: Main electronics enclosure

Tether

This year, a major design upgrade to our robot is our tether design. Bubbles' tether is neatly wrapped in polyurethane mesh to create a single cable interface with our robot, providing data and power connections. This single cable is easily managed poolside in a single neat coil, simplifying the use of the ROV and easing tether management. Additionally, our tether is completely removable from both the control station and the ROV. This allows for easy transport of the ROV, as well as providing a simple way to determine its mass for both competition and physics calculations. Our tether also has foam blocks attached intermittently in order to maintain buoyancy, which minimizes its effects on the ROV.

Cameras

The cameras are mounted in external enclosures in order to give us more control over their positioning and field of view. Our main camera is mounted on the side of the ROV, above to our manipulator. It is attached to a Blue Trail Engineering SER-1107 servo, enabling it to look up, forward, and down. The second camera is mounted at the side of the ROV on a hinge and looks downwards at a slight angle. Our cameras are positioned such that they can see the ends of our manipulators, yet are not obstructed by the main body of the ROV, giving us excellent situational awareness and the ability to approach tasks from numerous angles.

The cameras themselves are FLIR Blackfly IP camera modules. They communicate over Ethernet and are 12 Volt devices. Each camera is housed in an external enclosure (figure 5), and gives us low-latency, high-quality video. The cameras are pointed through a domed port on the front of the enclosure to prevent image distortion, and we chose wide-angle lenses for a wider field of view. The camera modules emit a significant amount of heat, so in order to keep our thermals in check, the camera mounting brackets are made of high thermal conductivity copper. This copper is mounted to the metal endcaps of each enclosure, allowing heat to conduct easily into the surrounding water.

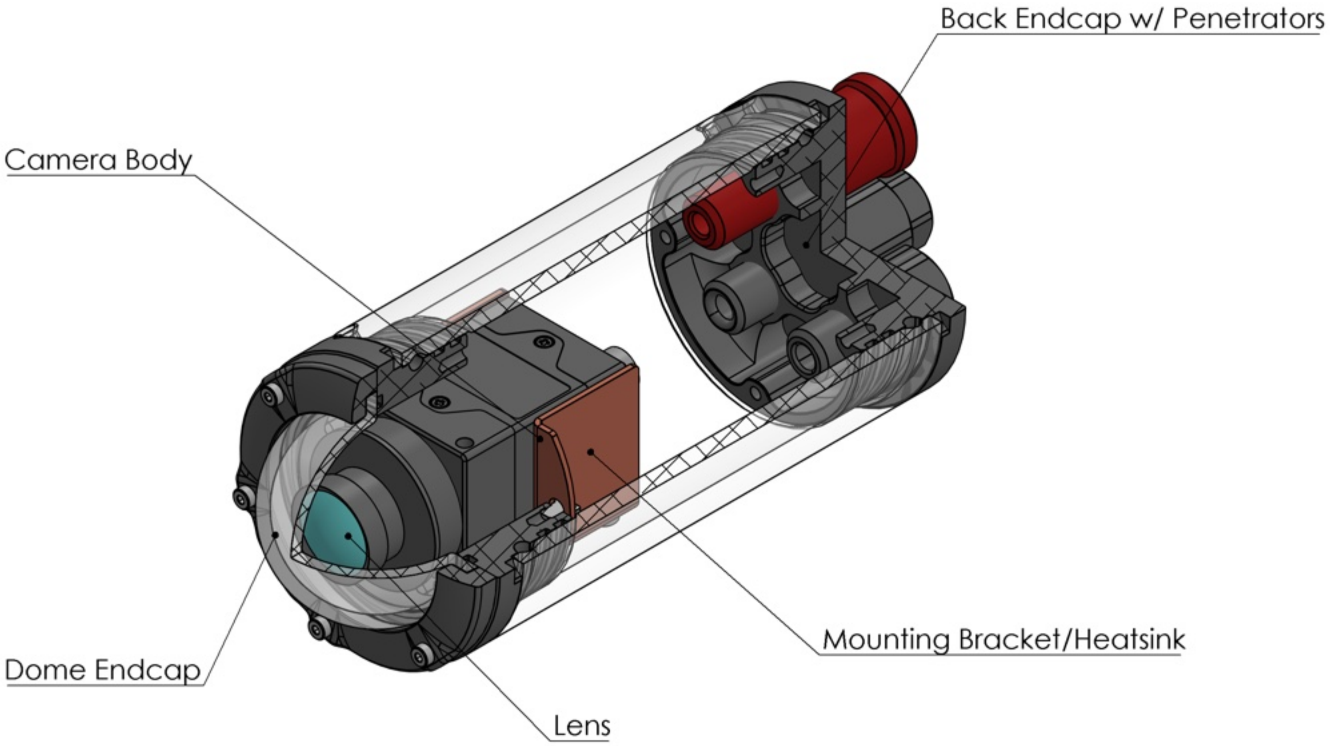


Figure 5: A cutaway diagram of Bubbles' camera enclosure.

Thrusters

The main constraint while deciding on a thruster layout was keeping everything as symmetric as possible, while maintaining 6 degrees of freedom control. In order to achieve this, we reused eight Blue Robotics T200 thrusters that have proven to be reliable, powerful, and waterproof. Our first thruster layout was found to be incapable of yaw control, so we utilized TAU to experiment with different thruster orientations, and finally settled on one that would give us 6 degrees of freedom control without warranting a complete redesign of the frame.

