# 2023 MATE World Championships

## Technical Documentation for *Besh Lo* ROV

### Palos Verdes Institute of Technology (PVIT)

Palos Verdes High School, Palos Verdes Estates, California, USA

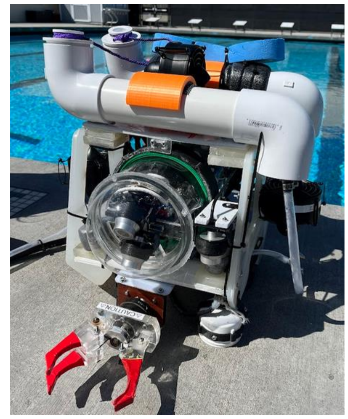

Photo 1: *Besh Lo* By: Cynthia Ho

2023 PVIT ROV Company:

| | | | |
|---|---|---|---|
| **Jenna Chow:** | President, Mechanical Engineer | 4th year | Class of 2023 |
| **Andrew Moore:** | CEO, Lead Electrical Engineer | 2nd year | Class of 2025 |
| **Azalea Lurie:** | CSO, Mechanical Engineer | 2nd year | Class of 2025 |
| **Allison Yu:** | Chief Info + Marketing Officer | 2nd year | Class of 2025 |
| **Zach Rapoport:** | Chief Financial Officer | 2nd year | Class of 2025 |
| **Cynthia Ho:** | Lead Design Engineer | 2nd year | Class of 2023 |
| **Lisa Lininger:** | CTO, Lead Mechanical Engineer | 2nd year | Class of 2024 |
| **Benjamin Peters:** | Lead Software Engineer | 2nd year | Class of 2025 |
| **Ruka Ito:** | Co-Lead Mechanical Engineer | 1st year | Class of 2026 |
| **Riko Negishi:** | Electrical Engineer | 3rd year | Class of 2023 |
| **Claudia Goldsworthy:** | Marketing and Information | 1st year | Class of 2023 |
| **Kharianna Gracie:** | Electrical Engineer | 2nd year | Class of 2023 |
| **Stuart Canario:** | Software Engineer | 1st year | Class of 2023 |
| **Skylor Sun:** | Mechanical Engineer | 2nd year | Class of 2023 |
| **Gavin Montgomery:** | Design Engineer | 1st year | Class of 2024 |
| **Timothy Keroles:** | Design Engineer | 1st year | Class of 2024 |
| **Eto Uchiyama:** | Design Engineer | 1st year | Class of 2025 |
| **Henry Argentieri:** | Mechanical Engineer | 1st year | Class of 2025 |
| **Annalia Henderson:** | Design Engineer | 1st year | Class of 2026 |
| **Connor Byrne:** | Mechanical Engineer | 1st year | Class of 2026 |
| **Trevor Jones** | Mechanical Engineer | 1st year | Class of 2026 |
| **Payson Cai:** | Mechanical Engineer | 1st year | Class of 2026 |

Mentors:

**Lorraine Loh-Norris:** Instructor
**Fred and Julie Smalling:** Mentors
**Fred Chow:** Mentor
**Isabel Moore:** Mentor

# Abstract

The Remotely Operated Vehicle (ROV) division of the Palos Verdes Institute of Technology (PVIT) from Palos Verdes High School, has designed and built the *Besh Lo* (see acknowledgements), a small, lightweight, low cost, versatile ROV to meet the challenges outlined in the 2023 Marine Advanced Technology Education's (MATE) Request for Proposals (RFP) and to address the needs of the global community. The *Besh Lo* and crew support work to: 1) Combat climate change by supporting marine renewable energy platforms by mooring solar array panels and removing biofouling on wind turbine mooring lines, 2) Maintaining healthy waterways by assessing coral heads, treating diseased corals and reintroducing native fish species to natural habitats, and 3) Designing, building and operating a vertical profiling float (the *Bumblebee)*.

The *Besh Lo,* a non-corrosive, sturdy yet lightweight, reliable vehicle suitable for harsh environments, is the result of 15 years of successful engineering in creating ROVs that have met past MATE challenges through our original designs with strict adherence to safety standards. Custom designed and fabricated parts, such as a manipulator, chassis, and variable buoyancy system, are prioritized to address our customers' specifications. The team consists of 22 members with expertise in ROV design, additive manufacturing, laser cutting, electronic hardware assembly, computer programming, and scientific data collection and analysis. Our pilots and deck crew are experienced and capable of accomplishing the tasks as outlined in the RFP.



Photo 2: PVIT Team By: Braden Colli

Back Row (L→R): Azalea Lurie, Benjamin Peters, Connor Byrne, Claudia Goldsworthy, Trevor Jones, Henry Argentieri, Skylor Sun, Payson Cai, Gavin Montgomery, Stuart Canario, Timothy Keroles

Front Row (L→R): Andrew Moore, Annalia Henderson, Allison Yu, Cynthia Ho, Jenna Chow, Kharianna Gracie, Riko Negishi, Ruka Ito, Zachary Rapoport, Eto Uchiyama, Lisa Lininger

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## Project Management

**Company Structure:** The Palos Verdes Institute of Technology is a company run by high school students with the goal of becoming more environmentally friendly through advancements in cutting edge technology. This year the company significantly expanded from 12 to 22 members, with 10 returning and 12 new employees who have a shared passion and drive. Sub teams were established at the beginning of the season according to members' interests and skills, and the sub teams lead the parallel development of different parts to reach the customer's goals. (See Appendix A.) At the beginning of each meeting, the full team would come together to discuss each group's goal for the meeting and make any other important announcements. Then each sub team would gather to complete their given tasks. A more experienced individual would be identified to whom a team member could ask for help. The team members encourage collaboration, respectful interactions, and a supportive learning environment so that the team members and the company can succeed. Important protocols such as keeping a safe working environment and focusing on completing work throughout the whole meeting were enforced and expected of each employee. (See Photo 3.)

Photo 3: Team Working
By: Julie Smalling

**Scheduling and Planning:** One of the biggest challenges this year was scheduling and planning. Having high expectations, the team called for a large time commitment from every employee. As a result, communication between employees was very important to maintain high attendance and productivity during meetings. Messages were sent out to the team via GroupMe, our messaging software, and by email, and all employees were encouraged to actively communicate with each other. An important organization tool was using a shared Google Drive. Every single document produced by the company resides on the drive which is organized into Design Documents, Photos, Competition Documents, Safety and other categories. Documenting all the company's work is vital to PVIT's success. Creating a project schedule posed a challenge. At the beginning of the year we attempted to use an electronic scheduling tool (Microsoft project). We were not able to get our school district to support the software for us. After that didn't work out, we functioned without a schedule for a while. We eventually created a master list of 96 items to do and posted it in our workroom with the intent of using it. (See Appendix B.) Although individual team members did not refer to it often, the master project schedule was a help. Project Scheduling is an area we can improve in.

**Challenges:** Learning new skills was the greatest hurdle our ROV team had to overcome. Our team is composed of 22 students, 10 returning and 12 new. Eight of our returning members have only one year previous experience. All the first-year members had to learn several crucial engineering skills. Building the ROV based on scattered knowledge from last year proved a difficult challenge. However, our team was able to find resources online, in the classroom, and from one another to obtain the knowledge needed to complete our project. Though this learning process took a great amount of time, our team came away with new engineering experience and a special team bond that will aid us in future projects.

## Design Rationale

At PVIT, we have many resources which we utilize in the design and manufacture of our ROVs. Our in-house tools, including 3D printers, soldering irons, drill press, and laser cutter provide us with the means to manufacture our ROV and fabricate its payload tools. We use design software, namely Autodesk Inventor, Corel Draw, and MultiSim, to create precise models of parts and components and test circuitry designs. As a result, the *Besh Lo* is our original design, custom-made primarily from base components as elaborated in the following sections.

**Overall Vehicle Design & Systems Approach:**
The driving factor in the design of the vehicle was simplicity, while still meeting the customer's needs: reducing the parts of the ROV to yield optimal efficiency and reliability. The design team spent weeks developing the final design. They began by looking at the customer's task requests and generated ideas how to solve each challenge. Ideas were sketched on whiteboards for the team's evaluation. The placement of key vehicle elements was also brainstormed. Sketches of the tools (syringe device, fish box) and variable buoyancy and thruster placement on the

overall craft were made. Designs were evaluated through discussion and brainstorming merits and deficiencies. Rejected ideas included non-parallel thruster placement and various syringe mechanisms. The best ideas were integrated into the final version. The overall design of *Besh Lo* was strategically built in 3D CAD software from Autodesk to plan its size and layout. In the software, we designed and assembled the major components of the ROV including the "Brain" of the ROV, thrusters, side frames, and crosspieces. (See Figure 1). The design also includes the most essential tool on the ROV, the manipulator. Our company prioritized the parallel positioning of the Brain to the side frames to make the vehicle more compact and hydrodynamic. We created a fully functioning ROV that meets the size and weight goal and is maneuverable to accomplish MATE's demanding tasks.

