Phoenix Robotics

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2020-2021 MATE ROV COMPETITION

Phoenix Robotics
Brooks DeBartolo Collegiate High School
Tampa, Florida, USA

PHOENIX
ROBOTICS

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Abstract

Phoenix Robotics is an 11-student company from Tampa, FL, attending Brooks DeBartolo Collegiate High School; the company is composed of driven members intent on raising awareness about marine pollution and degradation, and solving the most pressing problems with innovation, frugality, and practicality.

Phoenix Robotics has produced an ROV capable of completing the tasks necessary to the maintaining of Earth's oceans. The bidirectional brushless thrusters in conjunction with 2 bilge pump motors allows for optimal efficiency and effectiveness in the water. Using two laser-cut claws, the ROV can clean various debris, assist in the restoration of eel populations, and disconnect and reconnect the power converter of a Seabin. The ROV can capture and analyze images via waterproofed cameras and written software to determine the health of coral reef communities, estimate a mussel bed population, and create a subway car mosaic. The utilization of a slope-based computer program also allows autonomous navigation through a coral reef environment.

These capabilities related to the MATE-given tasks are critical for resolving the issues presented by ocean preservation in order to rectify humanity's impact on the ocean, benefiting the health and habitability of the planet and its ecosystems. This report will demonstrate these abilities as well as the experience gained through the design and construction process.

The U.S.S. Phoenix designed by our company has advanced capabilities to combat the issues that this competition has brought attention to and is a look into how technology can change the environment for the better today and in the future.

Figure 1: Phoenix Robotics team and U.S.S. Phoenix at the Florida MATE Regionals Competition, North Broward Preparatory School. Photo by Carlos Tassistro.

All pictures are taken by Elena Glow unless otherwise noted.

Teamwork: Project Management

Project Management

Figure 2: Company members working on wiring.

Phoenix Robotics is a company of high school students with the goal of soaring to new heights through advancements in cutting-edge technology. This year the company significantly expanded, with various members from last year returning, while also bringing in new members with a shared ambition. In order to perform the necessary tasks, groups were devised for various departments of the ROV. With groups working on their respective responsibilities, it allows for members to supervise one another, encouraging collaboration and learning opportunities. With company members monitoring each other, safety can be ensured as no one is operating machinery alone. Each department was strategically assigned tasks according to their strengths to promote efficiency (see Cover Page for positions).

Scheduling and Planning

One of the biggest challenges for the company was coordination and planning, as having ambitious goals calls for a large time commitment from each employee. Communication between employees was essential in order to maintain high attendance at meetings and efficiency. Before each meeting, a reminder was sent out to account for attendance and stress the importance of attending as much as possible. One tool used for this purpose was the Remind app, which allowed the company's administrators to send out announcements to all employees and served as a gateway to gather the company together across devices. The scheduling of meetings was mainly done on Google Calendar; this allowed all employees and parents to view the meeting schedule for the following week. The organization of work to each department was distributed on the application Trello, allowing the company to see what had to be done, what was done, and who was supposed to complete each assignment.

Over time, the schedule changed based on company and employee needs as well as based on jobs with pending completion. Phoenix Robotics would have meetings every Tuesday and Friday after school from 3:15 to 5:30 P.M. This evolved to add Thursday and finally, in January, the company made it every day after school hours in order to meet established deadlines for the upcoming competition. Alongside these meetings on school days, the company also had sessions over school breaks and weekends. These meetings typically lasted about five hours and were planned over a Remind announcement that was set up by the leaders. Due to the COVID-19 pandemic, the company switched to virtual meetings in small groups to work on technical documentation and coding, as well as a weekly full-team check in. Long term scheduling and can be seen in the Gantt Chart listed in Appendix C.

Meeting Organization

Figure 3: Company members working on connecting wiring to the frame.

In terms of resources, Trello, Remind, Zoom, and WhatsApp were the primary applications used for company communication. Each served an individual purpose and function based on the desired type of communication, whether it would be a company-wide announcement, individual communication, or a team database. This allowed for employees to access information from multiple departments if needed when troubleshooting systems. In terms of company procedures, each meeting day would follow a similar 3 step process which would effectively take us through each component needing completion, as well as through any potential issues. First, the full team would come together to discuss what each group's goal for the day was and to make any other important announcements or ask questions. Second, each team would split up to complete their given tasks for the day. An individual would be established during the meeting to whom one could go to ask for help. Finally, the team would once again convene to discuss their progress, whether they reached their goal for the day, and what issues they faced. Certain protocols such as keeping a quiet working environment, refraining from sudden movements, and focusing on completing work throughout the entirety of the meeting were enforced and were expected of each individual employee.

The Assembled ROV

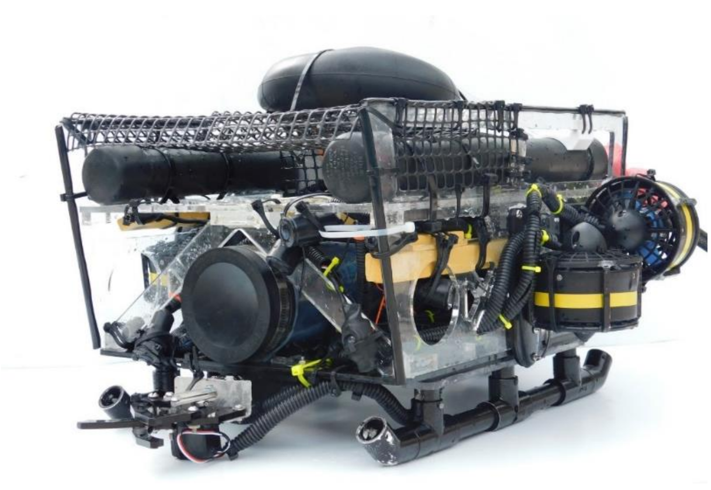

Figure 4: Completed ROV – Front

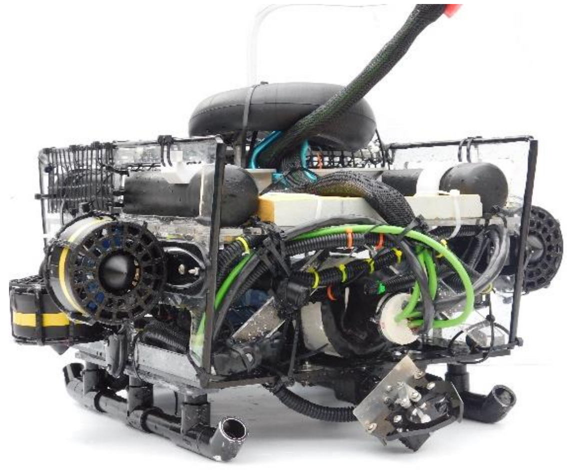

Figure 5: Completed ROV – Rear

Design Rationale

Engineering Design Rationale

An important decision to be made was the shape and material of the vehicle's frame. Various concepts of frame designs were drawn up for maximizing speed; however, the company decided that shape is less vital than accommodating the payloads used. For this reason, a rectangular prism shape was agreed on, for it holds better mounting opportunities. Having this availability allows for payloads like the claws and remediation task apparatus that are necessary to meet mission requirements.