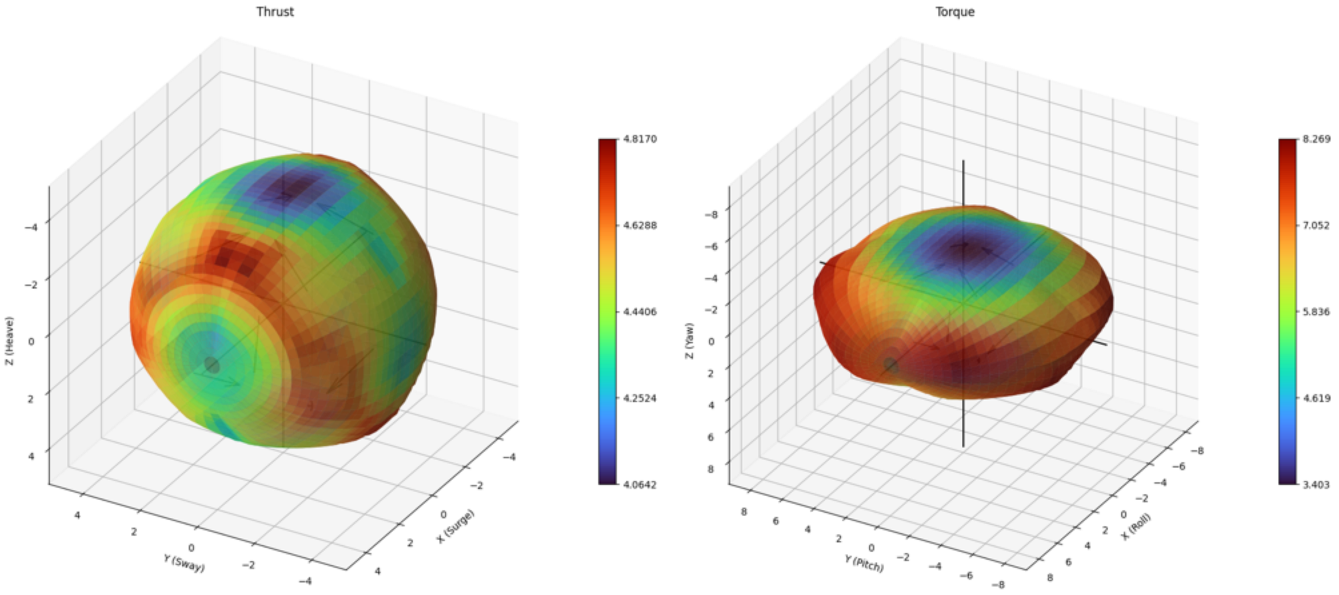


Figure 6: Graphs of the torque and thrust spaces of Bubbles' thruster arrangement.

Buoyancy

The next major aspect of the ROV we considered was buoyancy. Un-adjusted, the vehicle is negatively buoyant, meaning it's heavier than the volume of the water it displaces, and thus sinks. We wanted our ROV to be neutrally buoyant and neutrally stable so that we'd have more control and maneuverability. So we added some lightweight, low-density material to the ROV to increase its volume without significantly changing its mass so that it reached neutral buoyancy.

Control Station

The control box is made out of a Condition 1 waterproof case, 8020 T-slot aluminum extrusion, and an MDF panel. The control box houses a Dell Latitude E7470 control laptop and a multi-socket power strip. The power cables on the tether connect to the MATE provided power supply and the Ethernet cable connects to the control laptop. We chose this control box design because it is compact and easily portable, and gives the pilot and copilot enough screen space to display all the necessary video and sensor data. An Xbox controller connects to the control laptop and gives inputs to control the thrusters and manipulator. We used an Xbox controller because it is small, easily transportable, and intuitive to use.

Figure 7: Control Station

Software

Embedded Software

The embedded software written for the PCB microcontroller is capable of interfacing with I2C and SPI devices, as well as functioning as a control signal for 12 simultaneous servos. This allows the PCB to actuate manipulators and the camera tilt servo while also handling thruster control. Additionally, the embedded software converts raw IMU data into data about the current force and torque on the bot. This data is then transmitted through an Ethernet connection, the same connection which provides packets with instructions for manipulator and thruster settings.

Control Software

The topside control software is run on a Dell laptop within the robot control station. This software processes camera feeds and images, employs photogrammetry to construct mesh models of the environment, uses IMU data to generate corrective thrusts and torques for robot stability, and takes in operator inputs from an Xbox controller. This topside software is designed with a GUI to make operation of the robot intuitive.

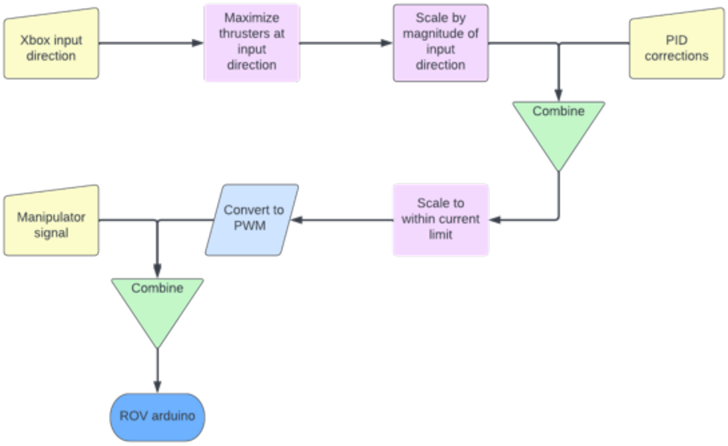


Figure 8: A flow chart detailing the operation of the software.