Figure 1: CAD Assembly
By: Cynthia Ho

**Mechanical Design and Fabrication:** We customized our side frame design to reduce water resistance by narrowing the side frames in the front and back of the ROV and incorporating cut-outs. After careful measurements made in CAD, each component was precisely cut using a laser cutter in our lab. The side frames (See Figure 2) are cut from polypropylene sheets; a material we chose because it is strong, lightweight, and machinable. We first laser cut the designs onto cardboard as a prototype. (See Photo 4). In this way, we were able to test many different designs without wasting premium materials. There were multiple redesigns adjusted to fit our claw and Brain. Once we were pleased with the design of the prototypes, we cut our final design onto the polypropylene. These components were then assembled according to the CAD. (See Figure 1). The *Besh Lo* is 42 cm in height, 54 cm in length, and 48 cm in width, and weighs 10.4 kilograms. (See Appendix E: Weight Table.)

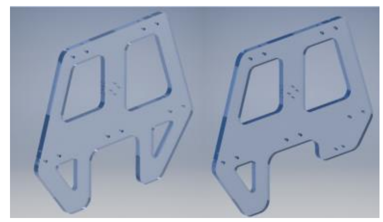


Figure 2: Side Frame Designs
By: Cynthia Ho

Photo 4: Cardboard Prototype
By: Cynthia Ho

The thrusters are oriented with the three axes to provide significant maneuverability, conserve power, and to facilitate the coding process and thruster calculations. The thrusters were placed outside the frame for unobstructed water flow and more space for components.

All Brain input connections are on the endcap of the enclosure to streamline the vehicle for better flying, minimize size and weight, and allow access for repairs if necessary. On the front, the Brain has a clear dome with a camera. There are two waterproof cameras, one facing forward and one facing downward, for maximum visibility needed to accomplish complete tasks such as inspecting a seagrass habitat and inspecting the buoy. We mounted our claw as a modular unit assembly on a single mounting plate for easy removability for servicing. The claw is in the center to facilitate clear viewing for the pilot while grasping objects such as the tent and solar panel array. The light is mounted at the back left of *Besh Lo* to facilitate treating the diseased coral. Careful consideration has been given to every detail of designing and building *Besh Lo*. Everything is considered for performance outcome and effect.

**Innovation**: The *Besh Lo* has a couple notable innovative features. The manipulator is the main payload tool which has very high functionality due to its innovative rotational feature. The rotation feature makes dumping the fish fry out of the box a simple task and allows the *Besh Lo* to grip items positioned either vertically or horizontally, serving the role of two manipulators. A second innovative feature of the *Besh Lo* is the custom endcap on the waterproof housing of the customized brain. (See Photo 5). The team cast the *Besh Lo*'s endcap out of epoxy resin. The casting process was chosen for its relative speed, ease and low cost compared to machining a cylinder blank. The cast was made by first designing the exact endcap and 3D printing a prototype out of PLA filament. Then, a mold was made by pouring silicone over the prototype in a box container. Once set, the prototype was removed from the silicone. The epoxy resin was poured into the silicon mold. Once set, the flexible silicone mold allowed for easy removal. We now have a low cost, light weight, machinable endcap and a reusable mold for future needs.

Photo 5: Custom Endcaps
by: Andrew Moore

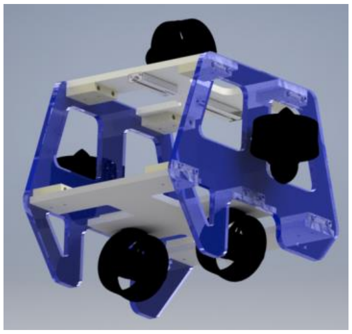


Figure 3: Thruster Layout
By: Cynthia Ho

**Propulsion:** Blue Robotics T200 thrusters, controlled by Blue Robotics ESCs, are used to propel *Besh Lo*. The team decided to implement a thruster configuration involving only 5 thrusters to optimize the thrust of the ROV for the amount of power (205 watts) it gets from the limited 12 V and 16.7 amp power source. One strafe thruster sits atop the *Besh Lo* yet close to its center of mass for limited sway, which is responsible for its sideways movement. *Besh Lo* has two vertical thrusters, one placed on each side panel, which propel it towards and away from the surface. Two thrusters are placed under the Brain that provide the ROV forward and backward mobility. (See Figure 3) The team opted for a configuration that does not include any vectored thrusters because having a purely linear configuration means one less thruster and allows the ROV to be as powerful and quick as possible under the amperage restrictions. In the horizontal plane, having 3 thrusters vs. 4 puts each thruster higher on the power curve for a net increase in power. (See Figure 8, page 11). Sufficient maneuverability is attained through use of sophisticated programming and pilot expertise. Each thruster is equipped with a secondary custom safety shroud in the form of round metal fan guards (See Photo 6). These are implemented to prevent injuries or damage to the user such as crushing or chopping off digits, or harm to any animal or plant life. The team's goal is to propel the *Besh Lo* as efficiently and with the greatest speed we can manage while being conscious and protective of its surroundings. We feel our fast vehicle best meets the customer's needs in accomplishing a myriad of tasks in a 15-minute timeframe.

Photo 6: Thruster
By: Azalea Lurie

**Buoyancy & Ballast:** The buoyancy and ballast on our ROV is carefully designed for optimization. The *Besh Lo* is guaranteed to be stable and fly horizontally with an even weight distribution. As we have used very light materials this year, and with a high volume brain tube, we had to add 1.8 kilograms of ballast to the lower front area of our ROV - the lower part for more stability and the front as it was more buoyant during our water tests. Likewise, we added more floatation to the upper rear for more stability. Our vehicle is designed to have our payloads near the bottom in order for the center of mass to be near the bottom. We use a variable buoyancy system for quick ascent to the surface. The system is made of two separate 2-inch PVC pipes with elbows as well as a manual bike pump attached to an air tube running into the pipes which allows our deck crew to pump in air at the direction of the pilot. (See Photo 7). Two PVC caps are removed at the surface to allow the pipe to be flooded with water so that the ROV can descend. Our craft is slightly negatively buoyant when the pipe is water-filled. When the pipe is filled with air, the ROV is highly positively buoyant.

Photo 7: Variable Buoyancy
By Eto Uchiyama

The lift capability of the ROV with thrusters alone is 40 *N*; two thrusters at 20 *N* each.
The lift of the variable flotation is:

$F_B = pVg$

$F_B = (1000\ kg/m^3)(6.178 \times 10^{-4}\ m^3)(9.8\ m/s^2) \times 2$

$F_B = 6.054\ N \times 2 = 12.1\ N$

Total lift capability (thrusters + variable buoyancy) is: 40 *N* + 12.1 *N* = 52.1 *N*

For additional lift capacity, the variable buoyancy system is not used, and a detachable lift bag (an inverted 3.8 L plastic bottle) is used instead. The lift bag helps the ROV lift up to 60 Newtons. Air is pushed into an air hose, which is connected to the lift bag, from a bike pump. This causes the lift bag to become buoyant.

The lift capacity of the bag is:

$F_B = pVg$

$F_B = (1000\ kg/m^3)(3.79 \times 10^{-3}\ m^3)(9.8\ m/s^2)$

$F_B = 37.14\ N$

Lift capability of the ROV with the lift bag is 77 *N*. The *Besh Lo* can lift heavy objects!

**Cameras:** The *Besh Lo* features three exploreHD 2.0 Underwater ROV/AUV USB Cameras purchased from DeepWater Exploration. One camera is in the front dome and shows the forward view. A second camera, also in the dome, is angled down to view the claw fingers. The third camera is mounted to the ROV sideframe and views the claw at an angle and includes a view well below the fingers to aid tasks such as installing the solar panel array and the eco mooring. The design team manufactured the custom camera mounts. The cameras are high definition, have a wide-angle view, color correction, automatic ambient lighting adjustment, and fisheye adjustment for underwater distortion. They provide excellent viewing for our pilot. They are sensitive to impedance issues and we discovered our SeaCon bulkhead connectors are not compatible with them as their signal wires have to be fully twisted. Consequently, we had to move one camera from in the water to inside the waterproof brain enclosure. The cameras were purchased a year ago and due to their superior performance and the cost investment, they are a reused component of the ROV.

**Underwater Measuring & Photomosaic Technology:** Underwater measurements are calculated from photo images of the measured item with a known size reference in the same image. A pixel to object ratio is created with a known prop and using OpenCV, the ratio is used to calculate the actual length of the desired object with an algorithm created in Python.

**Manipulator:** The *Besh Lo*'s manipulator, which we call "The Claw," consists of three fingers that are configured in a way that is similar to the shape of a hawk's claw. When deciding on the final design for the claw we chose a design that allowed the claw to pick up larger objects with greater ease such as an eco mooring. These fingers open using a single Firgelli L12 electric linear actuator, 50:1 gear ratio with limit switches, which is waterproofed by an acrylic tube, O-rings, and custom fabricated end caps. (See Photo 8). This design adaptation gives the claw a 12 Newton grabbing force at 12V. The fingers open wide and are interlocked when in their fully closed position, allowing gripping of items ranging in size from less than 1cm to 10cm. We wrapped the fingers with colorful tape as a safety feature, for visibility and grip. The claw is held together by a custom mount comprised of two custom bushings made of a very light, slick material (Epoxy Phenolic). The center point of the actuator end cap is attached to a waterproof servo with 90-degree rotation which provides the ability to pick up a variety of objects positioned either horizontally or vertically. The sophisticated "wrist" action of the claw makes tipping the box to release fish fry easy. The company this year made the decision to reuse a carbon fiber 3D printed custom mount for the servo. The mount was previously made of acrylic and laser cut which was known to break easily. Using a 3D printed part has solved that problem. The entire assembly is mounted on a rigid, lightweight plastic plate which makes it a modular payload tool that can be easily attached to the ROV in any desired position. The claw is custom made from base components. We custom designed the claw fingers, acrylic mounts, carbon fiber 3D printed mounts, backplate and numerous linkage pieces and cut them out of acrylic sheets with our company's own laser cutter. The bushings are custom fabricated in a lathe. The servo is a waterproof motor purchased from Blue Robotics. Electrical connections are made and waterproofed by our electrical engineers. This year due to problems with the fragile servo wires, we added a strain relief to protect them. (See photo 9).