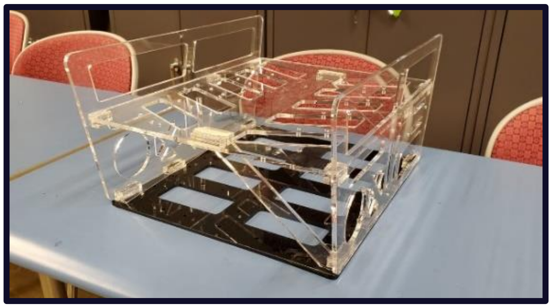

Figure 6: Main framework of the ROV.

For the material, the decision had to be made between sturdy aluminum, or a lighter material such as acrylic. It was concluded that the weight and density of the aluminum versus that of the acrylic made it worth using acrylic for the speed increase. Additionally, this material was safe to laser cut unlike all the other materials considered and was strong enough not to need aluminum reinforcement. Edges and danger points were reinforced with tygon tubing to protect the acrylic from damage.

The next step in the design process was geared towards minimizing the number of ascensions needed. Surfacing the ROV and going back down almost doubles task time, so this led to the implementation of two claws. This allows for the ROV to conduct several tasks and carry more loads while at the bottom, reducing surface trips. There were two different claw designs, each focused on solving specific mission tasks.

Thrusters were the next pivotal aspect of the design. The company picked the T100 brushless thrusters, as they were the most powerful thruster for the size as well as providing the least amount of current leaking from its wiring. One of the final decisions in the design process was whether onboard electronics would be used. Using onboard electronics poses a large risk, where any leak compromises the entire system. However, without the onboard electronics the tether would be significantly heavier, potentially slowing down the ROV. This is why onboard electronics were chosen with the necessary precautions taken to prevent water leakage. The ROV was specifically engineered to be capable in many conditions with a variety of instruments such as depth sensors for autonomous driving and 6 cameras for modular use. The ROV's lightweight and open-frame design allows it to be nimble underwater, as well as create easy access for modifications and repairs. It stands at 44 cm tall, 40 cm wide, and 51 cm long.

Innovation

There were several key innovations that made the ROV more efficient in terms of speed and cost. The most important of these innovations was the designing of the frame with the use of acrylic panels using the company's laser cutter. This acrylic is low-cost and extremely lightweight, with its low density of 1.19 g/mL allowing the ROV to reach high speeds easily. Additionally, this allowed for freedom of design; any shapes, patterns, and joint connections needed to put the frame together were cut with the company's laser cutter.

Figure 7: Sam and Chris working on coding for the ROV.

Additionally, the laser cutter was used to create custom designed manipulators which were from frame scraps of the same inexpensive acrylic. The company also utilized the laser cutter to construct the vehicle's claw design which were mounted on the front and rear. This allows for the reduction of trips to the surface and the versatility to carry different payload types.

Figure 8: 3D rendering of shroud model used for the Bilge Pumps.

The 3D printer facilitated innovations for the company. An example of this is the mounts and shrouds for the bilge pump motors utilized. Upon seeing that the U.S.S. Phoenix needed increased speed, members utilized CAD to design new mounts combined with shrouds for these thrusters. The PLA plastic filament used is an affordable material, and the 3D printers used were purchased in previous years by another party, making this innovation minimal in cost.

Several waterproofing techniques are implemented that demonstrate cost efficiency. Servos are packed with marine grease to prevent water intrusion and then covered in SALT hydrophobic spray. Finally, they are rubber coated. Additionally, the onboard electronics enclosure was also developed by the team. A 3-inch diameter clear acrylic tube was purchased. End caps are sealed with PVC glue, and the holes from wire entry are sealed with hard marine epoxy, marine-grade silicone, and wax. To seal the screw-on end cap, the company covered the threads with marine-grade Teflon tape, followed with flex tape and heat shrink. For internal protection, diaper gel was used to line the bottom of the tube in case of water leakage, as well as color-changing silica packages to detect any moisture. For the junction boxes housing external wire connections on the machine, marine-grade heat shrink was used on top of the joints followed by filling the boxes with silicone.

Problem Solving

Different groups of employees would be tasked with developing and implementing new systems onto the ROV. Ideas and designs would be written down and reviewed by several other employees and the CEO to make sure the presented design was the most efficient and cost-effective. When issues arise, the first step is to isolate the problem. Following that, key members discuss alternatives and troubleshooting methods. Finally, the new solutions are tested to make sure systems are fully functioning once again.

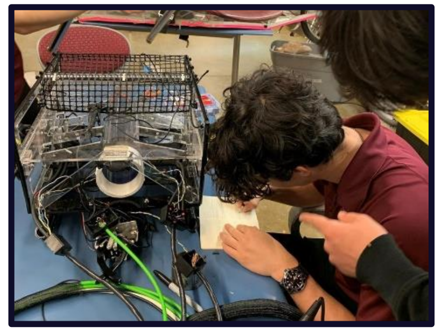

Figure 9: Matthew calculating measurements for on-board electronics.

When designing and redesigning aspects of the ROV, the team would draw inspiration from previous teams; at the MATE International Competition in 2019, the company was exposed to a myriad of teams from across the globe as well as their respective, differing solutions to the same challenges. Witnessing these teams in person gave way to a well of opportunities and ideas stemming from both the observation of said teams and the company's own members.

The claw design was centered around fixing problems found with its previous iterations, specifically versatility and load limits, along with adjustments made through experience during practices. Originally, the ROV utilized a combination of a pinch-to-close and a three-pronged claw, with the intent to allow the ROV to grab loads with precision combined with the capability to rotate, providing a variety of angles. However, it was soon evident that the three-pronged claw performed higher than its 2-pronged counterpart, with its improved grip, prompting the team to replace it with a copy of the three-pronged claw. With each claw on each end of the ROV, the U.S.S. Phoenix is able to carry double the load capacity of its precedents.

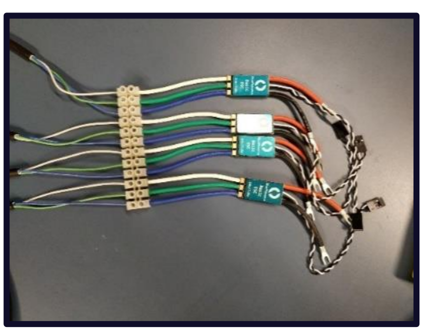

Figure 10: Blue Robotics ESCs connected to a bus board.