Payload and Tools

Manipulator

In order to interact with props, we have a Blue Robotics Newton Subsea Gripper mounted to the side of our robot, as well as a custom-built powered claw mounted on the other side. This gripper is mounted in a way that allows us to rotate it between horizontal and vertical positions easily, meaning that we can use it in the most effective configuration for various types of tasks. It can also fold further into the frame for easy storage and transport.

Figure 9: An image of the Newton. Credit: Blue Robotics

Fry Release Bucket

Our fry release bucket is made out of a plastic container and uses zip ties as handles. The bucket is weighed down and has holes in the bottom to help with deploying it with the ROV. The handles are placed into the manipulator and then it is filled with water before being deployed so that it will sink. Once underwater the robot can execute a pitch maneuver to release the fry from the bucket.

Float

For one of the competition tasks, we deploy a float we constructed to complete vertical profiles in the water. 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.

The float is also capable of transmitting data to a custom-built receiver. This receiver functions as a highly restricted WiFi access point, only allowing communications with the float to remain in accordance with competition guidelines and to eliminate possible sources of interference. Using this network, the float transmits the time, profile number, and MATE team number to the receiver. The time is kept onboard the float via the use of a real-time clock module. The transmitted data is then displayed on the receiver.

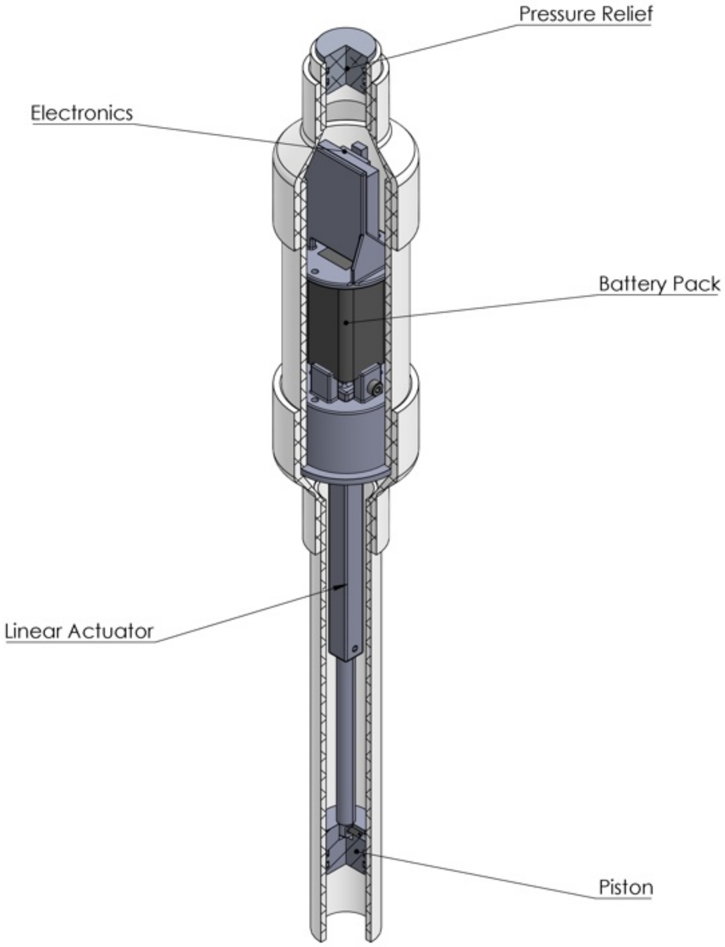


Figure 10: A diagram of the float design.

Build vs. Buy and New vs. Used

Bubbles uses a mix of COTS parts as well as custom-built components to lower costs while also ensuring ROV reliability and capability. Even though COTS parts are generally more expensive than custom components, their reliability makes them ideal for critical design elements such as the drybox. Additionally, some components are prohibitively hard to manufacture in-house, such as thrusters. Components where novel functionality is desired or significant costs can be saved are ideal applications for custom ROV components.

As this is the third year this company is competing with MATE, we were able to reuse a large percentage of our ROV components to lower vehicle costs and increase the sustainability of our team. The ROV's thrusters, main electronics enclosure, camera enclosures, ESCs, tether power cables, and control station are all reused from last year. However, many ROV components had to be completely redesigned in order to fit ROV upgrades and design changes to better suit this year's competition.

Problem Solving

For each problem that arises, we use the same system to work through the issue. The first step is always to find the root cause of the problem. This is an important step, as without it there is no way to know how serious the issue is or how to proceed. Once the underlying issue of the problem has been identified, we can then move on to discussing a solution. After that, we make the proposed changes and start testing. Based on the results of our tests, we then repeat this process until we are left with a thoroughly tested and reliable product.

During our first full enclosure test, we had a major leak from the front endcap. After further testing, the leak was determined to be coming from the cable penetrators. As it turns out, we had used non-waterproof epoxy, which did not make a proper seal around the cables. With the issue identified, we were then able to redo the cable penetrators, and additional testing proved that the leak had been fixed.

Safety

Operations

1. Check that enclosures are sealed and all plugs are closed.
2. Check that the strain relief is secure at both ends of the tether.
3. Check that all cables are clear of the motors.
4. Power on ROV and wait for signal beeps.
5. ROV is ready for launch.
6. Always walk at the poolside.
7. In event of an emergency leak, immediately power down ROV and pull it out of the water by the tether.

Construction

1. Always have teacher mentor present when operating power tools
2. Wear proper PPE (ear, eye, head, 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, jewelry, and hair.
5. Never leave CNC or laser cutter unattended.

