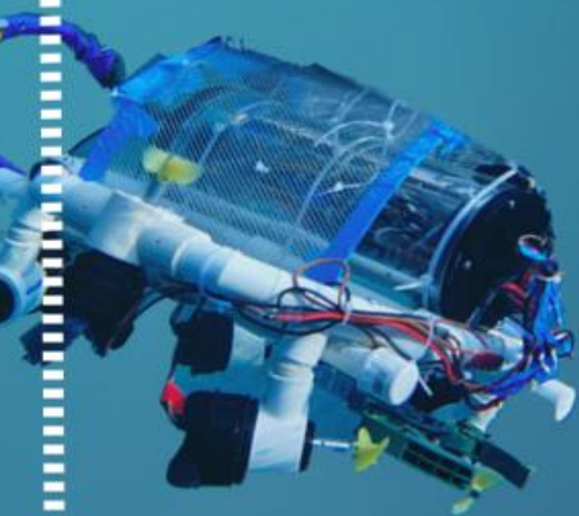
SeaPreme
Technical Documentation
2019

Tesla STEM High School
Redmond, WA (USA)



Meet the Team

CEO: Graham Sabin (11th)
CFO/Marketing Designer: QingHui Xie (11th)
Chief Engineer: Ayan Gupta (11th)
Mechanical Lead: Lahari Nidadavolu (11th)
Software lead: Arnav Sacheti (11th)
Pilot and Mechanical Technician: Adam George (11th)
Mechanical Technician: Alvin Liu (11th)
Mechanical Technician: Minu Padhye (11th)
Mechanical/Electrical Technician: Yusei O'Leary (11th)
Mechanical Team/Electrical Lead: Jakob Bjorner (11th)
Electrical Technician: Pamela Cheema (11th)
Software Technician: Devesh Sarda (11th)
Documentation Coordinator: Edward Vanica (11th)
Mentor: Steve Sergev
Mentor: Steve Wyse
Mentor: Don West
Mentor: Hannah Ebi
Mentor: Ian Averman
Mentor: Mark Roehrig

Table of Contents

1. Table of Contents	**2**
2. Abstract	**3**
3. Product Management	**3 - 4**
3.1 Timeline	**3**
3.2 Company Assignments	**4 - 5**
4.Competition Theme	
5. Design Rationale	**6 - 12**
5.1 ROV Frame	**6**
5.2 Flotation and Ballast	**6 - 7**
5.3 Thrusters	**7 - 9**
5.4 Electronics Enclosure	**10**
5.5 Control Station	**10 - 11**
5.6 Cameras	**11**
5.7 Manipulators	**11 - 12**
5.8 ROV Tools	**12**
6. Design Choices	**13 - 14**
6.1 Control Station	**13**
6.2 Onboard Electronics	**13**
6.3 Frame Components	**13**
6.4 Manipulators	**13 - 14**
6.5 ROV Tools	**14**
7. SID	**14 - 15**
8. Safety and Philosophy	**16**
8.1 Highlights of ROV safety features	**16**
9. Critical Analysis	**17 - 19**
9.1 Testing	**17**
9.2 Troubleshooting	**18**
9.3 Technical Challenges	**18**
9.4 Non-technical Challenges	**18**
9.5 Technical Lessons Learned	**19**
9.6 Non-technical lessons learned	**19**
10. Development of Skills	**19**
11. Future Improvements and Reflections	**19-21**
12. Accounting	**21 - 24**
13. References and Acknowledgements	**25**

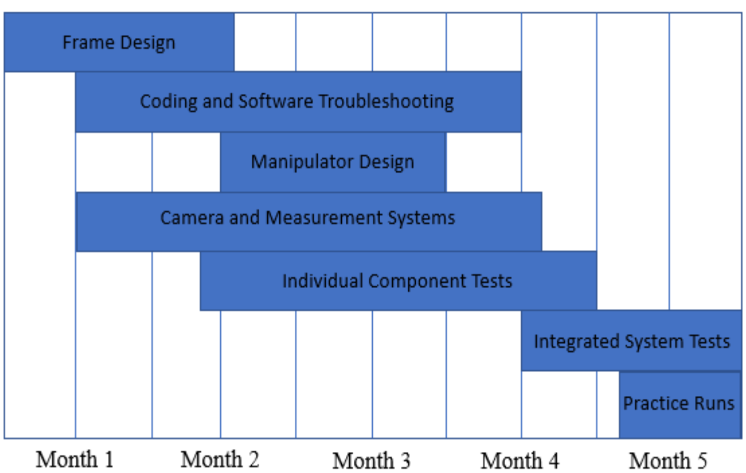
Abstract

The SeaPreme Company, representing Tesla STEM High School, is composed of 13 juniors and is based out of Redmond, Washington. This is the first year that SeaPreme has created an ROV for the MATE competition and all members are first time competitors. SeaPreme created a Remotely Operated Vehicle (ROV) capable of achieving the goals of Ensuring Public Safety, Maintaining Healthy Waterways, and Preserving History in the Boome Dam. With a diverse set of skills and expertise, each team member worked together creating a durable and affordable ROV meant to excel at all underwater operations, earning the name: “The Kraken”.

The Kraken’s measurement system consists of trapezoidal lasers along with traditional ruler to provide multiple options when measuring dimensions of the cannon. This system went through numerous changes during the design and build process to increase the accuracy, decreasing our error while completing tasks. The company’s camera set-up was created to support the measurement system by offering front and rear views, with the rear camera specific to the lasers and the front giving us a full field of view. The Kraken’s measurement system will be used in both measuring the length of the cannon, leading to determine if it can be rescued and in measuring the size of cracks on the dam wall to assess damage. This year, SeaPreme will be working with Eastman Global Specialty Company to fix the damaged dam and retrieve a historical canon from the Civil War.

Project Management

Our company had 5 months to plan, build, and test our ROV for the competition. All 13 of our members had no previous experience in the ROV field and most members were involved in many different extracurricular activities that limited the times that we could all meet outside of the designated team meetings. We had mandatorytwo-hourteam meeting every Wednesday after school, in which we got status reports from each member, worked on different aspects of the ROV, and assigned work to be done before the next team meeting. We also had additional meetings during the weekend to complete additional work on the ROV & for testing.



Timeline

The process of building, testing, and designing occurred during the five months leading up to the competition. Throughout this process work was split up between team members, leading to multiple tasks beingcompleted at once helping us speed up our R&D. The most time-consuming tasks that occurred were designing a frame to fit specific restrictions and designing the measurement system for important tasks.

Company Assignments

We divided our 13-member team into 3 different subsections; mechanical, electrical, and software. Each member in a subsection would report to a team lead, these team leads would then give progress reports to the CEO during each team meeting. With a team this size it is important to maximize efficiency in both working on the ROV and with communication. The company assignments are listed below. We created a calendar system which would allow us to set goals for certain dates; this calendar was available to everyone. Team lead were able to set deadlines for their sub-system team.

Figure 1 Team Photo:

First Row Left to Right: Minu Padhye, QingHui Xie, Pamela Cheema, Lahari Nidadavolu, Devesh Sarda, Edward Vanica.
Second Row Left to right: Yusei O'Leary, Alvin Liu, Arnav Sacheti, Graham Sabin, Jakob Bjorner, Adam George

CEO: Graham Sabin – Monitored progress of each team member and managed scheduling.

CFO: QingHui Xie – Kept track of the finances to make sure we were buying according to budget and recording what was brought. Also made sure the trifold was designed to meet criteria.

Safety Captain: Ayan Gupta – Works to ensure the ROV is safe and water ready, designed and 3D printed components for the ROV.