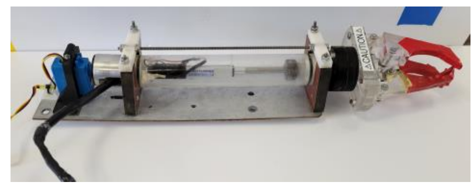


Photo 8: Claw
By: Lisa Lininger

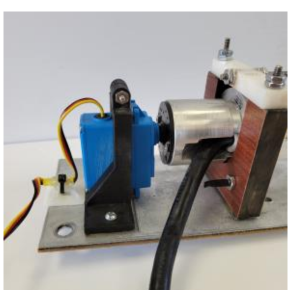


Photo 9: Claw, Servo, Strain Relief
By: Lisa Lininger

**Light:** We included a waterproof 12-volt light to simulate administering Rx to the diseased coral. (See photo 10). We have a 2-inch PVC pipe cap to focus the light source over the corral. We connected the light to the cap using Goop and then let it harden, so that the light stays in a fixed position. We custom designed the mount attaching the cap to the ROV and made it with a 3D printer using carbon fiber (See Figure 4). The light makes our ROV capable of administering Rx and saving corral.

Photo 10: Light
By: Connor Byrne

Figure 4: Light Mount CAD
By: Gavin Montgomery

**Water Sampler:** We built a water sampler using a 150 ml syringe and 3D printed parts such as 4, 1/2 inch by 6-inch support beams as well as a shower head shaped piece attached to a 3D printed piece that wraps around the syringe. (See Photo 11). Four springs create force to the extracting mechanism of the syringe. The device is "loaded" with springs compressed into the grasp of the claw. Upon opening the fingers of the claw, the sampler is "sprung" while the claw is still holding the device. We use this system to extract a sample using only mechanical energy. The water sampler is used to collect a 50 ml sample of liquid from above the coral head during the "Identify reef organisms using eDNA" task. The water sample will be analyzed for eDNA to identify coral fish species.

Photo 11: Water Sampler
By: Tim Keroles

**Fish Fry Release Box**: The fish fry release device is a custom designed 3D printed box with a weighted lid so that when turned upside down the lid falls open. (See photo 12). We designed this box intending to capture and transport fish fry. Three different handles were designed. We designed the handle by 3D modeling, then 3D printing it. First, we thought a rod sticking directly out from the box would be best. However, the rod proved too difficult for the claw to grip. Secondly, we tried to have the handle be a ring around the box but that wouldn't let the claw have a strong grip on the box. Lastly, we decided on a slanted square on the side as it allowed for the claw to grip the box with little to no issue. A key feature of the *Besh Lo* in releasing the fish fry is the rotating wrist action of the claw. What might be a challenging task of releasing Northern Redbelly Dace into their natural wetland habitat is easy for the *Besh Lo*.

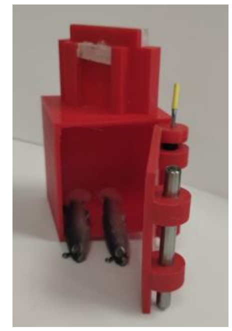


Photo 12: Fish Fry Release Box
By: Allison Yu

**Float:** PVIT offers a vertical profiling float constructed with a 5" PVC pipe and operated with a buoyancy engine comprised of a micro linear actuator and a membrane. (See photo 13). The Float, affectionately called the *Bumblebee*, is 73 cm tall with an outside diameter of 17 cm. The float is comprised of 2 major sections. The lower section is the buoyancy engine. It contains a mounted 6V DC micro linear actuator with an extending range of 10cm. The actuator is attached to a swimming cap which acts as a flexible membrane. The membrane has 5-centimeter expansion both upwards and downwards. The team found an innovative solution to the challenge in finding the best membrane for the float. Several different sheet thicknesses were tried. The chief float engineer is also a competitive swimmer and thought of using a swim cap. The cap is the right thickness and a perfect fit over the 5-inch PVC pipe, making the waterproofing easy. The upper section of the float houses the electronic components including the Arduino Portenta and battery. The cap on the upper section has a push button to activate the float. There is a waterproof antenna attached to the Portenta, which transmits via Wi-Fi the current UTC time and PVIT team name to the control desk using the team router and designated webpage. There is also a bilge switch, which is used to communicate to the Portenta that the float is on the surface, and that the signal should be sent to the desk. All safety requirements for the float have been met including fuse location and pressure relief device. See Safety Review document.

Photo 13: Bumblebee Float
By: Azalea Lurie

A member of the deck crew begins a timer preset in the Portenta by pressing the push button. The *Besh Lo* will deploy the *Bumblebee* and the vertical profiling sequence begins. The activated Portenta signals the linear actuator to retract five centimeters pulling the swimming cap inwards inside the housing. During this phase, the tensioned cap forms a truncated cone with a volume of 211cm$^3$ displacing approximately negative 211 grams of water thus making the float less buoyant and sinking. At the bottom depth the linear actuator is activated and will extend the linear actuator and start the Float's ascent. During this phase, the actuator extends 5 cm allowing the swimming cap to stretch displacing the identical amount of volume except outward. The increased volume of air in the float increases buoyancy and allows a consistent and smooth rise to the surface. At the surface the float switch triggers the Portenta to transmit the data. The float will complete as many vertical profiles as it takes for the signal from the antenna to be relayed twice.

**Tether:** The tether has 5 wires encased in an expandable mesh sleeve and is 18 meters in length. Two of the lines are for power and there are two others for ground and the remaining line is the ethernet cable. The power and ground consist of two 14 gauge wires and two 8 gauge wires each. We chose 8-gauge instead of 10-gauge for less voltage drop across the tether's 18 meters. Two separate power lines were necessary because the T200 thrusters pull enough power to cause the Raspberry Pi's to shut off; thus, separating the power between two lines with voltage regulators in the control box allows the brain and control box to have a steady stream of power even when the thrusters are at full throttle. The wires supply 12-volt power and ground to the remotely operated vehicle. The Ethernet cable provides wires for serial communications, video signal, and video ground. The Ethernet cable is CAT 6a and shielded. We chose CAT6a instead of CAT5 for less signal degradation. On the surface side of our tether, we have Anderson power pole connectors to connect to the control box. The tether has stress relief devices that attach it to the ROV and to the control box to prevent damage to its connectors if it is pulled. To ensure the tether does not drag and harm the environment, it has floatation attached to its wet end to help it float near the water's surface. Buoyancy is achieved by attaching small pieces of foam at 1-meter intervals. Air is delivered manually by a bicycle pump to the variable buoyancy system on the ROV. There is a check valve at the delivery end of the airline. The air line is on the outside of the tether so it is not too crimped. Tether management is an important aspect of flying the ROV. We adhere to the Tether Protocol when operating the ROV (see safety section).

## Software and Electronics

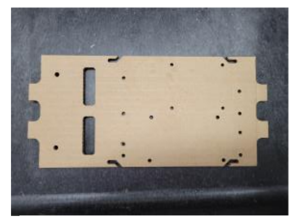


Photo 14: Cardboard Brain Plate Prototype
By: Cynthia Ho

Photo 15: Brain Tube
By: Andrew Moore

**Command and Control:** The "Brain" has been designed to fit into a 6 inch waterproof acrylic tube (See photo 15), where the electronics are carefully organized and compactly mounted to a custom backplane (see photos 14, 16 & 17). The Besh Lo is controlled by an original code written by PVIT programmers to allow the best control from our pilot with the Logitech 3D control stick. The ROV's brain communicates to the deck through an 8-pin ethernet connection. A Raspberry Pi computer and an Arduino microcontroller within the ROV brain handle the on-board electronics. Connected to the Raspberry Pi are all three of the cameras as well as the Arduino. From the Arduino there are signals for thruster motor controllers, the claw servo, and a relay board containing 6 relays for the claw and light. *Besh Lo's* brain receives two power and ground lines through two separate waterproof connections, where they are each then split on board. One power line supplies power for the Raspberry Pi and Arduino. The second power line and ground line are each connected to their own busbars to support the thrusters and payload tools. These separate power lines allow for all of the onboard electronics to be powered independently from the payload tools and thrusters thus eliminating power fluctuations to the sensitive electronics.