Safety Features

Strain Relief

Our tether is looped around a set of cable thimbles attached to a U-bolt 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).

Fuse

The ROV uses a 25 Amp fuse attached topside within 30 cm of our Anderson Powerpole connectors for overcurrent protection.

Critical Analysis

Challenges

Mechanical: A few days before the regional, we had numerous parts fail on us including our manipulator, float, and camera. This proved to be a big challenge and meant we had to come up with creative solutions quickly.

Interpersonal: In the summer of 2022 our mentor, Dan Zahner, passed away suddenly. Much of this year was spent figuring out how to run a team without him and all of his support. Our team worked incredibly hard to both build a robot and keep the robotics club alive.

Electrical: A challenge that was partly out of our jurisdiction was supply chain issues. When building our robot and control station we often had to go with a plan B, due to the strained supply chain, which caused some issues, especially when it came to building custom PCBs.

Software: A major challenge was developing an algorithm to control Bubbles in 6 degrees of freedom using 8 thrusters and IMU stabilization. This came with the added challenge of current stabilization for the IMU.

Lessons Learned

This year, we learned a lot about the process of designing and building a robot while also striving to provide mentorship to others. The Robosharks took on the challenge of mentoring two navigator teams while also designing our own advanced ROV. This proved to be a heavy time and financial commitment, and 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.

Future Improvements

- Improve the quality of build of the control box.
- Have a larger dry box to improve the maintainability of our control box.
- Improve mechanical structure to reduce drag.
- Better software for vision tasks.
- Improve our time management.

Accounting

We began the year by deciding what improvements we wanted to make to our previous ROV and then figured out how much they would cost. We also included budgets for the two navigator teams we sponsor. We made three budget requests, a bare minimum, a middle ground, and a dream budget. From there we sent the budgets to the Bartlett Foundation and the Boulder High PAC for them to evaluate. We received $6625 from the Bartlett Foundation and an additional $2,387.60 from the BHS PAC.

Throughout the year we recorded costs and kept receipts to make sure that we were sticking out the budget. At the end of the year with the help of our mentor, Ms. Zimmerman, we went through and got a total spent.

For worlds, we have purchased 3 hotel rooms for the team to have a home base. Our travel costs beyond that will hopefully be kept to a minimum. These costs are accounted for in a separate proposed travel budget of $6000.

Acknowledgements

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

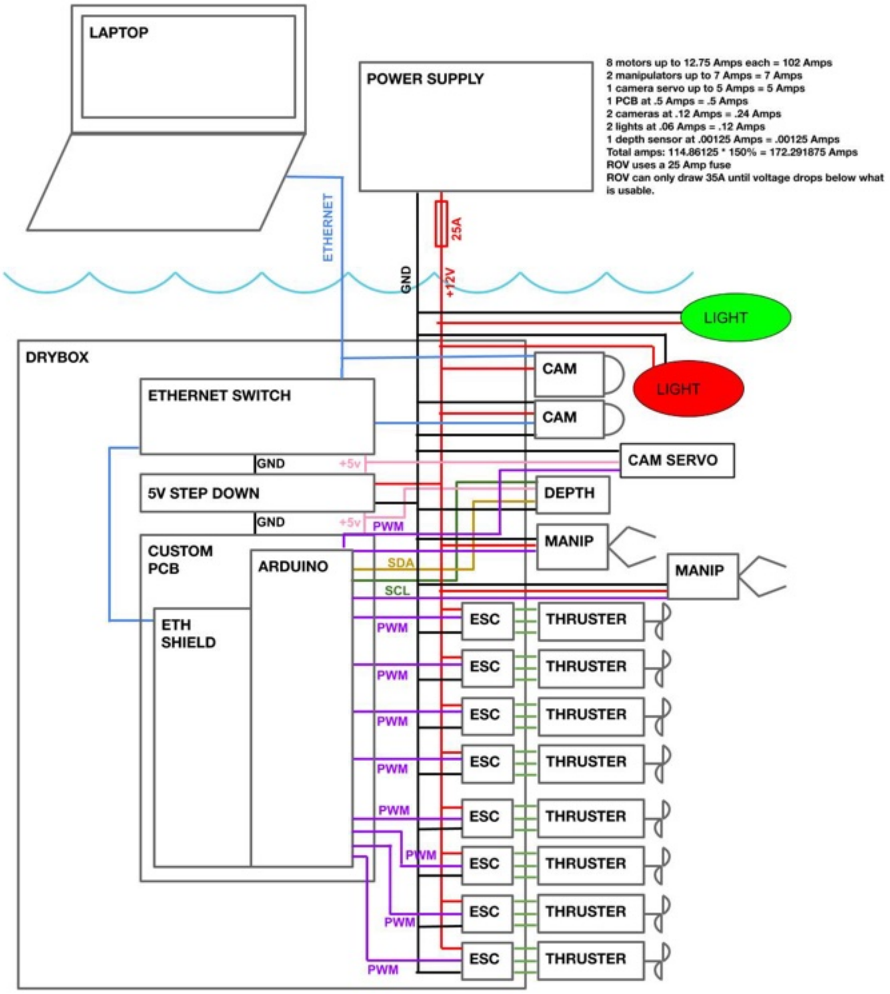
- Jim and Dede Bartlett Foundation and Boulder High PAC for financial support.
- Riana Sartori and Teledyne FLIR for our cameras.
- Blue Trail Engineering for additional underwater components and mentorship.
- Boulder Parks and Rec, Ocean First, Frasier Meadows, and the Rao Family for letting us use their pools for testing.
- Our mentors and sponsors Ms. Edwards, Mr. Kastengren, Mr. Tam, and Ms. Zimmerman for their time and guidance.
- Last but not least, MATE for the amazing educational opportunity.