Systems Approach

Functionality of the machine is dependent on the cohesive and cooperative design of each system. This was essential when it comes to correctly balancing payloads as well as balancing task items. This meant distributing the vehicle's payloads evenly, such as placing a claw on each side of the ROV to balance the vehicle when traveling and also when carrying various mission components to prevent limiting the ROV's speed and maneuverability. This philosophy was also applied in the installation of the on-board electronics, which were put in the center of the vehicle to distribute weight evenly. The motor pairs were also placed with this idea in mind, ensuring that they were in symmetrical locations to ensure straight and intentional movement as well as even weight distribution. The main goal of camera installation was to have large fields of vision while also having key viewpoints, such as the manipulators. Bilateral symmetry was a significant consideration to maintain good weight distribution as well as overall efficiency with the respective missions.

Vehicle Structure

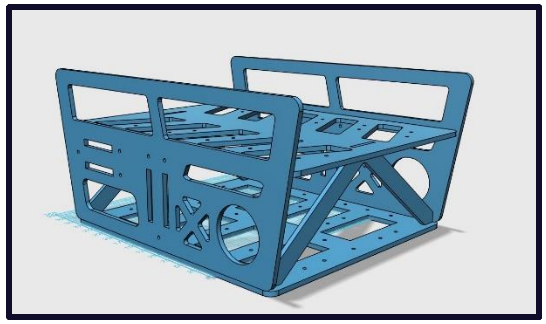

Figure 11: ROV Frame Schematic.

The frame of the ROV is made of both black and transparent ¼ inch acrylic sheets which were cut using a laser cutter. Thus, the use of this material permitted the company to cut the frame with the desired dimensions. The frame has a 48 cm length, a 36 cm width, and a 23 cm height. The density of acrylic being 1.19 g/mL keeps the frame relatively light-weight and this material is economical. Polycarbonate would have been used but it is not able to be cut with a laser cutter safely.

Figure 12: Matthew and Chris with the ROV frame.

Below is a table illustrating the considered materials and the primary factors used to evaluate which was most appropriate for the frame.

	HDPE	Acrylic	Polycarbonate	Aluminum	PVC
Density (g/cm^3)	1.0	1.2	1.2	2.7	1.38
Impact Strength (J/m)	260	74	440	294	250
Flexibility (MPa)	24	71	62	90	25
Cost	Low	Moderate	Low	Low	Low

See Reference 2

Vehicle Systems

Frame

Acrylic was chosen as the primary material used in frame construction due to its low cost and low density, as well as ease of use with laser cutter. The frame is held together with acrylic cement which distributes pressure across surfaces evenly as opposed to relying on screws or other fastening systems. The design includes holes deliberately placed throughout the body in order to mount payloads that aid in meeting the mission requirements.

Claws

Figure 13: The 3-pronged claws utilized on the ROV. Photo by Nicholas Tassistro.

The claws were designed to meet MATE's challenge with variable width of closing to effectively hold objects from tasks of varying size. There is a claw located in the front and the back because it allows for adequate spacing and balance between them. Having two claws allows for the ROV to complete tasks more efficiently because trips to the surface would be minimized, increasing the time available to complete tasks. These manipulators are used for assignments such as Task 2.3: The Propagation of Coral onto Reef. They are also ideal for the completion of Task 3.3 where an eel trap is be carried by its handle to the surface. The design process began with a rough sketch of the size and shape of the desired claw onto paper, which was then transferred into an "SVG" digital format for laser cutting on scrap wood to be used as a prototype. Once corrections were made to the design as well as the length of manipulators and rotating arms, the final model was cut on 1/4th inch acrylic which was previously used for the frame of the ROV. Acrylic of this thickness is strong overall enabling the claw to hold heavy objects without experiencing compromising strain and is strong enough to maintain stability under load and the servo will provide sufficient force to properly grip the handle. The servos used to control the claw's movement are rated at 20 kg of force. This force, based upon experience and in-water testing, was determined to be the correct amount for the designated tasks. The claw joints were initially made of a thinner acrylic, but they often broke when experiencing over-extension of manipulator arms. The joints were then replaced with aluminum to reduce the possibility of breakage during operation. Additionally, with most of each claw being cut from a panel of acrylic, exact copies can be made if either manipulator were to be damaged.

Camera System

Figure 14: The camera box.

The six cameras used are fishing cameras that were already waterproof, making them costly at $71 each, leading to a total cost of $355 in which one camera was remnant from a previous year. The cameras' signal and power wires are run through the tether and are powered by the camera box. The cameras are used constantly in all tasks for navigation and use of payloads such as the manipulators, surface debris catcher, and device for retrieving the sediment sample.

Thrusters

Figure 15: Blue Robotics T-100 (Reference 1)

When reflecting on company performance previous years, the conclusion was reached that a faster ROV results in better performance. After research was conducted, the company decided that transitioning to brushless motors would accommodate this need due to their speed capabilities. Although the effort was made for the company to waterproof such motors, it was revealed after testing the motors that they did not meet MATE's standards for the amount of electricity read in the water. Thus, factory waterproofed motors were essential, and six T-100 thrusters were purchased from Blue Robotics for a total cost of $714. Although the motors performed well, the shrouds provided did not meet MATE's safety standards due to the large open spaces where one could easily be injured by the thrusters, thus becoming a safety hazard. Because of this, employees designed pieces that were 3D printed which are attached to the provided shroud in order to meet safety requirements. Additionally, yellow tape was put on the shrouds to indicate a moving part as specified by OSHA.

Control/Electrical Systems

Software – Refer to Appendix B.

Control Box

Figure 16: Inside view of the earlier stages of making the control box.

Most controls for the U.S.S. Phoenix are contained within the control box, which consists of the claw and thruster controllers. The most important aspect is the mainline MATE 25-amp fuse, which is connected in series with the power supply. In addition to this, a priority was placed upon ensuring the security of connections by using strain relief to tug-proof the wiring, as well as to clearly label each wire for future reference. The control box serves as the hub which provides power for the camera box and its monitors as well as the ROV. The main changes as compared to the previous iteration of the U.S.S. Phoenix come in the form of improvements to the claw controller where joysticks replaced double-pole, double-throw switches in order to increase comfort for those operating the controls. Another improvement includes with the previously mentioned movement of the majority of electronics systems to on-board the ROV. The cost of the system was minimized through the repurposing of bus boards, wiring, and controllers. However, functionality and ability to fulfill requirements presented by MATE always took priority throughout planning and creation.