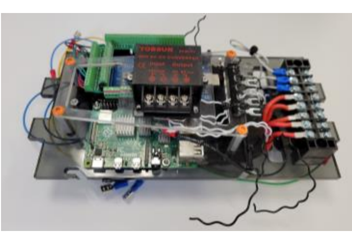


Photo 16: Brain Electronics Side 1
By: Andrew Moore

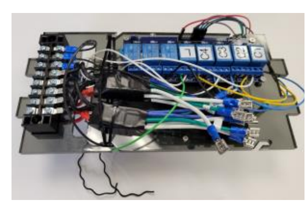


Photo 17: Brain Electronics Side 2
By: Andrew Moore

The on-deck control system of the ROV consists of several peripherals including a monitor with a separate keyboard and a control box. Inside of the control box are three busbars for power and ground, an ethernet switch, a mac mini, and two current regulators. Power is taken from the main power source into the box through a set of Anderson Power Pole Connectors. From these connectors, a 25 Amp fuse is present which leads to two switches. The first switch controls power to the box, and the second switch controls power down to the ROV. The ground from the Anderson connector goes to the ground bus while the power goes to the switches and then to the two separate power buses. One bus is smaller and one is larger. The larger one controls power to the ROV's thrusters and the current goes through a current regulator which ensures that it only uses 12 Volts. The smaller one controls power to the electronics in the brain and the control box. The power coming from these two buses exits through two pairs of Anderson Connectors which then connect directly to the tether. On the surface of the control box interface is a Volt and Amp meter which is connected in series to the rest of the control box circuitry

## Command, Control, and Communications (C3) Diagrams - Pictorial Block Diagram:

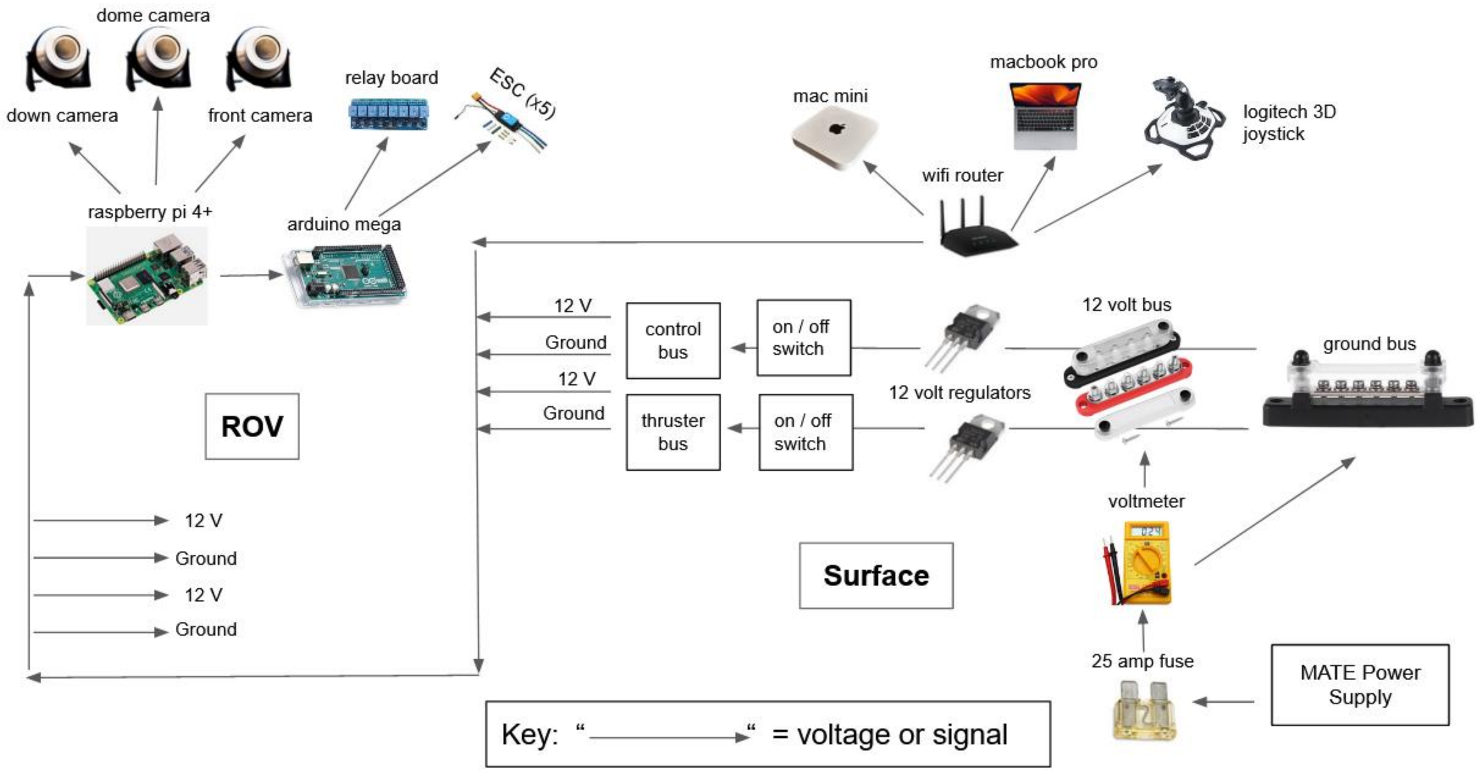



Figure 5: Pictorial Block Diagram
By: Allison Yu

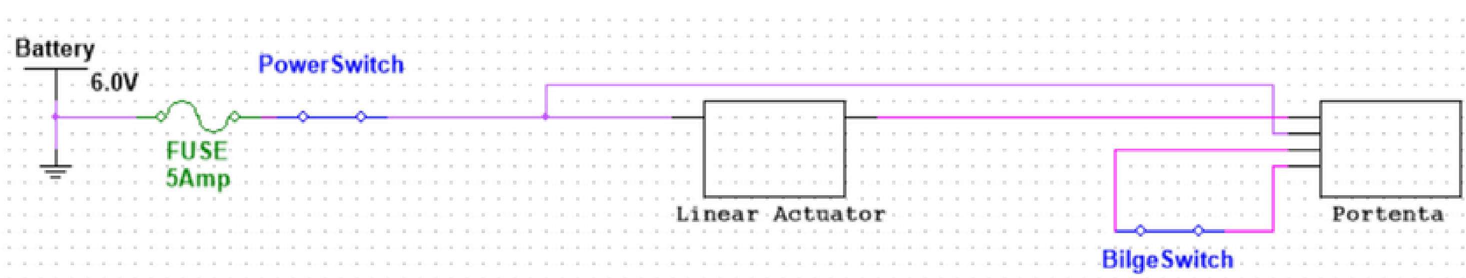
## Systems Integration Diagram (SID) for Float Device:

Palos Verdes High School, PVIT, 2023
System Integration Diagram (SID), NRD Float:
Legend: Purple = 6v, Pink = Signal
Note: a 5 Amp fuse is used due to availability.

Figure 6: SID for float
By: Lisa Lininger

**Fuse Calculation: Float**

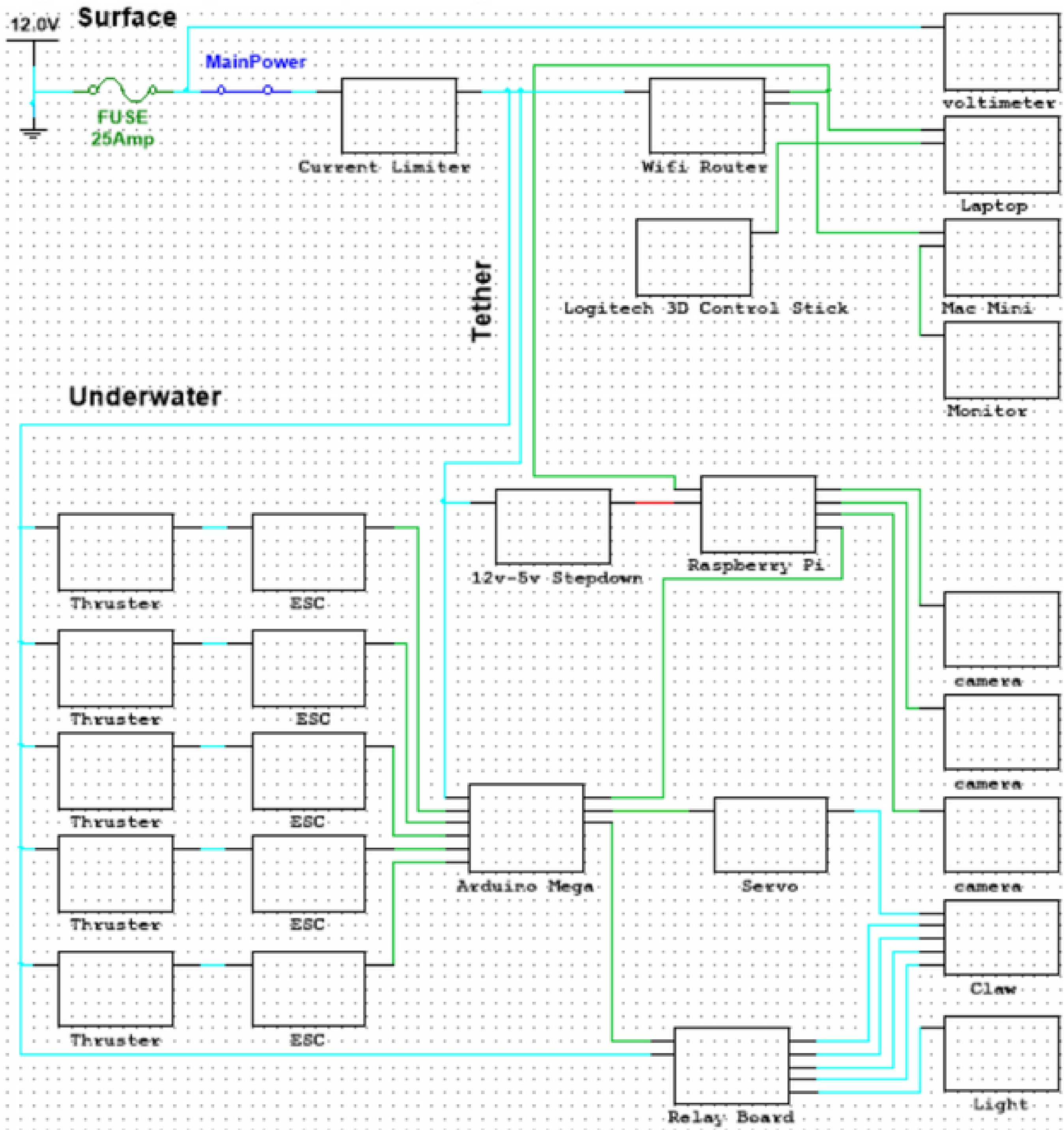
Overcurrent Protection= Float Device Full Load Current * 150%
Fuse Rating = [Linear Actuator] * 150
Fuse Rating = [(0.22)] * 150% = 0.33 Amps
Maximum Fuse Rating = 6 Amps



