Kepler Enterprises Technical Report

San Antonio, Texas

May 13, 2017

Nate Love - CEO (12th Grade, Third Year MATE)

Jake Love - CSO (9th Grade, Second Year MATE)

Grant Kahl - CTO (10th Grade, Third Year MATE)

Lance Kahl - CFO (7th Grade, Second Year MATE)

Alec Neiman - CPO (10th Grade, First Year MATE)

Kyle Killian - (9th Grade, First Year MATE)

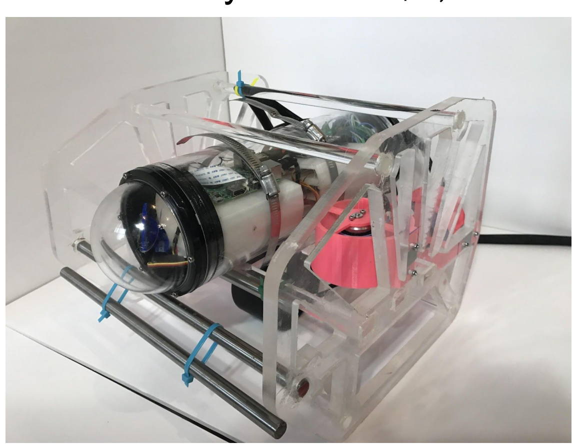
Myles Jonas - (10th Grade, First Year MATE)

Dr. Jeffrey Kahl - Team Mentor

ROV – Crystal 2.0

Total Project Cost - $3,566

MSRP Crystal 2.0 - $1,200



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1. Abstract

Team Kepler is focused on exploration, innovation and creating endless possibilities. The team is staffed with 7 students from various schools in the San Antonio area with team members ranging from the 7th to 12th grade. Each team member brings unique skills to the team that complements one another. This diverse team is focused on having fun and learning as much as possible. Team Kepler has designed and engineered a remotely operated vehicle (ROV) named Crystal 2.0. Crystal is a new and improved design from last years ROV. The number one priority for design and construction of Crystal 2.0 was safety. All team members worked under standard manufacturing procedures and personal protective equipment (PPE) was used during all aspects of construction and testing of Crystal 2.0. The ROV was designed to be simple yet effective in completing this year's demonstration missions. We used SolidWorks to design the structural components of the ROV that were milled out of cast acrylic, using Robert E. Lee STEM High School's computer numerical control (CNC) machine. Consistent with our theme, “Keep it Simple”, the team designed various 3D printed attachments designed to manipulate mission components. The team used QGroundControl software with ArduSub firmware to connect the onboard electrical systems to deliver a seamless operational experience. This allowed the team to successfully complete missions including: maintenance, construction, cleanup, discovery, inspection, and conduct miscellaneous operations.

2. Company Members

Nate Love – I am the Chief Executive Officer of Kepler Robotics. I am currently a senior at Robert E Lee High School's STEM Academy. This is my third year doing MATE. In high school, I participate in the FTC robotics team as well as our school's engineering courses. I also run varsity cross-country and track, participate in NHS and Mu Alpha Theta, and am president of STEM Ambassadors. Outside of school, I am an Eagle Scout and act as a student ambassador for the program Summer of Service, most recently traveling to San Antonio's sister city of Wuxi, China. Next year I plan to attend UT Austin to study electrical engineering.

Grant Kahl - I am the Chief Technical Officer of Kepler Robotics and am a current sophomore at Texas Military Institute (TMI) of San Antonio. This is my third year participating with MATE robotics and second year in the Ranger division. I have over 7 years of experience with the US FIRST robotic programs, one-year experience with Vex Robotics, and spend my spare time building first person view quadcopters. Outside of school, I am an Eagle Scout and actively involved in STEM enrichment programs. After high school I want to attend MIT to obtain a degree in aeronautical engineering to pursue my love of engineering.

Alec Neiman - I am the Chief Programming Officer. I currently am a sophomore attending Texas Military Institute (TMI) of San Antonio. I participate in varsity football and tennis. This is my first year participating in MATE robotics. I have experience coding and hope to improve on my skills over time by participating in robotics. I hope to get a degree in computer science after high school.

Lance Kahl – I am the Chief Financial Officer and take care of team finances. I am a 7th grader at Lopez Middle School and have participated in robotics since 4th grade. I also participate in football, basketball, and boy scouts. In the future, I would like to attend Stanford and get a degree in engineering.

Jake Love – I am the Chief Safety Officer for our team and my job is to enforce safety rules in everything we do. Currently, I am in the 9th grade and go to Lee High School's STEM program. I have been interested in engineering and robotics since the 5th grade. I was part of my schools FLL team and was the captain of the TCEA team. Along with robotics, I run track and hope to go to either

Princeton or Stanford and get a degree in some type of engineering.

Kyle Kilian – I am a new team member; this is my first year participating in MATE. I am a 9th grader attending the STEM Academy at Lee High School. I am an Eagle Scout. I have been in NEHS as well as NJHS. I partake in football, varsity wrestling, and baseball. In my spare time I enjoy computer games and flying quadcopters. I am interested in serving in the military.

Myles Jonas – I am a new team member; this is my first year in MATE. I am a 10th grader at Saint Mary's Hall where I participate in the robotics and science bowl clubs. Recently certified as a lifeguard, I have spent my life underwater, competitively swimming since elementary school, and getting third in the TAPPS Division II State Competition this past season. In the future, I hope to go to the Naval Academy to study engineering.

3. Budget

This year, we knew we needed more funding to build a fully operational ROV. Each team member contributed $250 toward financing the team, and we set up a Go Fund Me that raised $250 to help buy electronic components and ROV parts. In total, we raised $1,750 dollars that were used to buy equipment and supplies to manufacture our ROV. We also received resources and tools from our sponsors. Robotics Clubs USA sponsored the team with a $2,000 donation that covered all remaining expenses for the year. Our costs were dramatically reduced because we were able to use parts and tools from previous years competitions. Travel expenses were included in our budget. After regional competition we recalculated travel expense to include our trip from Texas to Long Beach, California. To help curb this cost each family paid for their own travel and expenses while travelling. Below is a table of our team expense for the 2016 – 2017 competition year.