Camera Box

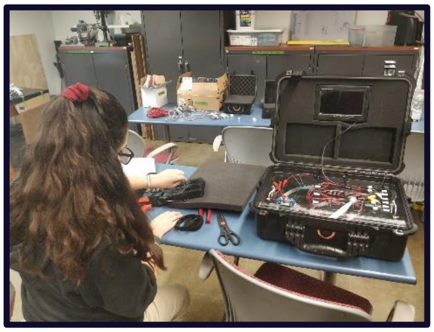

Figure 17: Julie Configuring the Camera Box.

The company decided to incorporate six cameras into the ROV which therefore required three dual-monitors within the camera box to properly utilize the cameras. The wiring plan for the camera was devised to ensure proper safety and adequate power, as can be seen within appendix _, and the proper sized control box was purchased to accommodate the needs of the camera and monitor system. The camera box is organized using an acrylic plate which was custom designed and printed using the company's laser cutter; this plate was created to perfectly sort the various wires and switches for easy and efficient access. Wiring included in the box includes where the monitors and cameras get their power from. Five of the six cameras get power from the on-board electronics, but 6 power plugs are available in case there was a necessity for the camera system to run individually from the onboard electronics. An Anderson plug that is connected to the control box is where the parts of the box are powered from. There is also a joystick powered by the camera box that receives its signal from the tether.

Onboard Electronics

Electronics Enclosure

Figure 18: Tube containing the on-board electronics.

The implementation of an on-board electronics system was new to the company, and because of this, it was dedicated to an extensive number of resources and thought into the safest and most efficient way to incorporate it within the ROV. The company began the process by creating true to size models of any electronics intended to be included within the enclosure. After heat dissipation, the size of the components, and space within the ROV were taken into consideration, it was found that a 3-inch transparent PVC tube was sufficient to fit all the necessary on-board electronics as well as effectively prevent leaks/water intrusion. Although PVC is slightly denser than acrylic, resulting in less dissipation of heat and an overall greater weight, the lower cost and added strength justified its selection over alternative materials; the light acrylic frame also made the weight an unnecessary concern. The clear tube allows for efficient diagnosis of any potential issues with the electronics for troubleshooting as well as easy monitoring of the tube's status.

Tether

This year, the tether was designed with the intentions of having a significantly slimmer design than that of last year's for easier maneuverability. This was aided with the addition of onboard electronics. The tether is composed of 4 main signal cables, 3 of which are 16 lead CAT5. The 4th is 10 lead-reinforced 22 AWG wire. Additionally, there is a power cable along with one of the camera feeds. It is held together by a sheath and has flotation thoroughly distributed across it to reduce the amount of drag that would be generated. The tether measured to an estimate of 15.24 meters to ensure that the ROV was allowed a sufficient range of movement. When the ROV is in use, tether that is not being used is neatly coiled and is placed poolside in order to prevent potential damage, maintain organization, and allow for quick addition and reduction of the amount of tether inside the pool. The tether is also neatly coiled and clamped together when the ROV is put away, allowing it to be tangle-free and undamaged when it is going to be used.

Payload and Tools

"Remediation" Task Apparatus

The remediation apparatus of the ROV was specifically designed to complete task 1.2 in the 2020 MATE ROV Competition Ranger Class Manual, which requires companies to collect surface debris, simulated by ping pong balls at the competition, and return them to the company for removal from the water. The initial design was a funnel-like system on the top of the ROV that would collect the ping pong balls; however, a company member had the idea of using plastic mesh to collect and trap the ping pong balls. This concept was chosen over the initial idea due to its greater efficiency in collecting surface debris as well as for its affordability. When the company researched what the initial system would cost, it was found to be out of the budget plan. The new system was only $10, which was easy to incorporate into financial planning. Water resistance is reduced by this apparatus being constructed from mesh in which water can travel through instead of around it. It was also designed to accommodate the diameter of a ping pong ball with a very large width to be able to skim large areas of the surface for debris. The apparatus design can hold all 6 ping pong balls required by the task and complete the task in one pass.

Depth Sensors

In order to meet the task 2.1 "Fly Transect and Mapping," it is necessary to have a depth sensor to keep the ROV at a stable level and all mission items in view. The sensors were waterproofed with a marine-grade silicone to prevent water intrusion and a rubber coating was added to withstand regular wear. The sensor came pre-calibrated, and coding was provided.

Micro-ROV

Figure 19: The Micro-ROV. Photo by Julie Fernandez

Mounted on the side of the ROV is a 3D printed vehicle and spool system designed to enable the collection of the sediment sample in task 3.1 to retrieve the sediment sample. The vehicle is designed to fit within the 15-inch diameter tube and ride along the sides of the tube using its two sleds and 12-volt thruster. After reaching the sediment sample, the vehicle will use the floating string as a 'grabbing' point and proceed to pull out the sample utilizing its thruster. A spool will be mounted on the ROV and contain the wiring required to power the thruster. This spool will be spun using a servo, and a slip ring will be implemented along the thruster power line to safely uncoil and recoil the device's tether upon being deployed and its return to the ROV.

Cameras

Figure 20: Waterproofed camera used on the ROV.

This year, the company decided to use six cameras as compared to last year's four in order to properly monitor all necessary angles and make maneuvering the ROV easier for the operator and better meet task requirements. The cameras used are fishing cameras that were already waterproofed and then coated in rubber to increase friction for better mounting. A crucial aspect that had to be established was the placement of the cameras. In the camera placement process, planning took place as a team, where all parties involved in design and operation gave input as to where the cameras would be placed. This was done to ensure the most efficient placement for the completion of the required tasks and efficiency in cooperation of all company sectors. There is a camera facing forward, backwards, towards each claw, at the surface debris catcher, and towards the sediment sample retriever. Thus, visuals provided by all cameras on the machine have sufficient clarity for piloting and meeting mission requirements.

Propulsion

The thrusters used on this machine are brushless Blue Robotics T-100s. They were chosen because of their power efficiency and speed, essential in meeting mission times. There are four on the vehicle; the first two are oriented straight up, for the purpose of vertical movement. One is positioned on the left and right sides of the machine. The other two are oriented straight forward for horizontal movement including turning, going forward and reversing. Each motor uses about 12.5 amps maximum but operates from 10-16 volts. They do not overdraw due to code in the ESCs limiting the amperage. An individual motor costs $120; six were purchased in order to have two spares leading to a total cost of $720. The maximum forward thrust of each motor is 2.36 kg F and the maximum reverse thrust is 1.85 kg F as specified in Reference 1.