## Systems Integration Diagram (SID) for ROV:

**Palos Verdes High School, PVIT, 2023**
**System Integration Diagram (SID), ROV:**
Legend: Red=5v, Blue=12v, Green=Signal

Figure 7: SID for ROV
By: Lisa Lininger




**Fuse Calculation:** ROV
Overcurrent Protection= ROV Full Load Current * 150%
Fuse Rating = [(Linear Actuator) + (Light) + (Blue Robotics Thrusters)] *150
Fuse Rating A (horizontal thrusters) = [(0.22 Amps) + (0.3 Amps) + (3*5.0 Amps)] * 150%= 23.28 Amps
Fuse Rating B (vertical thrusters) = [(0.22 Amps) + (0.3 Amps) + (2*8.0 Amps)] * 150%= 24.78 Amps
Maximum Fuse Rating = 25 Amps
Nota bene: Our program control logic prevents simultaneous horizontal and vertical movement.

**Control Systems Design:** Each component of the new software architecture has been written in the Python programming language. The Microsoft Visual Studio Code development environment was utilized in each of the operating environments used to develop the *Besh Lo*'s software which includes the Raspian OS, Windows OS, and MacOS. All code is currently hosted in a GitHub repository and can be accessed by each of the software engineers within the company. Each module in the (ROV) system has been developed as a separate component using an object-oriented programming style to make it easy to understand and extend. A RESTful web services architecture, the same protocol that most online web applications run on today, handles the communication between the on-deck commander system and the onboard ROV brain system.

**Main Command Module:** The main control modules of the ROV are the Brain and Commander applications. The Brain's main control module is a Python application with an embedded web services module whose core function is to distribute the incoming/outgoing data to the various components of the ROV system and to call the necessary functions within the components that make up the ROV itself. The application works like a web server where incoming requests are handled as an http call. It is asynchronous and does not require the Python main loop to operate. The command system sends data to the Brain via http API calls and waits for a return response before relinquishing control. The architecture allows multiple clients from the command system to communicate with it simultaneously. The Commander's main control module is also a Python application, but it has a traditional main loop architecture that waits for incoming messages from the Logitech 3D Extreme Pro Flightstick or other UI controls. Based on these messages, the Commander either forwards the data to the Brain or operates the different command system modules.

**Thruster Module:** The motors are one of the most crucial parts to any ROV and must be controlled efficiently. The motors are controlled from an Arduino Mega that sends Pulse Width Modulation (PWM) signals from the pins to each of the ESCs. The Arduino Mega is connected to a Raspberry Pi through a USB connection. The Raspberry Pi controls the Arduino Mega using PyFirmata and Firmata* open source libraries. Firmata runs on the Arduino and PyFirmata runs on the Raspberry Pi, and through Firmata, the Arduino and Raspberry Pi communicate with each other. The Python syntax that comes from the Raspberry Pi is translated into understandable instructions for the Arduino Mega that are used to turn on and off certain pins on the Arduino. The actual architecture of the Python application in the Raspberry Pi is quite simple. One key file, br_thruster.py, controls the thrusters. The file does the first initialization of the thrusters and pins, and uses the Logitech 3D Extreme Pro Flightstick inputs to call certain routines that allow the ROV to move. There are two types of key routines within br_thruster.py -- low level routines and high level routines. The low level routines include doing the first initialization of the thrusters and pins, assigning each pin to its own unique thruster. The high level routines are instructions given to pins that make the thrusters move the ROV forward, backward, up, down, etc., based on the inputs taken from the Logitech 3D Extreme Pro Flightstick. The Flightstick communicates via hardware device driver open source library known as Pygame*.

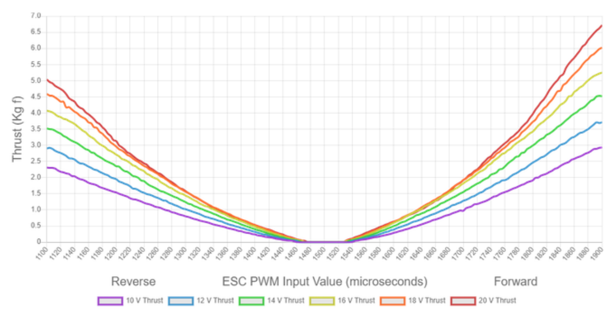



Figure 8: Thruster Power Curve By BlueRobotics.com

These high level routines send PWM signals to each pin with a set range of signals that control the thrusters. The 0 value (neutral) is 1500, the max value for clockwise rotation is 1900, and the max value for counterclockwise rotation is 1100. As the signals get farther from the 0 value, the thrust increases significantly, but this causes the thrusters to draw more amps. The ROV uses a 12V current when the thrusters run on the safety features within the program. Each action event generated by the controller is captured and saved in the Commander deck controller or in the Brain ROV controller. The saved data is called the "state" and is used to determine what action is to be executed next. A recent improvement includes the separation of main power into two lines, ensuring that the thrusters can maximize their pull of power while maintaining the power in the brain of the vehicle. Thus, we can operate the thrusters in a wider range of their power curves for greater performance than previous models. (See Figure 6).

**Open CV Module:** From a camera module, images are streamed to the main controller which then streams the images to the OpenCV* module. OpenCV takes in the image using the VideoCapture* function which turns the video into a still image in JPEG format. The JPEG is sent into OpenCV, which gives the location, name of the image subject, the width, and the height. This identifies an image subject, turns the image into a coordinate plane, and gives the coordinates of the subject, to make finding the subject easier for the operator. OpenCV can also detect object edges. This is useful in identifying colored lines to follow transects and predesignated pathways. OpenCV can also stitch together two images. Given two side-by-side images, it stitches them together to create one merged image.

## Build vs. Buy, New vs. Reused:

PVIT's ROV Team operates as efficiently and as organized as possible, which includes *Buy vs. Build* and *New vs. Used* decisions, following a distinct process. If we can build it based on the materials, tools and skills we have, we typically build it, as PVIT's first preference is always to custom build to meet specific customer's needs. One example is the custom made fish fry release device. If we decide to buy, we investigate the right product and make sure our money is spent effectively. We research on the internet to find a part that would work best, factor in cost, and shipping times. If we build, our building process is simple. We use design software as needed and use the correct tools and materials. Customization of newly built and reused parts is done using our software and manufacturing tools. PVIT's Markforged Onyx 3D Printer, which uses carbon fiber filament, was used to print our water-sampler housing with a custom clasp. This piece must be strong enough to oppose the loaded spring tension. PVIT's Makerbot Replicator 3D printer, which uses PLA material, was used for the light-service items like the fish fry release box. We use our ULS laser cutter to fabricate various thicknesses of acrylic and polypropylene for planar pieces including the claw fingers, brain mounting plate and ROV sideframes. Reused items are limited to high cost, sophisticated items. The thrusters, waterproof cameras, and waterproof bulkhead connectors are all reused.

## Testing and Troubleshooting

**Problem Solving:** When there is a problem, team members locate it and discuss troubleshooting methods with the rest of the team, and solutions are proposed by members. In manufacturing the *Besh Lo*, we tested our payload tools and other devices multiple times to optimize our design and performance. When producing the software, troubleshooting and debugging is key to writing an efficient and bug-free program. We test the software through mock tests, using LEDs and older thrusters to make sure the software is functioning properly. Each test results in new tweaks, like speed changes, and better movement routines to make the software more efficient. For electrical work, we test every connection after we complete it to make sure that there was no bridging and that everything is properly soldered. Upon completion of the *Besh Lo*, it is first tested in the lab where each operational function (thrusters, claw, light) is tested. After passing the dry test, the *Besh Lo* is tested against the customer's specs, which are simulated in a 2.1-meter-deep pool environment using company-built props and tools. If the *Besh Lo* is not functioning, the troubleshooting begins in one of three areas: the craft/Brain, the tether, or the surface control box. We utilize a methodical approach, testing that power is reaching all elements, and looking for unplugged or loose connections. Next, using a multimeter, we test the continuity of the electrical system in each of the three areas. If continuity is intact, we test circuits to see if they are complete. If any circuits are open, we replace the broken component and retest for a complete circuit. Once all subsystems are successfully functioning, we test the vehicle. On the vehicle, we look for physical problems like interference or loose or broken parts. If no further complications arise, the *Besh Lo* is ready to launch; otherwise, we repeat the troubleshooting process. Our rigorous manufacturing and testing practices, developed over the last decade, have resulted in a very reliable product.