Kepler Enterprises Expenses

Item	Quantity	Cost	Item	Quantity	Cost
Electronics			**Hardware**		
Waterproof servo - Reused	2	$86	O-ring grease	1	$16.56
Rasberry pie	1	$36.91	vacuum pump	1	$37.37
Hd camera	1	$24.99	Acrylic rod	3	$74.34
Rasberry pie warranty	1	$4.99	Acrylic sheet.	2	$65.68
Fathom X board	1	$162.00	Crimper - Reused	1	$23.00
Pixhawk controller	1	$72.99	4 inch enclosure	1	$203.00
m100 motors - Reused	5	$360.00	Penetrator wrench	1	$12.00
Depth/ Pressure sensor - Reused	1	$68.00	Penetrators	14	$53.80
temperature sensor - Reused	1	$56.00	Thruster cable - Reused	15	$105.00
30 ft USB cable	1	$13.88	buoyancy foam - Reused	2	$42.00
Ethernet cable - Reused	1	$5.25	Propellers - Reused	6	$72.00
Power module - Reused	1	$9.99	Wire relief	10	$ 20.00
Xbox controller	1	$49.99	Stainless steel rods	2	$ 35.00
Total		**$950.99**	**Total**		**$759.75**
Travel/Food			**Internation Competition Expenses**		
Meeting food weekly	24	$ 720.00	Hotel		$2,685.00
Shirts	8	$ 160.00	Travel		$2,100.00
Hotel	1	650.00$	Food		$840.00
registration	1	125.00$			
Travel	1	200.00$			
Total		**$ 1,855.00**	**Total**		**$5,625.00**
	Total Expenses		**$ 9,190.74**		

Kepler Enterprises Income

Activity	Total
Team Dues ($250 per team member)	$1,750
Robotics Clubs USA	$7,450
Total Income	**$9,200**

4. Design

The MATE ROV competition is an immense and complicated set of challenges and as such we designed our ROV to perform in all required areas. The central idea this year was *simple efficiency.* We wanted to have an ROV that performed well yet was not overly complicated in its mechanics or electronics systems. This idea guided us throughout the design process, as we decided materials, motors and shrouds, planning the ROV, and installing the electrical systems.

Material Selection

Before we began full CAD design of our ROV, we decided on the materials we would utilize. When looking at structural materials, there were several criteria specifications: strength, cost, availability, buoyancy, constructability, and reliability. Based on this criteria, we chose to use acrylic as it was strong, sturdy, cost effective, easy to acquire, almost neutrally buoyant, easily manipulated using power tools including a CNC machine, and resistant to water damage.

Design Ideas

The team brainstormed over the course of several meetings to establish design criteria and specifications. The primary goal was to include everyone’s ideas into the final design. We started by outlining basic principles and criteria, narrowing it down to the following criterion: sleek, compact strong, and easily modified using modular attachments.

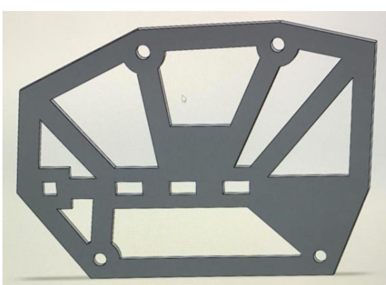


Figure 1. First generation Design

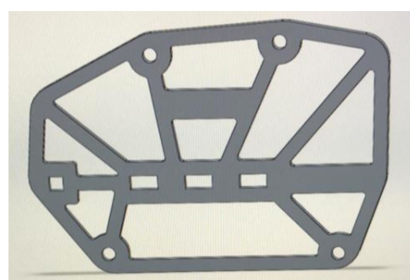


Figure 2. Second generation Design

After the team settled on the design criterion, we asked Matt Ebert, a STEM student who is proficient in SolidWorks, to help prepare several virtual models. The team discussed the virtual designs and voted on the best model to begin prototyping the ROV. This final design was optimal and met our design specifications: light, easy accessibility to hardware and motor mounts, maximized water flow for thruster efficiency, and modularity.

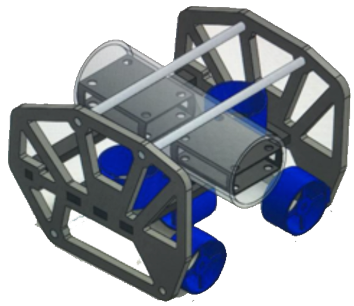


Figure 3. Solidworks model of team Kepler Enterprises ROV (Iso view)

Electronics

The electronics for our ROV are broken up into two sections, the top-side electronics and the onboard electronics. On the topside we have a central box with a fuse that manages the wires. Coming out of it are the Anderson power poles to the battery as well as two other power wires that we then plug into our tether. The box also connects an ethernet cable from the computer, running QGroundControl, to the FathomX topside board. This board takes the ethernet signal and translates it to a two wire signal. By doing this we can extend the ethernet signal much farther than we normally would with just and ethernet. It also allows us to declutter the tether and run a total of four wires down. The onboard electronics consist of a Pixhawk device, a Raspberry Pi, a second FathomX board, a power distribution board, and our electronic speed controls (ESCs). The tether leads into our brain tube connecting to the power distribution board and leading the two wire signal back to the second FathomX board. This board takes the two wire signal and puts it back into an ethernet signal, which then runs to the Raspberry Pi. The Raspberry Pi is running a special firmware made for ROV's called ardusub. Using ardusub the Raspberry Pi turns the ethernet signal into a USB signal that is then sent to the Pixhawk. A Pixhawk is traditionally used for geographical mapping on rc planes and UAVs. However, the simplicity and adaptability of the Pixhawk made it exceedingly easy to use ardusub and the Raspberry Pi to control the ESCs and servos. From there the ESCs give commands the the thrusters. The output from the Raspberry Pi also allows us to have HD video without adding an extra wire.

