2024 MATE World Championships

Technical Documentation for *Smokey* ROV

Palos Verdes Institute of Technology (PVIT)
Palos Verdes High School, Palos Verdes Estates, California, USA

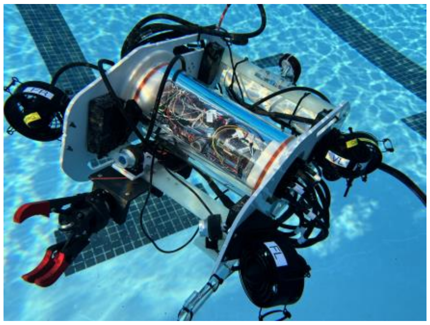

Photo 1: *Smokey* ROV By: Azalea Lurie

2024 PVIT ROV Company:

Lisa Lininger:	President, Chief Safety Officer	3rd year	Class of 2024
Benjamin Peters:	CEO, Lead Software Engineer	3rd year	Class of 2025
Azalea Lurie:	ESG and Outreach Manager	3rd year	Class of 2025
Andrew Moore:	CTO, Lead Electrical Engineer	3rd year	Class of 2025
Allison Yu:	Chief Information Officer	3rd year	Class of 2025
Eto Uchiyama:	Chief Financial Officer	2nd year	Class of 2025
Gavin Montgomery:	Lead Design Engineer	2nd year	Class of 2024
Ruka Ito:	Lead Mechanical Engineer	2nd year	Class of 2026
Chloe Choi:	Head of Marketing	1st year	Class of 2024
Henry Argentieri:	Mechanical Engineer	2nd year	Class of 2025
Timothy Keroles:	Design Engineer	2nd year	Class of 2025
Michael Fu:	Software Engineer	1st year	Class of 2026
Dean Choi:	Design Engineer	1st year	Class of 2027
Rayaan Jaffer:	Design Engineer	1st year	Class of 2027
Ryan Peters:	Software Engineer	1st year	Class of 2025
Noah Kim:	Electrical and Design Engineer	1st year	Class of 2025
Hailey Lee:	Mechanical Engineer	1st year	Class of 2027
Lucas Park:	Mechanical Engineer	1st year	Class of 2027
Megan Ashcroft:	Mechanical Engineer	1st year	Class of 2026
Neil Yeich:	Design Engineer	2nd year	Class of 2025
Payson Cai:	Props	2nd year	Class of 2026
Max Caryl:	Props	1st year	Class of 2027

Mentors:

Lorraine Loh-Norris: Instructor
Fred and Julie Smalling: Mentors
Fred Chow: Mentor
Isabel Moore: Mentor
Darin Lininger: 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 *Smokey*, a small, lightweight, low cost, versatile ROV, to meet the challenges outlined in the 2024 Marine Advanced Technology Education's (MATE) Request for Proposals (RFP) and to address the needs of the global community. *Smokey* and crew support work to combat climate change, protect environments, and collect data, specifically by: 1) Deploying and recovering our autonomous ocean-monitoring float (*Dipper*). 2) Deploying, replacing, and returning SMART cables that help connect our planet. 3) Deploying and operating irrigation systems for corals. 4) Creating 3D coral models. 5) Protecting sturgeon spawning grounds.

The *Smokey*, a non-corrosive, sturdy, reliable vehicle suitable for harsh environments, is the result of 16 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 rotating manipulator and streamlined chassis, are prioritized to address our customers' specifications. The company 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: 2024 PVIT Team By: Connie Lim

Back Row (L→R): Henry Argentieri, Payson Cai, Max Caryl, Noah Kim, Benjamin Peters, Rayaan Jaffer, Neil Yeich, Tim Keroles, Michael Fu, Ryan Peters, Azalea Lurie, Megan Ashcroft

Front Row (L→R): Gavin Montgomery, Eto Uchiyama, Dean Choi, Ruka Ito, Andrew Moore, Lisa Lininger, Allison Yu, Hailey Lee, Chloe Choi

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Project Management

Company Structure: The Palos Verdes Institute of Technology is a company run by high school students who share the goal of becoming more environmentally friendly through advancements in cutting edge technology. This year the company has 22 members, with 12 returning and 10 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 goals 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 as whom a team member could ask for help. The team members encourage collaboration, respectful interactions, and a supportive learning environment so that the whole company can succeed. Important protocols such as keeping a safe working environment and focusing on completing work throughout the whole meeting are enforced and expected of each employee.