Documentation Coordinator: Edward Vanica – Coordinated/ divided up the work needed to complete each individual document.

Mechanical Technician: Lahari Nidadavolu – Prototyped and iterated on prop shield designs, worked on the design for the Micro-ROV, and organized an outreach event as part of corporate and responsibility

Mechanical Technician: Adam George – Built mechanisms to complete certain tasks, helped with construction of laser mounts and motor cages.

Specs/Rules Specialist and Mechanical Engineer: Alvin Liu – Made sure that the ROV met the requirements of the competition, built mechanisms to complete certain tasks, made sure the mission specs/rules were met and followed.

Mechanical Technician and Claw Specialist: Minu Padhye – Prototyped hydraulic claw system and tested VEX claw, prototyped and helped finalize camera placement, tether management and strain relief.

Mechanical Technician and Mission Specs/Rules: Yusei O'Leary – Worked on specific tasks and challenges that could not be completed by the claw, ensured rules and mission specs were followed.

Electronic Lead: Jakob Bjorner – Attached each electrical component within the electronics hub, in charge of the maintaining the tether's functionality and meeting the constraints.

Electronic Technician: Pamela Cheema – Worked on the voltage regulation to maximize the power of the ROV and operation of the camera, helped with the prototyping and finalizing of the design for camera placement.

Software Lead: Arnav Sacheti – Handled communications between computer and ROV and accessing temperature on ROV

Software Technician: Devesh Sarda – Worked on converting the controller input into motor values, running motors, operating claws along with integrating all surface code.

Design Rationale

SeaPreme wanted to create a durable ROV that could efficiently survey a dam for damage and conduct inspections. To do this, we decided to use a hexagonal PVC frame to maintain a low profile. Because of the compact design, we could efficiently place six bilge pump motors for thrust (four pointing at outward angles for turning, and two facing up and down to move down and up respectively) to minimize power draw while maximizing our maneuverability. We intended to meet the lowest size and weight constraint for the most efficiency, and we succeeded with final dimensions coming in at 45.72cm x 45.72cm x 35.56 cm.

In addition, we encased the top area of the ROV with a wire mesh to expand our total surface area increasing the ease to which we can add and remove flotation, ballast, or other necessary equipment. This is highlighted with our 170-degree ELP cameras utilizing this functionality when we placed the camera on this mesh; providing a view of both the claw directly beneath the ROV and a view of what lay in front of our ROV.

We placed claws on both sides of the ROV to maximize workability. The front facing claw is a VEX claw, which we chose due to our team's understanding of and previous experience with. We placed the claw in a vertical orientation so it could be used to complete tasks utilizing lifting, opening, and moving (like adjusting the trash rack screen and obtaining the water sample). Our second claw was 3D printed, horizontally oriented, and had screws placed along the inside grip so it would be better suited for grabbing heavy objects (such as the rocks in task 1). We used simple VEX motors to power each claw to hone our team's existing skills using them, and they worked effectively.

Lastly, we housed our electronics in waterproof electronics chamber which has a dome on one end at the top center of the ROV, where its weight was distributed evenly, and it served as a source of buoyancy. We also added segments of pool noodle to the wire mesh as needed to maintain neutral buoyancy.

ROV Frame

Building and designing a custom ROV frame as a first-year team was particularly difficult. Our original design ideas came from previous years' documentation that we found on the MATE website; however, we soon found this to not match the needs the requirements for this year's theme. Using inspiration from several ROV teams we designed and built prototypes of our ROV using traditional PVC pipe because of the ease of use when it came to make quick changes. After multiple design prototypes, our team went through multiple sketch and CAD iterations of the final frame design before we reached the unique hexagon shape, we have currently. This frame design was ideal for the purposes for our team not only because it was easy to manipulate and make changes using off the shelf items but also it was easily produced using the resources and tools the company had available.

Picking PVC as the material for the ROV frame was relatively easy for our team. We saw that teams did use other materials such as acrylic or marine grade plywood for their frames; however, using PVC allowed our team to quickly build the frame so that we could focus on getting into the water which was the primary concern for us as a first year team. Due to the versatility of PVC piping and connectors, our ROV has evolved over the months and has allowed for easy integration of other materials such as metal mesh which act as protection for the electronics chamber and attachment points for mission specific attachments.

Flotation and Ballast

Our ROV is designed to be slightly positively buoyant to account for situations when the ROV might lose connection with the controller and naturally float upwards. Another reason behind this design decision was to maximize thrust while completing tasks that involve lifting. Initially, we opted to implement an adjustable ballast mechanism by creating a sliding tray mechanism with removable washers; this design choice created a challenge as our ROV was very negatively buoyant during testing. The natural weight of the ROV was already making the vehicle negatively buoyant, so we decided to use flotation foam to modify the buoyancy so that is was more positive. As the ROV frame didn't account for space to mount flotation, we added a metal wire mesh dome to attach the flotation along with other components such as cameras. For flotation, we used a synthetic foam, and for ballast, all we did was removed foam.

Thrusters

Looking at previous competition footage, we realized about our biggest demand was to be able to go up but also move effectively along the x- y plane. Initially, we broke up our motor placement into two subproblems: horizontal thrust along the plane and vertical thrust perpendicular to the plane. For the horizontal thrust problem, we initially came up with two ideas: Four motors all perpendicular to the frame or motors angled as shown in the images below:

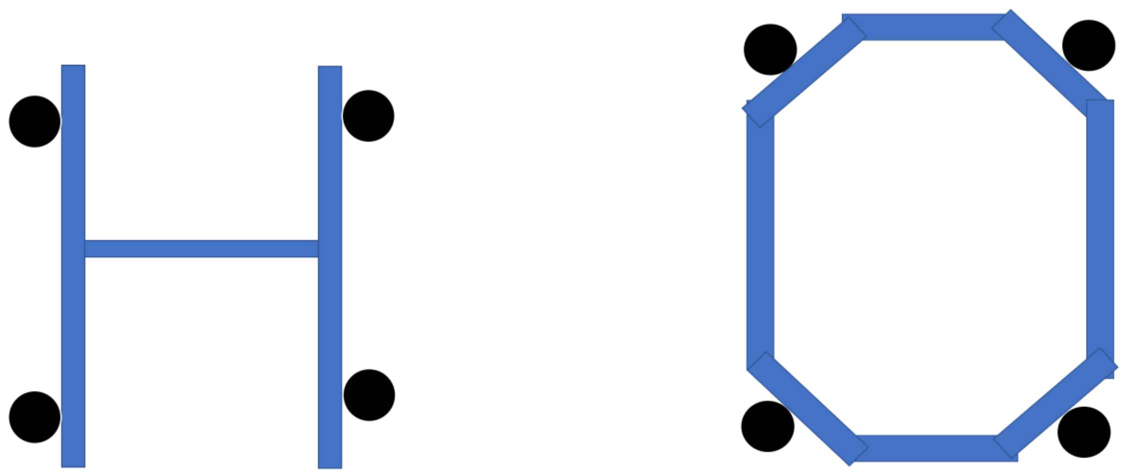


Figure 2: Prototype drawings of potential drive systems (Frame in Blue and Horizontal Motors are in Black)

We initially went with all 500-gallon bilge pump motors as last year's team from our school had left them for us and thus were inexpensive for us. We decided the design on the right as we would be able to strafe using that design which would allow us to complete the following a transect line tasks and not needing to turn the entire robot to move along the x – axis. Because moving forward and strafing was equally important to us, we decided to have the motors at a 45-

degree angle from the horizontal pieces of frame. The next part was the vertical thrust. We initially decided to put the remaining two 500-gallon motors on the horizontal pieces of frame, as shown in green in the diagram: We did a water test (see testing for more information) and we saw that these motors were not able to generate enough force for us to able to move up and down at a satisfactory rate. Because our top primary focus was to be able to move up and down quickly, we decided to make two modification to the design: Upgrade the side motors to a 1000 gallon instead of 500 gallon in order to generate more horizontal thrust. We also decided to angle the horizontal motors downwards so they that they would also provide thrust capacity even though that sacrificed some of our speed in movements along the plane. This time we decided to angle the motors at 60 degrees from the plane so that most of motors force would be available for downward thrust but later testing revealed that we lost more than an acceptable amount of thrust along the plane and thus reduced our angle down to 45 degrees which satisfied both our speed requirements. This had the bonus of giving us another degree of freedom: roll. We used Cytron Motor Controllers along with PWM (Pulse Width Modulation) values to control the speed and direction of our motors on the Arduino.