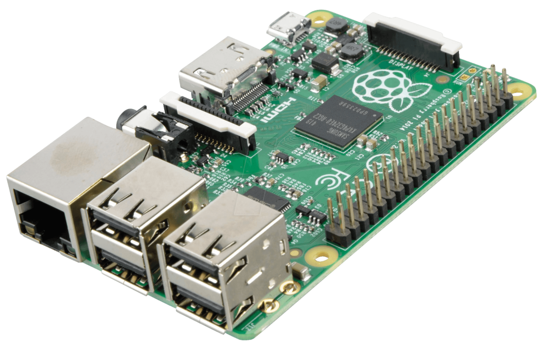


Figure 4. Raspberry Pi

Figure 5. Pixhawk

Figure 6. ESC

Figure 7. FathomX Board

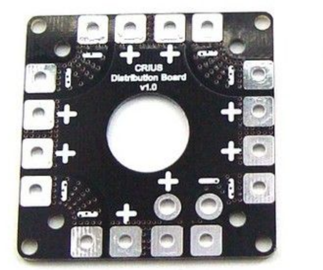


Figure 8. Power Distribution Board

Camera

The camera on the ROV is a High Definition (HD) Raspberry Pi 5MP camera. We chose this camera because compared to the widely used CCD cameras, which require an independent cable for video communication and gives a lower pixel count, this camera is designed to be used with the Raspberry Pi and gives an HD picture. The camera being designed for a Raspberry Pi makes it very simple to use and also helps with decluttering the tether as there is no extra wire required. With less than a millisecond delay the camera allows the driver to get a large and detailed picture of whatever they need to see. The camera is mounted in the front of the brain tube and is attached to a 3D printed gimbal that rotates up or down with a servo. This allows the pilot to look at varying degrees along the y-axis to fully see and comprehend any task presented to the ROV.

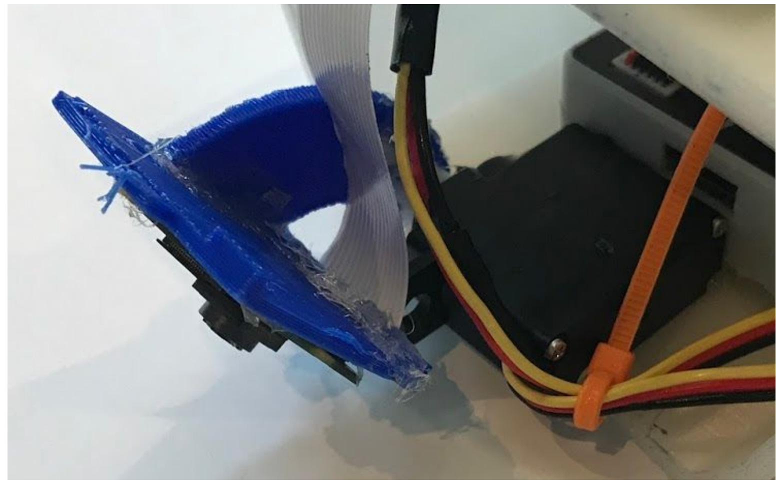


Figure 9. Camera in its housing and attached to the gimbal *Figure 10.* Back shot of gimbal and servo

Electronic Housing

The team's next challenge was to determine how to design, layout, and manufacture the ROV electronics. Electronic design standards were established based upon the functionality and utility we wanted in the ROV. We wanted the ROV to move on all three axes, have video panning capabilities to adjust underwater views, seamless communication, and enhanced capabilities to add sensors.

Our design specifications require the following onboard electronics and equipment: five brushless motor electronic speed controllers (ESC), a Pixhawk telemetry and communication device, a Raspberry Pi, and temperature/pressure sensors. The team decided that all of the electronics should be housed onboard the ROV and all communication and signals originate from the surface computer control, looking from real life examples that have succeeded. We used a LX200 V20 communication board to send computer signals from the surface to the ROV onboard controller.

The team decided to use a watertight 35.5 cm x 10 cm x .635 cm thick acrylic tube as the ROV onboard brain center, where the onboard electronic components are housed. The brain cavity required the team to design an electronic management system that enabled all of the electronic components to be assembled with easy access for repairs and manipulation. We had to insure there would be enough room for housing, and wire and camera movement, so the team designed and 3D printed shelving systems that enabled the components to be organized and neatly installed. Offering a simple and efficient way to organize the ROV electronic components, this design allowed the electronic systems to be elevated off the base of the tube, giving some protection from water leaks.

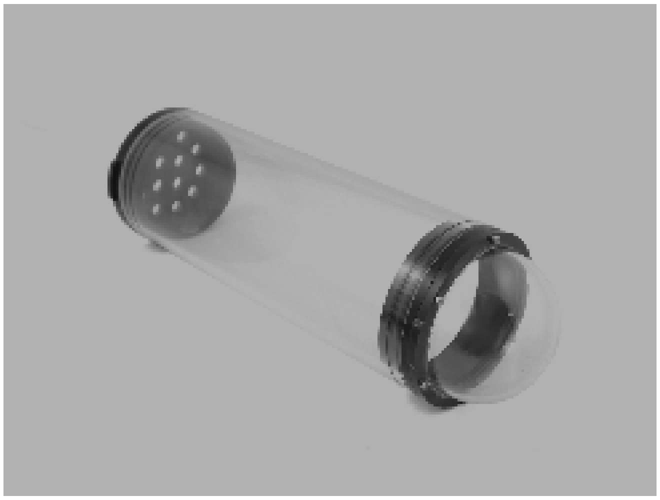


Figure 11. Brain Tube

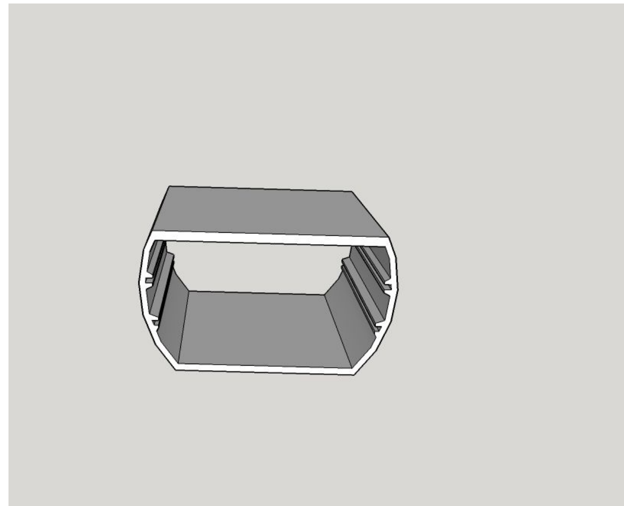


Figure 12. Electronics Shelf

Waterproofing

The brain tube is the most important aspect of to the success of the ROV. We took extra precautionary measures to ensure waterproofing this year. The basic sealant procedures we used were setting the control wires in the interface nuts, sealing them with mixed marine epoxy, using new O-rings, as well as using silicone grease on the O-rings. We use liquid electrical tape and flex seal on the external wires and surfaces to create redundant protection from water leaks. It was also imperative that the O-rings were properly maintained and greased to keep a watertight seal. In this case, we used silicon grease that helped lubricate the rubber seals and made a water resistant seal because of the hydrophobicity of silicone grease.