References

- Blue Robotics for T200 datasheets.
- McMaster-Carr for CAD of components.
- Stack Overflow for programming help.

Appendices

Appendix A: ROV SID



8 motors up to 12.75 Amps each = 102 Amps
2 manipulators up to 7 Amps = 7 Amps
1 camera servo up to 5 Amps = 5 Amps
1 PCB at .5 Amps = .5 Amps
2 cameras at .12 Amps = .24 Amps
2 lights at .06 Amps = .12 Amps
1 depth sensor at .00125 Amps = .00125 Amps
Total amps: 114.86125 * 150% = 172.291875 Amps
ROV uses a 25 Amp fuse
ROV can only draw 35A until voltage drops below what is usable.

Figure 11: ROV Electronics SID

Appendix B: Float SID

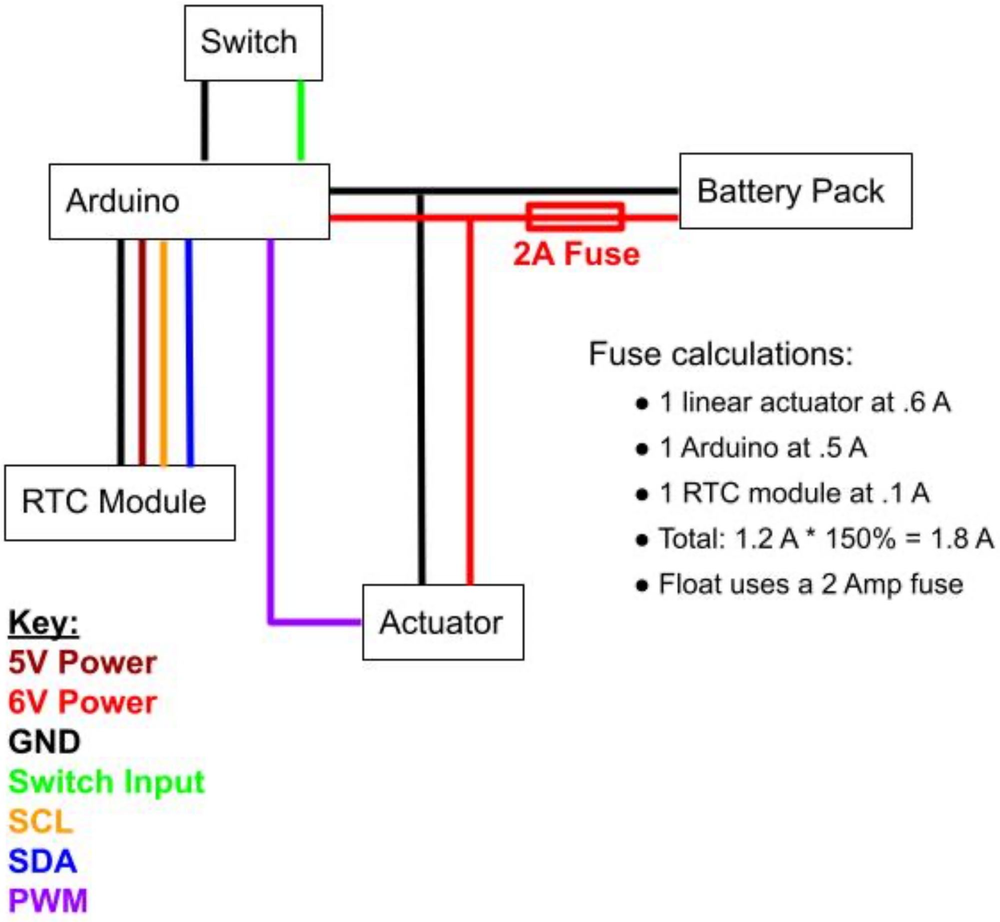
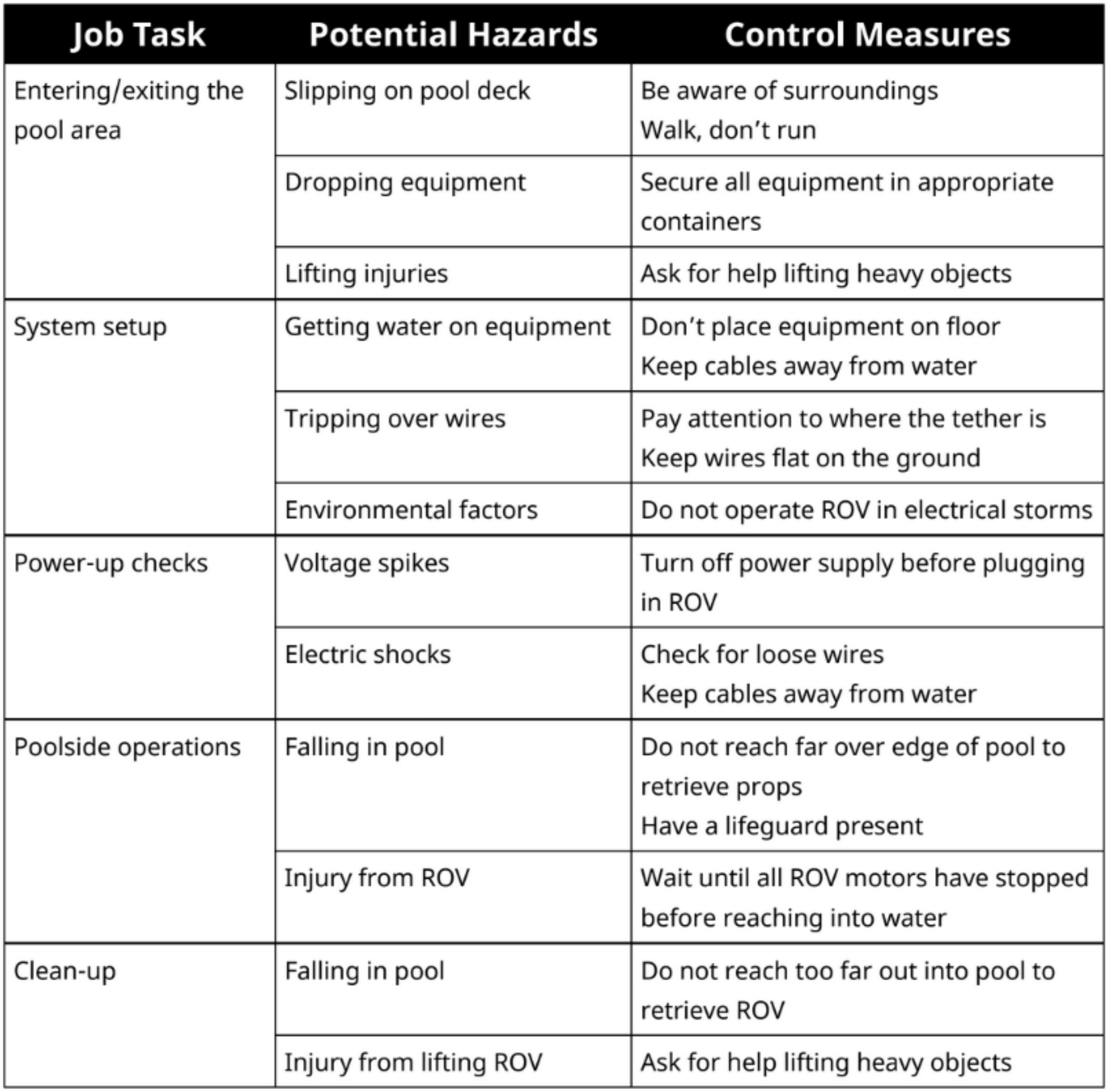