Scheduling and Planning: Our company has high expectations and calls for a large time commitment from every employee. As a result, communication between employees was very important in maintaining high attendance and productivity during meetings. Messages were sent out to the team via GroupMe, our primary messaging software, and by email, and all employees were encouraged to actively communicate with each other. An important organization tool we utilized was a shared Google Drive. Every single document produced by the company resides in our Google Drive which is organized into Design Documents, Photos, Competition Documents, Safety, and other categories. Documenting all the company's work is vital to PVIT ROV's success. Since our Google Drive is so important and has been used for several years, we reorganized it so that all documents have a specific label and neatly placed in a clearly labeled folder. Creating a project schedule posed a challenge to us last year, so we made it a point to improve upon it this year. Once the competition manual was released, the leaders of each sub-team (See Appendix A) created a weekly schedule for their team. Those individual schedules were then combined into a master schedule that all teams could refer to (See Appendix B). Having this comprehensive schedule kept us on a more comfortable schedule, instead of having to finish last-minute.

Challenges: Learning new skills was one hurdle our company had to overcome. Our 10 new members and 6 members with only one year of experience had to learn crucial engineering skills, such as soldering, using power tools, and learning the ropes of CAD software. Although some of our new ROV members came to the team with engineering skills, even they had to be taught the specifics of how to engineer an ROV, work together on a team and understand the full scope of the MATE competition. A second challenge was that our laser cutter was unavailable for several weeks for repairs. This happened when we were ready to prototype our frames and other designs, which delayed our progress. Additionally our design team had to make many more design iterations than anticipated until each part was perfected. (See Photo 3). A third challenge was receiving timely responses to our purchase requests. One example was not receiving the parts to support our fourth camera, so we had to compromise with three cameras.


Photo 3: Frame Design Iterations
Photo by: Gavin Montgomery

Design Rationale

PVIT's driving force and ultimate goal our ROV design is to meet our customers' needs. This year's ROV, *Smokey*, was designed to refine the structure of the craft, utilize space efficiently, and integrate new payload tools and systems, as required by the customer. In order to incorporate all of the features needed, we assembled a strong team of design engineers and used the plethora of resources offered in our company's lab. These include 3D printers, soldering irons, drill presses, and a laser cutter. We use design software including Autodesk Inventor, Corel Draw, and MultiSim, to create precise models of components and test circuitry designs. Powered by the creativity of our team members, as well as our tools and machinery, *Smokey* is our company's original creation, custom-made primarily from base components as elaborated upon in the following sections.

Overall Vehicle Design & Systems Approach:

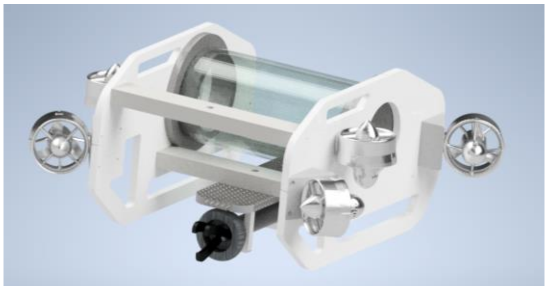


Figure 1: CAD Assembly
By: Gavin Montgomery

This iteration of PVIT ROV's design is sleek and refined, characterized by efficiency and simplicity. We opted for key payload tools and structural pieces that can serve numerous functions on their own. The overall design of *Smokey* was strategically built in 3D CAD software from Autodesk Inventor to plan its size and layout. In the software, we designed and assembled the major components of the ROV including the "Brain", thrusters, side frames, cross-pieces, and payload tools. The most important payload tool on our craft is the claw, which serves numerous functions underwater. This claw, whose predecessor had been rebuilt and reused for over a decade, is completely new this year and designed in-house entirely by members of the design team. Our company prioritized a perpendicular positioning of the Brain to the side frames, which makes the craft more compact and hydrodynamic. After 7 months of hard work, we created a fully functioning ROV that meets the size and weight goal of the customer and is able to accomplish demanding tasks. (See Figure 1).

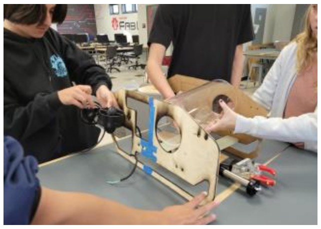


Photo 4: Cardboard Prototype
By: Dean Choi

Figure 2: Side Frame Designs
By: Gavin Montgomery

Mechanical Design and Fabrication: Our side frames are a vital feature that act as the backbone of our craft. (See Figure 2). We completely customized our side frames to reduce water resistance by narrowing the frames and opening them up in unoccupied areas that don't have structures or tools attached. After we made careful measurements in CAD, we precisely cut each component using a laser cutter in our lab. We first laser cut our designs onto cardboard as a prototype. (See Photo 4). This allowed us to test many different designs while conserving premium materials, which kept us in line with one of our company's missions: conserving natural resources and finding solutions to environmental challenges. We adjusted our design multiple times to fit our manipulator, brain, and other systems. (See Figure 1). Once we were satisfied with the prototype design, we cut our final panels from polyethylene sheets, which we chose because polyethylene is strong, slightly malleable, lightweight, and machinable. These components were then assembled according to the CAD. (See Figure 1). *Smokey* is 28 cm in height, 71 cm in length, and 63 cm in width, and it weighs 11.4 kilograms. Our primary design consideration is meeting the customer's needs. We scrutinized the RFP to determine exactly what performance is required of *Smokey*. Some additional criteria considered during design were weight distribution, field of view for each camera, optimal camera locations, thruster configuration, thruster location, unobstructed water flow into and out of each thruster, hydrodynamics, ease of assembly and maintenance and even visual aesthetics. These details are elaborated in subsequent sections of this paper. Careful consideration has been given to every detail of designing and building *Smokey*. Everything is considered for performance outcome and effect.