Shrouds

After our first year in the MATE competition, we learned that having thrusters without shrouded motors affected overall performance and created a safety hazard. Therefore, we made a significant change where we 3D printed motor shrouds. The overall performance was improved greatly increasing thruster output and performance. Additionally, we improved the ROV safety profile, making it easier to work on the ROV with covered propellers. The overall design generated a 8.89 cm shroud/motor mount that seated the motor and propellers perfectly.

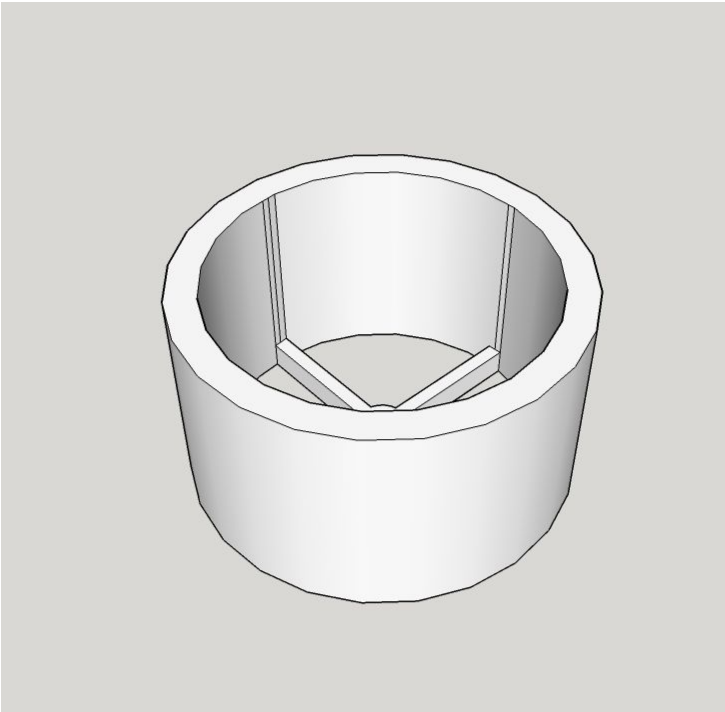


Figure 13. ISO view of shroud

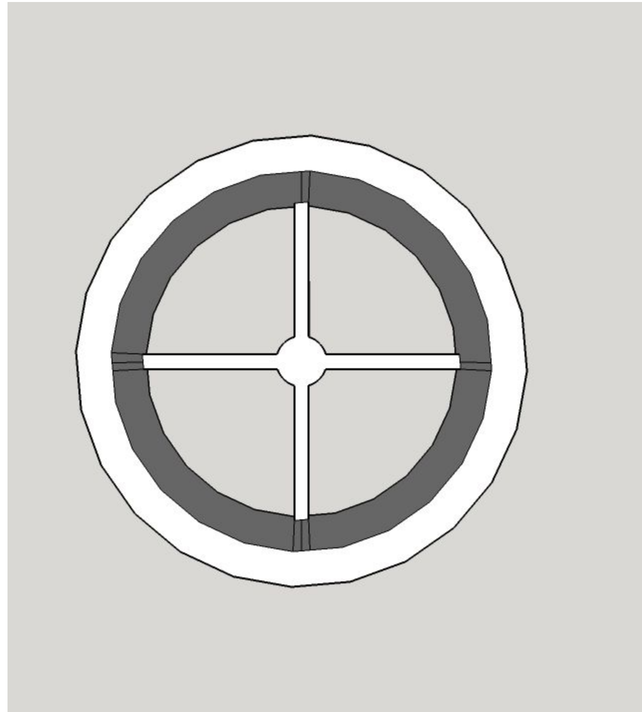


Figure 14. top view of shroud

ROV Frame

The frame was milled on Robert E. Lee STEM High School's CNC machine, where the assembly framing parts were prepared from a sheet of 91.44 cm X 91.44 cm casted acrylic. We test fitted the acrylic pieces and assembled them using a 2 part clear epoxy. Next, we placed and secured the brain tube with 11.43 cm hose clamps and double sided tape. The thrusters were mounted using machine screws and double sided tape. Once all the framing parts were assembled, we were able to install the electronic components and finalize electrical system design.

Tether

The tether is made out of expandable sleeving. We chose this because it was flexible, neutrally buoyant, and would contain our wires. Inside the tether are the two wires that the FathomX boards use to communicate with each other and the two power cables. The tether is 10 m, which allows the ROV to go very deep and farther away than we need it to. On the outside of the tether are pool noodles that supply buoyancy to the tether so it does not drag or interfere with the buoyancy on the

ROV. The noodles also make it easier for the tether operator to move it and avoid obstacles in the water or make a motion that will move the ROV. When we operate the tether we have a “macro” operator and a “micro” operator. The macro operator watches the full spool of our tether and releases more as the micro operator requests it. The micro operator is controlling the tether from the poolside and makes sure it does not interfere with the props, pool, or ROV in any way.

Figure 15. The tethers material and buoyancy device

Attachments

On the front of the robot is a PVC pipe that we can fit many different attachments into. In total we have three attachments each used for many different tasks. Each attachment is designed in Inventor CAD and 3D printed to fit the front PVC pipe. This allows a very modular and easy switch between attachments. It also allows the team to change our plan very easily as we can remove and replace attachments based on how the demonstration is currently going. Each attachment is also designed differently and with different intentions. Below are all of our attachments :

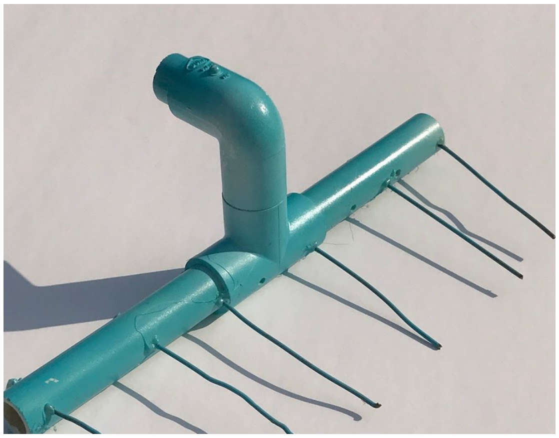


Figure 16. Clam retriever

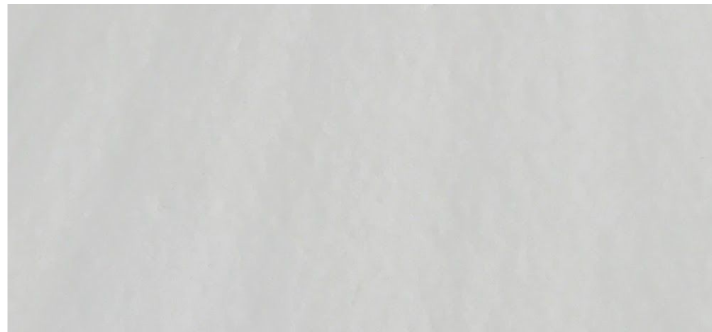


Figure 17. Large scoop

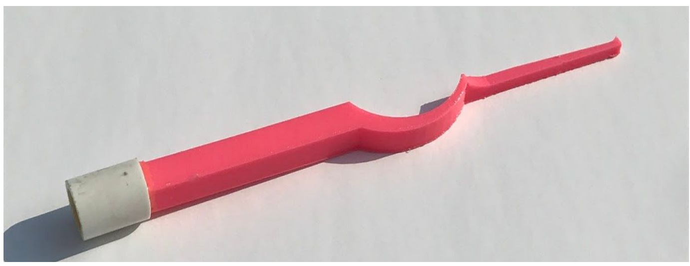


Figure 18. Skinny claw with scoop

5. Buoyancy

One of the most important aspects of an ROV is its ability to remain neutrally buoyant while submerged. Being neutrally buoyant means the upward and downward forces acting on the ROV, in water, are equal. Therefore, a neutrally buoyant ROV does not sink or float, but remains static in the water. This is vital for the ROV pilot to maintain precise control of the ROV underwater. This allows for completely dynamic movement and is necessary to complete complex maneuvers and tasks.

While calculating the buoyancy, we encountered a number of problems. Initially we tried to calculate the total volume of the ROV, including all components. We found this difficult and the calculations were not reliable enough to clearly define ballast needs. This was difficult due to approximation of too many parts and pieces.

Alternatively we used Archimedes' principle to calculate the volume. We filled a tub with water and submersed the ROV, calculating the displacement volume of water by measuring the difference in water height. The displacement volume was subtracted from the initial volume, yielding the displaced volume of water. After the displacement volume was measured, the mass of the ROV was measured using a metric scale. The displaced volume and mass were used to help calculate the ROV density by using the general density formula d = m/v.

After finding the density, we were able to calculate all of the forces acting on the ROV. Buoyancy for the ROV was calculated by taking the density of water and multiplying that by the volume of the ROV and the acceleration of gravity. The fully operational ROV was positively buoyant where the buoyant force was greater than the ROVs force of gravity. In order to make us neutrally buoyant, we added additional weight via # 4 rebar to the front of the ROV. We found that our experimental calculations were off and the ROV became negatively buoyant when we test it in the pool, sinking at a very slow rate. We made adjustments to the ROV by adding static ballast, General Plastics Last-A-Foam R-3312 to the topside of the frame, until the ROV became neutrally buoyant. The diagram below depicts the buoyant state of the ROV at the initial and final stages of balancing.

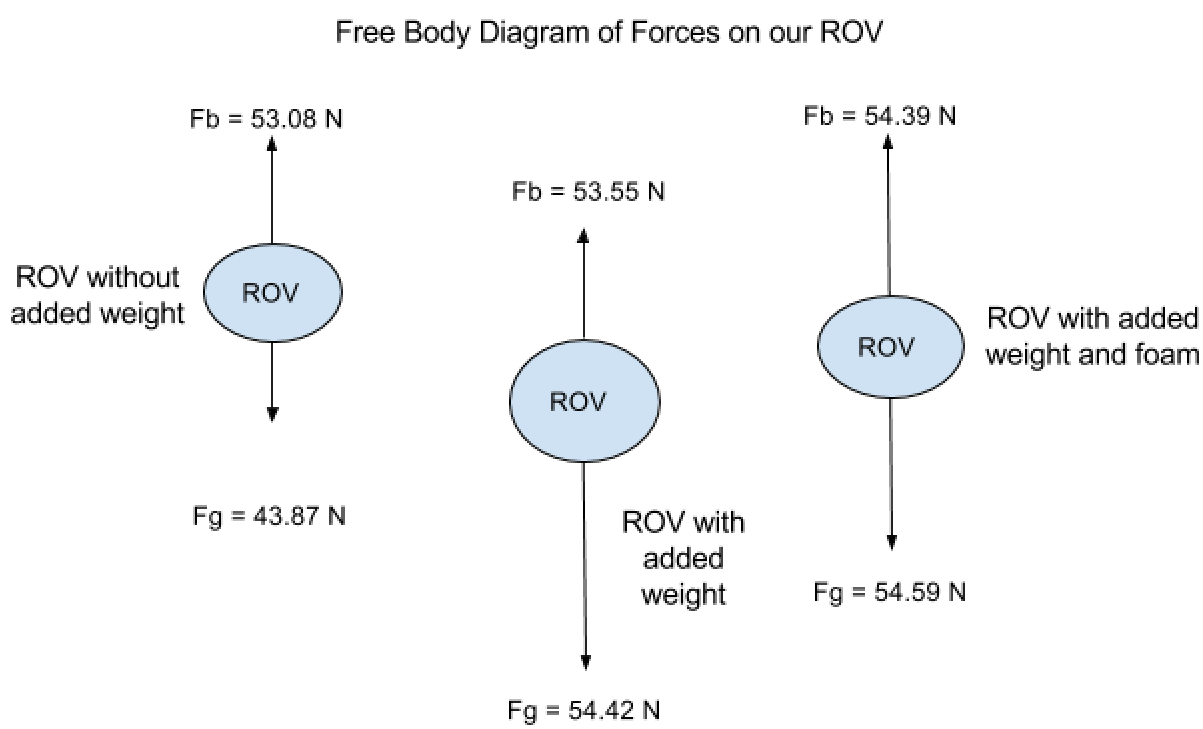


Figure 19. Model depicting buoyant forces acting on ROV

Buoyancy Math	Volume Calculations	Initial Calculations
v = Volume r = Radius d = density m = mass F = force FB = buoyant force Fg = force of gravity a = acceleration (9.8 m/s^2) h = height	Volume of long steel = 167.31 mL Volume of short steel = 109.40 mL Volume of ROV without steel = 5.4 L Volume of ROV w/ steel = 5.8 L	Mass of ROV w/o steel = 4.5 Kg Volume of ROV = 5.4 L Density of ROV = m/V = 4.5 kg / 5.4 L D = 0.83 Kg / L Fg = d * v * g = 43.87 N Fb = (1000 Kg/L) * (.00541691 L) * (9.80665 m/s^2) = 53.08 N 53.08 N > 43.87 N: so our robot will float, as the buoyant force is greater than the force the ROV is exerting. That means to be neutrally buoyant we want a buoyancy gravity (Fg) of about 53.08N or a little more.

Calculations After Adding Weight	Calculations After Adding Foam
Mass of ROV q/ steel = 5.55 kg Volume of ROV with steel = 5.5 L Density of ROV = m/V = 5.6 Kg / 5.5 L D = 1.01630855 Kg/L Fg = (1.01630855 Kg/L) * (5.5 L) * (9.80665 m/s^2) = 54.4 N Fb = (1 Kg/L) * (5.4 L) * (9.8 m/s^2) = 53.6 N 54.4 N > 53.6 N: so our ROV will sink as the buoyant force is less than the force exerted by the ROV.	Mass of ROV w/ steel & foam = 5.567 kg or 5567 g Volume of ROV w/ steel & foam = 5.648 L Density of ROV = m/V = 5.567 Kg / 5.648 L D = 0.985552198 Kg/L Fg = (0.985552198 Kg/L) * (5.648 L) * (9.80665 m/s^2) = 54.6 N Fb = (1 Kg/L) * (5.64 L) * (9.80665 m/s^2) = 55.4 N 54.59 N < 54.39 N: so our ROV will sink very slightly as the buoyant force is less than the force exerted by the ROV.

Table 1. Contains buoyancy calculations

6. Center of Gravity

The center of gravity (CG) plays an important role in the ability to control the ROV. The CG directly influences the way the ROV behaves underwater. Understanding where the center of gravity is located and placement of center of gravity is important because it can drastically change how the ROV behaves.

Another factor that became apparent in determining CG was the placement of thrusters. We found that, although the center of gravity was perfectly neutral on the x, y, and z-axis in its stationary state, that the ROV had a tendency to nose up when applying forward thrusters. Therefore we knew, the center of gravity was incorrectly determined and it was experimentally aligned toward the backside of the ROV. The forward thrusters are offset towards the bottom half of the ROV on the vertical (z-axis), causing the nose of the ROV to rise when thruster were engaged. The diagram below depicts the 3 dimensional axis on the ROV.

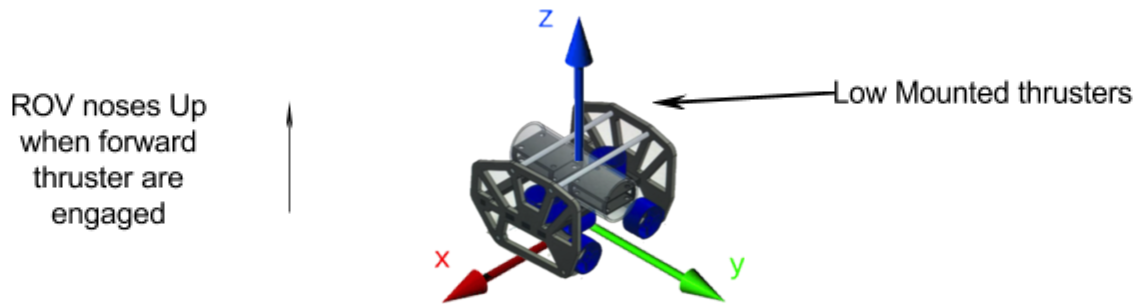


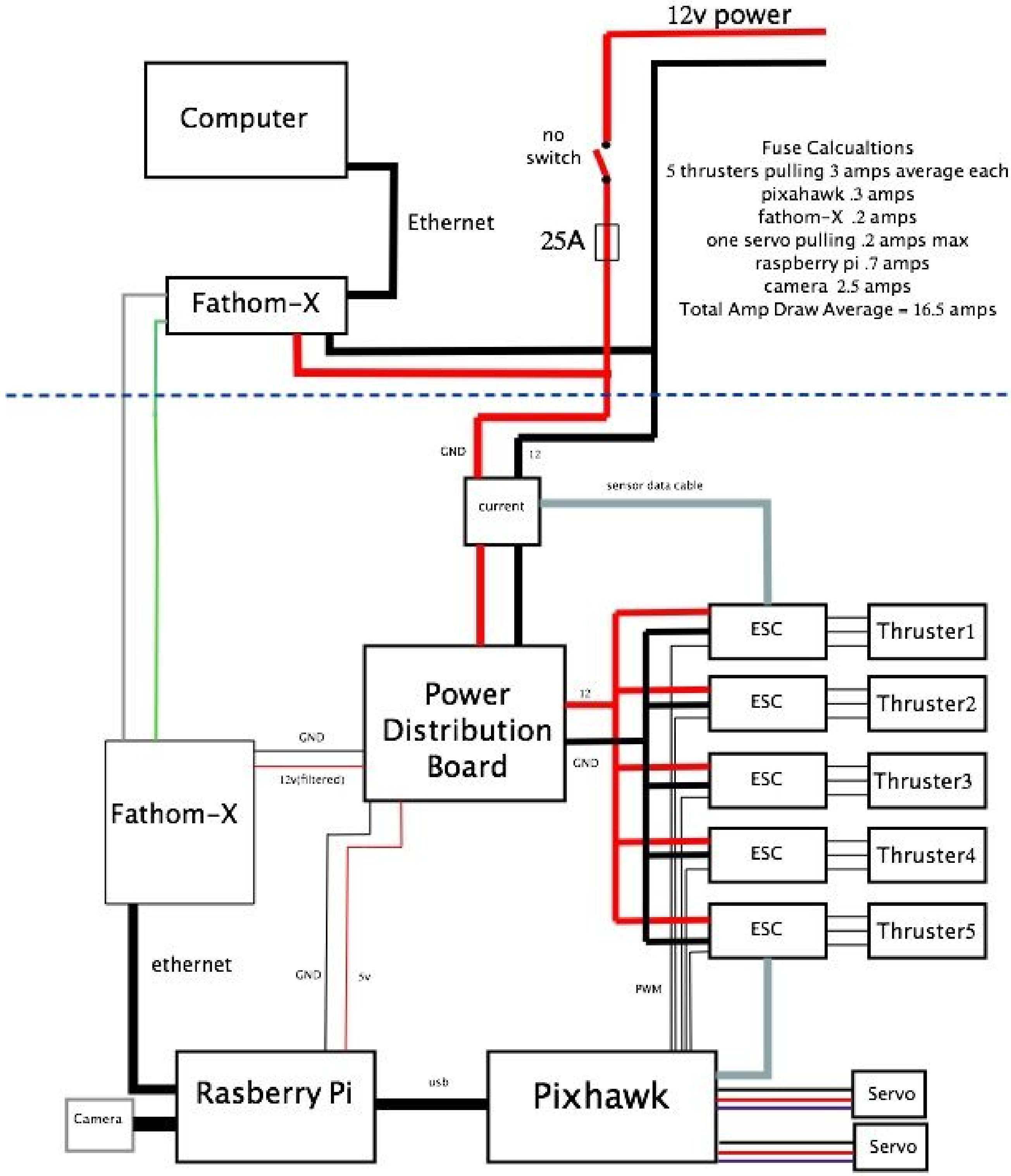
Figure 20. Model depicting forces balancing ROV

To fix this problem, we added the extra weight we needed for neutral buoyancy to the front of the robot. While this threw our stationary center of gravity off a little bit, it counterbalanced our center of thrust and allowed us to drive in a straight line when going forward or backward.

Length of Steel	**Weight of Steel**
33 cm	328 grams
33 cm	328 grams
21.6 cm	217 grams
	Total Weight Added - 873g

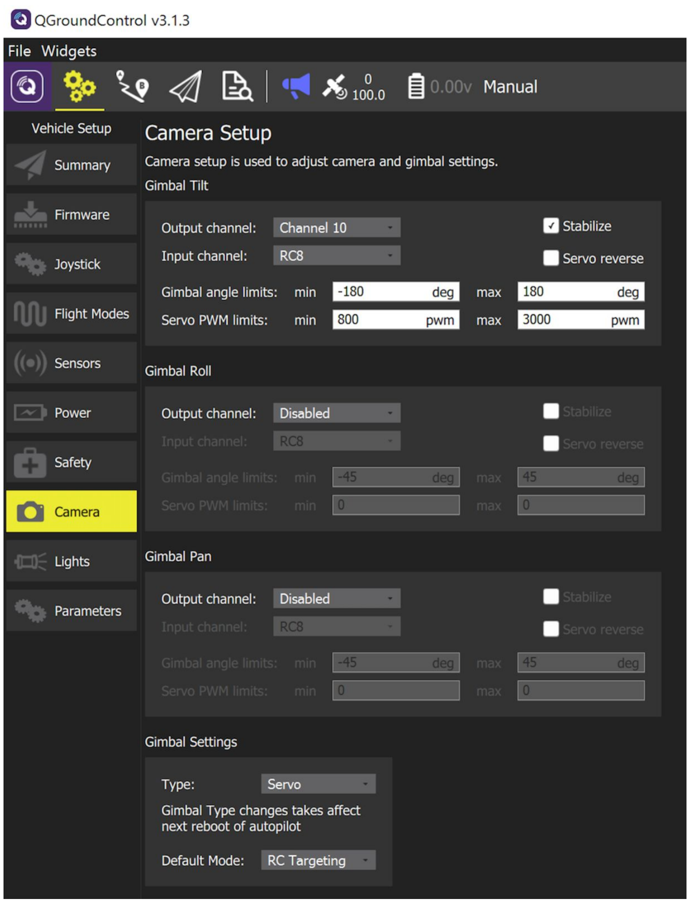
Table 2. Table explains how the different lengths of steel affect how much weight is added

7. ROV System Integrated Diagrams (SID)



8. Software

The controlling software we used is QGroundControl with a custom firmware named ArduSub that allows undersea vehicles to be utilized by it. The ROV has an onboard Raspberry Pi running a OS with ArduSub installed. The Raspberry Pi communicates with the laptop via ethernet connection from the controlling laptop. We decided on using a raspberry pi because we could utilize this ethernet connection as it has a much longer range than a normal USB connection. Using an ethernet connection also reduced the total amount of wires required to connect the ROV to the laptop. The Raspberry Pi connects using micro USB to a Pixhawk 3, which sends signals to each thruster, speed controller, and the camera servo. If we ever did need to edit the code we used C++ to edit the firmware file on Github to suit our needs.



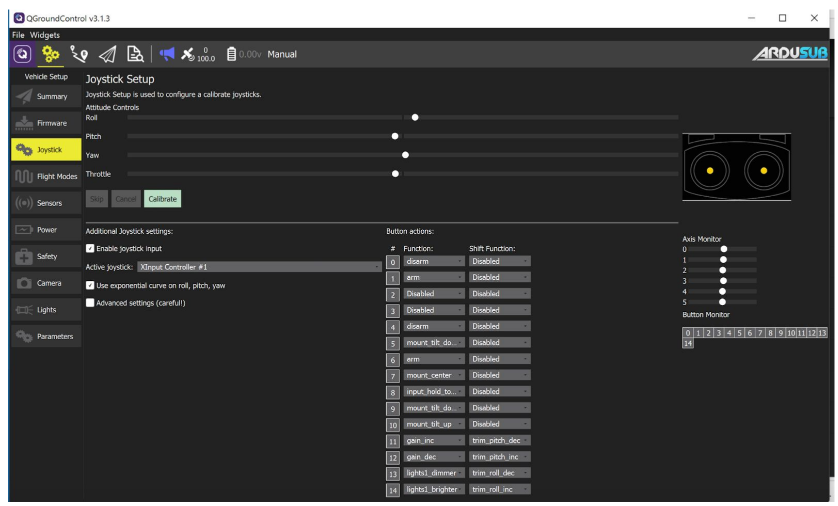


Figure 21. Screenshots of QGroundControl

Figure 22. Xbox One Controller used in conjunction with QGroundControl to control the robot

9. Safety

Throughout building and designing the ROV, safety was our company's main priority. All members were trained on how to safely and properly use power tools, and all other equipment that was being used. When using power tools and other equipment the appropriate personal protection equipment (PPE) was used at all times. Along with all the company members being trained properly to help reduce the risk of injury or accidents occurring, all members are trained in first aid. At all meetings there was at least one person able to drive as well, in the case of a major emergency.

Along with the team members being properly trained in safety, it was a major priority to make sure that the ROV is safe on the surface and in the water. To prevent any accidents, the ROV has many features put in place to help make sure no problems involving safety occur. The company installed a shut off switch on our topside control unit, for the case that something goes wrong. Along with that switch we have a disarm and kill function in QGroundControl. These switches will completely kill power to the ROV and shut it off in the water. We thought of everything that could cause shorts in the wires and tried to make the possibility of error as small as possible. All connections are double sealed properly and have been checked to make sure they are watertight. The brain of the ROV is contained in an acrylic cylinder, which has two caps on the end creating a near vacuum seal. This prevents any water from getting into the brain and shorting out the electronics. As a backup for waterproofing, in case the seal fails, tampons are in the brain to soak up any water. Other basic safety features of the ROV include: chamfered edges, shrouded thrusters, and waterproof thrusters. All possible steps and precautions were taken to ensure the robot is as safe as possible.

The tether of the ROV was 10 meters of expandable sleeving. The cables inside the tether were all properly sealed and wire management inside the tether was immaculate. Tether management was a major priority as the tether presented a tripping hazard. The tether was managed on the surface by two team members in order to prevent any accidents on the surfaces to occur and to prevent pulling of the robot by the tether.

Checklist

Area Safety

- Life jackets on
- Laptop plugged in
- Safety glasses on
- Tether coiled safely
- All tripping hazards clear

Pre Power

- Robot sealed properly
- All connections good
- Check all plugs

Power up

- Power on
- Robot safely placed in water
- Check to make sure no large bubbles arise
- Driver does a thruster check in all directions
- If thrusters and leaks are good, start the mission

Robot retrieval

- Driver drives over to side of pool
- Turns robot off
- Pull robot out of pool
- Ensure demonstration area is clean before leaving

Job Safety Analysis

Task	**Hazards**	**Precautions Taken**
Soldering Circuits and Wires	Risk of burning others or yourself Possible harmful fumes	Don’t touch yourself or anyone with the soldering iron Wear proper PPE when soldering such as safety goggle and a mask.
Dremeling Acrylic	Risk of cutting yourself Possibility of particles flying in your eyes	Make sure the Dremel was held safely and away from the person using it at all times Wear proper PPE, such as a mask and safety goggles
Heat Gun and Blow Torch	Possibility of objects catching on fire Risk of burning	Never operate the heat gun with flammable objects around Always keep the heat gun pointed away from individuals
Wire cutting	Risk of being cut	Carefully operate the cutters
Power Tools	Multiple risks	Always wear PPE, make sure tools are operated properly and safely

10. Reflections

Team Reflections

Looking back on the past robotics season, there are tasks that the team could have done more efficiently so that Kepler Enterprises could be more prepared for Saturday, May 13th, 2017. Time management is a key part in modern society that can make a or break a business, depending on the team.

- **Calculations**- In order so that the calculation of the buoyancy could be completed faster, approximations concerning the volume of the ROV should have been minimized.
- **Sharp Corners**- In the past, we have had points deducted for sharp corners, ex: edges of cut zip-ties. This year, we used hot glue on the end of the points as a simple solution. Our focus was on making sure the zip-ties were safe and secure, while we forgot about the ends of screws that may cause abrasions.
- **Practice**- When practicing for the Regional competition, our pilots were unable to utilize the late hours of the evening, due to lack of lights. In the future, we would explore innovative solutions so that we may take advantage of the time we were allotted.

Overall, we as a team came to the consensus of satisfaction in our work. Being proud of one's accomplishments, even the little victories, is an important life lesson that we as a team have learned over the course of the months of preparation.

Personal Reflections

Grant - Over the past three years I have learned a great deal from competing with MATE. Underwater robotics is one of the most challenging and advanced task that I have accomplished in the past few years. I love every minute of this competition and it has expanded my knowledge of engineering. By competing in this competition I have become a better engineer as well as a leader and has made me into the person I am today.

Lance - Through the last three years in MATE I have expanded my knowledge in engineering and underwater robotics. Every year our systems get more advanced and we learn an immense amount of information. Without MATE I wouldn't be the man I am today.

Nate - I've learned so much these the past three years, and I look forward to this competition every year. Underwater robotics is one of the most challenging tasks I have ever faced and I have loved every minute of it. This competition and my experience in it has shaped me as an engineer and a leader and helped make me who I am today.

Jake - Throughout the entire time of building this ROV I learned so much and at the same time it was such an enjoyable experience. I also liked the MATE competition as it allowed me to expand my horizons and help apply what I've learned into school into real world scenarios.

Alec - Getting involved in robotics has taught me a lot about how physical electronics work, and improved my skills at using code to solve practical problems. This was a one of a kind experience that I truly enjoyed participating in.

Kyle - I think MATE is a great experience, and I have really enjoyed it. It allows students to work on a team accomplishing a task that no in-school program has to offer.

Myles - Even though I had previous experience in robotics clubs, creating an underwater ROV with parts manufactured by the team was an entire new world. I like to think of my first year working on a MATE team as reverse Little Mermaid, leaving my comfort-zone on land to an earth-shattering experience that I will never forget.

11. Challenges

Throughout the year we had many different challenges. The first challenge we faced was getting our interface working. So, for a part time solution we ordered a 9.144 m USB cable to allowed us to get a working prototype. Although this worked we still wanted to achieve a better option, so we brought in Alec who has many years experience with programing. With his experience we are able to use the full ability of the robot.

Another challenge was water leakage. Each time we would put the ROV in the water it would always seep into our electronic enclosure. We tried many different solutions ranging from epoxy to grease. The final solution was to layer epoxy putty and marine electrical tape to ensure that the enclosure stays dry. We added another layer by using flex seal to fully cover all seals and stop water leaks.

We also had challenges calculating buoyancy and center of gravity as our robots shape is very complex and that caused many calculation errors. However we worked through this as a team and combined mathematics, programming, and real life testing to come up with a solution that made our robot work very well.

12. Acknowledgments

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