Figure 12: Float SID

Appendix C: Job Site Safety Analysis



Job Task	Potential Hazards	Control Measures
Entering/exiting the pool area	Slipping on pool deck	Be aware of surroundings Walk, don't run
	Dropping equipment	Secure all equipment in appropriate containers
	Lifting injuries	Ask for help lifting heavy objects
System setup	Getting water on equipment	Don't place equipment on floor Keep cables away from water
	Tripping over wires	Pay attention to where the tether is Keep wires flat on the ground
	Environmental factors	Do not operate ROV in electrical storms
Power-up checks	Voltage spikes	Turn off power supply before plugging in ROV
	Electric shocks	Check for loose wires Keep cables away from water
Poolside operations	Falling in pool	Do not reach far over edge of pool to retrieve props Have a lifeguard present
	Injury from ROV	Wait until all ROV motors have stopped before reaching into water
Clean-up	Falling in pool	Do not reach too far out into pool to retrieve ROV
	Injury from lifting ROV	Ask for help lifting heavy objects

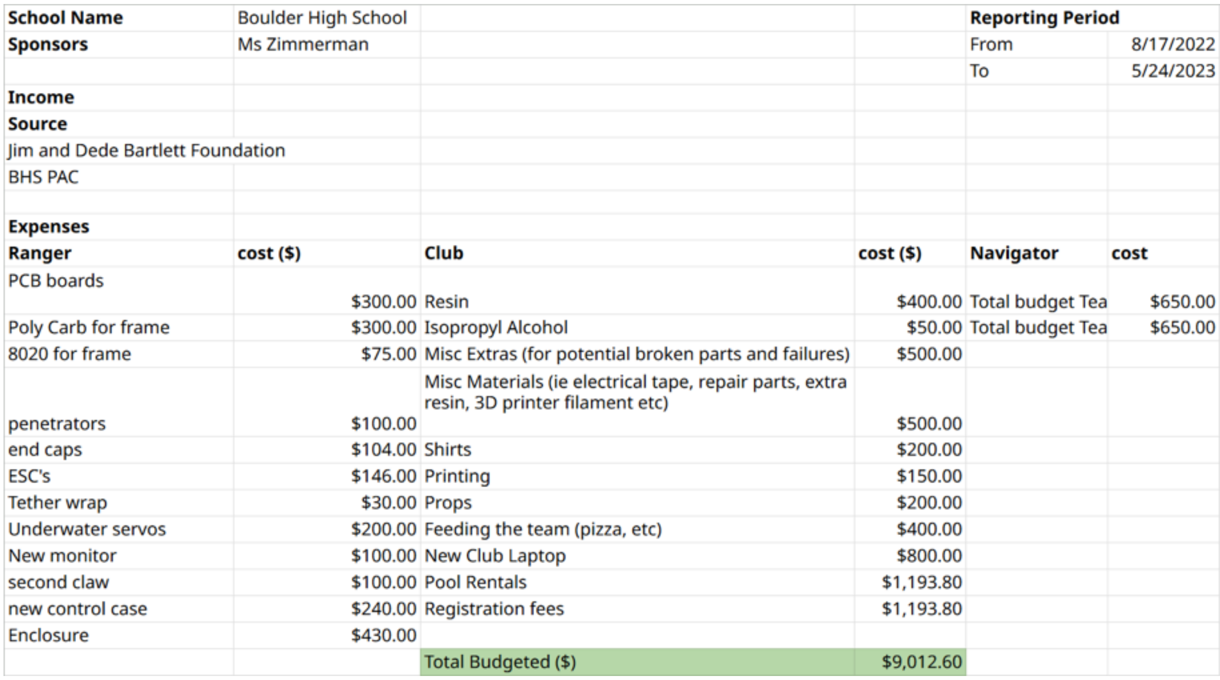
Figure 13: Job Site Safety Analysis

Appendix D: Bill of Materials

Type	Group	Item	Price	#	Cost
Purchased		Microcontroller	$17.50	1	$17.50
Purchased		Second Microcontroller	$14.95	1	$14.95
Purchased		PCB Boards	$40.00	3	$120.00
Purchased	Custom PCB	Peripherals	$69.69	2	$139.38
Purchased		Arduino ethernet shield	$27.00	1	$27.00
Purchased		Jumper Wires	$25.00	1	$25.00
Purchased		Depth Sensor	$72.00	1	$72.00
RE-Used		Headers	$1.00	7	$7.00
Purchased		IMU	$30.00	1	$30.00
Re-Used		Compact Gigabit Ethernet switch	$11.00	1	$11.00
Purchased		5v step down converter	$20.00	1	$20.00
re-Used		Multipurpose 110 Copper Sheet	$27.53	1	$27.53
re-Used		Space-Saver Terminal Block	$13.62	2	$27.24
Purchased		Servo	$395.00	1	$375.00
Re-Used	Electronics	Blue Robotics Basic ESCs	$36.00	8	$288.00
RE-Used		4.5 mm penetrator 5-pack	$12.00	3	$36.00
Purchased		4-5 mm M10 Potted penetrator	$5.00	9	$45.00
Purchased		3-4 mm M10 potted penetrator	$6.00	1	$6.00
Purchased	Penetrators	M10 penetrator blank	$6.00	10	$60.00
RE-Used		2" series enclosure	$108.00	2	$216.00
Re-Used	enclosure	4 inch tube	$216.00	1	$216.00