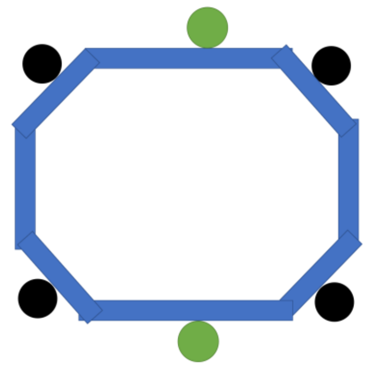


Figure 3:Final design of the ROV with horizontal motors in black, vertical motors in green, and the frame in blue.

Mathematics behind thrusters (Programming Standpoint)

We define the CG of the gravity to be the points (X_0,Y_0,Z_0) and we will say the theta is the angle that the motors form with the horizontal pieces of PVC pipe along our x-y plane while alpha equal the angle the motors form with the x – y plane with a positive alpha value meaning that the motors are pointing up, and that the unit thrust of a motor is **F**. We can see that the forces for motor n in the x, y, and z directions are given by the following equations:

$F_{nx} = F * \cos(theta)$

$F_{ny} = F * \sin(theta)$

$F_{nz} = F * \tan(alpha)$

Then we define the following values:

$Len_n = sqrt(F_{nx}^2 + F_{ny}^2 + F_{nz}^2)$

$A_{nx} = F_{nx}/Len_n$

$A_{ny} = F_{ny}/Len_n$

$A_{nz} = F_{nz}/Len_n$

Know we need to account for the torque created by the thrust of each of the motors. If the coordinates of the motors are (X_n, Y_n, Z_n) then we define the vector $R = (X_n – X_0) * I + (Y_n – Y_0) * J + (Y_n – Y_0) * K = R_x * i + R_y * j + R_z * k$ and because torque is the cross product (finding the determinant of the 3 by 3 matrix) of R and F we were able to find that the torque vector as the sum of the unit vectors i, j, k and we determine that

$A_{nTx} = R_y * F_z – R_z * F_y$

$A_{nTy} = R_z * F_x – R_x * F_z$

$A_{nTz} = R_x * F_y – R_y * F_x$

We define a matrix [A] such that for each col c in range [1,6] each column is:

A_{cx}
A_{cy}
A_{cz}
A_{cTx}
A_{cTy}
A_{cTz}

	x	y	z
CG	0	0	0

Lateral thrusters elevation angle	8.11
Toe-in Angle	20

Assuming a unit thrust for each thruster

	Thrusters					
	1	2	3	4	5	6
Thrust	1	1	1	1	1	1
Xrel	5.000	5.000	-5.000	-5.000	4.000	-4.000
Yrel	-4.000	4.000	4.000	-4.000	0.000	0.000
Zrel(up)	0.000	0.000	0.000	0.000	0.000	0.000
Xcg	5.000	5.000	-5.000	-5.000	4.000	-4.000
Ycg	-4.000	4.000	4.000	-4.000	0.000	0.000
Zcg	0.000	0.000	0.000	0.000	0.000	0.000
x-dir	0.940	0.940	0.940	0.940	0.000	0.000
y-dir	0.342	-0.342	0.342	-0.342	0.000	0.000
z-dir	0.141	-0.141	0.141	-0.141	1.000	1.000
Vec Length	1.010	1.010	1.010	1.010	1.000	1.000
f_x	0.930	0.930	0.930	0.930	0.000	0.000
f_y	0.339	-0.339	0.339	-0.339	0.000	0.000
f_z	0.140	-0.140	0.140	-0.140	1.000	1.000
t_x	-0.559	-0.559	0.559	0.559	0.000	0.000
t_y	-0.698	0.698	0.698	-0.698	-4.000	4.000
t_z	5.415	-5.415	-5.415	5.415	0.000	0.000

We saw define [F] as the values of the pilot input and [f] is the matrix of the thrust needed to be produced by each motor. We have that [A] * [f] = [F] and we use a technique called Gaussian elimination to find the values in [f]. Our mentors helped us develop a custom Excel program for us to be able to play around with the alpha, theta values along with the position of the motors and we used the thrust information we get from those values to determine our final position of the motors, along with the values from alpha and theta.

Excel Program we developed to determine the contribution of each motor to each of the six degrees of freedom along with customize various values to determine the most ideal location and orientation of the motors

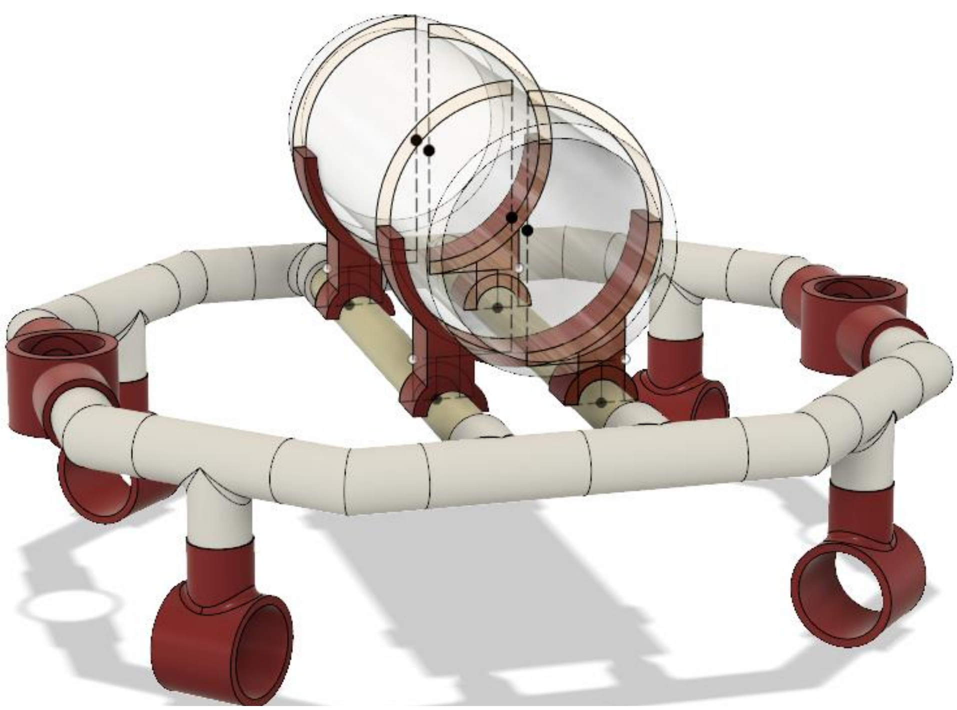


Figure 4:The image shows an early CAD model, later changed for performance.

Electronics Enclosure

When brainstorming ways to waterproof the electronics of our ROV, we wanted a clear cylinder that allowed us to get a clear view any connection errors in our electronics, and to solve issues as easy as possible. Keeping electronics safe was of top priority, so we elected to use a pre-designed electronics capsule from Blue Robotics. Not only are their electronics capsules decently priced, but they are also failsafe and easy to work with when waterproofing the electronics. After looking through different options for canisters on Blue Robotics website, we selected the 4" series clear acrylic capsule, with an inner diameter of 10.16 cm. This ended up being the perfect size for us, not only fitting all electronics well, but sitting within the constraints on our frame. For the best use of space, we chose to put a dome on one end to house the camera, and the adjacent end allowed for cable penetrators with tether and motor wires.

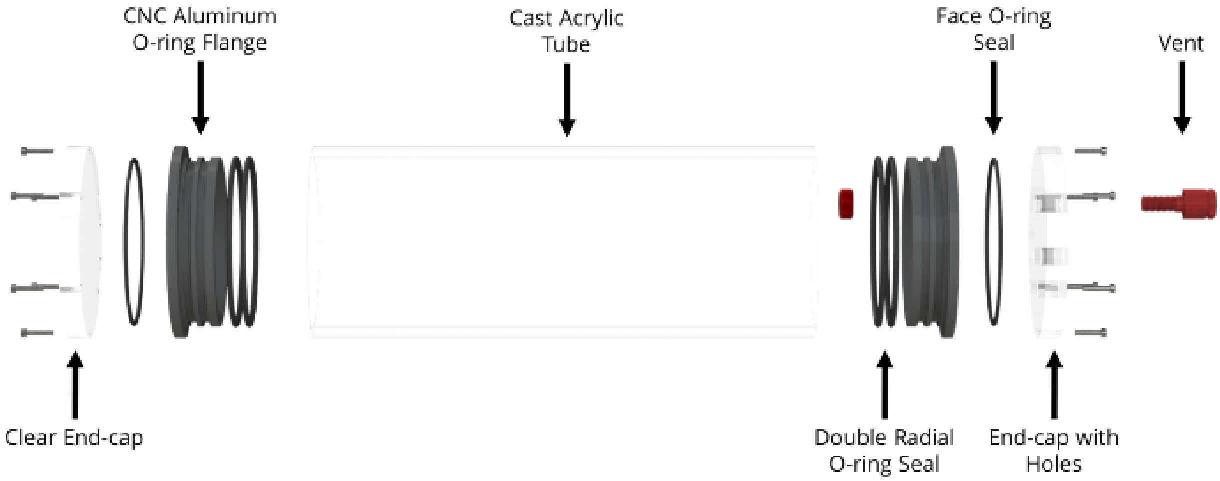


Figure 5:The image shows the layout of the electronics chamber, and the mechanisms involved.

Inside of our pressure chamber, all electronics were organized on a laser cut board which allowed for easy removal in and out of the pressure chamber. To conserve space and reduce confusion, all excess wiring was attached on the underside of the tray, and larger components such as motor controllers and Arduinos were on top of the tray. For modularity, all connections from outside the electronics tray were removable, allowing us to move the tray in and out of the chamber with ease. Finally, all cables coming out of the electronics chamber were attached on to the ROV frame to act as strain relief and reduce the risk of lost connections.

Control Station

We designed our control station in order to reflect the needs of our customers. In accordance with our desire to make our product accessible to a wide consumer base, we designed and implemented a simplistic and intuitive system usable by anyone. To achieve this goal, we enacted a multi-display system giving us an un-disturbed view of our camera and utilizing the familiarity of the Xbox controller, allowing our ROV to have the appeal of "plug and play." We further established this domain by building our system to be based off of a single computer, allowing us to retain control over our entire system from one control point and removing any confusion, all of which simplified the process and reduced the probability of errors.

This has come from an evolution of change with our station previously showcasing all our cameras on one muddled display resulting in us unable to discern what was happening leading our pilot to spend more time identifying what he needed to know rather than actually doing stuff with it, which led us to standardize our display system helping us increase our efficiency two fold.

Cameras

Cameras are our eyes in the water and thus one of the most important components to get right on our ROV. We wanted to minimize the cameras we were going to use as more cameras would not only increase the data being transfer but would also add more information for the driver to process, making it harder for him to do stuff and thus we decided to go with backup cameras, cameras used in cars to help drivers back out easily, as they wide angle lenses which could allow us to capture various components in the frame without the need for additional cameras.

We wanted to minimize the number of cameras in order to still provide the pilot with enough information to navigate the course and keep track of their statuses, while also preventing an overload of information. To formulate this, we chose to use backup cameras from their robust nature as well as having a wide-angle lens to view more of our surroundings at a glance.

We decided to have one camera solely focused on driving which would give the driver an uninterrupted view of what is in front of view and another camera focused on the claw. We initially had a system where we would just have one camera for the claw and driving but that hindered driving abilities and thus decided to use a camera specifically for driving. We are also going to have a third camera in the back which would dedicated to object and size detections task whose footage we would be able to toggle on and off as necessary and we wanted the lasers and the ruler necessary for the aforementioned task to be viewed unhindered which required them to be on the opposite side of the claw and thus a new camera was needed. We used all USB cameras as they would easily plug into our USB hub and thus work with our USB repeater to send footage to the surface.

Figure 6: The image shows the final camera in our ROV, before waterproofing.

Manipulator

We started this MATE season with the hopes of getting into the water and having an ROV which can do simple tasks. Clearly, we were able to surpass this level and as we attempted to do more complicated tasks,our company understood the importance of a manipulator. At first our team experimented with hydraulics to create the manipulator.However, as time ran low, we decided to buy one. Yet we ran into another issue, most ROV claws we found were drastically higher than what our team could afford. Therefore, we took an alternate approach. We bought a dual prong VEX Robotics claw and waterproofed the motor using Epoxy. After testing the claw and motor at depths over 3 meters, we concluded that the VEX claw was the most suitable design given the time constraints. As efficient as the claw seemed to work in above water testing, we soon realized that under water, the claw tended to slightly open and release unpredictably. Therefore, we went through a redesign where we replaced the VEX Robotics gripper system with a custom 3D printed one which had the capability to have “teeth” preventing items from releasing.

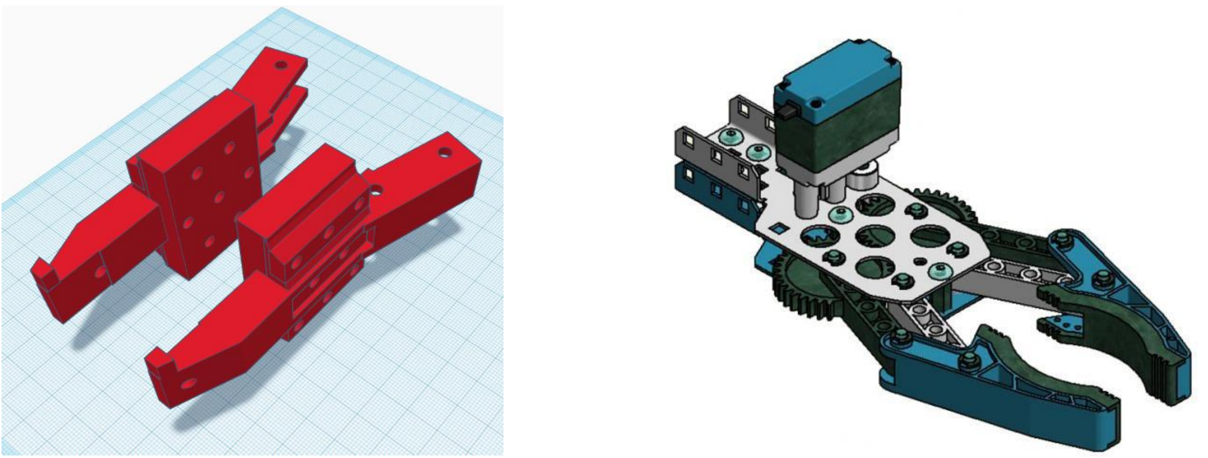


Figure 7:3D printed claw design to replace Vex claw

ROV Tools

Our company incorporated two main tools: a dropper claw attachment and lasers. For our claw system we utilized a funnel design that could be deployed when within the solo cup container when holding the grout as well as deployment for the small fry. Our laser system provides us with a relative distance measurement which is useful for measuring the cannon and comparing our lift capacity as well as determining the size of cracks on the dam wall.

