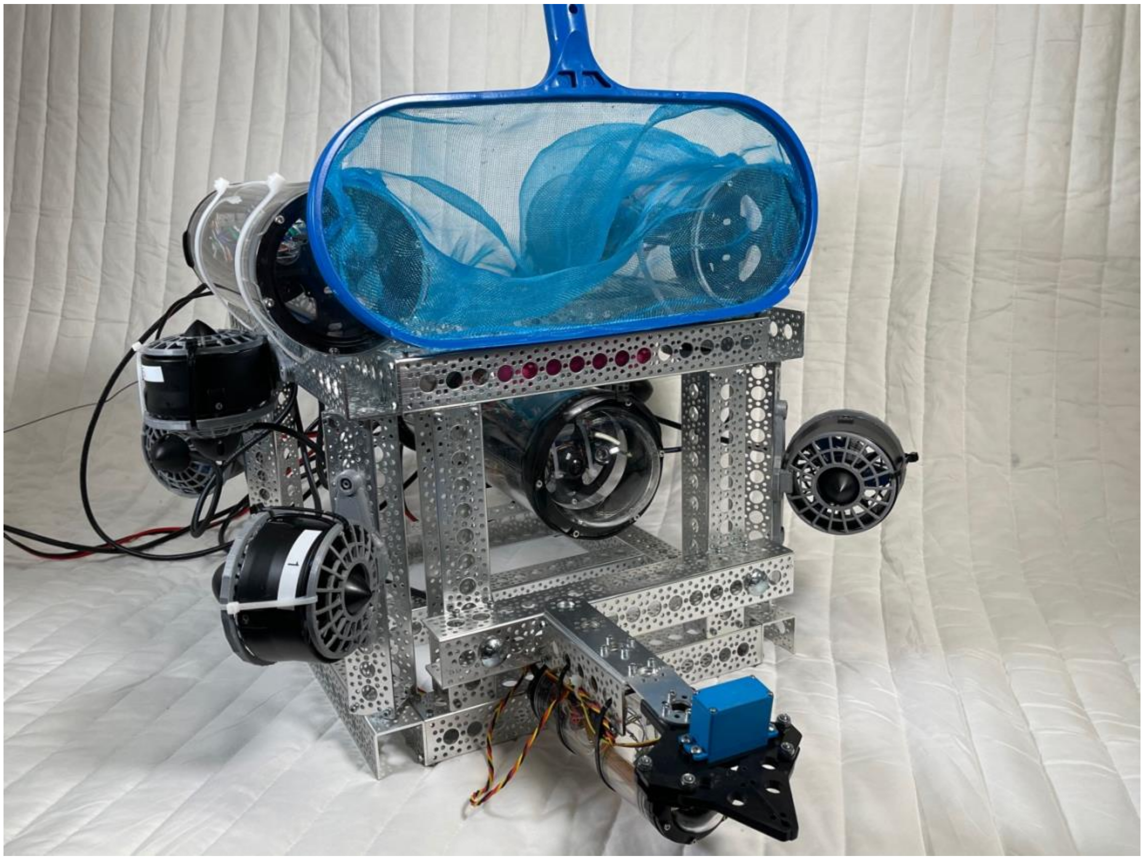
Talos ROV

HEPHAESTUS ROBOTICS

Santa Cruz, California
2021

Team Members

Andrew Sylvester	Chief Executive Officer
Jordan Weiss-Penzias	Chief Executive Officer
Konish Bhattacharya	Mission Strategist
Brian Carreno	Elec and Mech Engineer
Nathan Madsen	Chief Scientist, Photographer
Rinoa Oliver	Lead Writer, Software
Gabriel Orange	Elec and Mech Engineer
Om Shastri	Chief Technical Officer
Aden Sommerville	Mechanical Engineer
Saashin Subramaniam	Software Engineer
Tim Sylvester	Mentor
Parthesh Shastri	Mentor
Tim Madsen	Mentor



Talos ROV ¾ View. (Photo Credit: Nathan Madsen)

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Abstract

Hephaestus Robotics is an organization founded in Santa Cruz, California. We produce remotely-operated underwater vehicles which address pressing environmental concerns. Our latest product, Talos, aims to address some of the most adverse environmental issues faced globally - plastic pollution in oceans, coral reef bleaching, and the effects of industrial pollution on channels inland. It has the ability to remove harmful plastic debris ranging from the ocean surface to the depths of the Mariana trench. It is also capable of removing ghost nets, which can entrap and eventually kill marine animals. Additionally, it can collect coral reef samples to determine a reef's health, as well as aid in the growth of artificial reefs out of submerged subway cars to replenish the biodiversity of ecosystems that rely on healthy coral reefs to survive. Not only does this ROV aim to address the impact of pollution and climate change on the world's oceans, but it is also able to help analyze and work to mitigate some of the effects of poor environmental practices on inland water channels. It can collect samples of sediment at the depths of these channels to analyze for contaminants, as well as estimate the size of mussel populations to determine their health. Additional functionality includes the ability to remove eel traps and replace them with new ones which serves to remove eels from areas in which exist invasive species. This manual details our process of developing Talos.

Project Management

In the process of developing all our models, Hephaestus Robotics prioritizes ensuring that our team works together effectively and efficiently and that each member has the opportunity to showcase their unique talents and capabilities. Before beginning the process of constructing the ROV, everyone described their past experiences with designing robotics and shared their preferences of what parts of the design they would like to work on most. After agreeing on our team Chief Executive Officers, we decided to assign everyone else the team role of Senior Roboticist to allow for flexibility with what everyone worked on. By assigning everyone the same title, we avoided pigeon holing people into one area of the project and avoided conflicts over ownership of tasks. This proved to be beneficial, as many times while developing Talos, senior roboticists would discover a way to improve a certain aspect of the ROV and were able to do so while still fulfilling their team role.

We often tried multiple designs for a component and different team members worked different versions of the design. For example, we built three versions of the tether. Each build of the tether involved four or five team members. In the end, almost everyone worked on one or more versions of the tether. Each week, the mentors would train team members in different skills (e.g. crimping Power Pole and Ethernet cables, sleeving the tether, swaging wire rope, setting up Raspberry Pis and cameras, etc.). Over time, people specialized in one or two areas. Andrew Sylvester focused on the software and the electronics; Om Shastri worked on the frame, manipulators and potting cables; Gabe Orange became an expert builder and troubleshooter, 3D printing and leak detection; Brian Carreno was the expert at assembling cables, worked on the Raspberry Pi cameras and tether; Jordan Weiss-Penzias worked on potting, manipulators, testing and writing the report; Rinoa Oliver figured out how to stream video from the cameras to a web page and lead up the writing of the reports; Aden Sommerville was the genius behind the net for picking up debris on the surface; Nathan Madsen and Konish Bhattacharya worked on the strategy for completing the tasks; Saashin Subramaniam worked on the software.

Early on we decided to use an *iterative design process* where we quickly built a prototype, tested it and submerged it in the pool. This allowed us to *fail fast* and find flaws in our design earlier. Our process is modeled after how Space X designs rockets. Before designing Talos, everyone was assigned a prop to build as well as a land rover kit in order to give people experience with assembling robotics. Additionally, everyone was tasked with reading through the competition manual and *Underwater Robotics: Science, Design, & Fabrication* during this period to familiarize themselves with the tasks to complete and gain a better understanding of this year's theme. An above-ground pool was also constructed at our mentor Tim Sylvester's house so that we would be able to test submerging the ROV in water as soon as it was fully prepared. We also had access to a larger, deeper pool at a team member's house.

While building Talos, our team met over Zoom weekly to summarize what everyone had worked on over the past week and discuss what should be prioritized for the coming week. People were also able to come over almost every weekend in person to make progress on developing the ROV and test different materials. If there was an issue with any of the materials used, new materials could be tested the following week. Our iterative design process proved to be both efficient and flexible, as it ensured problems could be troubleshooted as soon as possible, and also allowed for people to have the ability to work in person whenever they were available during the weekend. Since it ensured we had ample time to test the ROV, we were more easily able to address many of the major problems encountered such as extreme leaking.

Design Rationale

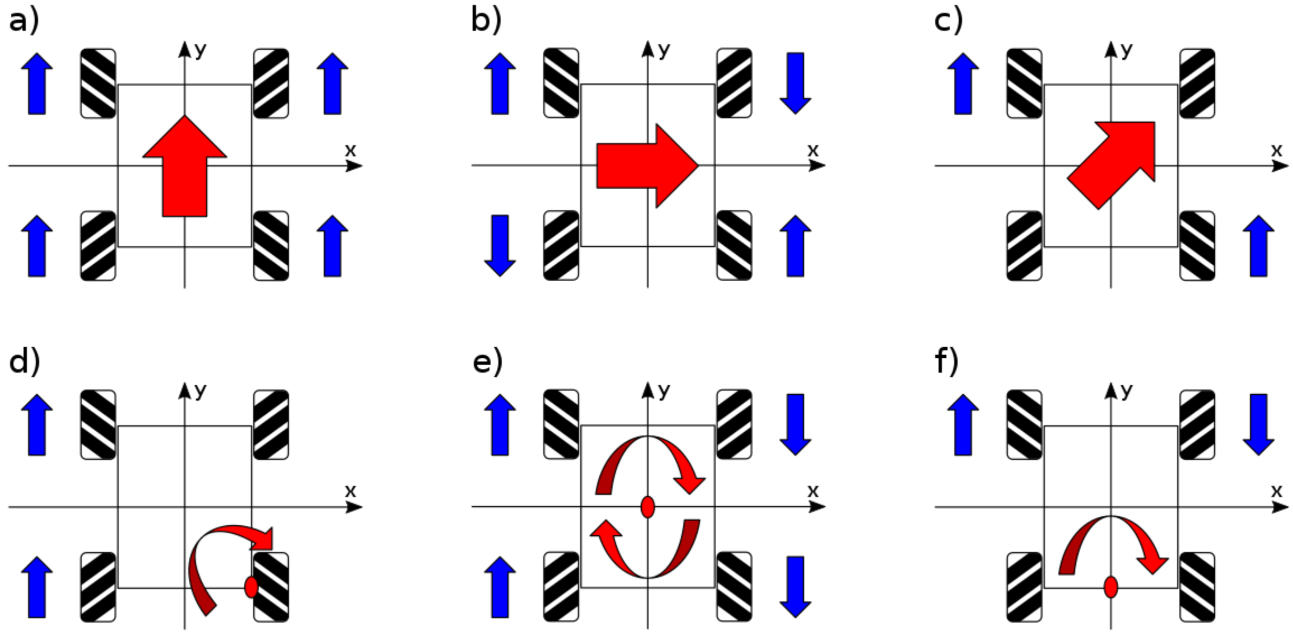
Philosophy

Something is always better than nothing, and there are plenty of things better than just something. This is one of our main philosophies when it comes to building robotics. We first design a prototype that may work. Before any part of the ROV was theorized, we assembled an above ground pool, followed by all the props. We thought that, more than anything, the most productive use of our time would be testing our prototypes. The only way to truly figure out what works the best is to try all of your available options. This philosophy allows us to fly through ideas at a very quick pace. We often buy components rather than designing our own, because it wouldn't be possible to assemble our prototypes as fast as we want to test them if we had made everything from scratch, and since we're a new team, we didn't have materials to work with that were left over from previous projects. We bought many different products to test their effectiveness, finally settling the best option we came across that would allow us to accomplish the required tasks without considerable hindrance. This rationale enables us to have a much more well-rounded design, as we are always sure to never spend excessive time designing one portion of the ROV. For example, we probably could have spent a full month engineering the best possible chassis, but if we had done so, we would not have as much time to make other crucial design decisions, such as switching from an Arduino Uno to a Raspberry Pi.

Above ground test pool and props. (Photo Credit: Andrew Sylvester)

Land Rovers

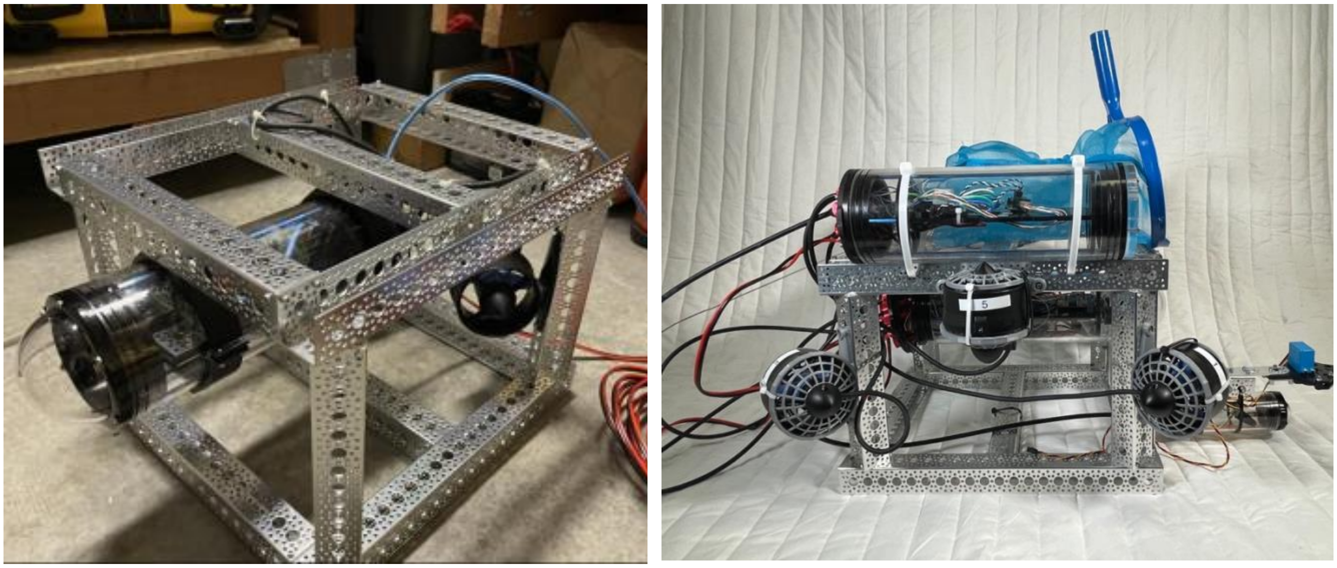
We began the designing of our ROV by having each team member build a land-based ROV. Our rationale behind this was that since every member of our team had varying experience, this would be a good way to teach everyone the basics of mechanical, electrical, and software design. It also allowed us to start testing out what parts we like and dislike, and many of the parts on the land rovers were usable on the underwater ROV. The land rovers had four mecanum wheels, which move at a 45 degree angle when turned. This motor layout resulted in a vectored control system, similar to ones used on underwater ROVs. The motors were each connected to Roboclaw motor controllers, which were controlled by an Arduino Uno, which read signals from a goBILDA Element-6 wireless transmitter. In the end we had 10 rovers and we now had experience with how to make a drive system for a robot.



Mecanum wheel vectored motion configuration. (Source: WikiMedia Commons)

Frame

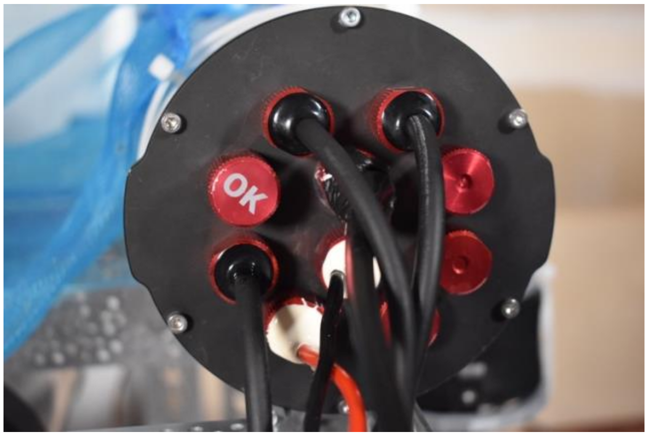
The frame is built out of aluminum channel from Actobotics. This channel is commonly used in FIRST robotics competitions. It is lightweight, sturdy, and has a mounting-hole pattern that allows us to attach and assemble parts quickly. Its size was decided by testing which parts fit well together and left ample space to add tools while fitting in the maximum dimensions. The frame has four vertical posts rotated 45 degrees to allow for a vectored thruster design. Three 4" watertight chambers are attached to the frame, with the main chamber attached in the center, and two on each side. These chambers house the electronics and also provide buoyancy due to their large volume. The enclosures provide enough buoyancy to make Talos positively buoyant. We added extra weight to make it sink and then weighed it in a pool with a digital spring scale. We determined that Talos was about 1.3kg positively buoyant. To counter out this positive force, we zip tied some small weights to the frame. These weights made Talos perfectly neutrally buoyant. A bar of channel sticks out from the front to give the gripper lots of clearance from the ROV when performing tasks. The frame has an eye bolt to attach the strain relieving wire rope.

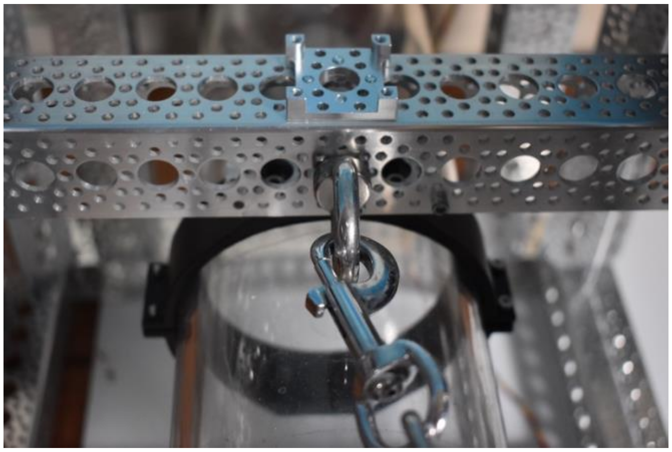


Early prototype of the frame and final frame. (Photo Credit: Nathan Madsen)

Tether

The tether is very simple; it contains one CAT6 cable for ethernet, two 12 AWG cables for power, and a ¼” wire rope. The CAT6 cable is a gel-filled burial cable, which ensures that the cable will not let water seep in, even if the casing gets nicked. The wire rope is attached to an eye bolt on the frame with a carabiner. The wire rope is included so that when the ROV is lifted, the ethernet and power cables are not strained. The wire rope is especially important this year, when operating in the SLAMR pool requires us to pull our ROV up 3ft from the water surface to the deck. This tether design was chosen because it is as simple as possible, it doesn’t have any extra wires for camera signal or fluid power.

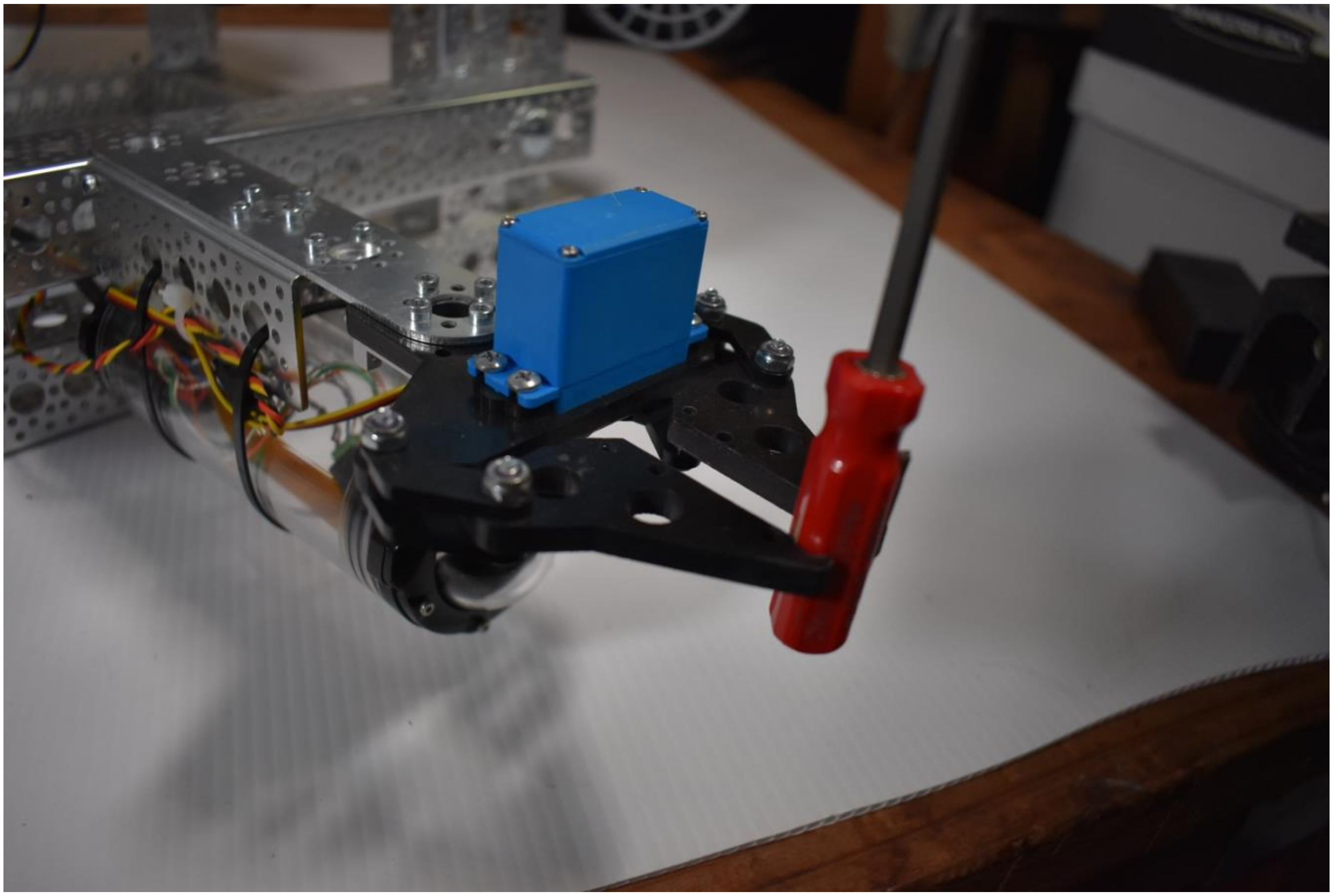




Cables entering tube and wire rope connected to eye bolt for strain relief. (Photo Credit: Nathan Madsen)

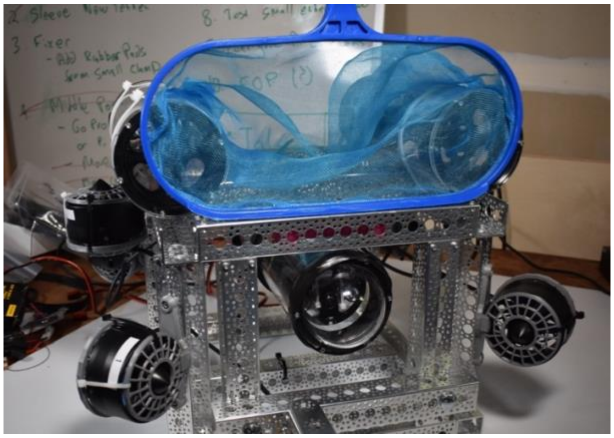
Tools

Talos is equipped with a small but effective tool set. The main tool used for the majority of the tasks is the parallel gripper. The gripper is powered by a HiTec D646WP waterproof servo. The servo is rated for only one meter in water however, through our testing we found it to be suitable for five meters. We are prepared to use coax seal in case of leaks but so far we have not seen any signs of leakage. The gripper is from the ServoCity parallel gripper kit. The gripper is made from plastic parts. Its simple mechanical design allows it to open and close while keeping the grips parallel. We compared this design with some of the other designs from ServoCity and found this to be the most effective. We went with a pre-made kit because it already fit the servo and the frame channel. In the future, we hope to experiment with designing and manufacturing our own designs for grippers. Through pool testing, we found that this gripper is able to effectively perform all of the tasks that require retrieving or transporting items with the exception of the surface debris and the drain pipe sample.



Gripper holding a screw driver. (Photo Credit: Nathan Madsen)

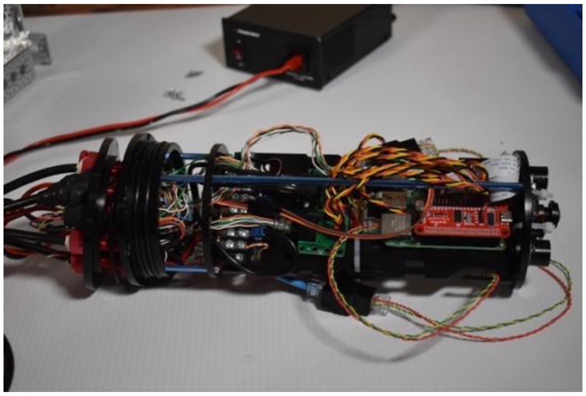
For the surface debris, we attached a net to the top of the ROV. We tried out three different sizes of nets. The net is simple and very efficient for completing this task.



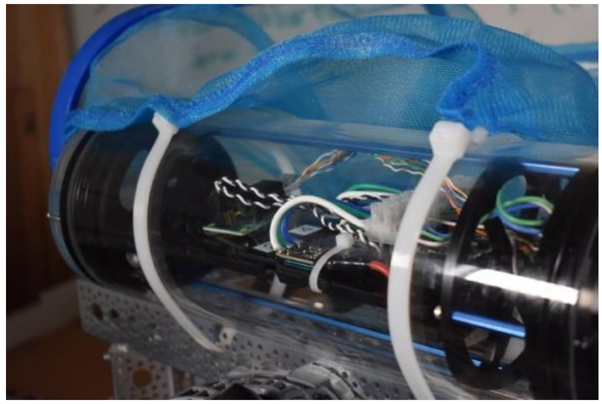
Early prototype of net and final net. (Photo Credit: Nathan Madsen)

Electronics

The ROV electronics are split across 3 four inch tubes. The main tube houses a Raspberry Pi and its accompanying electronics, while the side tubes each contain three motor controllers connected to their motors. The main tube receives the 12V DC and the ethernet cable from the tether. Power is distributed to the Raspberry Pi, the 5-port ethernet switch, and outside to the two side chambers. The Raspberry Pi uses a 12V to 5V, 3A USB Buddy from PowerWerx to provide power at the right voltage and amperage. The ethernet cable from the surface and the Raspberry Pi are both connected to the SwitchBlox ethernet switch. The Raspberry Pi has a 16-Channel Servo Hat attached on it's GPIO pins that is able to send the Pulse-Width Modulation (PWM) signals necessary to drive servos and motors. The servo for the gripper is directly connected to this hat. Six of these channels are connected to two servo extension boards, which allow us to send PWM signals over CAT6 cable. Both of the servo extenders are connected via CAT6 cables to their respective side chambers. Both side chambers have the receiving board for the servo extenders. Their outputs are connected to three BlueRobotics Electronic Speed Controllers (ESCs). The ESCs are connected to the chamber's power source and to three T200 thrusters. The ROV has four horizontal vectored motors and two vertical motors. This gives us three horizontal degrees of freedom and sufficient vertical thrust to lift the ROV. The vertical thrusters are on the sides of the robot to direct their flow away from items near the gripper. Back in the main chamber, the Raspberry Pi has an Arducam Raspberry Pi camera attached with a ribbon cable. We originally were using a Pi Noir camera, but the footage it gave was tainted red and low quality, so we later switched it to an Arducam. To provide a view of the gripper during operation, a Raspberry Pi zero with another Arducam Camera is housed in a 2" enclosure attached underneath the gripper. We decided to attach this camera in addition to the main camera so that the pool layout surrounding the gripper could be more easily seen, allowing us to be more precise while piloting the ROV. The Pi Zero is powered with a 5V output from the ethernet switch and it establishes an ethernet connection with four wires on a CAT6 cable. Power and ethernet are sent over a singular cable with four wires for ethernet and the other four wires for power.



Electronics in the main tube including Raspberry Pi, camera, servo booster, Ethernet switch and power distribution. (Photo Credit: Nathan Madsen)



Electronics in one of the auxiliary tube Electronic Speed Controllers. (Photo Credit: Nathan Madsen)

Software

Software runs on four devices in the system. The main Raspberry Pi, the secondary Pi Zero, the Intel NUC on the surface, and the Arduino on the surface.

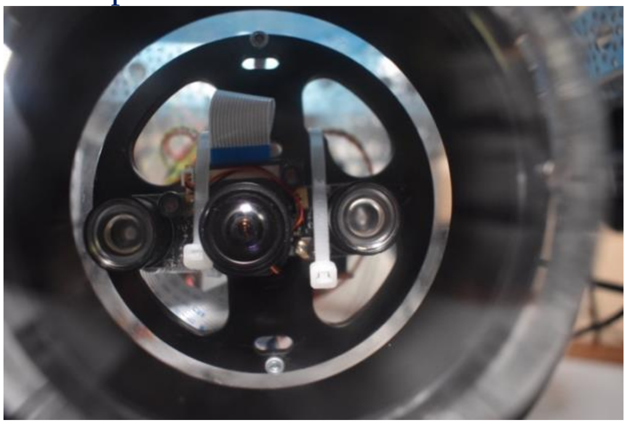
The Arduino on the surface is used to read the 6 channels from the transmitter and send them over Serial to the NUC.

A Python program running on the NUC reads the inputs given from the Arduino, mixes them and sends the values for the PWM controls down to the main Pi. User Datagram Protocol (UDP) is used to send these values.

A Python server on the main Raspberry Pi receives the values sent from the NUC over UDP, and sets each of the channels on the servo hat to the given values.

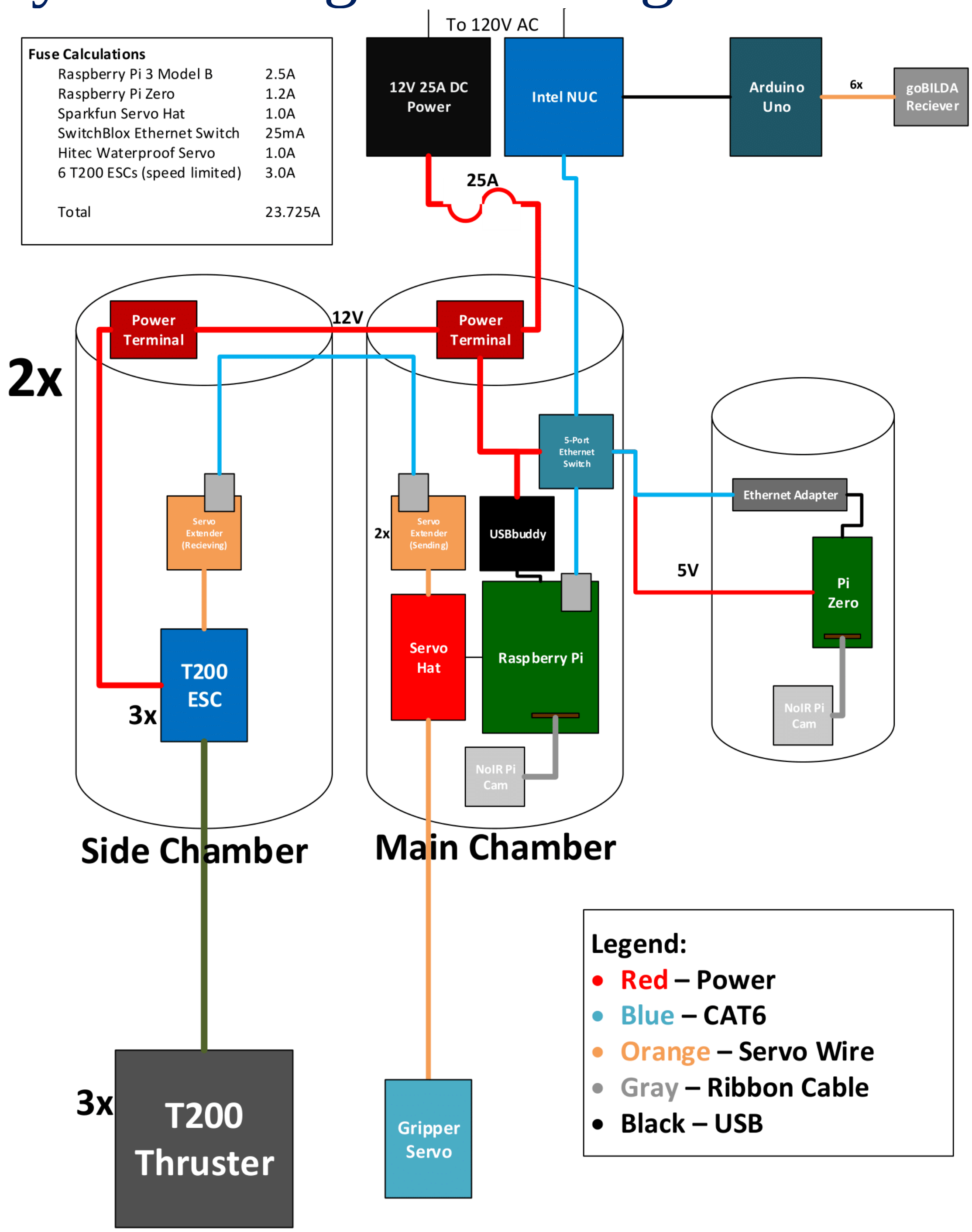
The main Raspberry Pi and the Raspberry Pi Zero both run code that streams their camera output to a Python Flask webserver. The pilots can access the video feeds by opening a web window at the IP address of both computers.

Top-side electronics with RC transmitter and receiver, Arduino and Intel NUC. (Photo Credit: Nathan Madsen)



Raspberry Pi camera streams video over IP to a web browser on top-side computer. (Photo Credit: Nathan Madsen)

System Integration Diagram



Safety

One of the many precautions we took was 3-D printing custom thruster shrouds. We originally were using a simple design that we found on Thingiverse, but we decided that it wasn't sufficient. We followed our iterative design process by using the design and then tweaking it until we found it sufficient. Our ROV, Talos, comes equipped with a pneumatic extendable arm. While pneumatics are incredibly useful, they can also be quite dangerous. Because of this, we had a member of our team, Andrew Sylvester, take the pneumatics test on the Mate ROV website, ensuring that we know how to deal with the pneumatics properly. Pneumatics aren't the only dangerous part of the ROV, however. In order to minimize potential danger when transporting the ROV as well as when taking it in and out of the pool, we always have two people lifting Talos at any given time, and even have two people managing the tether. One person stands on the pool deck where the ROV is deployed and feeds tether to the ROV so that there is freedom for it to move but not excess slack. The second person stands distanced by a few feet of tether, and feeds tether to the first person while ensuring that the tether is managed safely.

The T200 thrusters on Talos are able to draw up to 20A each, but we are only given 25A to operate off of. To prevent this excessive power draw, the thruster signal is capped at 50% in the control software. This percentage was decided on based off of data given on the thruster manufacturer’s website. When given a PWM signal of 1700 microseconds and voltage of 12V, the T200 thruster draws 3 amps. When given a signal of 1300 the thruster also draws 3 amps. Any signal in between draws less than 3 amps. The maximum power draw from the thrusters is 18 amps when they are all ran at full speed.

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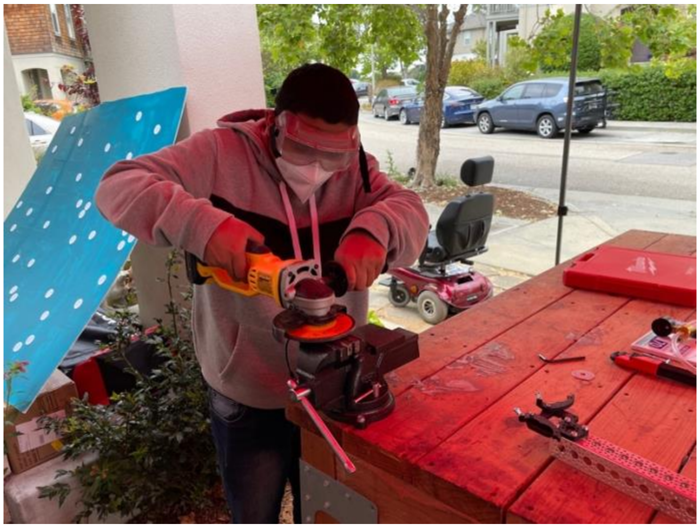
Sampson watching over the team. (Photo Credit: Nathan Madsen)



Brian grinding USB cable and wearing safety equipment. (Photo Credit: Nathan Madsen)

There is also a twenty five amp fuse so that if, at any point, the ROV would draw an unsafe amount of power, it shuts off automatically.

Before putting Talos into the water, we always test all systems to ensure that everything is working properly. We test for leaks using a method often used by plumbers fixing leaking pipes; we covered the joints in soapy water, and then pressurized the chamber. Using this method, we were able to see the leaks in the form of bubbles. Any leaks that were found that couldn't be sealed any other way were covered in coaxial seal, to ensure that the least amount of water would make its way into the enclosure. Even if all of our waterproofing failed, and the enclosure started to fill with water, however, the electronics would stay dry for a long period of time. This is because we have all of the main wiring and circuit boards mounted to the top of the enclosure, so that they will stay above the water.

This year has been far from normal when it comes to meeting people in person, which makes designing an ROV quite difficult. Despite this major hurdle we were able to gather together a whole team. With ten people on a team, COVID safety becomes a major concern. In order to mitigate this threat, we met almost entirely outside, and everyone wore masks the whole time and practiced social distancing as often as possible. Many members of the team also took a weekly COVID test and the majority of team members have already gotten a COVID vaccination.

Safety Checklist:

Powered On	Listen for speed controller beeps signaling that the ROV is receiving power Visually confirm that Raspberry Pis, cameras, and Ethernet Switch are receiving power by checking indicator lights Test connection to main and secondary raspberry Pi by pinging from computer terminal Turn on video feed for main and tool cameras and confirm their functionality Connect transmitter to computer Run control software and move thrusters lightly to confirm their functionality Activate gripper to test it
Before deploying:	Two capable people present for tether managing and lifting Talos Deck clear and not slippery Tether is neatly coiled, not strewn across deck Confirm wire rope strain relief is clipped onto eye bolt
Connection Lost:	Check if any of the camera feeds are working

	Check if motion is working Make sure ethernet cables are plugged in fully Power off ROV, wait a few seconds and then power on If connection isn’t back within a minute after power cycling, have tether team pull the ROV to the surface manually to inspect and repair the ROV.
Leak in chamber:	Power off ROV Pull to surface and out of the water Unplug vent plug from leaking chamber Gently remove electronics tray from chamber Drain and dry electronics tube Check penetrator panel for source of leak Patch the leaking penetrator with coaxial seal and electrical tape Check integrity with vacuum pump before redeploying

Critical Analysis

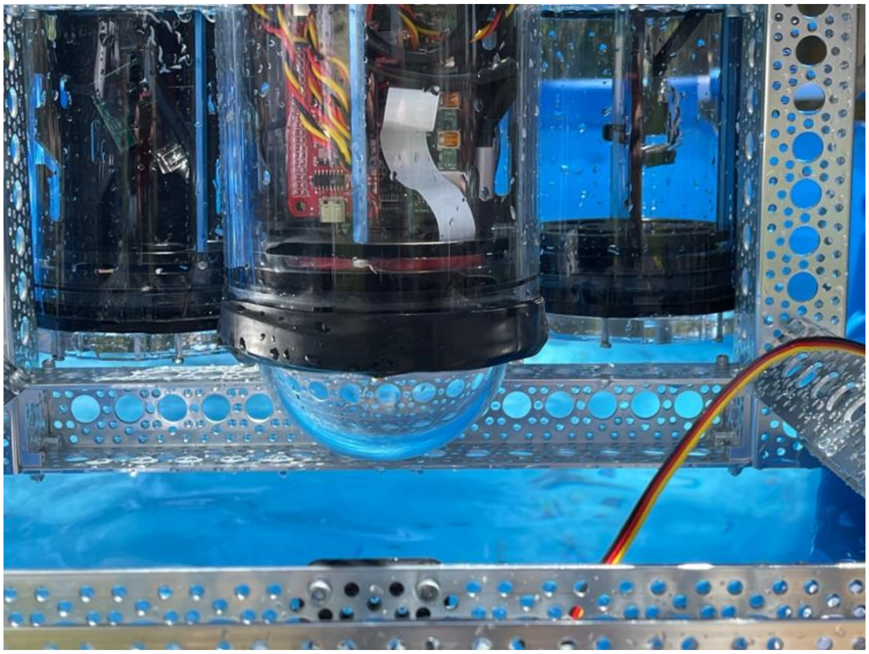
Testing and Troubleshooting

At Hephaestus Robotics, we prioritize testing our prototypes often and using the results to modify and improve upon the design. Our iterative model of design allowed us to test the ROV multiple times per week in the 3 foot deep above-ground pool as well as several times in the 9 foot deep pool, providing the ability to fully compare different varieties of materials. For example, we tested several different nets for collecting ping pong balls. We also had ample time to test different electronic designs, and we found that having three enclosures was more ideal when compared to only one, as more enclosures ensured both that the electronic components wouldn't become too convoluted, and also displaced additional water, which allowed the ROV to more easily achieve neutral buoyancy.

Technical Challenges

One of the most serious technical challenges we encountered was issues with the epoxy used to pot the penetrators, as well as the leakages that these issues resulted in. We had originally bought Wetlink Thixotropic 80a epoxy from Blue Robotics, which we used to pot the 2 motors that we had assembled so far. Since the epoxy had solidified perfectly, we used it to pot the remaining 4 motors as well as the power and ethernet the next week. However, the epoxy didn't harden that week as quickly as it had previously. We suspected that this may have been due to the cold temperature in the garage, so we let it sit for a few days longer, this time with a heater installed in the garage. However, it still never fully solidified, and at this point we realized that the epoxy we used had expired. We decided to buy new epoxy to pot the remaining penetrators, though we found that Blue Robotics no longer sold the wetlink epoxy and instead purchased Loctite Marine Epoxy, which we added on top of the wetlink epoxy. This epoxy did solidify, though it was far more brittle and shrunk significantly after drying.

By prioritizing testing and iteration, we were able to first test the ROV in the above-ground pool in early March. When it was submerged 3 feet deep for 15 minutes, we found that there was minor leakage in the single enclosure we were using at the time. After applying Coax-Seal Moldable Sealant which we also purchased at Blue Robotics, these leaks were significantly reduced. However, the potting had become sticky as well as soft to the touch a few weeks later. We found that the expired wetlink epoxy had expanded and was oozing out of the loctite epoxy. We then realized that we needed to redo all the potting. We purchased pre-potted connectors from Blue Robotics this time, which we tested for some of the penetrators. We simultaneously tested using solely the loctite epoxy for the other penetrators. After installing these new connectors, we tested the ROV in the testing pool and found that there were no leaks. However, significant leakage occurred when we tested it in a 9 foot deep pool the following week. In order to identify which penetrators were causing leakage, we added a valve to increase the pressure, and measured the pressure using a pressure gauge. We sprayed the penetrators with soap and water to see which bubbled, which is a strategy commonly used by plumbers to assess leaks. We determined that the loctite epoxy was causing leakage, likely due to its tendency to shrink while trying. The following week, Om Shastri repotted all the motors with the loctite epoxy using a syringe to add the epoxy directly into the penetrator. We are also using pre-potted penetrators for spare motors since we’re sure the current loctite epoxy works but haven’t tested the wetlink epoxy as thoroughly.



ROV main chamber with no leaks! (Photo Credit: Nathan Madsen)

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Interpersonal Challenges

Apart from the technical challenges encountered, there were also various challenges that arose from our inability to organize together. Since not all team members attend the same school, we weren't able to use campus as a meeting location to gather together in person. We instead scheduled weekly zoom meetings to update all team members on the progress we had made every week and what we hoped to work on the following week. Additionally, we were only able to meet in person during the weekends, and not all team members were available to come over every day to work. For this reason, before working in person on the weekend, we would plan out what tasks needed to be worked on most and assign available people to work on these in person.

Lessons and Takeaways

Although our iterative model gave us ample time to test different prototypes, if we had planned more thoroughly for each prototype we tested, we likely wouldn't have needed to test as much. For instance, we mapped out the motor placement before building the ROV and never needed to iterate on its design. However, we did need to change the electronic placement multiple times because we never thoroughly planned it out. In the future, we will definitely prioritize planning more in our projects.

Throughout creating Talos, we've also learned the usefulness of building off of other's work. For example, we used the soapy water test invented by plumbers to test for leaks. Building off of the ideas of others allowed us to be more efficient and thorough in our design.

Future Improvements

We consider this ROV a two-year project. With this year being our first year competing at the Ranger level, and many team members' first time competing in MATE, our goal for this year is simply to get a ROV with basic functionality. Our goal for the next year is to expand upon this ROV greatly, adding many features that we considered but ultimately never had time to implement.

One of our ideas for next year is to add a depth sensor and an Inertial Measurement Unit (IMU). These two parts open up lots of options for automatic control of our ROV. The depth sensor will give the ROV the ability to hover itself without the aid of the pilot. The IMU can be used to automatically balance the ROV.

Another goal for next year is to redo our electronics housing. We are very satisfied with our electronics design however, the way that our electronics are split over three tubes is very inefficient. To add to that inefficiency, the tubes are not even being fully used. We are looking into using a box design instead of a cylindrical design for next year. We are also looking at alternatives to cable penetrators such as cable glands or bulgin connectors. This would make it much easier to edit the electronics and it would also make the ROV much smaller.

For the electronics, we are also looking at making custom circuit boards, specifically for the speed controllers. The speed controllers from BlueRobotics work fine, but we didn't like how the boards have no mounting holes, and how the signal wires are flimsily soldered on. We had two speed controllers break because the signal cables snapped off. We hope to design our own board using the open source circuit diagram but with adding mounting holes and header pins.

Accounting

Budget

Income				Amount	
Parent Donations				$5,000	
Expense					
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Value**	**Actual**
Hardware	Purchased	Frame, Enclosures, Manipulators & Tether	$1,500	$1,500	$1,598
Hardware	Purchased	Thrusters and Motor Controllers	$1,500	$1,500	$1,236
Electronics	Purchased	Raspberry Pi, Servo, Cameras, Arduino, Sensors	$800	$800	$614
Electronics	Donated	Intel NUC, Monitor and Laptop	$2,500	$0	$2,500
General	Purchased	Entry Fee	$200	$200	$200
General	Donated	Travel to Regional Competition	$300	$0	$304
Total			**$6,800**	**$4,000**	**$6,452**

ROV BOM Costs

Category	Type	Description/Examples	Projected Cost	Budgeted Value	Actual
Hardware	Purchased	Frame, Enclosures, Manipulators & Tether	$1,500	$1,500	$1,598
Hardware	Purchased	Thrusters and Motor Controllers	$1,500	$1,500	$1,236
Electronics	Purchased	Raspberry Pi, Servo, Cameras, Arduino, Sensors	$800	$800	$614
Total			**$3,800**	**$3,800**	**$3,448**

Project Costs

Purchased					
Category	**Expense**	**Description**	**Source/Notes**	**Amount**	**Running Balance**
Hardware	Frame	Actobotics Aluminum Channel and Parts	Servo City	$283.00	$283.00
Hardware	Enclosures	3 Water Tight Enclosures and Penetrators	Blue Robotics	$1,101.00	$1,384.00
Hardware	Manipulatros	Gripper, Pool Skimmer	Servo City, Arswin	$25.00	$1,409.00
Hardware	Tether	Wire Rope, Cat 6 Cable, 12 AWG Zip Cord, Fuse Holder	PowerWerx, Amazon	$189.00	$1,598.00
Hardware	Propulsion	6 Thrusters and Electronics Speed Controllers	Blue Robotics	$1,236.00	$2,834.00
Electronics	Servo Components	Water Proof Servo, Servo Boosters and Cables	Servo City	$149.00	$2,983.00
Electronics	On Board Electronics	Raspberry Pi 4, Raspeverry Pi Zero, Cameras and Cables	Raspberry Pi and Arducam	$189.00	$3,172.00
Electronics	On Board Network	Ethernet Switch, Ethernet Adapter for Pi Zero, Cables	SwitchBlox, MonoPrice	$105.00	$3,277.00
Electronics	Sensors	Depth Sensor	Blue Robotics	$103.00	$3,380.00
Electronics	Top Side Electronics	RC Plane Controller, Ardunio and Project Case	Servo City, Arduino	$68.00	$3,448.00
General	Registration Fee	Registration Fee for Monterey Regional Competition	MATE	$200.00	$3,648.00

Purchased	Mileage	Santa Cruz to Monterey - 54 miles x 2 ways x 5 cars x $0.56 IRS milage rate	Parents	$302.40	$3,950.40
Sub-total					**$3,950.40**
Parts Donated					
Electronics	Computer and Monitor	Intel NUC and Computer Monitor	Donated by Team Member	$800.00	$800.00
Electronics	Laptop	MacBook	Donated by Team Member	$1,500.00	$2,300.00
Sub-total					**$2,300.00**
Cash Donated					
General		Parent Donations	Parents	$5,000.00	$5,000.00
Sub-Total					**$5,000.00**
Summary					
Total Expenses					-$6,250.40
Parts Donated					$2,300.00
Cash Donated					$5,000.00
Final Cash Balance					**$1,049.60**

Acknowledgements

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