RE-Used	Cable	Camera Power Cable	$35.00	2	$70.00
Re-Used		Power cable	$50.00	1	$50.00
Re-Used		Cat 5e termination kit	$20.00	1	$20.00
Purchased		Cat 6e cable	$24.00	1	$24.00
Re-Used		Connector/Fuse assembly	$15.00	1	$15.00
Purchased		Power Cable Penetrators	$42.00	2	$84.00
Purchased	Tether	Ethernet Cable Penetrators	$50.00	1	$50.00
Re-Used		Camera Lens Adapter	$5.00	2	$10.00
Re-Used		Lens	$74.00	2	$148.00
Donation	Camera	FLIR Blackfly cameras	$647	2	$1,294
Purchased	buoyancy	Pipe insulation tether buoyancy	$6.00	2	$12.00
RE-Used		Battery pack	$9.00	1	$9.00
RE-Used		mini breadboard	$10.23	1	$10.23
RE-Used		arduino	$20.00	1	$20.00
RE-Used		stepper driver	$9.00	1	$9.00
RE-Used		aluminum rod	$10.00	1	$10.00
RE-Used		o ring	$8.00	1	$8.00
Purchased		RTC Modules	$2.00	5	$10.00
Purchased		433 MHz Radio Module	$2.00	5	$10.00
RE-Used	Float	stepper motor	$89.69	1	$89.69
Re-Used	power supply	MATE standard power supply	$200.00	1	$200.00
RE-Used		Thimble	$3.00	3	$9.00
RE-Used	Strain relief	u-bolt	$6.00	1	$6.00
RE-Used		1/4-20 stainless nut	$8.00	1	$8.00
RE-Used		carbide drill bit	$12.00	1	$12.00
Re-Used	Tools	Updated penetrator wrench	$16.00	1	$16.00
Purchased		2-1 pvc reducer	$3.85	2	$7.70
Purchased	pvc	1 in pvc plug	$1.00	1	$1.00
Re-Used		guard mount screws	$7.00	1	$7.00
Re-Used		bus bar screw	$10.00	1	$10.00
Purchased		Assorted M3 Hardware	$6.00	6	$36.00
Purchased	hardware	Assorted M5 Hardware	$8.42	7	$58.94
Re-Used	pressure relief valves	pressure relief valve	$30.00	3	$90.00
re-Used		Unthreaded Spacer Stock	$11.54	4	$46.16
Purchased		polycarbonate	$150.00	1	$60.00
Re-Used		O-ring flange	$29.00	2	$58.00
Purchased	frame	New back cap	$48.00	1	$48.00
Re-Used		Dell Latitude Laptop	$600.00	1	$600.00
Purchased		Waterproof case	$251.95	1	$251.95
Purchased		21.5 inch monitor	$90.00	1	$90.00
Purchased	control box	PC components	$1,656	1	$1,656
Purchased	controller	Xbox Controller	$33	1	$33
Re-Used	tape	Cable Repair Tape	$8.00	1	$8.00
Purchased	grease	Silicone Grease	$3.00	1	$3.00
Purchased		Newton Gripper	$590.00	1	$590.00
Re-Used		pvc	$5.00	1	$5.00
Purchased	Manipulator	Linear actuator	$70.00	1	$70.00
Re-Used	Thrusters	T200 Thruster	$236.00	8	$1,888.00
Overall Total					$9,602.27
Purchase Total					$4,047.42