Innovation: The *Smoky* has multiple notable innovative features. The manipulator is the main payload tool which has very high functionality due to its rotational feature and new 3D printed design. The rotation feature allows *Smoky* to grip items positioned either vertically or horizontally serving the role of two manipulators. The brand new linear actuator, servo, and claw fingers serve as a huge upgrade to the previous claw. The claw operates with a high efficiency, with attachments for picking up smaller items. Another innovative aspect of the ROV is that our company employed a two wire ethernet this year. The *Smoky* uses a Fathom X splitter from Blue Robotics in the brain and control box. They allow us to use only two wires for data in the tether, which means the "ethernet" operates more quickly and consistently, and is considerably easier to attach waterproof connectors to.

Propulsion: Blue Robotics T200 thrusters, controlled by Blue Robotics ESCs, are used to propel *Smokey*. The team decided to implement a thruster configuration involving 6 thrusters to optimize the propulsion of the ROV

Photo 5: Thruster Shrouds
By Lisa Lininger

for the amount of power it gets from the limited 12 V and 16.7 amp power source. (See Figure 8). *Smokey* has two vertical thrusters, one placed on each side panel. The lift capability is strictly from the vertical thrusters as the ROV does not have any additional lift devices. The two thrusters provide a combined lift capacity of 25 Newtons. Our 4 horizontal thrusters are mounted in a vectored configuration at a 30 degree angle, which helps the craft to be more maneuverable and provides additional speed in the forward direction. The thrusters are mounted close to the ROV's center of mass for limited sway. To make sure that we have optimal performance for each thruster we make sure they have unobstructed water flow by mounting them outside the frame. This also allows more room within the framework for other components. 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 custom fitted for the craft. (See Photo 5). These are implemented to prevent injuries or damage to the user, or harm to any animal or plant life. The team's goal is to propel *Smokey* 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.

Buoyancy & Ballast: The buoyancy and ballast on our ROV is carefully designed for optimal stability and maneuverability. *Smokey* is guaranteed to be stable and fly horizontally with an even weight distribution. In general, stability is achieved by having buoyancy on the top and weight on the bottom of the ROV and the thrusters near the center of mass. Since our brain tube is large and holds a great volume of air, we mounted it near the top of the ROV. The claw and the brain are the two heaviest components on the ROV. The claw is mounted forwards so we balance the weight by placing the brain towards the back. We mounted our heavy claw off-center on the bottom of the ROV for greater performance and stability. We chose to place it on the right side because the brain has a heavy left side. Final adjustments were made after we submerged the ROV. We added buoyancy to the front and rear of the ROV by using two water bottles full of air but which are easily filled with water as needed. To calculate how much volume of air was needed to make the ROV balanced, we removed the bottles and made calculations using the mass and water density to get volume. After we found how much air was needed, we calculated the size of PVC pipe we needed with end caps to add the appropriate volume of air to duplicate the water bottles. We used 2-inch PVC on the rear of the ROV and made calculations for foam pieces for the forward flotation. We added more floatation to the upper rear for final stability. We designed our buoyancy as close to slightly positive or neutral as possible so our ROV will float to the surface if it suffers a catastrophic failure. (See Photo 6).

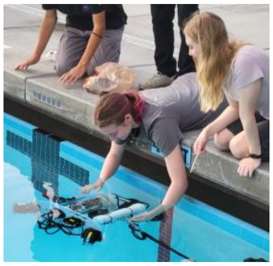


Photo 6: Perfecting Buoyancy
Photo by: Chloe Choi

Cameras: *Smokey* is equipped with three high-definition exploreHD 2.0 Underwater ROV/AUV USB Cameras from DeepWater Exploration. The cameras have high definition video quality, a wide-angle view, color correction, automatic ambient lighting adjustment, and fisheye adjustment for underwater distortion. Due to these benefits, the exploreHD cameras are essential and optimal for the ROV's operations, providing the pilot with multiple perspectives to enhance efficiency and effectiveness during tasks such as transporting corals, identifying spawn sites, and measuring areas for coral restoration. Our cameras are strategically mounted on the ROV's frame — one points straight downwards, one points straight forwards, and the last one is placed on a custom perch at a downwards angle so that the pilot can view the claw. The cameras were purchased two years ago and due to their superior performance and the cost investment, they are a reused component of the ROV.