## Safety

PVIT prioritizes the safety of all team members due to our delicate and sometimes hazardous work. With many new team members joining PVIT, we established an orientation that informs and reminds everyone of the proper safety protocols of the Environmental Health and Safety (EHS) policies and our team's Job Safety Analysis (JSA). Employees worked in pairs or small groups so that no one uses machinery on their own. Safety meetings are also held periodically, focusing on specific safety topics such as hand safety, eye safety, electrical safety, power tool safety, etc. Team members are educated on how to safely handle and operate the ROV to eliminate any potential accidents. Should a team member violate a safety protocol, they are immediately informed of the hazard and re-taught the proper procedure. The violation is then brought up in our next safety meeting to ensure that all team members are fully informed of the necessary safety procedure.

Since some of the payload tools pose potential dangers to divers or others working with our ROV, we have incorporated certain safety measures. Thruster shrouds cover each thruster, and rounded edges and warning labels have been integrated into the *Besh Lo* to prevent harm to personnel. The tips of our claw's fingers are colored red to signal a potential pinch point, all sharp edges on the ROV have been removed or covered to eliminate cutting hazards. Thrusters are shrouded with MATE compliant custom-fit shrouds based on MATE specification MECH-006. To protect the electronics and those working around the vehicle, we house the electronics in an acrylic tube. The tube is sealed with a nose cone and an endcap, with SeaCon bulkhead penetrators used on all wires coming in and out of the endcap. Additionally, we have a 25 amp fuse installed between the power supply and the control box. See DOC-001, Company Safety Review for proof of compliance to MATE's protocol. Pool safety rules include that team members never run on the pool deck and that electrical power supply lines are kept away from water. PVIT team members refer to safety checklists while operating or working around the ROV to reduce any dangers that threaten the safety of our team members or the ROV.

***General Safety Checklist:***

___ Establish communication with co-workers.
___ Ensure everyone has hair tied up, sleeves rolled up, and earphones/jewelry put away while using any tools.
___ Ensure everyone is wearing closed toed shoes.
___ Ensure everyone is wearing safety glasses.
___ Ensure passageways are clear of objects and wires.
___ Keep hazardous objects and materials away from members and ROV when not being used.
___ Keep all electronics, aside from the tether, away from water.
___ Ensure all wires are carefully and effectively covered.
___ Ensure the power connection and controller are connected before powering on the control box.

## Operational Checklists and Protocol

***Tether Protocol:***

***Set up:***

1. Unroll the tether. Eliminate all kinks.
2. Safely plug the tether into the control box.
3. Secure strain relief to the control box to prevent it from possibly becoming disconnected.
4. Prevent other employees from stepping on the tether by ensuring they're aware of its deployment
5. Connect the strain relief to the ROV.
6. Connect tether to ROV.

***Post Run:***

1. Safely unplug and disconnect the tether from the control box.
2. Safely unplug and disconnect the tether from the ROV.
3. Roll up the tether neatly on the hose reel.

***On Deck Checklist:***

1. Proceed with the tether set up protocol.
2. Connect power supply and turn on to 12v.
3. Power up the ROV.
4. Test the thrusters and claw.
5. Test the camera views on the proper Deck Screens.
6. Gently place the ROV in the water.
7. Release any trapped air pockets.

8. Deck crew gives the "ready" signal.
9. Pilot calls "3, 2, 1, Launch!"

***Pre-Run Checklist:***

1. Check the electrical power connections.
2. Dry run to check that cameras are working properly and are unobstructed.
3. Check to ensure that all waterproof seals are secure.
4. Check the thrusters to see if they are working and are clear of obstructions.
5. Check the claw to see if properly functioning.

***Post-Run Checklist:***

1. Turn off power in the Control Box.
2. Turn off the power supply.
3. Follow the tether disconnect protocol.
4. Dry the ROV and set it safely on the cart.
5. Clean up the work area of all materials, props, supplies, and trash.

## Budget and Cost Accounting

**Budget:** At the beginning of the year, we formed a budget to estimate total spending for the year. Our first budget (submitted in November 2022) was $11,765. It included purchased items, fees, and travel to Worlds. This budget was too high and rejected. With further scrutiny we resubmitted a budget request of $7100 which was approved.

**Funding:** Funding comes from the Peninsula Education Foundation (PEF). This foundation raises money for many different parts of our school district (PVPUSD), including our ROV team. PEF provides two thirds of our annual budget and our school's booster club and parent donations supply the rest.

**Spending:** We follow a procedure to purchase materials. First, we research on the internet. We put the chosen parts into a form on Google Sheets. The order form gets sent to our PVIT Director for approval and ordering. We maintain a spreadsheet to record everything purchased. Using this spreadsheet, we are organized in our purchasing method and can easily keep track of our parts and spending. Our total spending for this year to date is $3600. The company used purchased, donated, and reused items to construct a capable ROV below budget. Emphasis was placed on building an original ROV from fabricated components. Reused items were limited to tools, a few ROV parts like thrusters and cameras, and prop items.

**Table 1: Costing Summary For *Besh Lo* (vehicle and control systems):**

| | |
|---|---|
| Purchased | $3600 |
| Donated | $1180 |
| Reused | $340 |
| **TOTAL** | **$5120** |

**Table 2: Donated Items**

| Item | Qty | Source | Unit Value ($) | Total ($) |
|---|---|---|---|---|
| T200 Thrusters | 5 | BlueRobotics | 200 | 1180 |
| Pelican Large Case | 1 | Pelican, Control Box | 395 | 395 |
| **GRAND TOTAL** | **6** | | **595** | **1575** |

**Table 3: Reused Items**

| Item | Qty | Unit Value ($) | Total ($) |
|---|---|---|---|
| Control Box Shell | 1 | 250 | 250 |
| Waterproof Servos | 1 | 45 | 45 |
| T200 Thruster | 5 | 236 | 1180 |
| Prop Parts | 1 | 400 | 400 |
| Claw Components | 1 | 45 | 45 |
| 12V Power Supply | 1 | 150 | 150 |
| **GRAND TOTAL** | **10** | **1126** | **2070** |

**Table 4: Purchased Items**

| Item | Qty | Unit Value ($) | Total ($) |
|---|---|---|---|
| **ROV** | | **Subtotal ($)** | **$3600** |
| 8 gauge wire, 35m | 1 | 656 | 665 |
| Brain Power wire 35m | 1 | 20 | 20 |
| finger trap stuff, 35m | 1 | 23 | 23 |
| ethernet cable, 35m | 2 | 22 | 44 |
| logitech joystick | 1 | 33 | 33 |
| linear actuator | 2 | 140 | 140 |
| envirotex high gloss finish | 1 | 15 | 15 |
| High Density Polyethylene Board | 1 | 37 | 37 |
| Acrylic Dome | 2 | 15 | 30 |
| EnviroTex Lite® Pour-On High Gloss Finish | 1 | 15 | 15 |
| Water and Steam resistant EDPM O-rings | 1 | 19 | 19 |
| 6in 150mm Acrylic Dome | 1 | 18 | 18 |
| 6in 1/4 wall thickness Acrylic Tube | 1 | 114 | 114 |
| Straight Connectors, Female Socket Connect | 1 | 13 | 13 |
| Apple M2 Pro | | 1469 | 1469 |

| | | | |
|---|---|---|---|
| ELEGOO 8 Channel DC 5V Relay Module | 2 | 9 | 18 |
| Tolako 5v Relay Module 5V | 1 | 6 | 6 |
| Anderson Powerpole connectors | 1 | 17 | 17 |
| Power Busses | 1 | 12 | 12 |
| Voltmeter/ampmeter | 1 | 19 | 19 |
| 12v to 5v stepdown | 2 | 12 | 24 |
| 150ml Large Syringes | 1 | 7 | 7 |
| Basic ESC (T200) | 7 | 36 | 252 |
| T-Slotted Framing | 1 | 8 | 8 |
| Compression Spring | 1 | 8 | 8 |
| Various Screws | 35 | 6 | 197 |
| Polypropylene Sheet | 3 | 47 | 140 |
| 12 mm panel mount push button switch | 1 | 40 | 40 |
| High-Temperature Silicone Rubber Sheets | 1 | 55 | 55 |
| TYUMEN 100FT 16 Gauge wire | 1 | 19 | 19 |
| High-Temperature Silicone Rubber Sheet | 1 | 55 | 55 |
| Automatic boat bilge float | 1 | 17 | 17 |
| Epoxy Resin Kit | 1 | 161 | 161 |
| 12 mm panel mount push button switch | 1 | 40 | 40 |
| Super Elastic Silicone Mold Making kit | 1 | 52 | 52 |
| Wire connectors | 1 | 26 | 26 |
| Computer fan covers | 3 | 10 | 10 |
| Arduino Portenta | 1 | 120 | 120 |
| **Props and Other** | | **Subtotal ($)** | **$1436** |
| mini zip ties | 1 | 120 | 120 |
| 2 in. PVC Pipe Test Cap with Knockout | 1 | 1 | 1 |
| plastic syringe | 1 | 8 | 8 |
| Plastic Frogs Toy | 1 | 13 | 13 |
| 1-5/8 PVC Pipe Cutter | 2 | 20 | 40 |