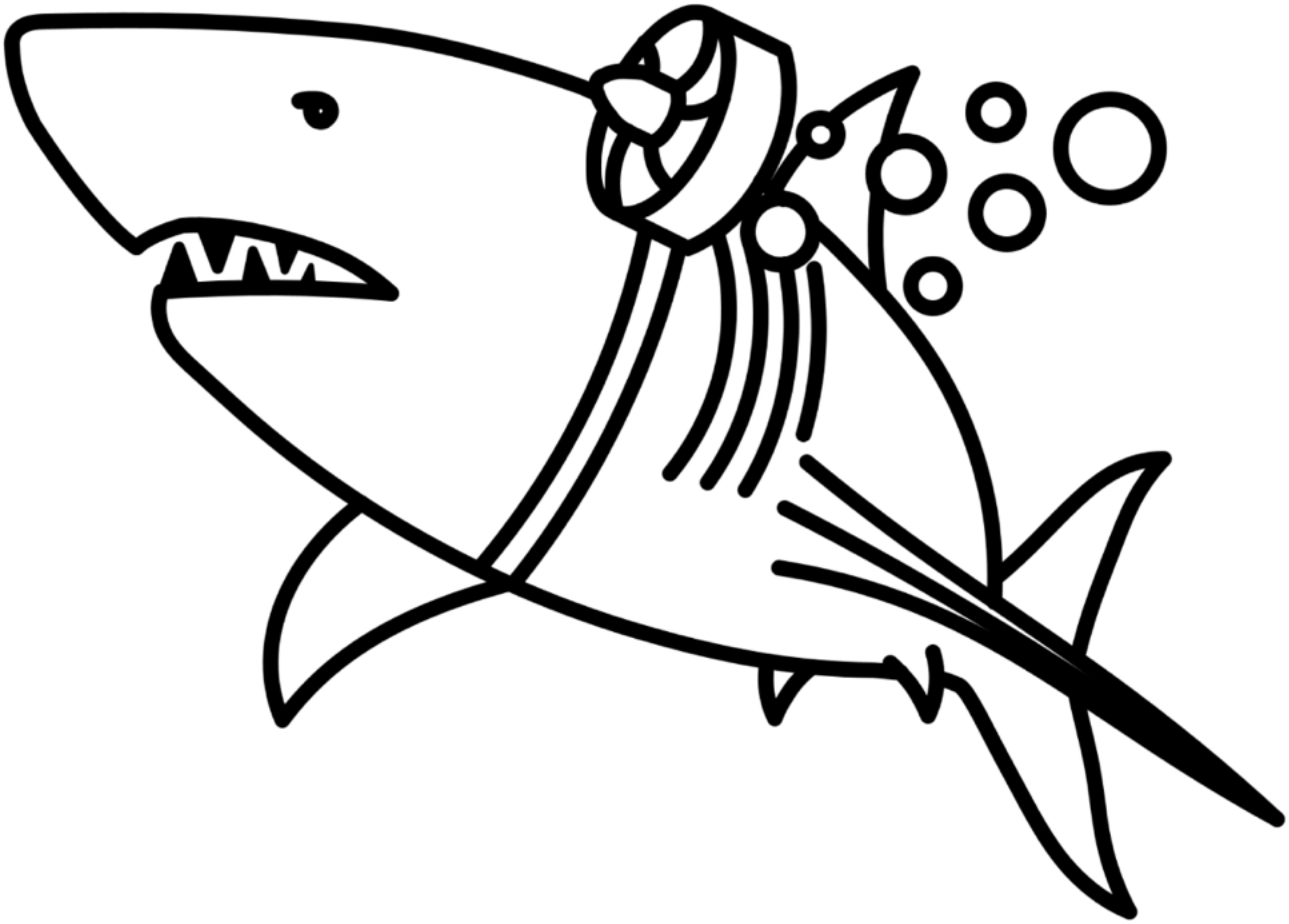
Figure 14: Bill of Materials

Appendix E: Project Costing and Budgeting



School Name	Boulder High School			**Reporting Period**	
Sponsors	Ms Zimmerman			From	8/17/2022
				To	5/24/2023
Income					
Source					
Jim and Dede Bartlett Foundation					
BHS PAC					
Expenses					
Ranger	**cost ($)**	**Club**	**cost ($)**	**Navigator**	**cost**
PCB boards	$300.00	Resin	$400.00	Total budget Tea	$650.00
Poly Carb for frame	$300.00	Isopropyl Alcohol	$50.00	Total budget Tea	$650.00
8020 for frame	$75.00	Misc Extras (for potential broken parts and failures)	$500.00		
penetrators	$100.00	Misc Materials (ie electrical tape, repair parts, extra resin, 3D printer filament etc)	$500.00		
end caps	$104.00	Shirts	$200.00		
ESC's	$146.00	Printing	$150.00		
Tether wrap	$30.00	Props	$200.00		
Underwater servos	$200.00	Feeding the team (pizza, etc)	$400.00		
New monitor	$100.00	New Club Laptop	$800.00		
second claw	$100.00	Pool Rentals	$1,193.80		
new control case	$240.00	Registration fees	$1,193.80		
Enclosure	$430.00				
		Total Budgeted ($)	$9,012.60		

Figure 15: Project Costing and Budgeting



"Of course we have holes in our robot! That’s why it leaked!!"
- Fiona Gettelman