Underwater Measurement & Modeling: To accurately measure and model the coral restoration area, we use Autodesk software for drawing and ImageJ software for measuring. ImageJ is an open source program that does pixel counting. To measure the coral reef, we place a known standard next to it and capture an image with our high quality cameras. We use the software to ratio the known dimension to unknown dimensions. Our team of expert designers quickly and accurately create a 3D CAD image in Autodesk and add our accurate dimensions. This entire task is completed in about 5 minutes.

Manipulator: *Smokey*'s manipulator, which we call "The Claw," consists of three fingers that are attached to a PA-06 electric waterproof linear actuator, which allows the fingers to open & close, and a waterproof servo, that rotates the claw. (See Photo 7). Besides the linear actuator purchased from Progressive Automations and servo from ANNIMOS, we custom designed and built all of the claw's parts - the actuator mounts, fingers, mounting plate, and numerous linkage pieces. When deciding on the design, we considered the customer's need to pick up large objects such as the acoustic doppler current profiler, as well as pull pins, collect rocks, and turn valves.


Photo 7: Claw
Photo by: Noah Kim

Our claw's fingers are 3D printed out of carbon fiber-nylon and they are configured in a way that emulates the shape of an eagle's claw. (See Photo 8). The fingers open wide and are interlocked when in their fully closed position, which allows the claw to grip various objects ranging from < 1 cm to 10 cm wide. The fingers are attached to both a ring fastened around the end of the linear actuator and the plate attached to the center of the extendable shaft of the linear actuator, which provides a 22 Newton grabbing force at 12V. The linear actuator is supported by two custom-designed and printed saddles which are attached to the mounting plate.


Photo 8: Claw Fingers
Photo by: Noah Kim

The center point of the back end of the actuator is attached to a waterproof servo with 190-degree rotation, which allows the claw to pick up objects positioned either horizontally or vertically and to turn valves. (See Figure 3). Electrical connections to the servo and actuator are made and waterproofed by our electrical engineers. The entire assembly is mounted on a rigid, lightweight polypropylene plate with just three bolts and wing nuts which makes our claw a modular payload tool that can be quickly and easily attached to and removed from the ROV for maintenance and repositioning. The claw is strategically mounted at the bottom of the craft, a little off-center for better visibility in the camera views and suitably forward to reach beyond the frame of the ROV.

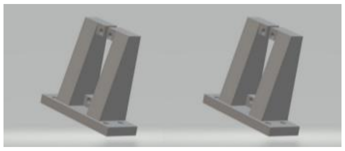


Figure 3: Servo Mount CAD
Photo by: Dean Choi

Additional Payload Tools/Instruments: An additional payload tool we use is a simple hook, which acts as a backup to the claw, and is also a secondary lifting tool. We also use a thermocouple, mounted beneath the hook, to test water temperatures. It communicates data through the Brain.

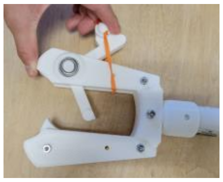


Photo 9: Carabiner
Photo by: Dean Choi

360-Degree Latch (Carabiner): Creating an appendage for the ROV that can position itself 360 degrees around a U-bolt was a challenging task, as there is a surprising amount of force necessary to open even a simple carabiner. Our design first began with modifications to existing carabiner designs and a focus on the most difficult aspects of its fabrication. Our company decided upon an easy-opening one-way latch as the only way to get around the limited available force underwater. The largest challenge we faced was creating a strong enough grasp that wasn't too difficult to open and attach underwater, because the open-closing motion of the carabiner relies completely on the force created by the ROV's propulsion into the U-bolt.

Float: Our vertical profiling float, *Dipper*, has a height of 70 cm, a diameter of 17 cm, and a weight of 8 kg. (See Photo 10). The float is operated by a buoyancy engine, which is composed of a 500 ml syringe attached to a linear actuator. The buoyancy engine has 3 phases: ascending, descending, and stationary. During the ascending phase, the float is slightly positively buoyant. The linear actuator is fully extended during this phase, which completely compresses the syringe. During the descending phase, the linear actuator retracts, which expands the volume of the syringe. At this point the lower pressure inside the syringe pulls in water from outside the float, increasing the mass of the float by 500g. Since net volume of the float does not increase, the increased change in density allows the float to descend. When the float reaches the bottom, the linear actuator will extend again, expelling water out of the syringe and causing the float to ascend to the surface. In the control system, we use a timer to extend and retract the linear actuator corresponding to the time it takes to descend and ascend a predetermined depth. At the surface of the water, before the float descends, the Arduino Portenta will transmit the UTC via a WiFi signal to the deck crew. During ascent and descent, the pressure transducer will measure the pressure in relation to time every 5 seconds. When the float is above water, it will re-establish connection with the deck crew and send depth measurements in relation with time and the UTC. Our deck crew uses software to calculate the depth from the pressure data using the hydrostatic water pressure formula:

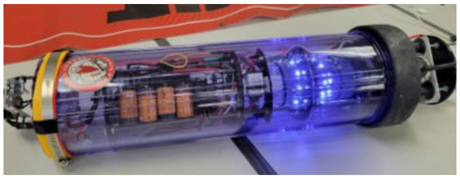


Photo 10: *Dipper* Float
By: Azalea Lurie

$$P=pgd$$

in which hydrostatic pressure is dependent on density of water (1.00g/cm^3), gravitational acceleration constant (9.80665 m/s^2), and depth (m).