| | | | |
|---|---|---|---|
| LASCO PVC Cap | 2 | 45 | 908 |
| Waterproof Heat Shrink | 1 | 10 | 10 |
| 75 ft Rope | 1 | 6 | 6 |
| 5" Schedule 40 White PVC Pipe | 1 | 118 | 118 |
| 5 in. Schedule 40 PVC Coupling | 1 | 12 | 12 |
| 5 in. Schedule 40 PVC Slip Cap | 1 | 15 | 15 |
| 3 in. x 2 ft. PVC DWV Sch. 40 Pipe | 1 | 17 | 17 |
| 3 in. PVC Pipe Test Cap with Knockout | 2 | 1 | 3 |
| Soldering tips | 1 | 32 | 32 |
| 150 ft extension cord reel | 1 | 15 | 13 |
| 3/4 waterproof heat shrink 10 ft | 1 | 12 | 12 |
| U-Bolt | 1 | 2 | 2 |
| Coarse Zinc-Plated U-Bolt | 1 | 2 | 2 |
| 3/4 in. PVC Sch 40 Female S x FPT Adapter | 1 | 1 | 1 |
| 3" Aluminum Carabiner D Ring, | 1 | 10 | 10 |
| LED Diode Lights Assortment | 1 | 7 | 7 |
| 48 Pack Plastic Test Tubes with Caps | 1 | 14 | 14 |
| 1 liter soft water bottle | 1 | 13 | 13 |
| 2-gallon bucket lid | 1 | 7 | 7 |
| Glad ClingWrap Plastic Wrap | 1 | 4 | 4 |
| Photoresistor Photo Light | 1 | 7 | 7 |
| 12" x 18" Foam Sheet | 1 | 1 | 1 |
| (13-Inch) 6-Quart Plastic Serving Bowl | 1 | 10 | 10 |
| PVC Pipe Fitting for Water, Cap, 2-1/2 Fem. | 1 | 41 | 41 |
| 2 gal. Plastic Bucket | 1 | 5 | 5 |
| 12 oz. Semi-Gloss Black Spray Paint | 2 | 6 | 13 |
| **GRAND TOTAL** | | | **$5036** |

# References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21. PyFirmata and Firmata Reference - Microcontroller communications protocol: https://roboticsbackend.com/control-arduino-with-python-and-pyfirmata-from-raspberry-pi/
22. BlueRobotics Depth Sensor Python Library: https://github.com/bluerobotics/ms5837-python

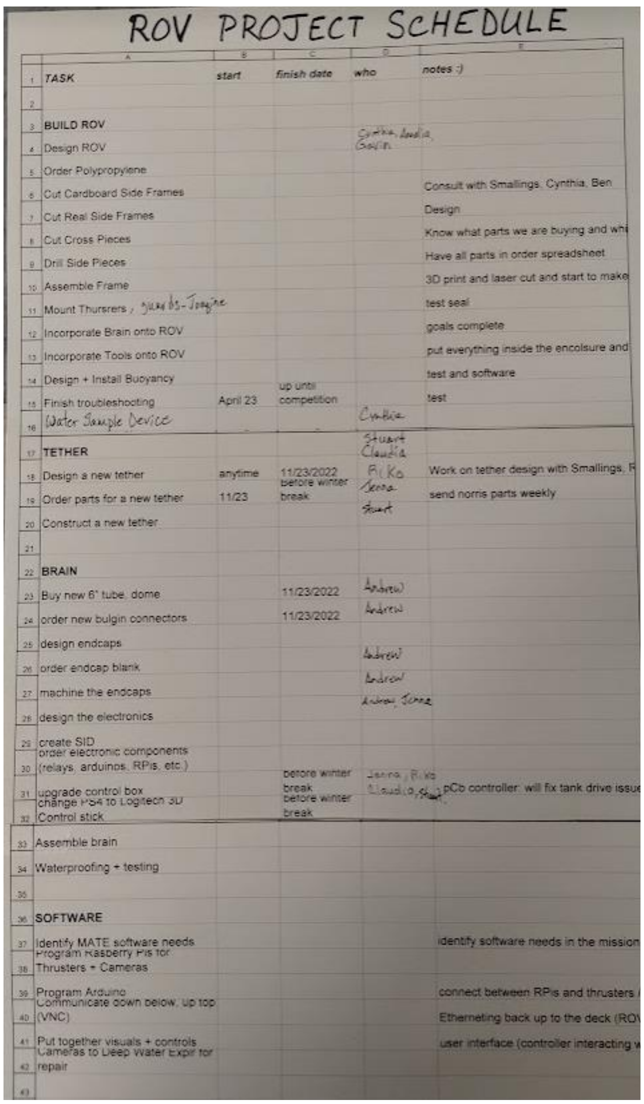
# Appendix

## A: Sub Team Structure

* Denotes Lead

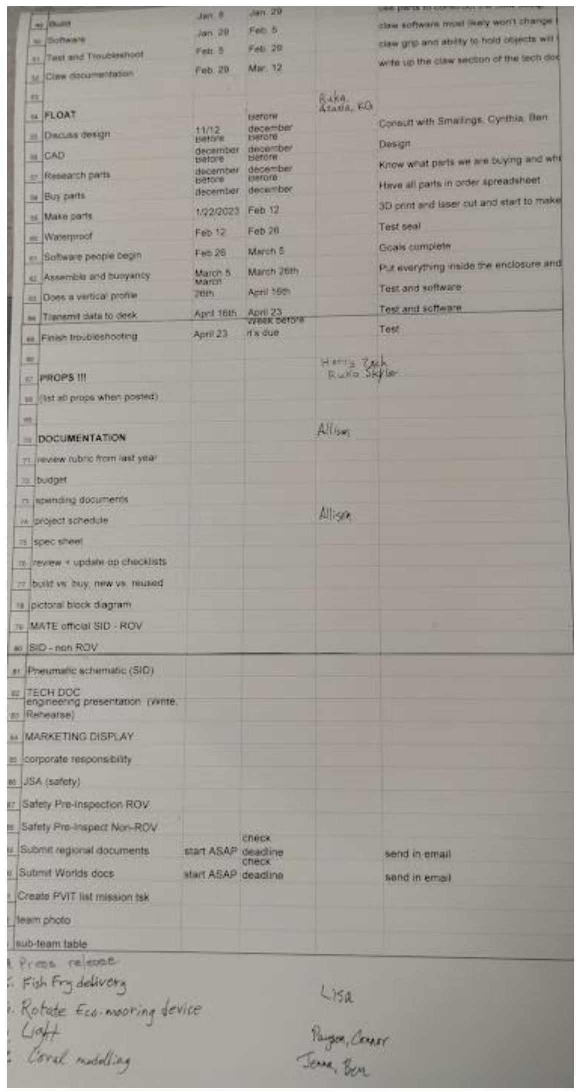
| Design | Mechanical & Electronics | | Software | Marketing & Information |
|---|---|---|---|---|
| Cynthia* | Riko* | Kharianna* | Ben* | Allison * |
| Andrew | Jenna | Ben | Allison | Zach |
| Azalea | Ruka | Andrew | Gavin | Kharianna |
| Gavin | Payson | Riko | Annalia | Claudia |
| Eto | Trevor | Skylor | | |
| Annalia | Annalia | Henry | | |
| Timothy | Connor | Zach | | |
| | Tim | | | |
| | Henry | | | |

## B: Project Schedule



ROV PROJECT SCHEDULE

| | TASK | start | finish date | who | notes :) |
|---|---|---|---|---|---|
| 1 | TASK | start | finish date | who | notes :) |
| 3 | BUILD ROV | | | | |
| 4 | Design ROV | | | Cynthia, Azalea, Gavin | |
| 5 | Order Polypropylene | | | | |
| 6 | Cut Cardboard Side Frames | | | | Consult with Smallings, Cynthia, Ben |
| 7 | Cut Real Side Frames | | | | Design |
| 8 | Cut Cross Pieces | | | | Know what parts we are buying and wh |
| 9 | Drill Side Pieces | | | | Have all parts in order spreadsheet |
| 10 | Assemble Frame | | | | 3D print and laser cut and start to make |
| 11 | Mount Thursrers | | | | test seal |
| 12 | Incorporate Brain onto ROV | | | | goals complete |
| 13 | Incorporate Tools onto ROV | | | | put everything inside the encolsure and |
| 14 | Design + Install Buoyancy | | | | test and software |
| 15 | Finish troubleshooting | April 23 | up until competition | | test |
| 16 | Water Sample Device | | | Cynthia | |
| 17 | TETHER | | | Stuart, Claudia | |
| 18 | Design a new tether | anytime | 11/23/2022 | Riko | Work on tether design with Smallings |
| 19 | Order parts for a new tether | 11/23 | before winter break | Jenna | send norris parts weekly |
| 20 | Construct a new tether | | | Stuart | |
| 22 | BRAIN | | | | |
| 23 | Buy new 6" tube, dome | | 11/23/2022 | Andrew | |
| 24 | order new bulgin connectors | | 11/23/2022 | Andrew | |
| 25 | design endcaps | | | Andrew | |
| 26 | order endcap blank | | | Andrew | |
| 27 | machine the endcaps | | | Andrew, Jenna | |
| 28 | design the electronics | | | | |
| 29 | create SID | | | | |
| 30 | order electronic components (relays, arduinos, RPis, etc.) | | before winter break | Jenna, Riko | |
| 31 | upgrade control box | | before winter break | Claudia, Stuart | pCb controller: will fix tank drive issue |
| 32 | change PS4 to Logitech 3D Control stick | | | | |
| 33 | Assemble brain | | | | |
| 34 | Waterproofing + testing | | | | |
| 36 | SOFTWARE | | | | |
| 37 | Identify MATE software needs | | | | identify software needs in the mission |
| 38 | Program Raspberry Pis for Thrusters + Cameras | | | | |
| 39 | Program Arduino | | | | connect between RPis and thrusters |
| 40 | Communicate down below, up top (VNC) | | | | Ethernetting back up to the deck (RO |
| 41 | Put together visuals + controls | | | | user interface (controller interacting w |
| 42 | Cameras to Deep Water Expr for repair | | | | |