In development of our dropper claw attachment we attempted to employ a solo cup container to interface equally with the grout reservoir. This system ended up being too large to easily interface with the grout reservoir, so we modified the spout of the dropper to be more constricted for the grout. We had to maintain the capability of the dropper to deposit the fry, which limited the constriction that we put on the spout.

Our initial thought for the lasers was to have a four-laser square array which we would attach to the ROV, hoping that would give us reliable measurements between 4 points. We found that the square shape of the lasers was difficult to keep static, resulting in inaccurate lasers measurements at distance in water. Our solution was a trapezoidal laser array. With the trapezoidal laser array individually attached, meaning that the lasers remain static with less surface area taken while still measuring the same dimensions.

Design Choices (Build vs. Buy | New vs. Reused)

Control Station

To build a cheap and simplistic system we decided to build our station from the ground up, allowing us to specifically chose what components we want. This allowed us to focus on tailoring the station to fit the needs of the ROV, instead of fitting our capabilities to around that of the ROV. This serves as an advantage, as it ensures a more robust fitting to our ROV, and enables a more reliable connection, as a result of this we are able to promote our own communication system between the ROV and our control system for video, sensor readouts and control data all over one communication structure. This system also enabled us to furnish our own design allowing us to move to including control of our power delivery truly becoming the center of our operation.

Onboard Electronics

We opted to start off and use existing electronic structures such as the popular open source platform Arduino, this allowed us to incorporate our own system and modify it to meet our criteria, while also not having to go through the hassle of designing a brand new system from the ground up. Once we got comfortable with our structure, we opened to the idea of prototyping our own system on top of that with the combination of our own custom PCBs. This allowed us to cut down on troubleshooting loose wires and solidify our layout, however also taught us how PCBs work with copper controlling the flow of electricity. This improvement led us to one of the faults of our linear regulators, with their poor efficiency causing them to overheat and shut down. After we our electronics began turning on and off repeatedly we moved away from creating our own system and instead purchased Buck Converters for Dc to Dc voltage conversion with a high efficiency rating meaning less wasted energy as heat.

Frame Components

PVC Piping (New, Commercial)

Because this was our first year competing in the ROV competition we did not have many resources available to us. Considering the cheap price of PVC, our team decided it was not worth the time to go hunting for PVC parts and instead bought.

Metal Wire Mesh (Reused, Commercial) The wire mesh was a later add-on to the original frame design. Because we were looking for a quick, easily accessible solution, one of the team members pitched us the idea of using wire mesh as attachment points for buoyancy foam and cameras.

Custom 3D parts (New, Custom Frame)

As the ROV evolved so did out needs. Because not all off the shelf parts meet our exact needs and many “oddballs” parts which do are very expensive we opted to 3D print many components for the frame including the vertical bilge pump motor mounts as well as prop guards to name a few.

Manipulator

Prebuilt VEX Claw (Reuse, Modified)

The prebuilt vex claw is a crucial component to the ROV which we were able to modify after waterproofing the motor attached. Because the claw is such a primary component of the ROV it made sense for it to be robust (made of aluminum) and reliable. Once the claw was correctly installed, we iterated through multiple gripper designs which we later replaced the stock grippers with. Because the claw was built to be modified by robotics teams' it allows for easy changes to occur which otherwise would have been difficult to make.

Custom 3D Parts (New, Custom Grippers)

Like mentioned earlier, the grippers on the off the shelf VEX Robotics claw did not meet the needs of our company. Therefore, instead of spending a large amount of money on various grippers we designed our own knowing it would perfectly fit the needs of our team.

ROV Tools

Lasers (New, Commercial, and Modified holders): we used reliable waterproof lasers and retrofitted them into our trapezoidal array for our custom distance separation of 5 and 3 inches.

Dropper claw attachment (Modified solo cup and constricted spout): We constricted a solo cup with the spout in order to be easily moldable for different applications for our customer.

Systems Integration Diagrams

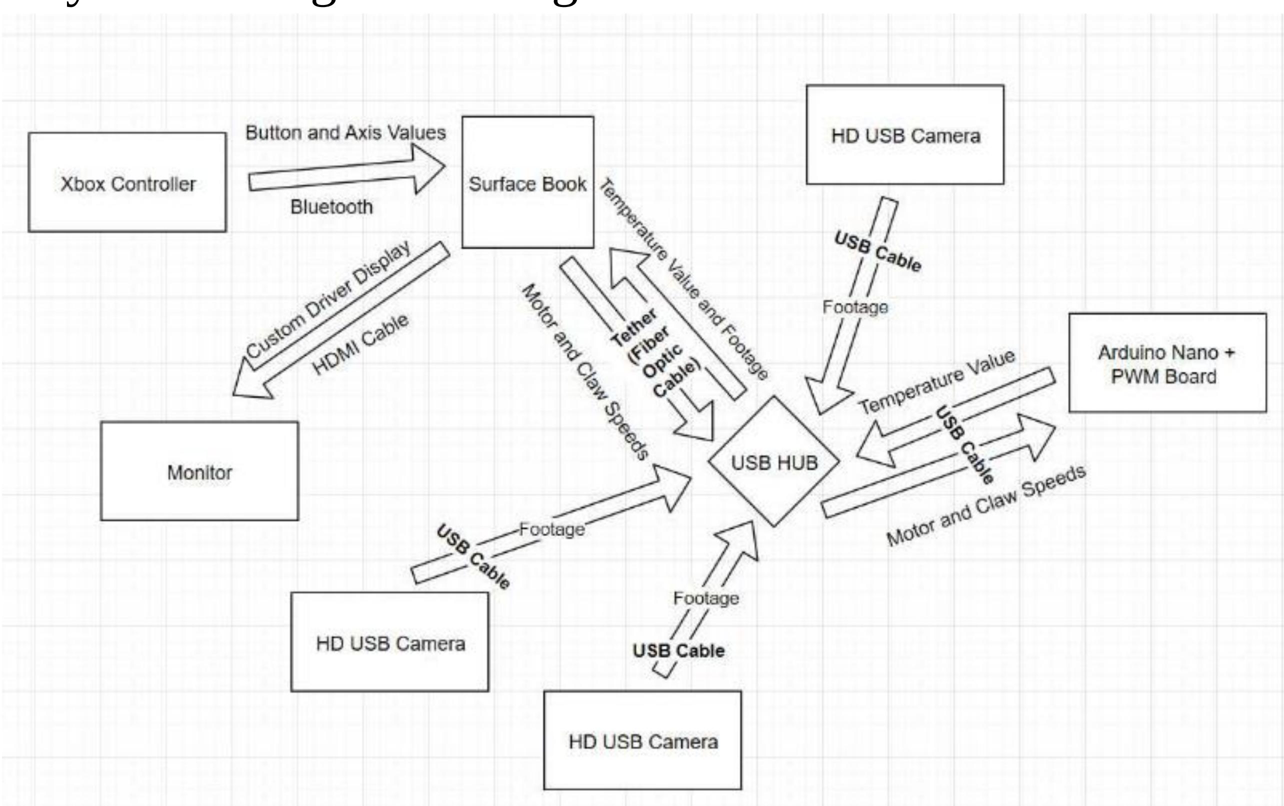


Figure 8:Computer flow diagram.

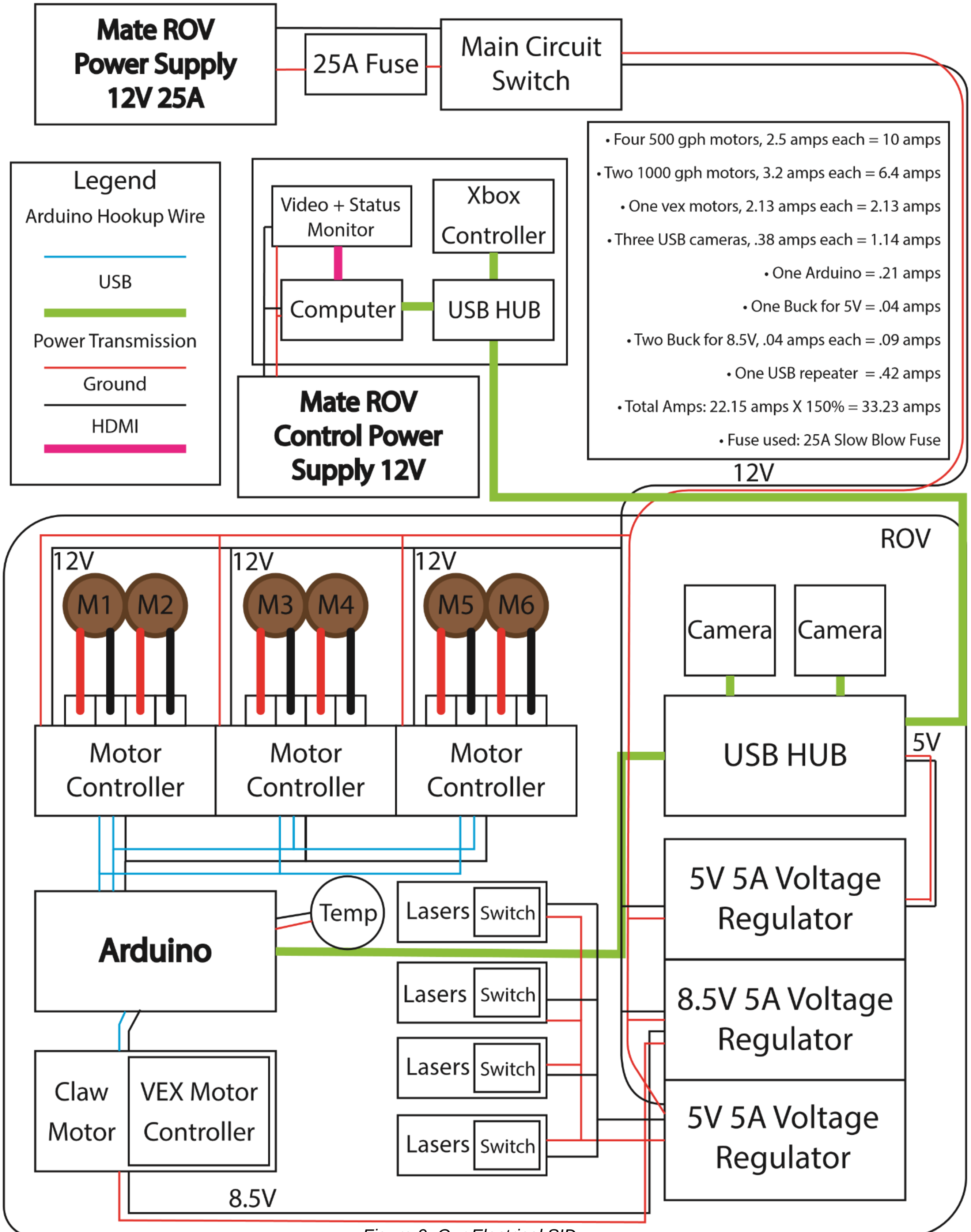


Figure 9: Our Electrical SID

Safety and Philosophy

Our company always keeps in mind that safety is the most important part of building a successful product. In order to keep our large team on board and our productivity up, we followed a philosophy of STRIVE (Safety, Teamwork, Respect, Inclusion, and Versatility leads to successful Engineering). We all "strived" to remember this acronym through our design choices and work as a company to stay creative while designing!

Safety: Follow protocols while handling dangerous tools and wear protective gear. Keep water away from the electronics, hair pulled back, feet in closed toed shoes, and workspace clean to avoid accidents.

Teamwork: If you can't manage a task single-handedly, ask a teammate. As a company we rely on group effort. We overcome challenges through problem-solving.

Respect: We respect other teammates and will always hear out their ideas. We recognize we each have strengths and weaknesses and must collaborate to bring up the best qualities in our company. Update the team before making major design changes and ask for other teammate's opinions.

Inclusion: We separate into subsystems to tackle tasks one at a time but have weekly meetings to keep everyone on the same page. This is a large project and we can be most successful by delegating responsibility.

Versatility: If we disagree or face a challenge, we adapt and make the most of our skills to overcome it.

Engineering: Keep the MATE challenge in mind and build our product! Keep it simple and be safe. We want to expand our engineering skills and have a fun experience.

Highlights or ROV Safety Features

When it comes to designing and building the ROV, it is vital to produce safety features to ensure those operating and constructing the ROV have proper protection. Some of these safety features arI.

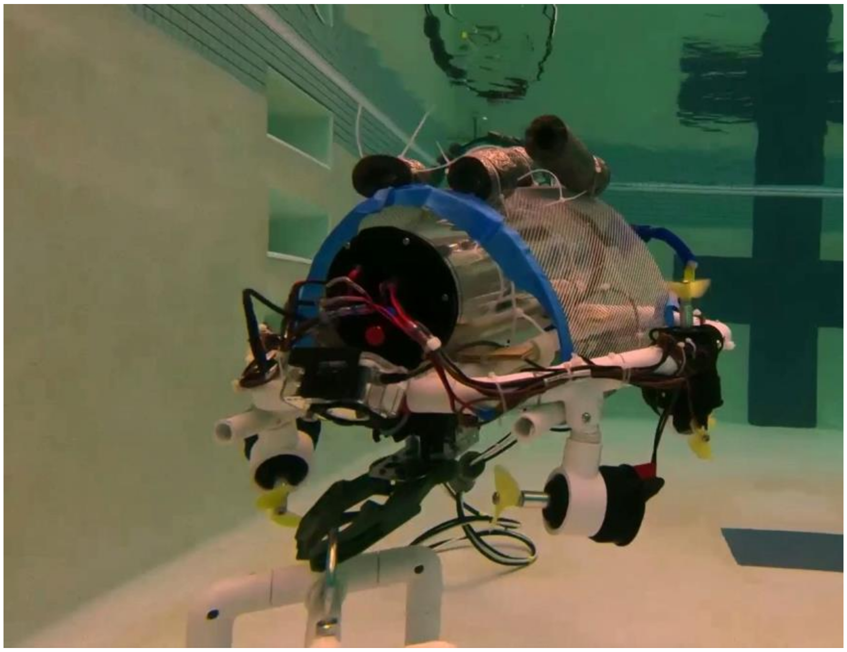
- **Waterproofing:** Epoxy was often used to seal off connections between any machines not already waterproofed (Small Cameras, Lasers). The electronics enclosure however was waterproofed using silicone O-rings on a flange and any cables connections using electrical tape.
- **Prop Guards:** Designed in 3D-Modeling software to keep operators safe but to also allow for water to flow easily.
- **Laser Shield:** Painted matte black to absorb any laser light and to prevent and reflecting. Can be applied and removed without any struggle.
- **Power Cutoff Switch:** In case of any malfunction or leakage in the electronics enclosure, we have a switch implemented so power can immediately be cutoff.
- **Safety Glasses Protocol:** Anyone working on the ROV whether its construction or operating it always needs to be wearing a pair of safety glasses . When lasers are on, Laser safety glasses must be worn by all operators in the vicinity of the ROV and no one should be directly in front of them.

CRITICAL ANALYSIS

Testing

Cameras: When we first got the cameras we tested them by connecting them to our computers, both directly and through a USB hub, to ensure that we discovered any manufacturing issues and that the cameras would meet requirements when it came data transmission, viewing angle, focus, etc.. After waterproofing a camera, we tested both above ground and, in a bathtub, to ensure that we can reliable footage through the casing and we repeated the above steps for all the cameras. Our next stage of testing occurred after the integrated the cameras both to the frame and electrical system of the ROV. We performed a dry run in which gave power to the robot while we were above ground and made to sure that we were getting footage from all the 4 cameras without any slowdowns through the USB repeater. The final stage of testing for the cameras was to put them, along with the rest of the ROV underwater at depths up to 4.5 meters for about 45 minutes to ensure that they would be sustainable to extreme conditions at extended time periods During this time period, if we encountered any problems with our main cameras we quickly that camera with the back camera, which went through the same testing ordeal.

Motors: We went through a similar technique of testing with the motors as we did with the cameras. We initially tested all the new motors we got by using a 12-volt power supply to ensure that all of them were in working order. Then we hooked them up with the Arduino and the motor controllers to make sure that they worked both individually and together while retaining the ability vary the motor speeds. We then finally attached them to the motor mounts and performed another test before we went into the water. This final dry test with consisted of both the motors and cameras working simultaneously, simulating the actual setup of the ROV's electronics. After passing all those tests we finally began to test them in the water. First, without prop guards and afterwards with prop guards to see what effect if any the prop guards had on our speed. This was where we found that the prop guard had a significant impact on our speed leading to us redesigning the prop guards to allow for a better water flow and improving our speed .



Underwater testing of the ROV (Credit: Arnav S)

Troubleshooting

Troubleshooting was an important aspect during the testing of our ROV as we need to be able quickly identify and solve problems that may show during the competition. Being a first year, we were all learning new concepts and working with unfamiliar equipment that initially led to many technical errors that took us way too much time to solver like properly powering the surface hub. Throughout the year, as we all got familiar with our equipment, we saw many common errors with our system, and we were able to develop lists of actions to take if certain systems were failing. The checklist for camera failure is included below as an example:

- If the camera case is hot, unplug the power and open the case to let the cameras cool
- Next, unplug and re-plug the power supply to do a forced startup for the cameras
- Take out the electronic chamber from the pressure chamber and make sure the wire is plugged in properly
- Try connecting the hub directly with the computer without the USB repeater
- Attach the wire of the camera directly to the computer without any intermediate wire

Technical Challenges

Software: The first challenged we encounter was to design a system that would allow us to easily convert user input into motor output in a way that would allow for multiple operations like rolling while going up. We developed a 6 by 6 matrix for the contribution of each motor in each of the six degree of freedom and the coefficients adjust based on the angles and placement of the motors with respect to the center of gravity and thus we could use the same code base even if we changed up motor arrangements. Then the user input would be modeled by a 6 by 1 and used Gaussian elimination (a system to linear system of equations) to solve for the 6 variables (the force of each of the motor) which we later send to the Arduino. Our next challenge was to be able to theoretically have the capabilities to run all 6 motors, all the cameras, storing images and image recognition at the same time to do so we thread each of the operations so that one would not a detrimental impact on the other while still being able to perform the tasks. Because we were using python for programming base, we were able to use many of python helpful APIs like pyserial, which allowed used to easily communicate between Arduino and python or opencv, which helped us combine various incoming footage into one display. While image recognition seemed like a challenging task, we are able to use the Tensorflow API to relatively easy train a convoluted neural network using a custom training developer program and then which we could call to get our desired results, thus limiting the amount of work we would have to do.

Non-technical Challenges

Team Communication: When we initially started working on the ROV, communication amongst teammates and mentors was strong as we had setup all sorts of group messaging systems and public calendar boards. As we progressed further into the MATE season, contact between team members however began lacking more and more, losing any sort of collaboration between sub-systems. Towards the end of the season the communication picked up again and we were able to come through with a functioning ROV. If we were to participate again, we would like to make sure that everyone can share information and be contacted easily through multiple programs and implementing mandatory updates whenever work is completed so everyone knows what is going on.

Technical Lessons Learned

While creating their ROV, every member in SeaPreme developed some sort of technical skills through their participation, and their defined tasks during the building process. Notably, small skills such as soldering or properly using epoxy were learned by everyone, whereas other things were particular learnings of individuals. For example, Devesh was given the opportunity to apply skills he'd learned in computer science, along with developing an image recognition software. One of the most important lessons learned overall is that planning leads to success. As we progressed through the project this was clear through 3d design in CAD, which allowed us to avoid mistakes made earlier.

Non-technical skills learned

A wide range of non-technical skills were needed to complete this project and to make sure it is the best possible. First there is becoming adept in the many different forms of communication that we use to contact each other. Then there is also the skill of resilience to failures like when lasers fail or cameras disconnect and you have to be able to get through it and still compete the best you can, this skill can be expanded past this competition to the rest of our lives as an important non-technical skill.

Development of Skills

As part of a large team, learning to compromise and collaborate with other members was integral to succeed in the project. Therefore, all team members acquired the skills required to work effectively in teams. Communication was another key component, and our team progressed through the duration of the project to develop efficient communication skills to keep everyone well-informed. Aside from the non-technical skills, building the ROV demanded the accuracy of strong technical skills, especially in the subsystem that a member was part of. All members developed a solid foundation on using technical equipment, following the engineering design process, and most essentially, understanding the mechanics of a remotely operated vehicle. As students of a STEM-focused school with a project-based learning environment, all members were exposed to engineering or computer science related activities and had developed a passion for STEM fields. Due to this, all of us were eager to participate and contribute to the team with our various expertise in coding, Arduino, and designing using digital tools.

Future Improvements and Reflections

Minu: In the future we might try more sophisticated claw designs, such as using actuators or pneumatics, to make our claw extendable. This could give our ROV more workability. We could also consider more powerful thrusters to increase our ROV's lift capacity.

Pamela: In the future we might invest in more tests using a multimeter to identify if our regulators are properly working by measuring the amount of voltage running through our battery, in order to avoid short-circuiting our system. This could save us both time and materials, and significantly reduced our overall costs.

Lahari: As the lead mechanical engineer, I would like the mechanical subsystem members, including myself, to invest in learning 3D modeling to create more customized parts. Considering the availability of resources such as 3D printers at our school, I want to utilize them to not only reduce costs, but to expand on the type of designs that can be built and implemented without the limitations of purchased parts.

Hui: The CFO's job is to keep the market product affordable for its functionality. As we enhance our ROV and adjust, I would like us to consider the multi-functions of different parts to save on the expenses as well as taking advantage of 3-D printed models in replacement of current parts because of its unique fit for our ROV.

Yusei: Team communication and collaboration was lacking during the middle of the MATE season; in the future I would hope to see that there's a strong sense of a team throughout the whole season. Also, I would like to produce a mechanism that could solve most miscellaneous tasks on its own.

Devesh: In the future we want to able to develop technology for each driver to able to customize his interface and display instead of having one set GUI system for all the drivers. Additionally, we want to develop a piece of software that would allow us to successfully (high accuracy) measure the size of various objects like the cannon and the crack without the need for much human work and effort. We also want to improve communication between the various subsystems through potentially having some people dedicated to the integration of the various subsystems.

Alvin: General team communication and planning near the end of the MATE season was very limited, and this hindered the team's overall productivity. If we were had better means of communication, had more planned team meetings, and set out clear objectives for each month then our ROV at the regional competition could have been more polished.

Ayan Gupta: As the chief engineer, I have a lot to learn from my various experiences this year in integrating systems from each sub team. For the future, I would like to find better organizational methods to ensure that each member is aware of components of each sub team to help in designing a coherent ROV. Through the course of the year we had to go through multiple redesign phases which could have been avoided through better planning and communication. Along with this I would want to find better techniques we could use to manufacture the ROV in the future. This year we opted for PVC and given the circumstances it was a good choice; however, better materials will allow us to drastically reduce the weight of the ROV and improve operating efficiency.

Arnav Sacheti: Some improvements would be to improve our research and development efficiency, costing us less time, this would help us gain more time to test our ROV and not end up worrying about things not working in the end. One thing I thought we did well was research as we spent less time worrying whether something would work as we had already found out even before getting the item.

Adam George: In the future I think we should put our thrusters more at the center of gravity of our ROV to make it more stable while maneuvering. Our cameras also needed better positioning before the competition because we spent a lot of time during the competition figuring out what worked best. Also, we needed to have better communication while demoing to make sure we don't break any rules.

Graham Sabin: In the future, my biggest priority is to get everyone on the team fully commited and active throughout the entire process of prepping for the competition. I think this starts with communication, and everyone being on the same page. During our design process, we were very inconsistent with responses throughout the time, making it very difficult to collaborate. I also want to see us spend more time reaching out and teaching other people about our ROV and how it works, like we did in our outreach event.

Jakob Bjorner: I have found that due to the size of our team, many of our members felt as though they were not as involved as they would have liked to have been. In the future I would like to improve our initial organization of subsystem work teams in order to provide more equal opportunities for people to work.

ACCOUNTING

Budget

Our company set a budget for **2.5 thousand dollars** to leave room for any repairments or replacements of materials due to breakages. We managed to stay within our budget by making some of the parts ourselves through 3D-printing and laser-cutting materials with the tools that were provided by our school. For example, we decided to 3D-print our finalized camera mounts, along with some other parts, instead of purchasing these parts. By making some of the parts ourselves, we not only managed to reduce some of our costs, but also adapt certain parts to best accommodate for our ROV design.

Because this is our first year, many of our parts are to be bought and could not be reused. Other parts, such as the pressure chamber, were more efficient and reliable bought than made despite our efforts. We were sponsored by our school and so our budget was more flexible than others.

Budget of Categories

Category	Estimate Price
Hardware	$1150
Electronics	$700
Props	$150
Tools/Extraneous	$300
Fees	$200
Total	$2500

Cost Accounting

Estimate Travel Expenses

Description	Cost	Quantity	Total
Roundtrip Flight (2	$570/person	8	$4,560

Adults, 6 children)			
Hotel- Red Roof Inn Kingsport	$65/night	3 rooms, 4 nights	$780
Total			$5,340

Purchased Items Breakdown

Item	Vendor	Cost
Hardware		
PVC	Home Depot	$89.28
PCB	JLCPCB	$40.70
Acrylic Tube	Blue Robotics	$50.16
Watertight Enclosure	Blue Robotics	$116.60
Screws/Bolts	Amazon/Home Depot	$35.43
Cameras	Home Depot	$98.60
Propeller Parts	Seamate	$161.70
Coleman Cable Wheel	Amazon	$13.24
Electrical Tape	Amazon	$43.23
Cable Penetrator/Tools	BlueRobotics	$90.75
Clear Acrylic	Amazon	$9.89
Bilge Pump	Amazon	$72.84
Glue/Epoxy	Home Depot	$57.07
Vex Claw	Robot Mesh	$19.99
Washers	Home Depot	$25.82
Mounts	Amazon	$14.38
Storage Boxes	Home Depot	$51.74
Solder Seals	Amazon	$25.40

Spares	Home Depot	$101.14
Total		$1117.96

Electronics		
Motors	Amazon/Robot Mesh	$156.31
Arduino	Amazon	$76.86
Wires	Amazon	$42.66
Cables	Amazon	$126.04
USB Hubs	Amazon	$62.56
Port Converters	Amazon	$29.38
Total		$493.81
Props	Home Depot	$140.84
Tools/Fees		
Dremel	Amazon	$108.90
Safety Glasses	Amazon	$60.79
Digital Caliper	Amazon	$10.88
Extra Shipping	Varied	$64.00
Registration Fee	MATE	$200
Total		$444.57
Grand Total		$2397.00

Re-used/Already Purchased Items

Item	Market Cost

Xbox Controller	$21.99
Hack Saw	$4.96
Soldering Iron	$11.33
Propeller x 4	$96.00
Vex Claw	$19.99
Toolbox	$45.00
Metal Mesh	$56.29
Computer Monitor	$119.99

References and Acknowledgements

"Arduino Nano Store Page." *Arduino*, store.arduino.cc/usa/arduino-nano.
Chan, Genevieve. "Using MDD10A with ARDUINO UNO." *Tutorial by Cytron*, 5 Apr. 2015, tutorial.cytron.io/2015/04/05/using-mdd10a-with-arduino-uno/.
Earl, Bill. "Adafruit PCA9685 16-Channel Servo Driver." *Overview | Adafruit PCA9685 16-Channel Servo Driver | Adafruit Learning System*, 22 May 2019, learn.adafruit.com/16-channel-pwm-servo-driver/overview.
"Cloud Powered 3D CAD/CAM Software for Product Design | Fusion 360." *Get Started with Fusion 360*, Autodesk, f360ap.autodesk.com/courses/getting-started-in-fusion-360/lessons/lesson-1-course-overview.
Moore, Steven W., et al. *Underwater Robotics: Science, Design & Fabrication*. Marine Advanced Technology Education (MATE) Center, 2010.
Mordvintsev, Alexander, and Abid K Revision. "Getting Started with Videos." *OpenCV*, 2013, opencv-python-tutroals.readthedocs.io/en/latest/py_tutorials/py_gui/py_video_display/py_video_display.html#capture-video-from-camera.
"NumPy Reference." *NumPy Reference - NumPy v1.16 Manual*, 31 Jan. 2019, docs.scipy.org/doc/numpy/reference/.
"PCB Prototype & PCB Fabrication Manufacturer." *JLCPCB*, jlcpcb.com/.
"Pygame Joystick." *Pygame.joystick - Pygame v1.9.5.dev0 Documentation*, www.pygame.org/docs/ref/joystick.html.
"TensorFlow Lite Guide | TensorFlow Lite | TensorFlow." *TensorFlow*, Google, www.tensorflow.org/lite/guide.
"Watertight Subsea Enclosure for ROVs and AUVs." *Blue Robotics*, www.bluerobotics.com/store/watertight-enclosures/4-series/wte4-asm-r1/.

SeaPreme would like to give a special thank you to all of our supporters and sponsors!

Thomas Stahura: Friend through School, supported us by giving us time in their pool allowing us to test.
YMCA: Community Pool, supported us by giving us time in their pool allowing us to test.
Sebastian Horstmann: Friend through School, supported us by giving us time in their pool allowing us to test.
Mentors of STEM ROV: Our mentors guided us through understanding the workings of ROVs, they guided us and kept us on track, and they were constantly available for questions and advice at any time.