Buoyancy and Ballast

One of the benefits of using acrylic is its density of 1.19 g/mL, thus the frame does not add much negative buoyancy due to water's density of about 1 g/mL. This combined with the addition of payloads makes the ROV somewhat negatively buoyant; however, in relation to a frame of materials such as aluminum the buoyancy is less negative. The on-board electronics tube has air spaces which bring the ROV closer to being neutrally buoyant. The rest of the needed buoyancy is compensated for by using high density foam at key locations to result in the perfect slightly negative buoyancy. For example, more high-density foam is located in the back half of the machine to account for there being more thrusters located there. A variable buoyancy system was added in which a tire tube is inflated through a hand pump connected by tygon tubing. This aids in movement up and down and allows the ROV to adjust when loads being carried impact buoyancy. This allows the machine to stay upright and move fluidly.

Build vs. Buy

Phoenix Robotics keeps a balance between parts that are purchased from external sources and parts that are both manufactured and tested by employees within the company. This is done to ensure cost effectiveness and to enable the design and creation of components which met specific needs that externally manufactured components could not fill.

Purchasing raw materials was essential for cost efficiency and the company's ability to create custom parts. Manufacturing parts internally gave Phoenix Robotics the advantage of creating an end-product that completely aligns with the company's desires for shape, size, and functionality. The company's Glowforge ™ laser cutter allowed for components that had complex shaping to be custom-made to the company's desire (e.g. the manipulators). This alone was found to greatly justify the cost of the machine. Another crucial component designed by Phoenix Robotics employees was the frame of the vehicle. This was done through laser cutting various panels of transparent acrylic with openings in order to fit them together to form the overall structure of the ROV. The frame also contains slots intended to hold the various sorts of equipment required, including the thrusters, onboard electronics, and cameras. The acrylic leftover from cutting the frame's panels was later used to create the claws and its spare parts, showing that the acrylic panel served several purposes in building various systems.

Purchased parts mainly consisted of the aforementioned raw materials used for developing in-house components and the equipment used to power and control the ROV, including the thrusters and onboard electronics. The company bought these directly from groups and suppliers that sold this equipment ready for use. Bilge Pump and brushless motors were compared to determine which would be optimal in the most use cases. This comparison resulted in the T-100 motors bought from Blue Robotics being selected for use on the company's vehicle due to better speed capabilities. Along with these motors, the company also purchased servo motors that are used to control the pair of claws installed on the vehicle. Onboard electronics boards such as Arduinos and a Raspberry Pi were purchased and used to enable the software needed to remotely activate the various actions that the ROV can complete such as tasks calling for image recognition.

New vs. Reused

This year's ROV is created using various new materials supported by a laser cut acrylic frame, making it significantly different from the PVC and aluminum frames used in previous years. Despite this major difference, the company was able to reuse many old system parts that were still functional and integrate them into the build of the current rendition of the U.S.S. Phoenix as means of maximizing cost efficiency.

Acrylic is the new material used for the side panels of the ROV, which was cut to shape by the company's Glowforge ™ laser cutter. The laser cutter was also frequently used to create other smaller acrylic pieces such as pillars that hold the top plates of the camera box, control box, and both claws.

In order to operate the previously mentioned T-100s, the company also had to purchase bidirectional ESC's. Other systems also required for new materials to be purchased; for example, the remediation task called for a mesh netting to capture the surface debris.

To simulate objects that would be used in competition, the company reused PVC to create the different obstacles and items. In addition to PVC, rope, ping pong balls, connectors, and various other materials were also reused and utilized toward these ends. PVC material was used to design landing skis which prevent potential damage when the ROV is on a surface, and many wires were reused to prevent wasting valuable materials while simultaneously saving money. For example, approximately 30% of the tether is made from recycled wire.

Safety

Phoenix Robotics is a company dedicated to ensuring that all employees understand the importance of safety and its role in everyday operations. Along with the help of six employees that are Certified Production Technicians through the Manufacturing Skill Standards Council who are certified in their understanding of OSHA safety procedures, every member has been trained on how to operate all the tools in the workshop to ensure all safety protocols are followed and the risk of an unsafe working environment is minimized. Wearing goggles consistently is a necessity to prevent any unwanted substances or forces from infiltrating the eyes, and proper tool handling and maintenance are essential knowledge for any member working with or near a tool to prevent and amount of injury caused by too misuse. Hazardous practices and tool handling are reinforced as an unacceptable oversight and employees found to be in violation of the procedures and rules in place are informed of their mistake and shown the proper methods to ensure that it is not repeated.

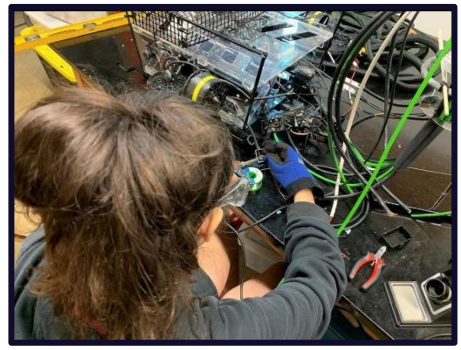

Figure 21: Example of Julie conducting proper safety procedures.

The U.S.S. Phoenix takes safety precautions through eliminating sharp corners that can cause cuts or bruising through filing or by design. Additionally, motor shrouds have yellow tape stripes due to the OSHA standard that moving parts are indicated with this color. Tygon tubing lines the frame to protect the machine from fracture due to the fragility of acrylic. There is a kill switch to cut power quickly in case of an emergency with any systems. Cabling on the machine and control station is secured to be protected from tension, keeping the wires from becoming damaged. Wires on the ROV are additionally surrounded by corrugated tubing to further hinder any harm to wiring.

Safety Procedures	
Construction: • Gain approval for the task intended to be worked on. • Confirm a cleared space appropriate for the task is available to avoid making a mess, potentially resulting in an employee tripping or falling as well as possibly damaging a tool or mixing up equipment.	**Operation:** • Check all fuses to ensure they are fully functional. • Check charge on battery to prevent battery completely draining during operation or amount of power being provided from other DC power supplies.

• Ensure personal protective equipment is used or in reach for when needed to provide employees with the necessary protection when operating in any department. • Confirm that all tools to be used are in working condition to prevent damage to components worked on and to also hinder the user of the tool from being harmed. • Moving parts are secured to prevent them from being accidentally released when in use and possibly be damaged. • Make sure all cables are intact to avoid a loss in power flow. Confirm that all members are working on the tasks to alleviate time-wasting.	• Ensure power source and plugs are in a safe and dry space to prevent damage, shorting, or the risk of electrocuting an employee. • Ensure certain "quick fix" tools are within reach such as zip ties, pliers, and screwdrivers. • Set up workspace so that commonly used tools are within reach for efficiency and organization. • Check controls to make sure they work before the ROV enters the water for it to be fully prepared for operation. Check on-board electronics for visible water in the tube to hinder the possibility of flooding inside the ROV.