| | TASK | start | finish date | who | notes |
|---|---|---|---|---|---|
| 49 | Build | Jan. 8 | Jan. 29 | | |
| 50 | Software | Jan. 29 | Feb. 5 | | claw software most likely won't change |
| 51 | Test and Troubleshoot | Feb. 5 | Feb. 20 | | claw grip and ability to hold objects will |
| 52 | Claw documentation | Feb. 20 | Mar. 12 | | write up the claw section of the tech doc |
| 54 | FLOAT | | | Ruka, Azalea, KG | |
| 55 | Discuss design | 11/12 | before december | | Consult with Smallings, Cynthia, Ben |
| 56 | CAD | before december | before december | | Design |
| 57 | Research parts | before december | before december | | Know what parts we are buying and wh |
| 58 | Buy parts | before december | before december | | Have all parts in order spreadsheet |
| 59 | Make parts | 1/22/2023 | Feb 12 | | 3D print and laser cut and start to make |
| 60 | Waterproof | Feb 12 | Feb 26 | | Test seal |
| 61 | Software people begin | Feb 26 | March 5 | | Goals complete |
| 62 | Assemble and buoyancy | March 5 | March 26th | | Put everything inside the enclosure and |
| 63 | Does a vertical profile | March 26th | April 16th | | Test and software |
| 64 | Transmit data to deck | April 16th | April 23 | | Test and software |
| 65 | Finish troubleshooting | April 23 | week before it's due | | Test |
| 67 | PROPS !!! | | | Henry, Zach, Ruka, Skyler | |
| 68 | (list all props when posted) | | | | |
| 70 | DOCUMENTATION | | | Allison | |
| 71 | review rubric from last year | | | | |
| 72 | budget | | | | |
| 73 | spending documents | | | Allison | |
| 74 | project schedule | | | | |
| 75 | spec sheet | | | | |
| 76 | review + update op checklists | | | | |
| 77 | build vs. buy, new vs. reused | | | | |
| 78 | pictoral block diagram | | | | |
| 79 | MATE official SID - ROV | | | | |
| 80 | SID - non ROV | | | | |
| 81 | Pneumatic schematic (SID) | | | | |
| 82 | TECH DOC | | | | |
| 83 | engineering presentation (Write, Rehearse) | | | | |
| 84 | MARKETING DISPLAY | | | | |
| 85 | corporate responsibility | | | | |
| 86 | JSA (safety) | | | | |
| 87 | Safety Pre-Inspection ROV | | | | |
| 88 | Safety Pre-Inspect Non-ROV | | | | |
| 89 | Submit regional documents | start ASAP | check deadline | | send in email |
| 90 | Submit Worlds docs | start ASAP | check deadline | | send in email |
| 91 | Create PVIT list mission tsk | | | | |
| 92 | team photo | | | | |
| 93 | sub-team table | | | | |
| | Press release | | | | |
| | Fish Fry delivery | | | Lisa | |
| | Rotate Eco-mooring device | | | | |
| | Craft | | | Payson, Connor | |
| | Coral modelling | | | Jenna, Ben | |

## C: PVIT 2023 Budget

| Item | Quantity | Unit Value ($) | Total ($) |
|---|---|---|---|
| **Regional Budget** | | **Subtotal ($)** | **5720** |
| 6 in clear tube | 170 | 1 | $170 |
| front dome | 150 | 1 | $150 |
| custom end cap | 500 | 1 | $500 |
| bconnector male | 20 | 12 | $240 |
| bconnector female | 20 | 12 | $240 |
| expandable sleeve | 20 | 1 | $20 |
| 10 guage wire | 100 | 1 | $100 |
| 20 guage wire | 40 | 1 | $40 |
| ethernet | 100 | 1 | $100 |
| flight simulator joy stick | 200 | 2 | $400 |
| basic game controller | 50 | 1 | $50 |
| pelican case control box | 200 | 1 | $200 |
| claw | 500 | 1 | $500 |
| waterproofed servos | 140 | 2 | $280 |
| computer fan covers | 15 | 6 | $90 |
| props | 500 | 1 | $500 |
| polypropylene sheet | 15 | 4 | $60 |
| tools | 100 | 1 | $100 |
| buoyancy foam | 135 | 1 | $135 |
| raspberry pi 4GB | 200 | 2 | $400 |
| raspberry pi 8GB | 250 | 2 | $500 |
| laptop | 1500 | 2 | $3,000 |
| float | 250 | 1 | $250 |
| esc | 40 | 6 | $240 |
| arduino mega | 50 | 2 | $100 |
| **Worlds Budget** | | **Subtotal ($)** | **1380** |
| brochure | 50 | 1 | $50 |
| poster | 150 | 1 | $150 |
| Teacher Hotel and Food | 600 | 1 | $600 |
| Teacher Airfare | 240 | 1 | $240 |
| ROV Transportation | 340 | 1 | $340 |
| **GRAND TOTAL** | | | **7100** |

## D: PVIT 2023 Job Safety Analysis (JSA) for Deck Ops/Launch and Recovery

### ENTERING/EXITING THE POOL DECK AREA

| TASK | HAZARD | PROTOCOL |
|---|---|---|
| Carrying ROV and ROV supplies | Heavy lifting | Always lift ROV with a lifting partner. |
| | | Lift with knees. |
| | | Have clear communication and synchronization with the lifting partner. |
| | Crushing of fingers | Use handholds when available. |
| | Dropping heavy objects | Keep the load close to one's body. |
| | | Communicate with the lifting partner. |
| | Awkward Positioning of body | Communicate with the lifting partner. |
| | | Keep the load close to one's body |
| | Tripping | Always walk, refrain from running. |
| | | Always know the location of the tether and other tripping hazards. |
| | | Watch where you are going. |

### SYSTEM SET UP

| TASK | HAZARD | PROTOCOL |
|---|---|---|
| Setting up the control deck | Shorting of electronics due to water | Keep the control deck at least 6 feet from the pool. |
| Setting up the tether | Tripping | Inform employees of the location of the tether. |
| | Electrical shock | Safely plug the tether into the control box. |

### POWER UP CHECKS

| TASK | HAZARD | PROTOCOL |
|---|---|---|
| Product Demo | Exposing electrical system to water | Perform the pre-run checklist prior to run. |
| | | Ensure that electronics are waterproof. |
| Pre-run check | Hand injury | Test claw to ensure proper function. |
| | | Inspect thrusters to see if they are working and clear of obstructions. |
| | Electrical shock | Check all electrical power connections |
| | | Check that all waterproof seals are secure |
| Troubleshooting control system | Electrical shock | Turn the power off before troubleshooting any electronics. |

### POOL SIDE OPERATIONS

| TASK | HAZARD | PROTOCOL |
|---|---|---|

| | | |
|---|---|---|
| ROV operation | Injuring of body parts. | Always wear close toed shoes. |
| | Claw and hand injury | Alert the pilot when hands are near the claw |
| | Tripping | Manage tether position. |
| | | Keep passageways clear of objects. |
| | | Always walk, refrain from running. |
| | | Maintain clear communication with all employees. |
| | Electrical shock | Follow all checklists. |
| | | Keep the extension cord dry. |
| | Falling in water | Kneel on deck when placing ROV in the water. |
| | | Always walk, never run in the pool area. |
| Co8ntrol deck operation | Shorting of electronics | Ensure that the control deck always remains dry. |
| Supplying props to the ROV | Hands/fingers caught in the claw fingers | Place the prop between claw fingers, ensure all body parts remain clear of the claw, hold object in place as the claw grips it, then release the object and give a thumbs up to the pilot. |
| Troubleshooting control system | Shock | Turn the power off before troubleshooting any electronics. |

**SYSTEM BREAKDOWN**

| TASK | HAZARD | PROTOCOL |
|---|---|---|
| Disconnect the power | Electric shock | Turn off all power. |
| | | Safely disconnect tether from the ROV. |
| | | Dry off the ROV. |
| Put away the tether | Tripping | Roll up the tether carefully. Use 2 people. |
| Clean the area | Tripping | Remove all props, materials, supplies, tools and trash from the area. |

## E: Weight Table

| Component | Weight (g) |
|---|---:|
| Tube | 1,033g |
| Dome | 65g |
| Claw, Lights, and connections | 1,464g |
| Thruster with Guards | 455g |
| Frame, 5 thrusters, all crosspiece, tube mounts | 4,570g |
| End cap with female SeaCons | 877g |
| Variable buoyancy with mounting | 1,505g |
| Brain disc mount | 187g |
| Brain camera mount | 89g |
| Brain electronics on mount | 713g |
| **Total ROV** | **10,414g** |

## F: List of Tables and Figures

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We acknowledge the Navajo native peoples of the Colorado region and recognize those who served in World War II as the famous "Code Talkers" by naming our ROV "*Besh Lo.*" This is the Navajo expression for *Submarine* which translates literally to *Iron Fish*.

Additionally, we acknowledge: