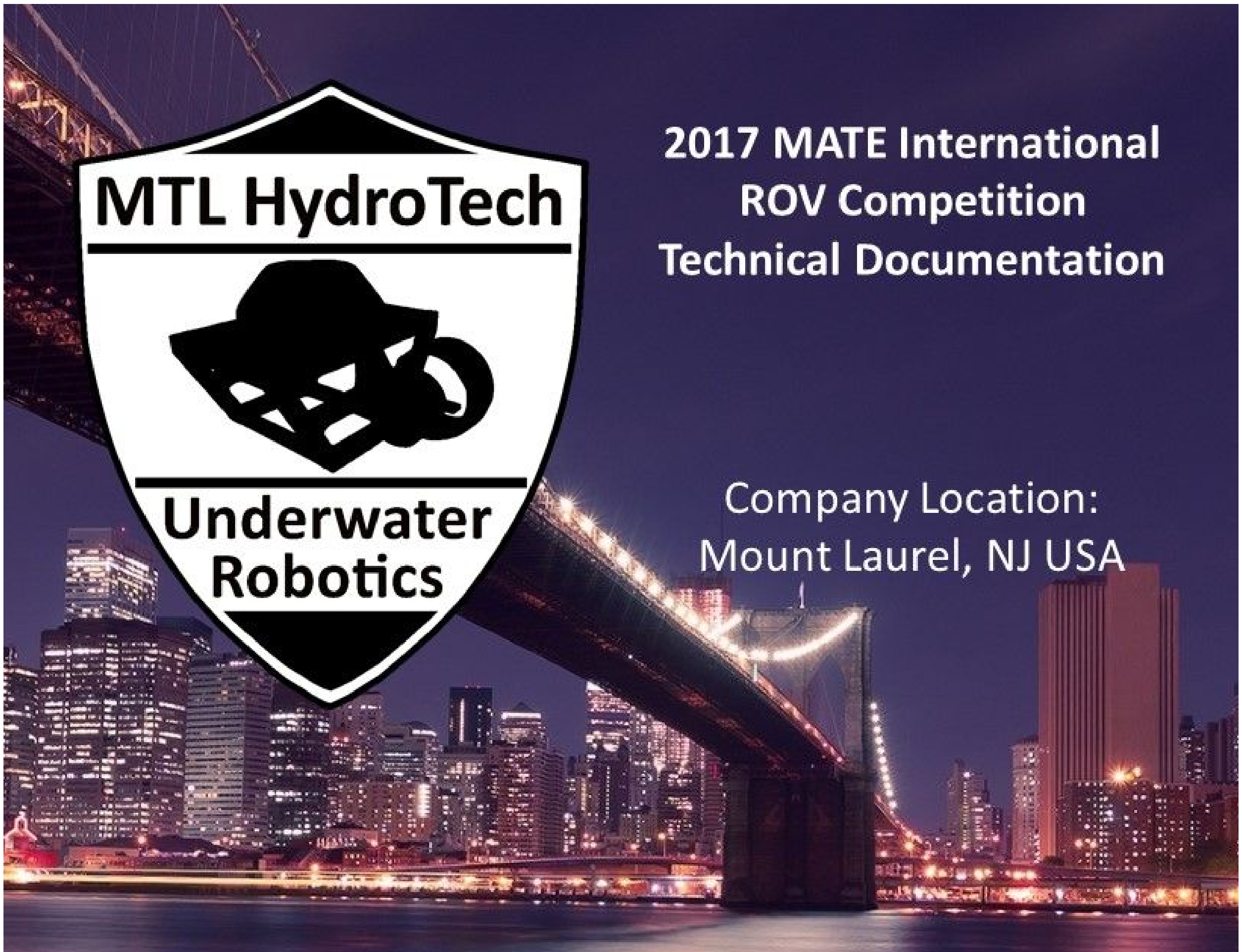
MTL HydroTech

Underwater Robotics



2017 MATE International ROV Competition Technical Documentation

Company Location:
Mount Laurel, NJ USA

Member Name	Company Role
Ahmed Fouad	CEO, Electrical Engineer
Andrew McCorkle	Mechanical Engineer, Pilot
Ethan Stillman	Mechanical Engineer
Vincent Cariello	Mechanical Engineer
Daniel Lam	CFO, Software Engineer, Co-Pilot
Mr. Van Lam	Mentor
Mrs. Jeanette McCorkle	Mentor

*MTL HydroTech is not associated with a school or an organization.

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1. Abstract

We established MTL HydroTech in 2016 to assist in underwater exploration and perform tasks that humans cannot safely or realistically accomplish underwater. This year, we're focusing on answering a request for proposals issued by the Port of Long Beach. The City of Long Beach needs an ROV that can operate in the dangerous and confined environment of the port and waterfront. There are a few specific tasks involved. We need to assist in installation of a Hyperloop system, which would speed up delivery of goods and commerce. We also need to perform maintenance on the water and light show of the port. Additionally, we must identify and collect samples of sediment to determine whether they are contaminated, and remove them if necessary. Lastly, we need to identify contents of containers that fell off of a cargo ship, and map the site to help ensure safety of port operations. In order to accomplish all of this, we use a Remotely Operated Vehicle (ROV). Our ROV has features tailored to assisting the Port of Long Beach, such as a proximity sensor, a dual servo system that allows a manipulator arm to be rolled, a 15 Watt LED light, and custom 3D printed parts. Some of the many safety features include a main power kill switch and a leak detection system. Our solution is cost effective, and will get the job done right. All of this was created by our company consisting of three Mechanical Engineers, an Electrical Engineer, and a Software Engineer.

2. Description of Project Management

As a company, we created an overall project timeline (see Gantt chart below) to assist us in managing our time efficiently by completing our individual engineering tasks before our deadlines. We soon realized, however, that the Gantt chart was not an effective plan by itself since everyone did not know which specific tasks needed to be completed, by whom, and the firm deadline. The solution was to collectively create a spreadsheet listing: tasks that required completion, by whom they should be completed, and the deadline for each. Our CEO made sure the schedule was followed by holding all company members accountable for their assigned tasks, whether the task was working on essential pieces of the technical report, and/or working on the ROV. Even though we fell behind at times, the timeline allowed us to get our product materials ready for our clients.

2.1 Project Timeline

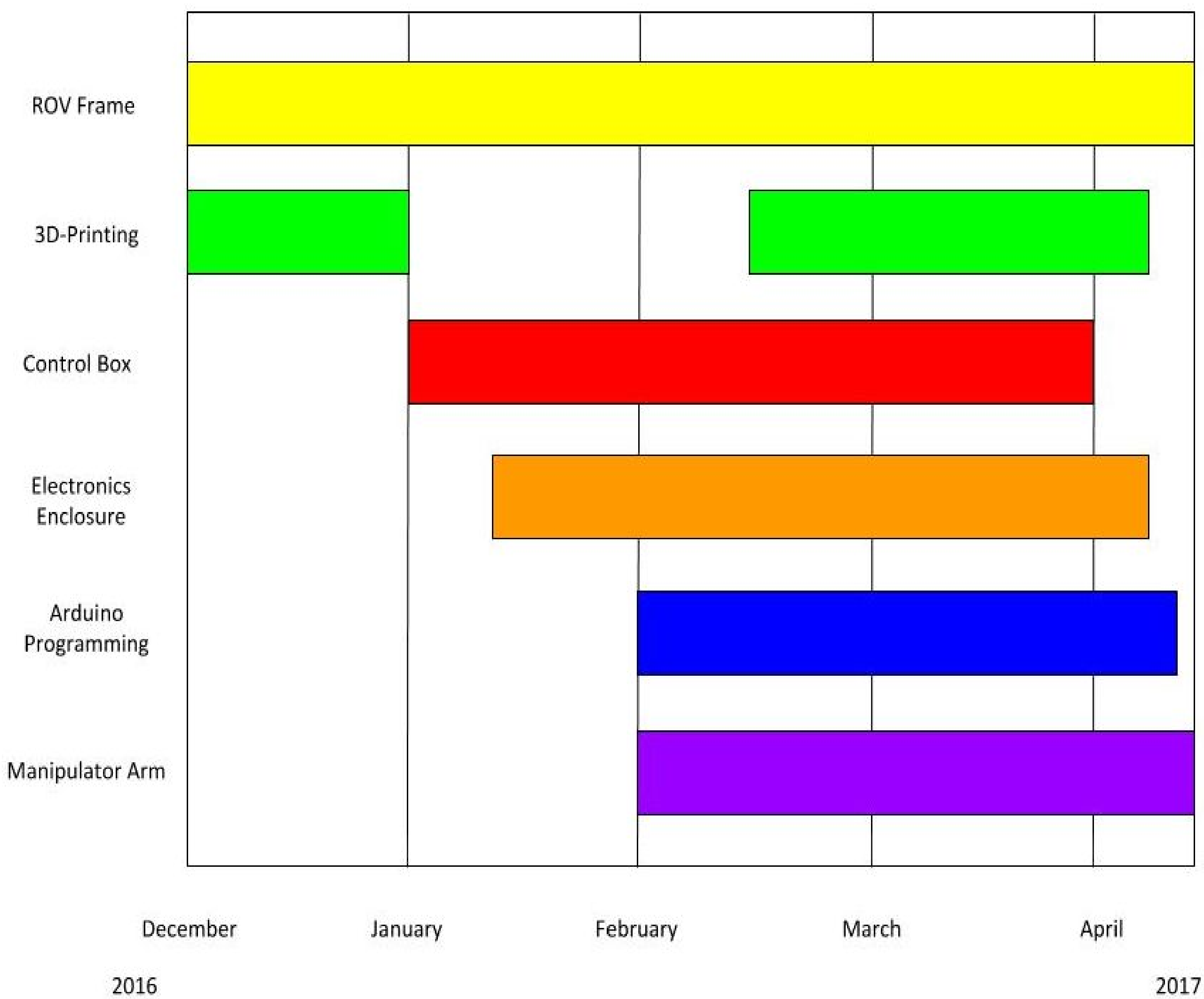

Figure 1: Gantt Chart illustrating our project timeline

2.2 Company Assignments

Mechanical Engineers	Electrical Engineer	Software Engineer
❖ Design and build an ROV frame capable of completing the four tasks needed by the Port of Long Beach. ❖ Research motor placement and find the most optimal location for the motors on the ROV. ❖ Create CAD sketches of parts that can be 3D printed for use on the ROV.	❖ Design and construct the control system on both the watertight enclosure and the control box. ❖ Waterproof all the electrical connections and seal the electronics enclosure. ❖ Ensure that no circuit is being overloaded or shorted. ❖ Illustrate the SID.	❖ Create code tailored for ROV systems. ❖ Create 3D prints of necessary parts for electrical components. ❖ Work with the Electrical Engineer and Mechanical Engineers to integrate systems creating a functional ROV.

Figure 2: Job Descriptions

Figure 3: Company Photo with our 2017 MATE PA Regional Competition ROV
(Photo Credit: V. Lam)

3. Design Rationale

Our company used the Triggerfish Vector design as the base for the ROV. We wanted to challenge ourselves by upgrading our electronics, but we had our budget to keep in mind. PVC is very affordable and easy to put together, which made it optimal for creating our ROV. We started with the Triggerfish Vector and utilized custom 3D printed parts to keep our frame small and stable, with its weight below the buoyant electronics tube. The speed and maneuverability of a small frame are essential for efficiently completing tasks in the Port of Long Beach.

An important part of being able to complete missions is a manipulator arm. Our full manipulator arm consists of two servos: One to open and close and function as a gripper, and the other to rotate it for increased versatility like turning the valve in the water and light show maintenance. However, the gripper can be used in all of the missions. Examples include picking up or grabbing objects such as the pin that releases the chain in Task 1, re-engaging the lock mechanism at the fountain base in Task 2, picking up clams and placing the cap over the contaminated area in Task 3, attaching the buoy to the contaminated cargo container in Task 4, and more!

A major influence on our design is the size and weight restrictions. Our ROV's total weight came out to be around 5.8 kg. The final dimensions of the ROV are 46 by 40 by 22 cm. Since the size of the ROV is under the 48 cm mark, we earn 20 bonus points, and with the weight under 11 kg we earn an additional 20 bonus points. Decreasing our ROV's size and positioning our motors under the enclosure tube came with additional benefits, like decreased frontal surface area, increased maneuverability, and faster speeds due to the low weight.

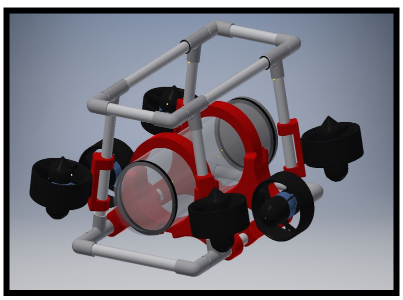

Figure 4: CAD drawing of ROV Frame
(Credit: E. Stillman created in AutoDesk Inventor)

Figure 5: Manipulator Arm
(Photo Credit: D. Lam)

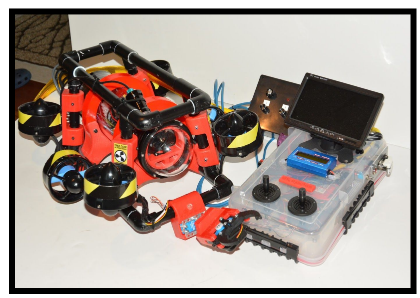

Figure 6: Final 2017 MATE International Competition ROV
(Photo Credit: D. Lam)

3.1 Frame and Flotation

Our Mechanical Engineers created the final ROV frame after several large design modifications to the **Triggerfish Vector** design. This design was easy to use, modify, and was accessible in both usage and in purchasing (PVC can quickly be bought in-store rather than be shipped). However, we made modifications based on several factors, including our electronics enclosure tube, our thrusters, and the competition size and weight restrictions.

One mistake we made with our first frame (as seen in Figure 3) was staying too true to the Triggerfish design. While the frame worked, we suffered because the weight of the motors was above the buoyant air-filled enclosure. This caused our center of buoyancy to be below our center of mass. This meant that our ROV would flip without any changes, so we had to add rebar and buoyancy tubes to move our center of buoyancy up and our center of mass below that to remain stable. This caused our ROV to be heavier than we anticipated. We also didn't shrink our frame as much as we could have due to time constraints and the long times of 3D printing parts. However, these problems were all addressed in our second frame.

The key difference in developing our second frame was building around the enclosure tube and its parts. The design is similar in shape to MATE's Triggerfish Vector, but our shortened 3D printed clamps allowed us to make the dimensions of the bare frame smaller. However, in order to maximize the use of our ROV's reduction in size and still have space for vertical motors, we purchased an additional two motors for vertical use. The four motors could now be placed on the four support struts that hold up the top of the frame. The two horizontal motors are centered on the bottom lengths of the ROV. These changes helped in being able to move all of our motors below our enclosure tube, making it so that our center of buoyancy remained over our center of mass. Now our ROV did not require additional weight. While the second design is wider with the motors splayed to the side, it is much shorter both height wise and lengthwise. The design is more square, and is smaller than the 48 cm limit for gaining 20 additional points.

The motor clamps mount using two screws, and are easy to move. The PVC can be turned to fold the motors in for sizing checks and turned back out for usage.

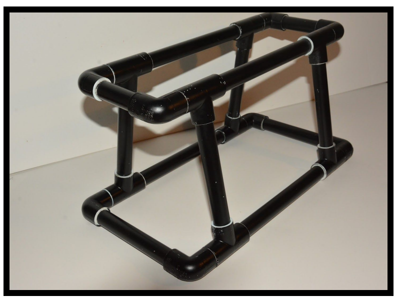

Figure 7: PVC Frame
(Photo Credit: D. Lam)

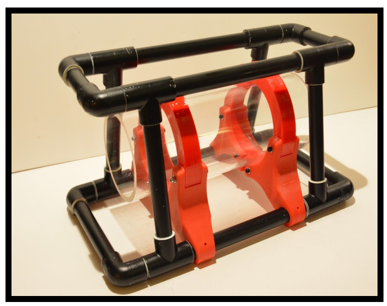

Figure 8: Frame with Electronics Enclosure
(Photo Credit: D. Lam)

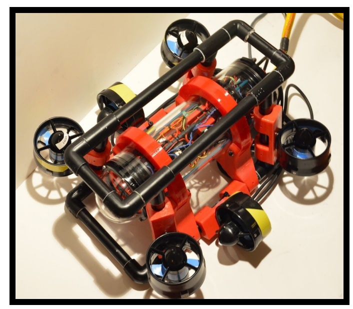

Figure 9: Frame with components
(Photo Credit: D. Lam)

3.2 3D Printed Components

We have a variety of 3D printed parts in our ROV. We created mounts for the motors, holders for the enclosure tube, the main strain relief, the camera, the perma-proto wiring boards, and in parts for both servos. The advantage of 3D printing is that we can customize and design the parts more finely and to our own needs, as purchased parts aren't always exactly suited, cost more, and take more time to ship than the time to print. However, we needed to waterproof these 3D printed parts, as if they're not sealed, water can enter them irregularly, causing slight changes in buoyancy. While this is a problem if every part is being influenced the same, it's made much worse when one side's prints take on more water than another. This tilting can be prevented by sealing the prints with Acetone. Brushing on a thin layer of Acetone slightly melts the prints, and allows strands to fuse together to form smooth layers that aren't littered with holes. Even though these parts are now buoyant, the most important part is that they stay consistent.

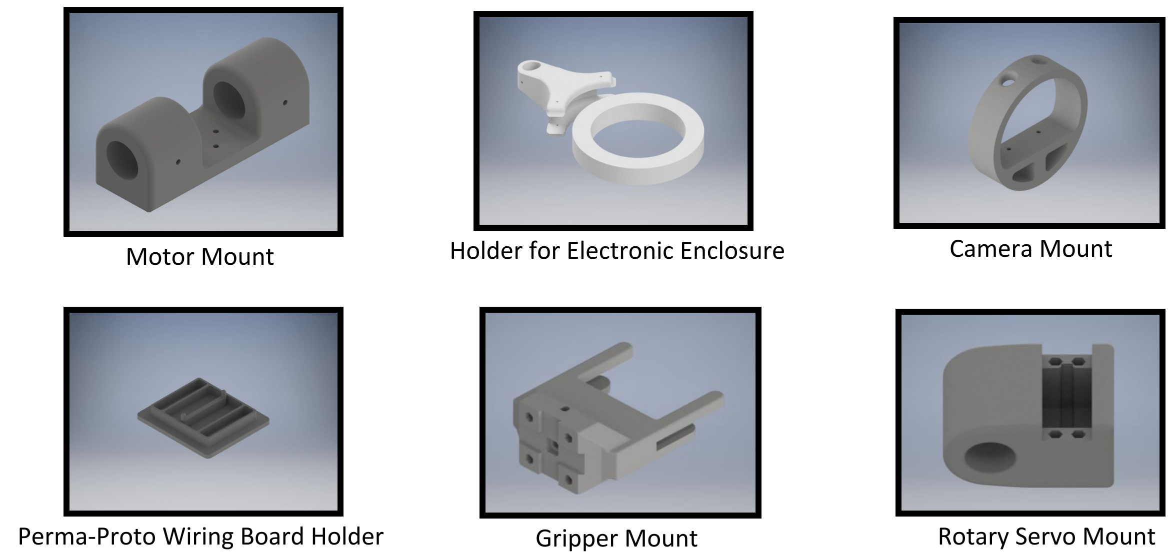

Figure 10: 3D Printed Components
(Credit: All CAD renderings of 3D printed components created by D. Lam in Autodesk Inventor)