Critical Analysis

Testing

When choosing which motors would be used for the ROV's thruster system, several tests were conducted such as leakage tests and speed to make sure the appropriate choice was made. The company used a megohmmeter to test the current leakage of the brushless motors to make sure they were in line with MATE's insulation requirements. The company chose T100s as they were factory verified to meet the MATE ohm requirement. A Bollard Pull test was conducted to make sure the thrusters were up the company's standards of use. Bidirectional speed was documented along with the efficiency of different propellers.

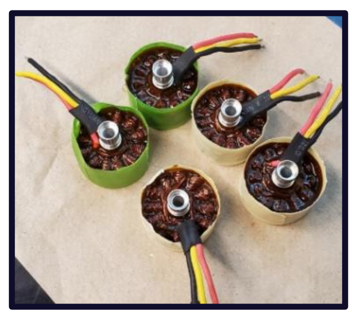

Figure 22: Waterproofed DT

From previous years we have prerecorded the Bilge Pump Motors forward pushes 2.8 kg F and the reverse pushes 1.9 kg F. The charts below are for the DT 750's at varying amperages, as the T100's information was found in Reference 1.

Forward

Current (A)	1	2	3	4	5	6	7	8
Force (kg)	0.5	1.5	2.0	2.5	3.3	3.7	4.7	5.5

Reverse

Current (A)	1	2	3	4	5	6	7	8
Force (kg)	0.6	1.2	1.8	2.0	2.7	3.3	4.1	4.6

Despite these tests having decent results, the failure of the resistance leakage tests of the DT750's resulted in the selection of the T100's.

Manipulator prototypes were created with wood before being made from acrylic with the company's laser cutter. The wood prototypes allowed for the company to test different lengths and angles of the manipulator arms to reach the desired versatility of the claws.

The same thing was done with the frame construction, with an initial cardboard construction and following that, a wooden frame with the company's laser cutter to ensure the model was correct before cutting into the acrylic. Similarly, claw pinchers were also cut out of the draft board to ensure that the desired shape would be properly replicated.

When testing the ROV in the water, the company met every day after school and used the props as specified by MATE. Early on, the company focused on only a few tasks at a time to get accustomed to the process. It also allowed for slight changes to be made to the machine to better complete the tasks. Later on, several full runs were done each practice.

Troubleshooting

The bulk of the company's troubleshooting was concerned with the electrical systems. After tests would be conducted, code issues were patched where needed; many times, a code segment would not act exactly as desired and would have to be adjusted. For example, the joysticks of the machine took several trials before the perfect settings in terms of the speed potentiometers and the desired dead zones were found.

The claw was a system that also took significant troubleshooting. One big challenge was finding the best way to waterproof the servos used for claw control. After several trials as well as past years' experience, the company began using a three-layer system of marine grease, hydrophobic coating, and a rubber coating. Additionally, the mechanical design of the claws went through several sizes and models, until they each closed and opened completely.

Furthermore, originally, the ROV utilized a frontal two-prong pinch-to-close model claw with a 3-pronged posterior claw; however, through practicing the product demonstration, the superiority of the posterior model was made clear due to its controlled grip on the props. Because of this, the company switched the front and back claws for the Florida Regional Competition. Afterwards, Phoenix Robotics created another three-pronged claw with the laser cutter to replace the two-pronged model in the back.

Camera placement was also a prominent example of multiple trials, where the company experimented with several angles and positions until the final decision was made. This decision was essential to the efficiency of the pilot while operating the machine.

When speed issues were noticed with the ROV, the voltage loss across the tether was measured; it became apparent that the wire was not facilitating enough voltage to reach the thrusters as needed. To preserve the onboard electronics tube, two 1250 GPH bilge pump thrusters were added and powered by a different cable than any other systems to divide the amperage across more lines. Consequently, the ROV would use more of the available power rather than lose it to the insufficient wire gauge. Team members utilized a Bollard Pull Test to measure the amperage draw of each of the additional thrusters. It was evident that the thrusters were able to pull up to 7 amps each, meaning they could add sufficient speed to meet task needs. It also meant that a voltage regulator needed to be added inline to ensure that this new system would not overdraw and consequently negatively impact other systems.

Accounting

Budget

A realistic budget for this year's project was established within the first weeks of meeting and was referenced throughout construction to avoid overspending. All purchases were made with the approval of mentors, allowing for accurate documentation and to ensure that purchases were within the budget.

Affording the T100s thrusters was a financial priority, as powerful thrusters are necessary for efficient operation. Due to this expense, the company was made to compensate in other areas by utilizing screws, nuts, wires, and several other materials recycled from previous years.

Travel costs accounted for 12 employees and 2 mentors to Tennessee and was estimated at $8,000. Refer to Appendix E.

Cost Accounting

Most of the company's costs came in the form of purchased materials and hardware for construction, as well as in electronics for the vehicle's function. Significant costs crucial to the ROV'S development include the acrylic used to construct the vehicle's frame and the T-100 thrusters purchased from Blue Robotics to power the company's vehicle. Other electronics purchased include digital servos for providing motion in the vehicle's claws and other mechanisms, and cameras that give vision underwater for all tasks. Additionally, the company received generous donations for crucial components of the ROV such as 500 feet of Cat 5 wire donated to Phoenix Robotics by OmniCable. To keep track of purchases, a Google Sheet was used and regularly updated with each purchase made. A comprehensive chart of costs and donations can be found under Appendix E.

Acknowledgement of Contributors

The company would like to express gratitude towards all of those who donated to the Phoenix Robotics GoFundMe. The proceeds from the GoFundMe were used to purchase many materials critical to the completion of the ROV, and this company would not have been as successful without their generous support. Phoenix Robotics greatly appreciates Publix for their financial contribution, which allowed for purchases of several necessary items. Additionally, the company would like to thank OmniCable for donating high quality tether wire and providing the team a valuable learning experience at one of their locations. The donated wire accommodated the large amount of signal wire needed to enable communication between controls and on-board electronics. Phoenix Robotics would finally like to thank Calypso of Tampa for teaching seven employees how to dive through PADI's Open Water certification and educating these employees regarding coral reef conservation. Calypso of Tampa also generously allowed the company to utilize their pool for testing systems and practicing tasks with the U.S.S. Phoenix, along with being a donor to the GoFundMe page. Phoenix Robotics could not have progressed as far as it has without the help of these sponsors.

The members of Phoenix Robotics are extremely grateful to Mr. Fernandez, Mrs. Fernandez, Mr. Fimbel, and Mr. Egosi for being mentors and providing an environment where the team was able to learn and grow abilities to meet the many challenges presented throughout competition preparation.

Lastly, Phoenix Robotics is very appreciative towards MATE for hosting this competition as it provides amazing educational opportunities for many.

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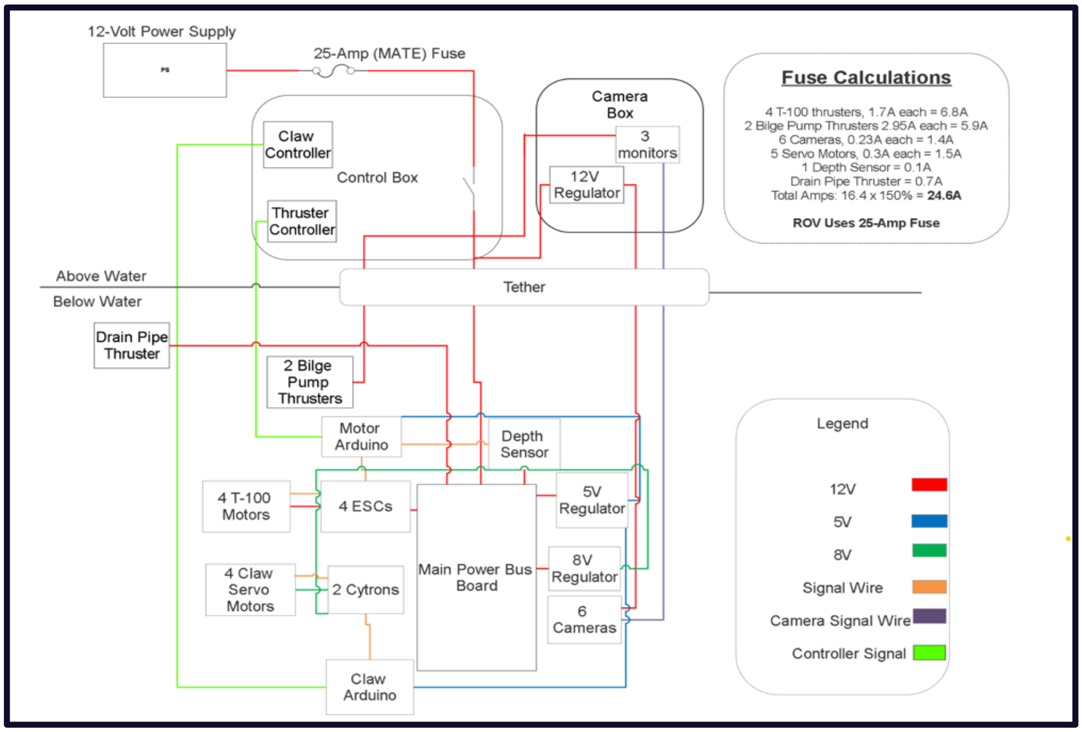
Appendices

Appendix A: SID



Appendix B: Software

The company software was mostly written using C++. This part of the software is used for basic function of the thrusters, as well as the essential movement of the manipulators. Using this software gave us the additional ability for speed control of our thrusters to allow greater movement variety. The other part of the software uses Python. The function of this section is for the image recognition of the coral reefs, the photomosaic of the subway car, and the maneuvering autonomously through the reef. This software is what incorporated a Raspberry Pi for the autonomous task as well as a depth sensor

Appendix C: Safe Operation

In the Workplace

General

- Clear workspace when finished to provide a smooth resume of operations upon returning.
- Always wear appropriate protection such as goggles to alleviate the risk of physical harm from using tools.
- Ensure all equipment is in working condition before using it to prevent injury to the user from a damaged tool that will not function correctly.

Glowforge™ Laser Cutter

- Ensure lid is fully closed before and during operation to allow the device to function properly.
- Keep lid closed for at least 20 minutes after operation to allow air to filter.
- Ensure the table and laser cutter are clear of miscellaneous objects to avoid the device being damaged during and after use.

Solder

- Wear protective glasses to avoid getting harmful substances in the eyes.
- Keep hands away from end of solder to prevent hand injuries.
- Always use marine grade heat shrink to cover exposed wires to prevent any possible power loss and avoid members being electrocuted.

Power Tools

- Wear protective glasses and gloves to prevent substances from entering the eyes and reduce possibility of physical harm to hands.
- Ensure electrical supply is unobstructed so the supply can smoothly deliver power.
- Keep tool away from the edge of work area to prevent the tool from falling and potentially being damaged.
- Never have hoses or electrical cords in walkways to prevent the possibility of tripping and/or falling.
- Be aware of those surroundings to reduce collisions with other employees and possibly severe accidents.

3D Printing

- Never touch the nozzle, especially when hot to avoid burns.
- Ensure the filament won't get tangled to alleviate any waste of material in the printer's work area.

Setup, Boot, and Launch

- Ensure the area is clear and all team members are ready in order to prevent distractions.
- Alert all team members when powering on the ROV to prepare the entire team for further instructions.
- Connect the tether wires to the camera box carefully, making sure to keep the area clean in

preventing damage to the camera box and electronics. • Notify the pilot team after gently placing the ROV next to the pool. • Place ROV in pool carefully, being aware of the location of the tether so it does not get stepped on or tripped over.
ROV Retrieval • Pilot alerts the deck crew that the ROV is surfacing so the crew can be prepared for an efficient change of materials or to lift the bot onto the poolside. • The deck crew informs that the ROV has surfaced to verify the pilot does not need to perform further action. • The pilot removes their hands from the controls for the deck crew to adjust the ROV safely. • The deck crew retrieves the ROV with the vehicle being grasped on opposite ends after surfacing to prevent the ROV from being dropped or damaged.
ROV Maintenance • Verify that all electronics are in working condition and all sensors are reading correctly to ensure they provide accurate data when the ROV is in use. • Check for scratches, holes, water damage, or other signs of wear to ensure the electronics and ROV are safe from leaks and malfunctions. • Rinse the ROV in fresh water to prevent damage from chlorinated water.

Appendix D: Budget

School: Brooks Debartolo				
Organization: Brooks Robotics				
Mentor: Eric Fernandez				
Period: August 2019 - August 2021				
Income				
Source				Amount
Brooks DeBartolo Club Grant				$500
Donoation from Derrick Brooks				$5,000
Expenses				
Category	Type	Description	Projected Cost	Budgeted Value
Hardware	Purchased	Acrylic Panels, Aluminum	$200	$200
Electronics	Purchased	Servos, Motors, Arduinos	$1,120	$1,120
Sensors	Purchased	Depth Sensor, Cameras	$200	$200
Travel	Purchased	Ticket fares, hotel	$8,000	$8,000
General	Purchased	Marketing, Events	$150	$150
	Re-Used	Controllers, PVC	$100	N/A
	Donation	Cameras, Wire	$200	N/A
			Total Income:	$5,500
			Total Expense:	$9,930
			Total Fundraising Needed:	$4,430

Appendix F: Costing

Date	Type	Category	Item	Amount	Running Balance
	Cash Donated	N/A	GoFundMe	(+$1980)	$1,980
	Cash Donated	N/A	School team fund	(+$500)	$2,480
	Donated	Electronics	Wire	$350	
	Donated	Electronics	Camera (2)	$75.08	
	Re-Used	Electronics	Joysticks	$5	
	Re-Used	Material	Zip Ties	$3.99	
	Re-Used	Sealant	Marine Grade Silicone	$8.99	
	Re-Used	Sealant	Salt Spray	$12.98	
8/25/2019	Purchased	Material	Plastic Mesh	$10	$2,470.00
8/25/2019	Purchased	Electronics	30A RC Brushless Motor electronic Speed Controller with XT60 & 3.5mm	$15.98	$2,454.02
8/25/2019	Purchased	Electronics	DYS Sumguk Series Motor	$13.99	$2,440.03
8/30/2020	Purchased	Hardware	Stainless Steel Nuts, Screws, & Washers	$50	$492.72
9/29/2019	Purchased	Electronics	HexTronik DT750 (6)	$126.00	$2,314.03
9/3/2019	Purchased	Hardware	Uxcell RC Boat CW Propeller	$10.69	$2,303.34
10/18/2019	Purchased	Hardware	Propellers for DIY ROV Thruster	$10.00	$2,293.34
10/18/2019	Purchased	Material	Black Acrylic Sheet 1/4" Thick	$72.00	$2,221.34
10/24/2019	Purchased	Glue	SCIGRIP 16 10315 Acrylic Cement	$14.48	$2,206.86
10/24/2019	Purchased	Hardware	3/4" x 3/4" Aluminum Angle 6061, 24" Length	$11.20	$2,195.66
10/24/2019	Purchased	Tool	Red Devil 1170 Plexiglass Cutting Tool	$4.95	$2,190.71
10/24/2019	Purchased	Material	Source One Premium 1/4 Clear Acrylic PlexiGlass Sheet (24' X 48")	$99.99	$2,090.72
10/25/2019	Purchased	Hardware	Norseman 7pc Acrylic Point Drill Set	$39.95	$2,050.77
10/28/2019	Purchased	Material	Lexan Sheet-Polycarbonate- .236"-1/4" Thick, Clear, 24" x 48" Nominal	$64.99	$1,985.78
11/15/2019	Purchased	Hardware	5-Pack 25T Round Type Servo Horn Robot Arm Aluminum	$6.99	$1,978.79
11/18/2019	Purchased	Glue	Weld-On 4 Acrylic Adhesive-4oz	$18.20	$1,960.59
11/30/2019	Purchased	Electronics	DC Bucks Module Voltage Adjustable Regulator Power Supply	$12.86	$1,947.73
12/1/2019	Purchased	Hardware	Digital Caliper, Adoric 0-6' Caliper	$8.49	$1,939.24
12/9/2019	Purchased	Electronics	Zephyr Fast Acting Ceramic Cartridge Fuse 6x20mm 250V (12 Amp)	$7.99	$1,931.25
12/17/2019	Purchased	Hardware	SMR84C-2YS Ceramic Ball Bearing	$14.97	$1,916.28
12/17/2019	Purchased	Sealant	Maxima 80916 Waterproof Grease	$12.24	$1,904.04
12/17/2019	Purchased	Sealant	Mys Lb Marine Grease	$11.59	$1,892.45
12/22/2019	Purchased	Hardware	Oatey 33402 Mechanical Test Pluc, 3in, 5 Psi, 110 Deg F	$4.38	$1,888.07
12/22/2019	Purchased	Hardware	3in Diameter Clear PVC Schedule 40 Pipe, 15in long	$28.45	$1,859.62
12/26/2019	Purchased	Tool	VICI VC60B+ Megohmmeter	$44.59	$1,815.03
1/13/2020	Purchased	Hardware	SiliPacks Silica Gel Packet (Blue to Pink)	$5.99	$1,809.04
1/15/2020	Purchased	Electronics	5pcs Nano V3.0 AVR Atmega328P-AU Adapter	$11.99	$1,797.05
1/16/2020	Purchased	Electronics	Rasberry Pi Zero W	$25.99	$1,771.06
1/27/2020	Purchased	Hardware	Apache 2800 Weatherproof Protective Case	$27.99	$1,743.07
1/27/2020	Purchased	Hardware	ShareGoo 5PCS 25T Aluminum Servo Horns M3	$9.98	$1,733.09
1/28/2020	Purchased	Electronics	30 Amp Reulated Home Lab Benchtop AC to DC Converter w/ 13.8 Volt DC 115/230V AC Switchable	$72.29	$1,660.80
2/5/2020	Purchased	Electronics	Zixtec LM2596 DC-DC Buck Converter Step Down Module Power Supply	$13.99	$1,646.81
2/5/2020	Purchased	Electronics	DEYUE Jumper Wires Set	$9.99	$1,636.82
2/11/2020	Purchased	Electronics	BlueRobotics T100 (6)	$720.00	$916.82
2/11/2020	Purchased	Electronics	BlueRobotics ESC (4)	$108.00	$808.82
2/12/2020	Purchased	Electronics	HiLetgo JSN-SR04T Integrated Ultrasonic Module Distance Measuring transducer Sensor (2)	$16.29	$792.53
2/13/2020	Purchased	Electronics	Saim Waterproof Electric Project Case Junction Box	$22.12	$770.41
2/14/2020	Purchased	Sealant	Seal Bond 105 Black-Marine/Indutrial Adhesive Sealant	$11.99	$758.42
2/14/2020	Purchased	Sealant	3M Marine Adhesive Sealant 5200FC, PN05220	$14.09	$744.33
2/17/2020	Purchased	Sealant	Trident Silicone Grease	$9.95	$734.38
2/20/2020	Purchased	Sealant	Waterproof Automotive Electrical Heat Shrink	$14.99	$719.39
2/20/2020	Purchased	Sealant	2 inch 3:1 Waterproof heat Shrink Tubing Kit	$9.89	$709.50
2/27/2020	Purchased	Electronics	ANNIMOS 20KG Digital Servo DS3218MG (6)	$113.82	$595.68
2/29/2020	Purchased	Electronics	Car Front View Camera (3)	$38.97	$556.71
3/6/2020	Purchased	Electronics	Veanic Mini Digital Electronic Temperature Humidity Meters	$13.99	$542.72
4/10/2021	Purchased	Electronics	Fishing Cameras (5)	$354.97	$187.75
6/8/2021	Purchased	Hardware	1250 GPH Bilge Pump Thrusters (4)	$120.00	$67.75
				Spent:	Remaining:
				$2,462.25	$67.75