3.3 Electronics Enclosure

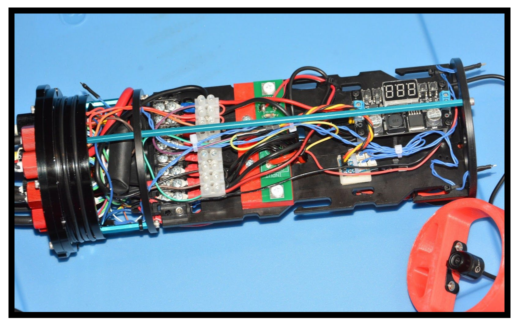

Figure 11: Topside view of Electronics Enclosure
(Photo Credit: D. Lam)

The **electronics enclosure** is a vital component of our ROV systems. We needed to have a central location on our ROV to easily connect to the electronic components such as the servos for the manipulator arm, and the thrusters. To place the tube in the correct central location, we designed and 3D printed **enclosure clamps**. Each clamp has two “stems” and one “ring”. The ring has an inside diameter equal to the outside diameter of the electronics enclosure, and slides over the enclosure tube for a snug fit. The stems attach to the rings by pushing flush against it, but also have structures that wrap around it and are flush with the inner diameter of the ring. The pieces that wrap around the ring allow us to screw through and clamp the pieces together, and the structure remains strong because no force is being put against layers of the 3D prints. Force that separates 3D printed layers tends to have more damaging effects more quickly.

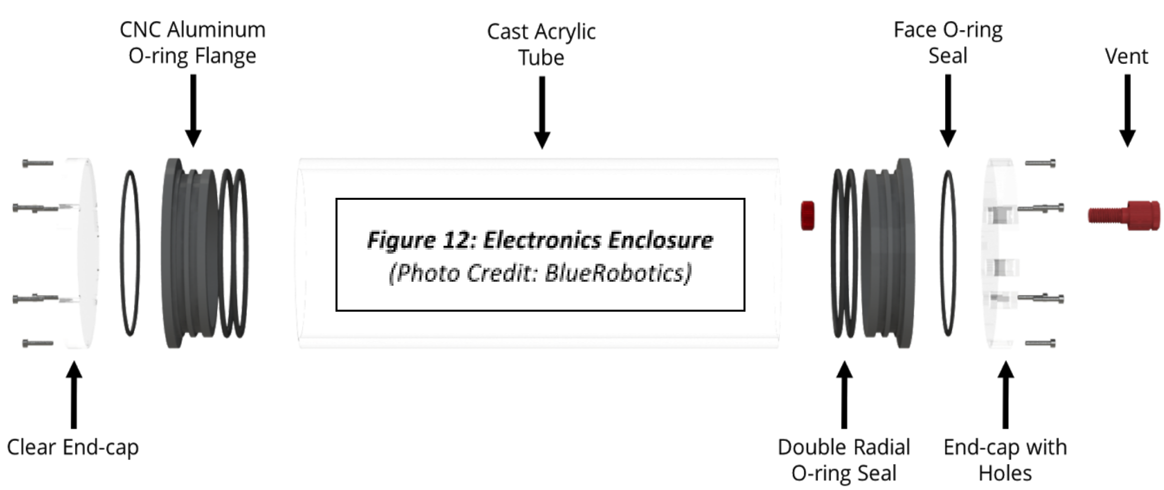

Figure 12: Electronics Enclosure
(Photo Credit: BlueRobotics)

Figure 13: Power Distribution Block (Photo Credit: A. Fouad)

Inside the electronics enclosure there is a pair of **power distribution blocks** that allows for power to be distributed easily, the setup is more aesthetically pleasing than having many wires and they reduce the number of wires required to be run down the tether. Instead, all we need are two 8-gauge wires, one for power, and one for ground.

Because we aren't running power to each component directly, and are using the distribution blocks instead, the power available without a voltage regulator would only be 12V. The servos and SOS leak sensor can't run on voltage that high, which prompted us to use a **voltage regulator**. Another upside to using a regulator is that output is always consistent and doesn't waver, as our main power supply should never be below 5V during usage.

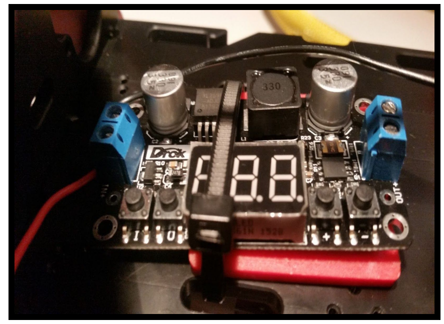

Figure 14: Voltage Regulator (Photo Credit: A. Fouad)

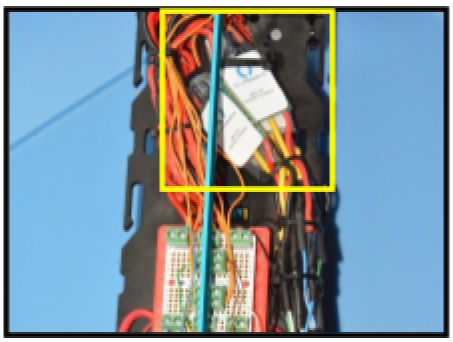

Figure 15: ESC (Photo Credit: D. Lam)

30A **Electronics Speed Controller (ESC)**, created by Afro, are an essential part of our ROV. They are needed to run a three-phase motor, which in our case, are the brushless BlueRobotics T100 thrusters. BlueRobotics programmed the ESCs with forward/reverse firmware to allow for easy user assembly. The ESCs allow our motor to be controlled by one of our Arduino Uno's in the control box. They connect to a single motor using three wires, are powered using two wires, and only need one wire for data. While normally, more wires would be needed to be used for data, like a ground wire and a data wire, the ESCs already have the data ground with their power source's ground. We discovered this when we were doing testing. We had overlooked plugging in the ground wires, and found that the motors were still working fine. We performed additional research afterwards to verify that an internal ground was in use.

The **SOS Leak Sensor** is an important safety measure in our electronics enclosure. It alerts us if water penetrates the enclosure tubes seal. The watertight seal of the enclosure is primarily due to the rubber O-rings. However, if for some reason this system fails, the SOS leak sensor will warn us before any damage can occur. The sensor uses four re-usable sponge tipped probes with an adhesive backing that attach to all the corners of the enclosure. If water touches a sponge, the sponge will swell up and the water connects two wires, completing the circuit. The SOS leak sensor then sends up a "1", which our Arduino can use to shine a LED light to inform us in less than half a second.

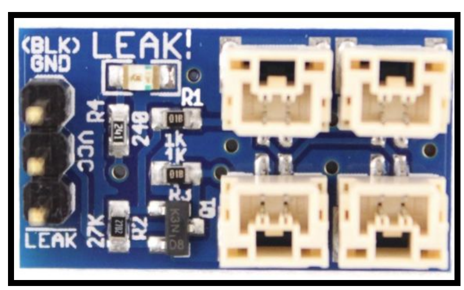

Figure 16: SOS Leak Sensor (Photo Credit: BlueRobotics)

For our **tether**, we took several precautions in order to ensure safety and functionality. Where the tethers leave the control box, we used a **strain relief** to ensure that the wires inside the control box couldn't be pulled. Before the tether reaches the enclosure, we designed a 3D printed strain relief that prevents the connections from being directly pulled upon and possibly becoming disconnected. On the outside of the electronics enclosure, **cable penetrators** are attached to an **aluminum end cap with 14 holes.** The cable penetrators allow the wire to pass through the aluminum end cap without allowing water to enter.

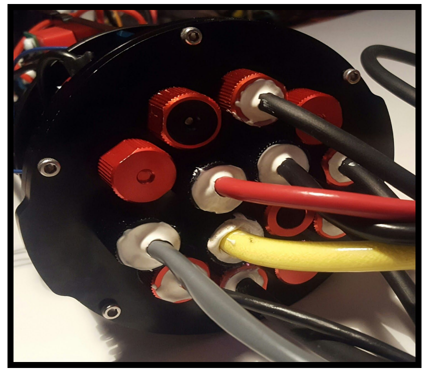

Figure 17: Aluminum End Cap
(Photo Credit: A. Fouad)

3.4 Control Box

Our ROV's control box has 2 **kill switches** on it. The first is for main power. In case any emergencies occur, the ROV can be easily shut off using this kill switch. In addition, there is a light attached to it to warn the user when the ROV is being operated. The second kill switch, which has a purple handle, was added in order for our ROV's motor system to function. The Afro ESC has to be powered before receiving signals from the arduino. This kill switch controls the Arduino's power so that we can turn the Arduinos on after the main power is turned on.

The **watt meter** on our control box helps us get readings like input voltage, intensity and wattage. This can be used to determine if the battery is low, which could cause problems like a flickering monitor. The voltage helps the user tell if there isn't enough power to the system.

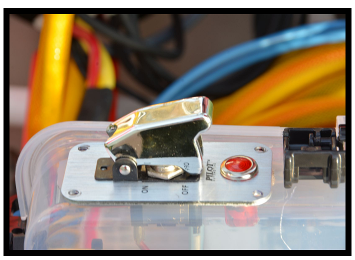

Figure 18:
Main Power Kill Switch
(Photo Credit: D. Lam)

Figure 19:
Arduino Kill Switch
(Photo Credit: D. Lam)

Figure 20:
Watt Meter
(Photo Credit: D. Lam)

Another feature in our control box is 2 **Perma-Proto boards**. We used one to connect our tether wires to our Arduino Uno boards, and the other to connect our servo potentiometer wires to our Arduino. Like we mentioned before, these boards are similar to breadboards, and can be used for prototyping, but are very thin, small, and can have pins or wires soldered to them. In our case, we took advantage of the direction of the traces on the board. By laying out small terminal blocks and cutting traces, we could solder terminal blocks onto the board. Using these, we can connect all of the tether wires to the Arduino Uno boards neatly, the same applying for the servo potentiometer wires.

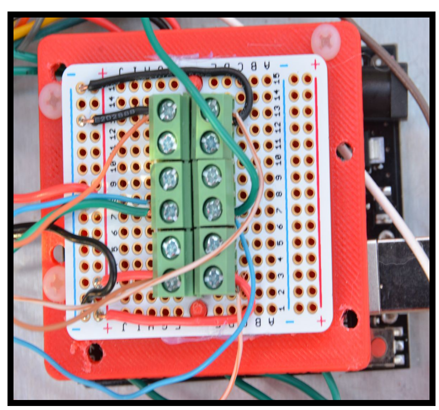

Figure 21: Perma-Proto board
(Photo Credit: D. Lam)

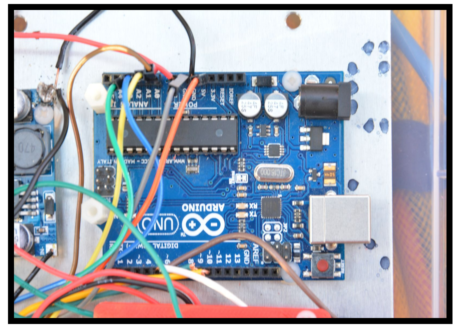

Figure 22: Arduino Uno board
(Photo Credit: D. Lam)

The most essential components in all our ROV systems are the **Arduino Uno boards**. They allow us to control all our ROV features, including the T100 Thrusters, HS-646WP Servo, Subsea Lumen Light, and the SOS Leak Sensor. One Arduino Uno controls the T100 thrusters. To do this, it sends signals to the ESCs in the form of pulse width modulations, or PWM. These are digital signals which can only be 1 or 0. However, by alternating between these so that the signal is sent in pulses of different percentages of "1" or "0", a wide range of options are available to control the motor's speed. In order to send these signals, our Arduino needs to read analog inputs from our joysticks and output the correct signals from there. Our joysticks consist of 2 potentiometers, which have a reading of 0-1023 on each axis as a value that is outputted depending on our joystick's position. The potentiometer on the right controls the throttle of the motors. However, the potentiometer on the bottom (when looking from straight above) influences this, and is the turning potentiometer. The Arduino starts with the center position of the axis, which corresponds to a PWM of 1500, and means no moving motors. It then adds the turn command's throttle value to the forward command's value to one motor, and subtracts the turn command from the forward command on another. This means that if the joystick is moved left or right, the motors will go in opposite directions, allowing turning. This also allows our ROV to tilt upwards and downwards. While we could've just made both vertical motors have the same throttle values, if we made them turn, we could tilt upwards and downwards, assisting in control and in the missions. The other Arduino Uno is in charge of both servos, the Lumen light, and the SOS leak sensor. All of these except for the SOS leak sensor, rely on PWM signals to control them, like the motors. One servo and the Lumen function very similarly to the motors. A single potentiometer with an analog output to the Arduino Uno is mapped to a value of ranges, ranging from an angle of 0 to 170 degrees on the servo and varying brightness levels on the Lumen. However, our other servo is different. Even though the code is similar, our rolling servo needed physical modifications to rotate continuously, which we mention later.

3.5 Motors and Motor Mounts

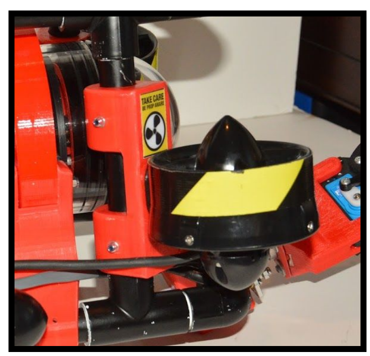

Figure 23: T100 Motor with custom 3D printed mount
(Photo Credit: D. Lam)

The **T100 thrusters** from BlueRobotics are powerful and cost-efficient. They can output 5.2 pounds of thrust normally, but because of our 25A fuse limit, we ran the motors at 47% power, which has an amp draw of 2 for each motor. We were able to calculate all of this using the graphs on BlueRobotics's website, which has correlations between thrust and PWM, power and amps compared to PWM, power and amps compared to thrust, and efficiency compared to PWM. Even though 47% may not seem like much, our ROV moves extremely quickly compared to years past.

The T100 thrusters have 4 screw holes for mounting the motors. We decided to create our own mounts for the motors, made specifically for attaching to PVC. The design that BlueRobotics made was short, and couldn't be secured reliably onto PVC, as it was a flat surface mounting on a round object. We initially tried using mounts that we found online that could be 3D printed, but the sizing was inconvenient, and even though the price was low, we still had the problem of a flat surface on PVC. We then tried making our own, first with one attachment point. This turned out to be too weak to handle the thrust of the motors, so we re-designed with two attachment points. These new custom mounts solved the problem, and we were even able to minimize the amount of screws we used.

3.6 Manipulator Arm

Our **manipulator arm** works using **2 servos**. The **gripper servo** controls the opening and closing of a gripper while the **rolling servo** rolls the whole arm to allow the opening and closing of the fountain valve. We had to modify the rolling servo so that it could continuously rotate to be able to complete the 3 turns necessary. To do this, we removed the metal barrier that prevented the gears inside the servo from turning all of the way. While we initially tried to dremel the small piece off, we found out that it could be hit through, as it wasn't in one piece with the rest of the gear. Next, we had to remove the potentiometer inside of the servo that allows it to travel towards a certain degree, as this limits the turning too. We replaced it with a resistor ladder made of 2 2.2K resistors, which had to be low tolerance to be as close to the resistance given off by the potentiometer when it was at the 0 position. This tricks the servo into thinking that it's always in the 0 position, which means that we can assign values either higher or lower to make it continuously try to reach that point and not stop until we tell it to go to 0 or the opposite direction again. However, we were still slightly off, and we found that when we gave a position of 11 to the servo, it stayed still, which meant that 11 was the real 0. This may have been caused by extra resistance through the wires or the solder job. Nevertheless, the modification still worked, and we were able to roll our manipulator arm. However, we also needed to deal with the wire of the other servo, which would wrap up, twist, and get tangled if left alone. To solve this, we ran a tube through the servo in place of the potentiometer we had to replace with a resistor ladder. We were able to lay the circuit board and resistor ladder sideways in the servo to allow the tube to run through, which let the wires spin without getting tangled.

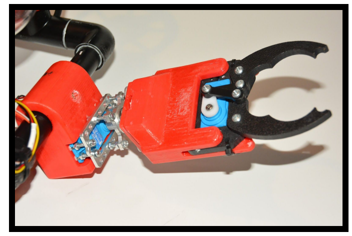

Figure 24: Manipulator Arm
(Photo Credit: D. Lam)

In comparison, our gripper servo is fairly simple, especially because we already have experience using it. It works like a normal servo, and is attached to an arm that we purchased. We made the decision of purchasing an arm because we already had success and were familiar with it, and it is very accurate in terms of size. It's also priced reasonably at $10, and is easy to assemble and set up. We created mounts for both servos. The servo for the gripper portion wraps around the arm that we purchased, and can be screwed to the arm. We also designed it with hexagonal holes in the back that we could tap standoffs into so that we weren't screwing directly into the printed ABS, which can rip and break with a moving part. The head of the rolling servo could be attached with marine epoxy to the back of the gripper servo, and a plate connected to the back using M3 screws to sandwich the servo head. This made it so that we could attach both servos.

Because of problems we had with our gripper servo and its mount falling out, we purchased a hub shaft to move the load from the small surface area of the gears to the hub. We screwed the hub to our 3D printed holder, and used nuts to keep it steady. This hub ensured that our gripper servo and its holder didn't fall out during usage.

3.7 Cameras

In order to maintain an uninterrupted video feed, we added a **camera filter**. The camera filter strengthens the camera input to increase the quality of color on the output. The camera filter consists of a Radial Inductor, a diode, a 220uf capacitor, a 1KΩ resistor, and a bi-color LED. The camera we use is a **170° Esky Car Backup Camera**. This camera lays inside a 3D printed cylinder, between the electronics enclosure tube dome. The camera outputs to the monitor and enhances color contrast.

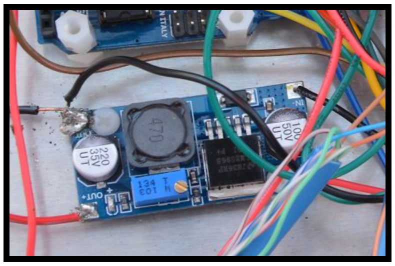

Figure 25: Camera Filter
(Photo Credit: D. Lam)

Figure 26: Camera
(Photo Credit: Amazon)

Figure 27: Monitor
(Photo Credit: D. Lam)

4. System Decisions (New vs Reused/Commercial vs. Original)

Most of our systems are original in design and setup but contain commercial components. Each system discussed below is labeled based on whether or not the parts are new or reused, as well as custom made (original) or commercially purchased.

4.1 Power System

- **Main Kill Switch (Reused/Commercial)**

Our ROV features a main power switch that we use to easily shut off the ROV. Even if it was only a little, we saved money by reusing a kill switch that one of our members acquired from his scout team’s control box, used two years ago. We unsoldered the connections and used the old kill switch, which came with an outer plate, a silver cover and a light to help the user easily identify whether there is power running.

- **Arduino Kill Switch (New/Commercial)**

For our Arduino Kill Switch we simply used the kill switch that came with the new MATE ROV Triggerfish Kit. Although we had the option to reuse last year's kill switch, we opted to use the newer part.

- **Watt Meter Digital LCD Display DC Battery Power Analyzer (New/Commercial)**

The Watt meter we used came new directly from our Triggerfish ROV Kit. Although we had the option to reuse last year's Watt Meter, we opted to use the newer part.

- **Voltage Regulators (2 Reused/Commercial)**

We reused two different types of voltage regulators. One simply took an input of 12 volts and outputted 7 volts. We used this voltage regulator in our control box for the Arduino Uno boards. The other type is adjustable, although we kept it at 5V to power our servos and our SOS leak sensor. Both of these were reused from the control box we used last year.

4.2 Propulsion System

- **Arduino Uno (New/Original)**

The Arduino Uno is an integral device to our system and although we had a few Arduino boards from last year, we found their reliability to waver as we used them more and more. While we started and performed testing with our older Arduino Uno boards, we had to cycle through new boards if the old ones stopped functioning. The problems most of the time were just an inability to upload new code.

- **BlueRobotics T100 Thrusters (6 New/Commercial)**

The thrusters are new, and purchased from BlueRobotics. We did not reuse last year's motors that came in the Triggerfish Kit for a few reasons, the main one being the sheer power with each motor having over 5 pounds of thrust. Even though we had to run the new motors at 25% throttle because of the 25 amp limitation, our ROV is much faster than last year's. Even with the hefty price of $120 per motor plus $25 per ESC, these were a good improvement in performance for our ROV. Even more importantly, these were something new, and our first experience with digitally controlled motors. We challenged ourselves by using these thrusters.

- **Afro Electronic Speed Controllers (6 New/Commercial)**

We purchased the ESCs from BlueRobotics directly, as they were already preloaded with the necessary firmware. These allow us to send digital signals, which can work over long distances better than analog ones, to the motors. ESCs are required for controlling three-phase motors, and since our propulsion method was new, we didn't have any old ones to reuse.

4.3 Manipulator Arm

- **Custom Servo Mount (New/Original)**

Each mount was designed by our company and 3D printed using ABS plastic.

- **Sparkfun Gripper Kit A ABS Gripper (Reused/Commercial)**

We reused the gripper from the ROV from last year, as it worked well and has many potential attachment points for our 3D printed parts.

- **HS-646WP Gripper Servo (Reused/Commercial)**

We reused our gripper servo from last year's ROV. We had success with it, as it's already waterproofed, integrates well into kits such as the one we used for our gripper, and it's easy to use.

- **HS-646WP Rotary Servo (New/Commercial/Original)**

While this servo started off the same as what the gripper servo is now, which is a stock HS-646WP, we had to make modifications to let it move indefinitely, like removing the mechanical stop and using a resistor ladder. Another important modification was running a tube through the shaft of the servo. This allowed us to run the wires of our Gripper Servo through without them wrapping around and getting twisted.

- **Sparkfun ServoBlock Kit - Hitec Standard (New/Commercial)**

We used a hub shaft and mounted it onto our 3D printed holder to reduce the load on our full rotational servo's shaft. This greatly reduces the chance of the gripper falling off, and the natural tendency because of the weight of the gripper is supported by the hub.

4.4 Frame Components

- **Custom Motor Mounts (New/Original)**

We created our design for our motor mounts in AutoDesk Inventor because we needed sturdy mounts that would hold up well against the power of our T100 thrusters. We also designed them for usage in a PVC frame, which was one pro our custom mounts had compared to BlueRobotic's mounts. Once we had our design, we 3D printed them using ABS filament.

- **Custom Enclosure Clamps (New/Original)**

We custom designed and 3D printed the clamps to hold the acrylic tube for the watertight container. They screw onto a ring that wraps around the enclosure tube to reduce the chance of failure, as we had problems with epoxy coming apart in previous renditions.

- **Custom Strain Relief (New/Original)**

We 3D printed the strain relief design to prevent the tether from pulling directly on the electronics enclosure, risking the enclosure tube opening while submerged.

- **½” PVC (New/Commercial)**

While we could’ve reused PVC from last year’s ROV, we decided to use new tubes for a few reasons. The first is that if our new frame didn’t work, we could always use our old frame. Secondly, our old frame was littered with holes for components like the buoyancy tubes, servo, and for air to escape. We need holes to secure the 3D printed parts of our new ROV, and if holes conflicted, we would have moving parts. Another reason is that we needed to build our frame at a different size to accommodate the larger motors and the enclosure tube. On top of all of those pros, PVC is cost-effective compared to other materials like UHMW.

4.5 Camera System

- **Camera Holder (New/Original)**

To complete task 4 and map the distance between cargo containers, we tried using a camera with a built-in proximity sensor. While this worked normally above water, when we tested it behind the dome of our enclosure tube, it didn’t function, so we replaced it with a model that could be adjusted and was smaller. We designed and 3D printed a mount for the camera to screw on to, holding it in place. We then set the design inside of a ring that could fit snugly inside our dome. This worked perfectly to hold the camera.

- **Monitor (Reused/Individual)**

We took our monitor off of our ROV from last year and incorporated it into our ROV due to budget restraints. This monitor was reused from a scout ROV that one of our members competed with in the 2015 MATE PA ROV Competition, transferred last year to our ranger ROV, and is now incorporated into our current ROV.

- **Esky EC170 Waterproof Backup Camera (New/Commercial)**

We purchased a different camera with a built-in proximity sensor, but it didn’t work as explained above and in section 3.7. We switched to a smaller camera that did not have monitor lines and the angle is adjustable.

4.6 Miscellaneous

- **Lumen Subsea Light (New/Commercial)**

After we were able to save money on the tether, we decided to use some of the extra to purchase the Lumen light, which we need for task 3. We bought the Lumen from BlueRobotics, and we planned to use it to shine a light for the mission but also to assist the camera in viewing.

- **SOS Leak Sensor (New/Commercial)**

We deemed the SOS Leak Sensor necessary to detect for any leaks. With this part, we can be alerted if there’s a leak, which could save us a lot of time and money, much more than the cost of the sensor.

5. Systems Integration Diagram (SID)

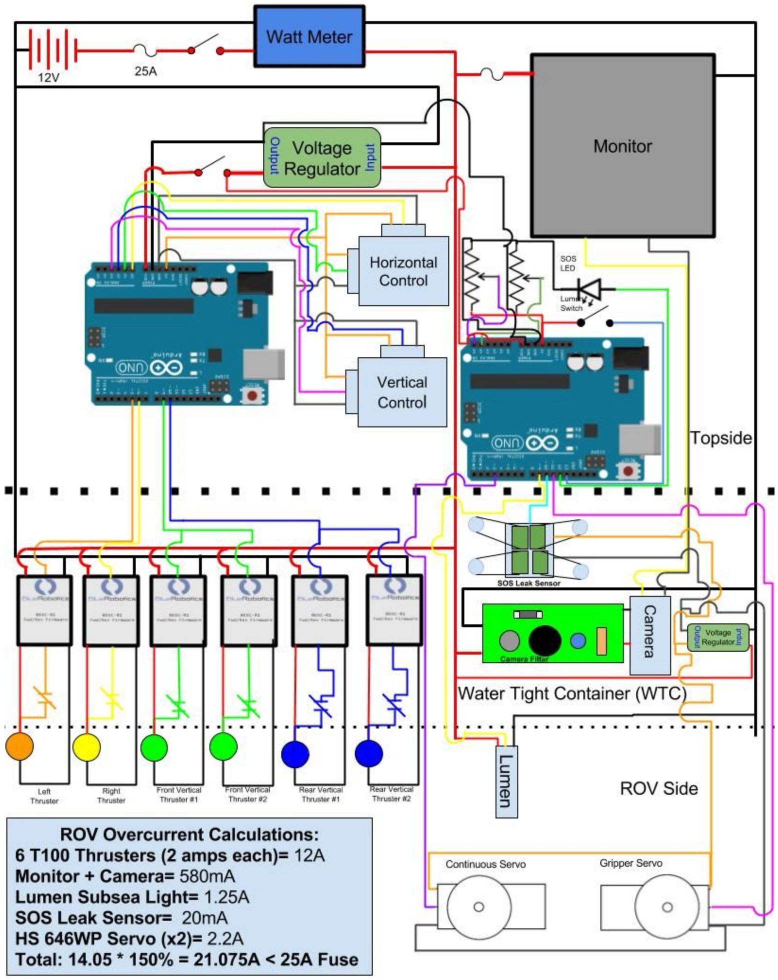

Figure 28 : A Full Diagram of the Systems Running our ROV

6. Technical Flowcharts

6.1 Hardware Flowchart

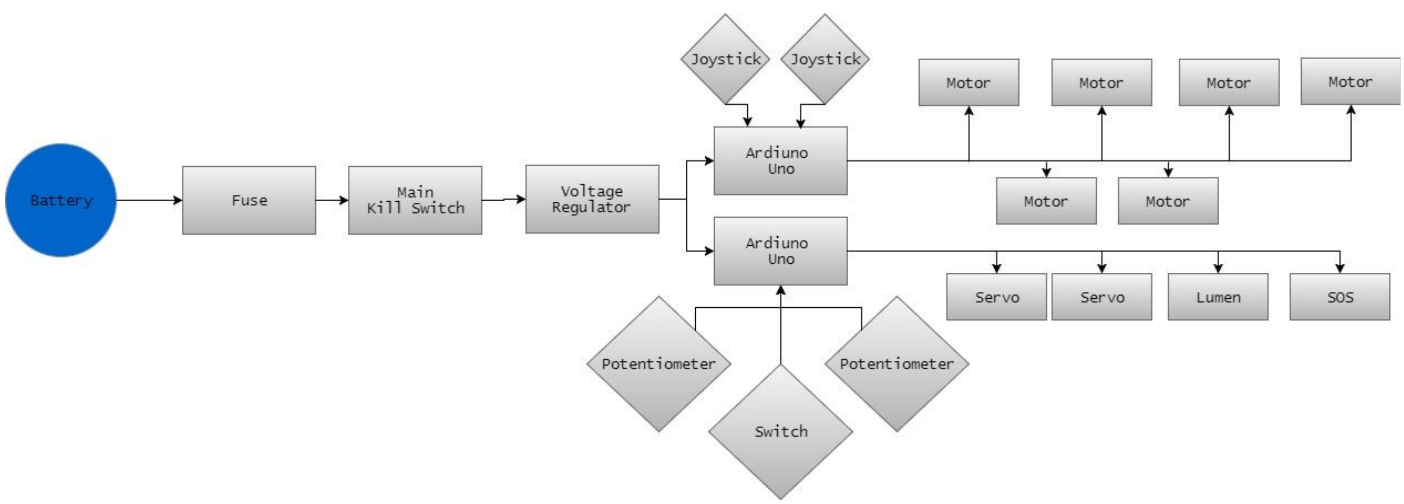

Figure 29: Hardware Flowchart

6.2 Software Flowcharts

Figure 30: Software Flowcharts

7. Safety Features and Philosophy

Incorporating safety is very important to our company, as it can prevent dangerous accidents and help protect the ROV, as well as anyone that may be working on it. It is better to be safe than sorry, as a malfunction can bring an ROV down. Time is well spent when putting safety precautions into place. It is important to prevent things like short circuits, electrocution, fires, and cuts. The dangers that come from neglecting different risks is too great to simply ignore, so we always go out of our way to make sure that precautionary measures are in place. The following is a list of components that incorporate safety into our ROV:

- **Kill Switch**: The Kill Switch is able to immediately stop the power that is being sent from the battery to the control box. This is a safety feature that prevents short-circuiting, incidents, or electrical accidents.
- **Shrouds:** Our T100 thrusters have built in shrouds as a safety feature. They provide protection for people who may be adjusting something on the ROV, and for the propellers by preventing objects from coming in contact with them, which could cause damage to the propellers and motors. The shrouds are also effective in making our motors more efficient by directing the flow of water.
- **Fuses**: Fuses are a very important safety precaution in case of any unfortunate events such as short circuits, electrical malfunctions, or even power spikes, which will cause the fuse to blow. This ensures that electrical problems do not lead to permanent damage. Our ROV system consists of two fuses: a 25-Amp inline fuse for our main power, and an inline fuse incorporated in the standard wiring.
- **Metal Plate Heatsink**: Inside the control box is a metal plate. It helps with the mounting of our printed circuit boards, while also acting as a heatsink. The heat is held away from the electrical components, increasing efficiency and reducing the risk of overheating parts, which can lead to many more electrical problems.
- **Watt Meter:** The Watt Meter helps us monitor the power in our control box. We can see dangerous or wrong values which would help us to troubleshoot a problem and prevent further damage to the control box's components.
- **Onboard Strain Relief for Wires**: Our three tethers wires are wrapped around a custom designed 3D printed strain relief, that prevents the enclosure end cap from being pulled upon directly, risking the cap popping off, water flooding our tube, and short circuiting our electronics inside.
- **Waterproofing:** Waterproofing is an important aspect of our ROV because otherwise, without waterproofing, we wouldn't have a single component operating. Our enclosure tube contains a power distribution block so if water were to reach inside, none of the components would operate, and there would no longer be power to our system. To waterproof the electronics enclosure, we added a layer of silicone grease to a series of O-rings before placing them on the flange accordingly.
- **The SOS Leak Sensor**: The SOS Leak Sensor is an essential component when it comes to user and vehicle safety. If water enters the enclosure tube and touches a probe on the SOS Leak Sensor, it completes a circuit, which triggers the SOS Leak Sensor to send back a high signal to our Arduino. This Arduino then turns on an LED to alert us, allowing us to kill power and prevent short circuits before more water enters.

7.1 Safety Protocol/Checklist

Performing a safety check prior to every product demonstration is vital to ensure that all safety measures are followed by our company members.

Check (✔)	Initials/Date:
☐	All ROV frame components are secured by screws or other methods of attachment.
☐	All wires are secured onto the frame and are not in proximity to moving parts.
☐	Electronics Enclosure Pressure has been tested with vacuum plug.
☐	There are no sharp edges.
☐	Robotic Arm is turned in before inserting into ROV bin.
☐	All wire inside the control box and/or on the robot is secured.
☐	One member is holding the control boxes while the ROV is removed from the bin.
☐	The tether is organized neatly and doesn't serve as a tripping hazard.
☐	The ROV is being held by a member before product demonstration period begins.
☐	Members on the pool side are wearing life vests.
☐	All modifications and tools are in the ROV bin.
☐	All members are aware of emergency procedures.
☐	ROV is not pulled by the tether.
☐	Motors, servos, and light are to remain off while ROV is on the surface.
☐	SOS Leak Sensor Light is being constantly monitored.
☐	Members are to be cautious and alert when reaching out above the pool.
☐	Ensure servo wire isn't wound tightly and twisted before operation.
☐	Members will keep their body away from hazard points and follow warning labels.
☐	Tether is to be wrapped starting from the ROV side during mobilization.

Figure 31: MTL HydroTech Safety Checklist

8. Critical Analysis

8.1 Testing

- **Buoyancy (Flotation and Ballast)**

To test flotation and ballast before regionals, we took our ROV to our local pool and brought along several pieces of flotation and ballast. At the pool, we added several lengths of ballast (in the form of rebar) and floats (in the form of capped 3” PVC Tubes) until we had a slight positive buoyancy on our robot.

- **Servo Values**

After creating the resistor ladder for the full rotational servo, we tested code that simply sent an angle to the servo instead of being mapped to a potentiometer. We started at zero and worked our way up to our final value of 11. We were able to tell because this value caused the servo to stay in one place.

- **Servo Wire Solutions**

During our testing to get the correct servo value of 11, we found that our gripper servo's wire kept wrapping around our rotational servo's mount. We didn't initially think of this, and we thought of numerous solutions, ranging from an original 3D coil that would hold enough wire for the three turns to commercial solutions that fed wire through servos and a slip ring that would eliminate twisting. Because of cost, we decided to drill through our servo and insert a tube in the space the potentiometer used to be in, which allowed us to run wire through.

➢ **Motor Power**

As we continued to test our ROV in a local pool, we began noticing that both servos would rotate whenever the motors were running at the high of 40% thrust. This was because we didn't prepare for the extra amperage of motors underwater. When our ROV's total amperage would raise over 8 amps, our servos didn't have enough power. As a temporary solution, we changed the throttle 40% to 1%. After regionals, to maintain a reasonable motor power, we used capacitors for our servo.

8.2 Troubleshooting Techniques

Troubleshooting is an important element for a working ROV. Over the past two years, we've had to learn to troubleshoot effectively, like deciding whether to go back to the basics or experiment with new methods. Most importantly, troubleshooting really has to do with an overall understanding of the parts. Sometimes there's simple and easily fixable mistakes, like unplugged wires or missing grounds, but sometimes things aren't as tangible and easy to see, like wire interference and bad connections/cold joints.

➢ **Control Box**

- Fuse - make sure that the fuse didn't blow
- The Potentiometers (2) - make sure wires are not loose, broken, or improperly soldered
- Voltage Regulators - make sure wires are not loose or barely held together by a wire

➢ **Electronics Enclosure**

- SOS Leak Sensor - remove the ROV from the water, open the container and let any water dry out, then check each component and reseal

➢ **Arduino Uno and Hardware Components**

- HS-646WP Servo - test with another servo, connect directly (don't go through the tether), look for loose connections, make sure there are common grounds, check power wiring and watch for shorts indicated by no Arduino lights
    - Check voltage regulator and adjust accordingly, as the servos and SOS can be burned out
    - Check for overheating
    - Analyze code to make sure everything is correct
- Uploading Complications
    - Verify the program for errors
    - Test using different Arduino Uno boards
    - Change USB ports and check that the board and port are correct
    - Restart the computer

8.3 Technical Challenges

➢ **Electronics Enclosure and Tether**

We planned to reuse our VideoRay neutrally buoyant tethers from last year, but researched the size of the penetrators into the holder and found that the tether was too large. We decided on using an electronics enclosure because of past problems with data disruption and to hold our ESCs. Because we could not use the tethers, we bought new ones that would fit in the cable penetrators, have a relatively low cost, and work with our system. To minimize the wires, we sent power to be distributed in the enclosure. Our final solution was 2 8-gauge power tethers and 1 tether with a set of 10 wires. This is the most cost effective and efficient method.

➢ **Setting Up T100 Motors**

Using the T100 thrusters was a new experience for us but luckily there were many resources online to help us. The first thing we did was test our motors with no control using the "Quick Start" guide on the BlueRobotics website. We ran a single motor directly to the Arduino, gave it a PWM to initialize, and then issued a command. This worked perfectly, so we moved on to control with joysticks comprised of 2 potentiometers. We conducted research and found that another team tried to integrate the triggerfish with the T100s. Rusty, the designer of the thrusters, along with many others, guided that team with advice, code, and example wiring. They also recommended certain joysticks, although we weren't able to get them to work. However, using an original joystick along with provided code, we were able to control a motor. One progressed to two, and we were able to see how turning would work. At this point, we made changes to suit our own needs. By modifying the code for the vertical motors to be like the turning code of the horizontal motors, we were able to tilt our ROV. When we needed to add two additional motors, we simply controlled them with the same data wires in the tether.

- **Mounting the Motors**

When figuring out the design for the motor mounts, we went through several different ideas and physical design iterations. Our first design faced the problem of our two vertical motors having to be right on top of the enclosure tube to stay stable. This meant that they needed to be distant to maintain waterflow. We made the mistake of trying to conform a Triggerfish around our enclosure tube. For our second frame, we built starting from the enclosure tube and worked our way out with smaller 3D printed mounts. We also added two additional vertical motors so that all of them could go around the enclosure tube and keep the center of mass below the center of buoyancy. There was much less unused space on our second frame.

8.4 Non-Technical Challenges

- **Project Management**

As we approached the MATE PA Regional competition, we realized that we were extremely behind on our project timeline in comparison to our progress by that time last year. This was due to a lack of communication, organization, leadership and direction. With these problems occurring, we unanimously decided to promote a company member to the position of CEO. Directly following this decision, we collectively created a list of tasks that needed to be completed. Tasks were properly delegated to each member based on their strengths and engineering role in our company. Once the tasks were delegated, the next step was to establish deadlines for each task. After this reorganization took place, our productivity greatly improved.

- **Meeting Management**

Since our company is separate from our school district we had to meet outside of school at a company members' home. We also had to organize the meeting times amongst ourselves. While we could decide our own meeting times, the problem we encountered is that it is difficult to plan group meetings around everyone's activities. At first we thought it would be best to all meet together and do individual work between meetings, but not enough work was getting done individually. The solution to this problem was to complete the assigned tasks and when small meetings were needed between a few members, those members would meet and at the end summarize what they did and inform everyone. This way everyone was updated without large meetings, and tasks were always being completed.

- **Communication**

We found communication to be a major contributing factor to our early problems stated above. Using text messages and emails was not working for our company as there were always resulting miscommunications. We came up with a few solutions to this problem. We used

Google Drive to create a spreadsheet of all the tasks which still required completion. The spreadsheet included columns for the tasks, company member assignment, deadline and status. This way the task assignments and deadlines were clear to all company members. Additionally, we used the Remind phone application for company announcements, and GroupMe for larger summaries of completed tasks.

8.5 Technical Lessons Learned

★ **Measure Twice, Cut Once**

This saying means always think before you do something. We have utilized this lesson throughout our robotics experience. When we originally started robotics, we remembered this phrase whenever cutting PVC so as not to waste any. However, now that we are an independent company, we are separate from any organization or school. As a result, we have to buy all of our needed equipment with the money donated to us by our families, making this lesson especially important. We budgeted $2,450 for our MATE ROV and we could not risk breaking parts, or buying expensive parts that were unnecessary, because we were on a strict budget. Before purchasing a part, we collectively thought about when, why, and how we would use the part. It was especially important to understand how to use the part because we may have needed to buy additional components to make one part work.

★ **Safety First**

We were very fortunate to have the proper safety equipment when building and modifying our ROV. We have learned through past experiences that safety is the number one priority at all times. However, sometimes company members were careless. For example, one of us accidentally touched a solder iron to bare-skin, causing a minor burn. A situation such as this could have easily been prevented if our member was more cautious or had worn heat protective gloves. We always need to practice good safety measures and wear proper personal protective equipment (PPE). We make sure that we use the correct safety precautions by following the job safety analysis (JSA).

8.6 Interpersonal Lessons Learned

★ **Collaboration is KEY**

Our company would not be what it is today if it was not for our ability to work together. For example, after our Mechanical Engineers built the ROV frame, it had to be properly wired by our Electrical Engineers to make the entire system functional. Additionally, our Software Engineer had to communicate with our Electrical Engineer to meet the needs of the Arduino. Collaboration brought all the individual systems together.

★ **Never Give Up**

Our company came across many challenges throughout the year. One instance was the growing worry a few weeks before the regional competition, as the control system and frame were still nowhere near completion. This was due to a lack of communication, organization, and direction. Even though it seemed as if it would be impossible to complete the ROV, we persevered. With a few company changes, we were back on track. Each of us performed our tasks in an efficient and timely manner to create an exceptional product.

8.7 Development of Skills

Our company is fully prepared to meet MATE's expectations because each member has strong knowledge of underwater robotics due to the following experiences:

- Every member took the STEM class at Harrington Middle School (located in Mount Laurel, NJ) that was focused on underwater robotics. This class inspired us to think about how our ocean is unique and why it is important. We then had to form teams of four to create ROVs that were most suitable for the challenges given by our teacher. This class also introduced us to the MATE underwater robotics program.

- For the last two years, every member of our company has participated in two different underwater teams at the middle school. In September of 2016, we all started 9th grade at Lenape High School (located in Medford, NJ) which does not offer an underwater robotics team. Since we couldn't participate through our high school, we decided to start our own company under the name of "MTL HydroTech" in order to continue participating in the MATE program.
- During the HMS STEM class and through participation in underwater robotics we learned the following skills: soldering, wiring, basic frame construction, motor manipulation, how to calculate buoyancy and ballast, and how to apply technical concepts such as center of buoyancy and mass to improve the frame.
- In the summer of 2015, four of our members took a MATE online summer workshop entitled "Diving into Underwater Sensors and Arduino" so that we would be able to incorporate the Arduino Uno circuits into our ROV. After this course, our Electrical Engineer and our Software Engineer, further pursued Arduino to obtain more knowledge in order to incorporate it on our ROV.
- All of our members participated in the 2016 MATE Pennsylvania Regional Competition, where our team placed first overall. Our team then competed in the 2016 MATE International Competition in Houston, where we placed third overall. Before that year of underwater robotics, one of our members participated in the 2015 MATE Pennsylvania Regional Competition, in the Scout division, placing 1st overall. Through participation in all of these competition events we gained invaluable knowledge about underwater robotics and are very appreciative for the opportunity to participate in the MATE program.
- For the last three years, two of our members have been going to the Villanova ROV Workshop to gain more information about the competition.
- In the summer of 2016, our team worked on building an OpenROV. Building the OpenROV allowed us to have a better understanding of more complex ROV features, like the onboard electronics enclosure tube. This sparked the idea of incorporating onboard electronics into our ROV.
- This year we were able to capitalize on our previous knowledge of Arduino and experience building the OpenROV in order to incorporate digitally controlled motors and onboard electronics. We learned about electrical properties of motors such as torque, intensity, stall, amperage draw, etc. As for software, we learned about different types of communications, controlling ESCs, coding/programming with Arduino, and more.

9. Future Improvements

Even though our ROV is functional and works very well, we still realize that there is always room for improvement. An improvement for our company for next year would be to begin our design process much earlier. Since we wanted to challenge ourselves to controlling our motors digitally and having onboard electronics, we had to do a lot of research to learn how to incorporate these upgrades into the Triggerfish Vector frame design. As a result, we began building our systems much later than we would have liked resulting in not having sufficient time practicing for the product demonstration. Another improvement to our company would be with regard to our budget. We are fortunate this year to have financially supportive families, but in the future we need to think of ideas for fundraising.

9.1 Reflections

- **Andrew McCorkle -** There are several improvements that I feel could be made to the frame in the future. To increase sturdiness, I would like to try using a different material, such as UHMW. This is highly impact and abrasion resistant and lasts much longer than other materials. We were unable to test this material this year due to budget restraints and the cost of upgrading our electronics system.
- **Vincent Cariello -** Even though our ROV has gone through many changes, it could still be improved by using a different flotation method, such as syntactic foam. It would be more beneficial because it is aesthetically pleasing and it is easier to adjust than buoyancy tubes. It is also more resistant to wear and tear.
- **Ethan Stillman -** There are several improvements that we could make to all of our final products, including our technical documentation, marketing display, and ROV, as well as our collaboration as a company. For example, an area that really needs improvement is our communication. There were several times where it was unclear who was to perform a required task, which is something that we would like to work on for next year.
- **Dan Lam -** I think that this year was a good learning experience for us, as we weren't under the heavy supervision of a coach, and only had mentors to guide us. We had to work hard on our own accord without being dragged into doing tasks, and we all needed motivation and interest. I think that with more experience, we could improve our company's ability to work cohesively, which would allow us to improve our ROV. Some changes that I think our ROV could undergo would be attempting to use I2C connections to reduce the number of wires in our tether, getting a button to stop the rotational servo, and adjustable buoyancy through ballast control.
- **Ahmed Fouad -** As CEO, I played a role of assigning tasks and creating deadlines. In addition, I planned and coordinated meeting times that incorporated everyone's schedule as much as possible, and made important decisions. My second role as the Electrical Engineer required me to integrate both the work of Mechanical Engineers and the Software Engineer onto one functioning device. The ROV could be improved by using a three-arm servo and using a smaller enclosure tube.

10. Accounting

10.1 Budget

Since our company is not associated with a school or organization we had to carefully plan our budget at the beginning of the design process. While we wanted to challenge ourselves by controlling motors digitally and having onboard electronics, it would be unwise to simply purchase parts and try to figure them out afterwards. The cost of these motors and all the parts needed for the enclosure tube add up to around $1,100. We had to map out how power would work, how many holes we needed, how many tether wires we needed, and more. Our company is very fortunate to have supportive families who donated $2,250 for our start-up costs. In addition to donations from our families, we were awarded $150 from the MATE Center for our third place finish at the 2016 MATE International ROV competition and $50 for winning the Harry Bohm/Jill Zande "Sharkpedo" award at the 2017 MATE PA Regional ROV Competition, bringing our total budget for the year to $2,450. Additionally, five company members traveling to Long Beach City, California costs approximately $2,500 for flights and $4,225 for a five night hotel stay totalling $6,725.

10.2 Cost Accounting

Category	Amount Spent (USD)	Donated/Discounted/Re-used/New	Fair Market Value (USD)
Frame/Flotation	**$26.81**		**$52.55**
Charlotte Pipe 1 1/2-in PVC Cap Fitting	$7.62	New	$7.62
Steel Rebar (.5-in x 6-ft)	$5.72	New	$5.72
Charlotte Pipe 1 1/2-in PVC Schedule 40 Pipe (5-ft)	$0.00	Donated (Lam)	$4.78
Charlotte Pipe 10-Pack 1/2-in PVC Schedule 40 Cap	$2.80	New	$2.80
Charlotte Pipe 1/2-in PVC Schedule 40 Pipe (10-ft)	$1.94	New	$1.94
LASCO 1/2-in 90-Degree PVC Schedule 40 Tee	$0.00	Re-used	$8.00
1 1/2-in Conduit Strap	$2.44	New	$2.44
PVC Cement	$0.00	Donated (McCorkle)	$6.00
Valspar Color Radiance Spray Paint	$0.00	Donated (Lam)	$4.98
M4-32 x 50 mm Screws	$4.70	New	$4.70
4mm - 0.7 Nylon Nuts	$1.59	New	$1.59
Stainless Steel Finishing Washers	$0.00	Donated (Lam)	$1.98
Watertight enclosure for ROV/AUV (4" series)	**$238.46**		**$264.95**
Cast Acrylic Tube - 11.75", 298mm (4" series)	$48.60	New/Discounted	$54.00
O-ring flange (4" series)	$52.20	New/Discounted	$58.00
Dome End Cap (4" series)	$53.10	New/Discounted	$59.00
Aluminum End Cap with 14 Holes (4" series)	$25.20	New/Discounted	$28.00
Enclosure Vent and Plug	$7.20	New/Discounted	$8.00
Cable Penetrator for 6mm Cable (Qty. 8)	$24.48	New/Discounted	$27.20
Cable Penetrator for 8mm Cable (Qty. 3)	$11.48	New/Discounted	$12.75
Cable Penetrator Blank (Qty. 2)	$7.20	New/Discounted	$8.00
Enclosure Vacuum Plug	$7.20	New/Discounted	$8.00
O-Ring Set for Cable Penetrators	$1.80	New/Discounted	$2.00
Thrusters	**$803.46**		**$881.89**
T100 Thruster (Qty. 6)	$658.60	New/Discounted	$714.00
Basic 30A ESC (Qty. 6)	$135.00	New/Discounted	$150.00
Duck Brand Printed Duct Tape (Black and Yellow Stripes)	$9.86	New	$9.86
Stainless Steel Finishing Washers	$0.00	Donated (Lam)	$1.78
M3-0.4 x 12 mm Screws	$0.00	Donated (Cariello)	$6.25
Electronics	**$249.27**		**$291.97**
Luman Subsea Light for ROV/AUV	$89.10	New/Discounted	$99.00
Electronics tray (4" series)	$71.10	New/Discounted	$79.00
SOS Leak Sensor	$26.10	New/Discounted	$29.00
SainSmart Arduino UNO R3 Microcontroller (Qty. 2)	$22.98	New	$22.98
Arduino Uno R3 Microcontroller	$0.00	Donated PA Regional MATE Center	$22.00
Hammond Black ABS Project Box	$8.41	New	$8.41
Uxcell 5K Ohm Linear Taper Rotary Potentionmeter	$6.31	New	$6.31
Perma-Proto Breadboard	$6.99	New	$6.99
DROK LM2596 Digital Voltage Regulator	$7.70	New	$7.70
2 Pole 5mm Pitch PCB Mount Screw Terminal Block	$2.59	New	$2.59
Male/Female .5mm Banana Plug Bullet Connector	$7.99	New	$7.99
Video System	**$19.99**		**$54.99**
Esky EC170 Backup Camera	$19.99	New	$19.99
Esky 7 inch LCD Color Monitor	$0.00	Re-used	$35.00
Tether	**$128.30**		**$178.30**
15 Meters 8 AWG Red Super Flex power cable (616 strands)	$64.15	New	$64.15
15 Meters 8 AWG Black Super Flex power cable (616 strands)	$64.15	New	$64.15
15 Meters VideoRay Performance Tether	$0.00	Donated PA Regional MATE Center	$50.00
Tooling	**$62.71**		**$152.71**
Standard Gripper Kit A - Channel Mount	$15.67	New	$15.67
HiTec HS-646WP Water Proof Analog Servo (Qty.2)	$0.00	Donated (Lam)	$90.00
ServoBlock Kit - HiTec Standard	$26.99	New	$26.99
2.2k Ohm Resistors	$7.60	New	$7.60
HEX STANDOFF M3 ALUMINUM 12M	$12.45	New	12.45
Miscellaneous	**$836.50**		**$1,832.51**
Team Shirts	$150.30	New	$150.30
Pool Rental - Moorestown Community House	$375.00	NA	$375.00
Professional Marketing display printing (PA Regional)	$70.00	New	$175.00
Professional Marketing display printing (International)	$95.00	New	$95.00
Registration fee	$0.00	Donated	$150.00
Cable Penetrator Potting Kit	$9.00	New/Discounted	$10.00
Cable Penetrator Wrench	$10.80	New/Discounted	$12.00
Self-Fusing Silicone Tape	$7.75	New	$7.75
MATE Triggerfish ROV Kit	$0.00	Donated PA Regional MATE Center	$640.00
3D Printer ABS Filament	$0.00	Donated (Lam/McCorkle)	$60.00
LOCTITE Marine Epoxy	$5.33	New	$5.33
Sheet Metal Screws #6 5/8 in	$0.00	Donated (Stillman)	$7.00
Hookup Wire (22AWG)	$6.99	New	$6.99
The Hillman Group 2-Pack Hole Plugs (7/8)	$1.50	New	$1.50
The Hillman Group 12-Count 3mm to 0.5 x 10mm	$1.90	New	$1.90
Cable Ties 4-in	$4.48	New	$4.48
Cable Ties 8-in	$5.50	New	$5.50
Cable Ties 11-in	$0.00	Donated (McCorkle)	$26.00
Shipping Costs	$50.00	NA	$50.00
Utiltech Spade Wire Connectors	$6.00	New	$6.00
Split Bolt for power connectors (Qty. 4)	$25.00	New	$25.00
Heat Shrink Tubing	$7.00	New	$7.00
3/4 Scotch Electrical Tape	$4.95	New	$4.95
ATO 25 Amp Fuse	$0.00	Donated (Mostafa)	$5.81
Total Amount Spent (USD)	**$2,365.50**	**Total Fair Market Value (USD)**	**$3,709.87**

Figure 32: An itemized list of purchases including fair market value of donated & discounted items in USD

11. References and Acknowledgements

This year, we worked with many new components that we were not all familiar with. We had to conduct research and use websites for help:

- "MATE - Marine Advanced Technology Education :: TriggerFish ROV Curriculum." *MATE - Marine Advanced Technology Education :: TriggerFish ROV Curriculum*. MATE, n.d. Web. 24 Oct. 2015. <http://www.marinetech.org/triggerfish-and-arduino>.
- "Index of Curriculum Lessons_year3." *Index of /curriculum/lessons_year3*. Cornerstone Robotics, n.d. Web. 29 May 2015. <http://cornerstonerobotics.org/curriculum/lessons_year3/>.
- "The Physical Properties of Water." Marietta College, n.d. Web. 29 Oct. 2015. <http://www.marietta.edu/~biol/biomes/water_physics.html>.
- "Hydrodynamics: Fluid Motion." *Hydrodynamics: Fluid Motion*. ReefQuest Centre for Shark Research, n.d. Web. 27 Oct. 2015. <http://www.elasmo-research.org/education/white_shark/hydrodynamics.htm>.
- "Prototype Fish Robot, UPF-2001." *Prototype Fish Robot, UPF-2001*. National Maritime Research Institute, n.d. Web. 25 Oct. 2015. <http://www.nmri.go.jp/eng/khirata/fish/experiment/upf2001/body_e.html>.
- “Blue Robotics Forums.” *Blue Robotics Forums*. Blue Robotics, n.d. Web. 4 Feb. 2017. <http://discuss.bluerobotics.com/>.

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- Villanova University for hosting the 2017 Pennsylvania MATE Regional ROV Competition.
- Our Regional coordinators and Teams Liaison, Ms. V. Vanessa Morris and Ms. Jane White, as well as all the volunteers and judges for making the Pennsylvania MATE Regional ROV Competition possible.
- VideoRay for donating a performance tether.
- The MATE Center - Jill Zande (Competition Coordinator), Matt Gardner (Competition Technical Manager) and all the MATE Center staff, volunteers and judges for making the MATE International ROV Competition possible.
- Long Beach City College for hosting the 2017 MATE International ROV Competition.

11.1 Sponsors

Figure 33 : MATE sponsor logos