Power is supplied internally from two banks of four C batteries connected in a series, totaling 12V DC. Following safety requirements, a 5-amp fuse is wired to the power wire of the battery packs and another 5-amp fuse is wired to the ground wire of the battery packs. A rubber plug with a diameter of 2.6 centimeters is located on the cap and acts as a pressure relief system in accordance with safety specs. As an additional safety measure, we covered all sharp edges, such as the ends of metal bracings and zipties.

Tether: The tether has 6 wires encased in an expandable mesh sleeve and is 18 meters in length. (See Photo 11). The first pair of wires is for power, the second pair of wires is for ground, and the remaining pair is for data transfer. The power is split between a 14-gauge wire, which supplies the control system, and an 8-gauge wire, which supplies the thrusters. (Likewise for the ground). Two separate power lines were necessary because with a single power line, the T200 thrusters pull enough power to interrupt the Raspberry Pi’s function. Separating the power between two lines (with voltage regulators in the control box) allows the brain and control box to receive a steady stream of power even when the thrusters are at full throttle. We chose an 8-gauge power wire for the thrusters for less voltage drop across the tether’s 18 meters. The smaller 14-gauge wire is more than adequate to supply the control system. The pair that isn’t for power or ground is a two-wire alternative for the Ethernet cable, which supports serial communication and video signals. The two wires are converted to Ethernet signals at each end of the tether - the control box and the ROV’s brain. In previous years, we have been challenged by waterproofing Ethernet connections, so we switched to the two-wire alternative for more reliability. On the surface side of our tether, we have Anderson power pole connectors to connect to the control box. On the ROV end of the tether, we use SeaCon bulkhead connectors. (See Photo 12). The tether has stress relief devices that attach it to the ROV and to the control box to prevent damage to its connectors if they are 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. Tether management is an important aspect of flying the ROV. We adhere to the Tether Protocol when operating the ROV (see Operational Checklists and Protocol).


Photo 11: Tether Fabrication
Photo by: Michael Fu


Photo 12: Tether connections
Photo by: Lisa Lininger

Software and Electronics

Command and Control: The “Brain” has been designed to fit into a waterproof acrylic tube with a diameter of 15.24 centimeters (See photo 13), where the electronics are carefully organized and compactly mounted to a custom backplane (see Figure 4). The *Smokey* 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

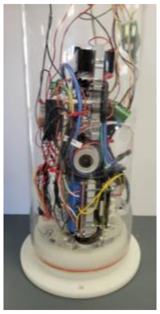


Photo 13: Brain Tube
By: Andrew Moore

deck through a 2-wire Ethernet alternative. 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 4 relays for the claw. *Smokey'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.

Figure 4: Mounting Plate Design
By: Ben Peters

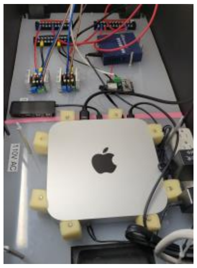


Photo 14: Lower Control Box
Photo by: Andrew Moore

Our Control box's electronics consists of three buses for power and ground, an ethernet switch, an ethernet-to-2-wire converter, a mac mini, a WiFi router, and two current regulators. Power is taken from the main power source into the box through Anderson Power Pole Connectors. From these connectors, a 25 Amp fuse is present which leads to two switches, one to power to the box, and the second to control power to the ROV. The ground from the Anderson connector goes to the ground bus while the power goes to the fuse, the switches and then to two separate power buses. One of these buses is smaller, and the other 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 23 Amps. 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. The control box is completely new utilizing a new Pelican case large enough to mount a monitor, house all the internal components on a lower deck and a keyboard, mouse, and a Volt and Amp meter on the surface of the control box interface. A great deal of design effort went into the box layout considering access to the lower level, wire/cable management and separating AC and DC power. (See Photos 14 and 15). Strain relief is mounted on the box for the tether attachment.

Photo 15: Control Box
Photo by: Andrew Moore

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

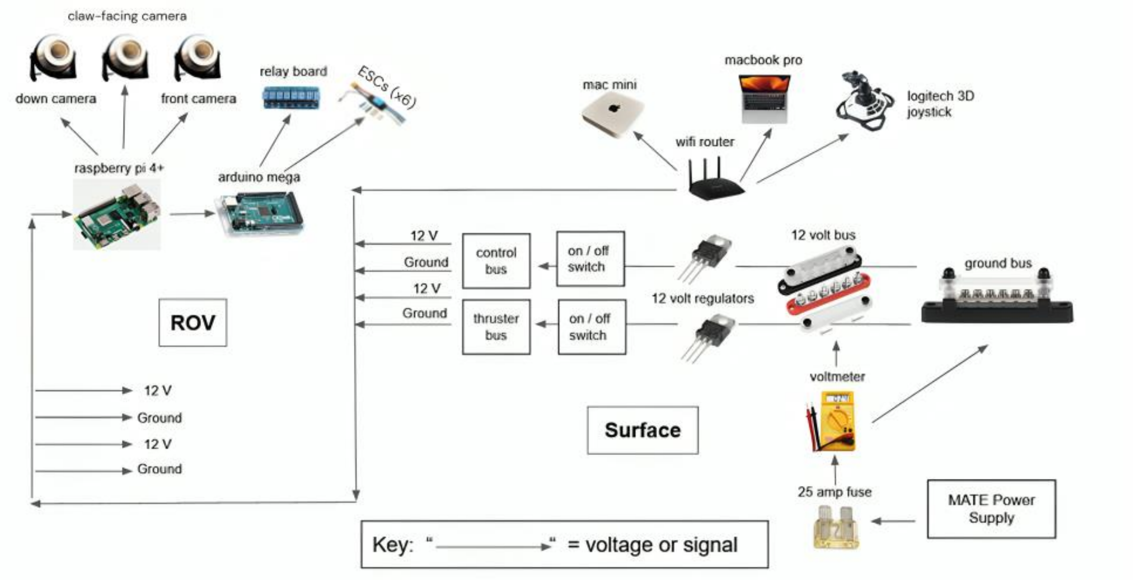


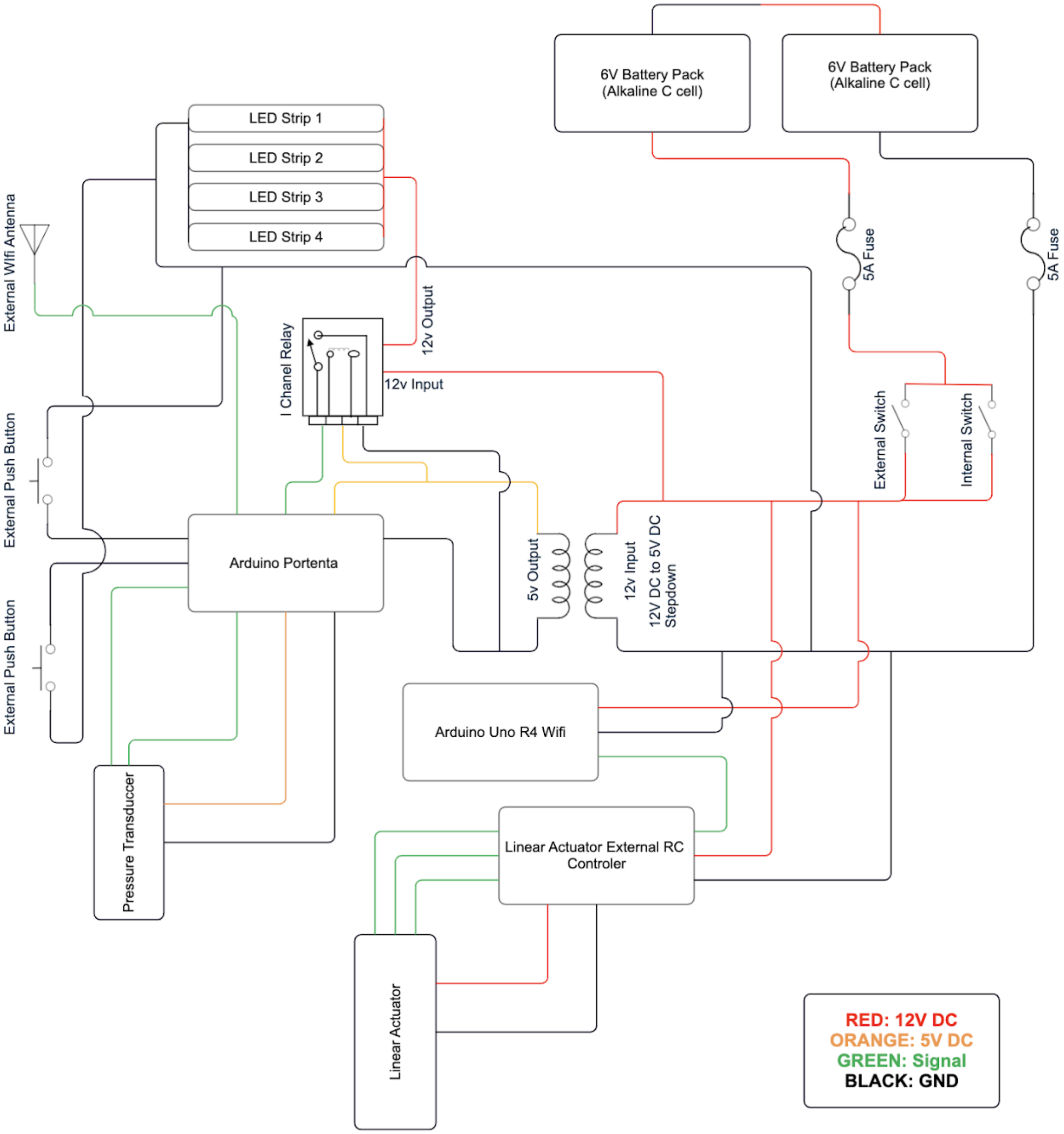
Figure 5: Pictorial Block Diagram
By: Allison Yu

Systems Integration Diagram (SID) for Float Device:

Palos Verdes High School, PVIT, 2024
System Integration Diagram (SID), NRD Float:

Figure 6: SID for float
By: Ruka Ito

Note: a 5 Amp fuse is used due to availability.



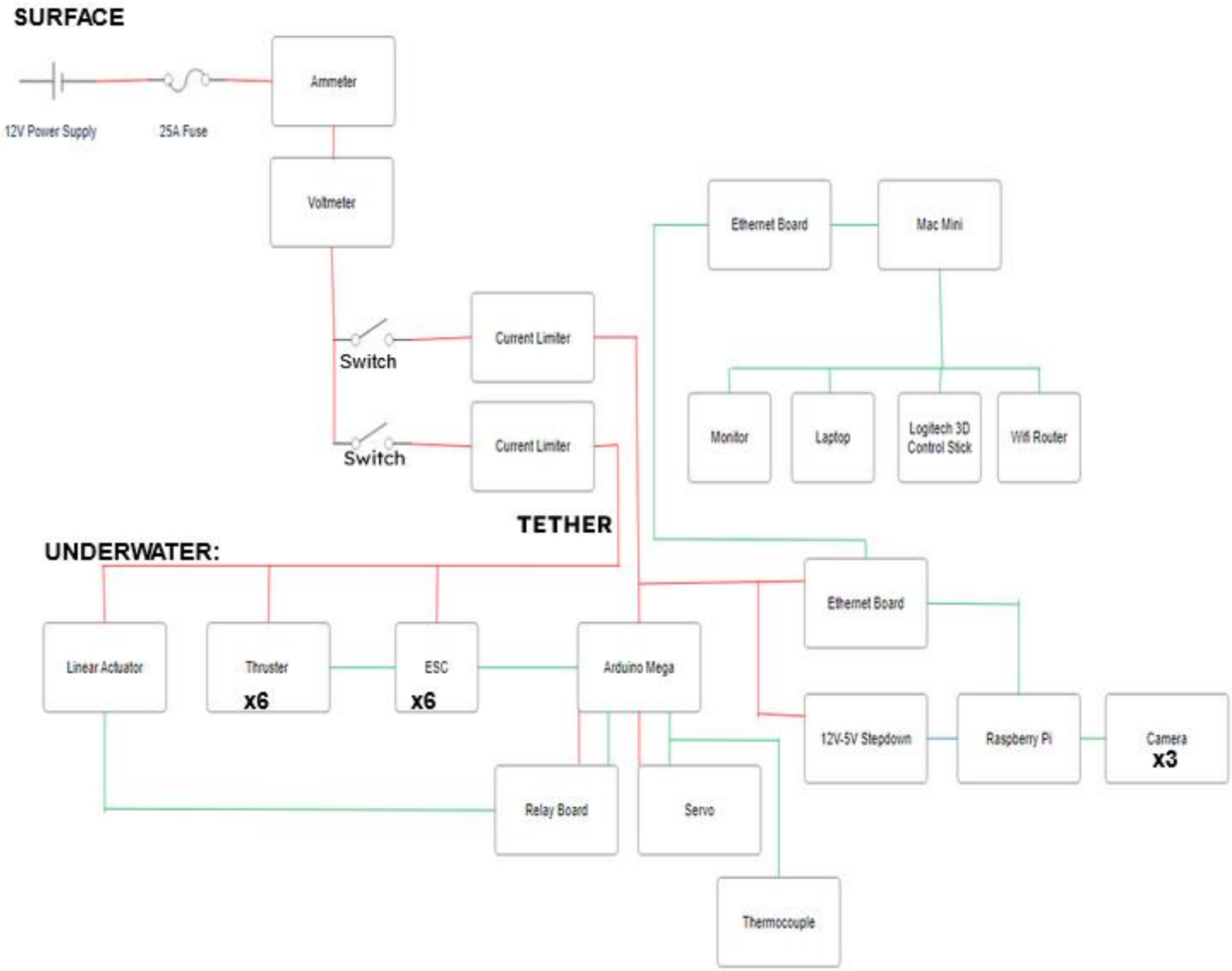
Fuse Calculation: Float

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, 2024
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) + (Blue Robotics Thrusters)] * 150
Fuse Rating A (horizontal thrusters) = [(2.5 Amps) + (4*4.5 Amps)] * 150% = 30.75 Amps
Fuse Rating B (vertical thrusters) = [(2.5 Amps) + (2*7.0 Amps)] * 150% = 24.75 Amps
Maximum Fuse Rating = 25 Amps

Nota bene: Our program control logic prevents simultaneous horizontal and vertical movement and prevents the thrusters from running simultaneously with the linear actuator.

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 *Smokey*'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 *Smokey*'s 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.

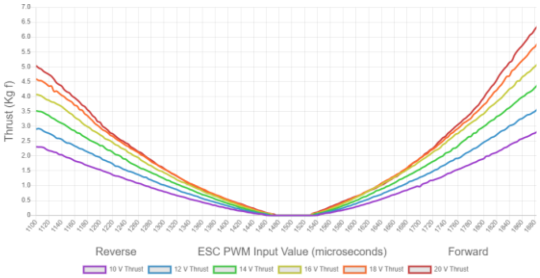


Figure 8: Thruster Power Curve
By BlueRobotics.com

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 8).

Camera Module: The cameras are crucial to the success of a pilot. The DeepWater Exploration 3.0 cameras are plugged into the USB ports of the Raspberry Pi. GStreamer, an open-source library, retrieves the streams from the Raspberry Pi and sends them through the ethernet to a designated port on the Mac mini. The application located on the Mac Mini takes the streams from the cameras and displays them on a web server for our pilot to view.

Build vs. Buy, New vs. Reused:

PVIT's ROV Team operates as efficiently and as organized as possible. This includes decisions on whether to build or buy parts, or decisions on new or reusing parts, which follows a distinct process. If we can build it with the materials, tools and skills we have, we typically do it, as PVIT's first preference is always to custom build to meet customer's specific needs. If we decide to purchase, we research and find the right product and make sure our money is spent efficiently. We try to establish relationships with key suppliers as we have with Blue Robotics and Deep Water Exploration. We search the internet to find a part that would work the best, factoring in cost, shipping times, and reliability. When we decide to build the part, our process is simple: we use design software as needed and use the appropriate tools and materials. Using our software and manufacturing tools, we customize our newly built or reused parts. Our Markforged Onyx 3D Printer, which utilizes carbon fiber filament, was used to print many of our custom parts, particularly on the "claw." PVIT's Makerbot Replicator 3D printer, which uses PLA material, was used for light-service items and prototypes such as our 360-degree latch. We use our ULS laser cutter to fabricate various thicknesses of acrylic and polypropylene for planar pieces including the brain mounting plate and the ROV's side-frames. 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 *Smokey*, 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 *Smokey*, it is first tested in the lab where each operational function (thrusters, claw, cameras) is tested. After passing the dry test, the *Smokey* 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 *Smokey* 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 *Smokey* 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. (See Appendix D). 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 *Smokey* 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 two endcaps, with SeaCon bulkhead penetrators and Cobalt connectors 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 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 this school year, our CFO and team leaders created a budget to estimate our total spending for the year. Our budget (submitted in November of 2023) was approved on the first try. Our subtotal for regionals was $5,876 and with the World's budget, which was $1760, came up to $7636 for the grand total. (See Appendix C).

Funding: Funding for our ROV company and the PVIT program comes from the Peninsula Education Foundation (PEF), a foundation that raises money for many different branches of our school district (PVPUSD). The PEF provides two thirds of our annual budget, while our school's booster club and parent donations supply the remaining third.

Spending: We follow a certain procedure in order to purchase materials and parts. First, we research the internet for the items we need. We then put information on the chosen parts into a weekly form on Google Sheets. The order form then gets sent to our PVIT Director for her approval and ordering is then done by our school district purchasing department. We maintain an overall spreadsheet to record everything purchased. By utilizing 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 $4127.91. The company used purchased, donated, and reused items to construct a capable ROV below budget. This year, emphasis was placed on building an original ROV from fabricated components. Reused items were limited to shop tools and a few ROV parts – particularly thrusters and cameras, and bulkhead connectors – and supplies to build props. (See Tables 1, 2, and 3).

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

Donated	$1,835
Reused	$2,732
Purchased	$2,756
TOTAL	**$7,323**

Table 2: Donated Items

Item	Quantity	Donator	Unit Value ($)	Total ($)
Control Box	1	Pelican	395	395
Equipment Cases	2	Pelican	400	800
T200 Thrusters	6	Blue Robotics	200	1200
Motor Controllers	8	Bob Waters	30	240
Grand Total	**19**			**2635**

Table 3: Reused Items

Category	**Item**	**Quantity**	**Unit Value ($)**	**Total ($)**
ROV			**Subtotal ($)**	**2333**
Electronics	Wires	Various	21	21
Cameras	exploreHD Underwater Cameras	3	280	840
Connectors	Seacon Pairs	12	120	1440
Electronics	Fuses 25A, 5A	2	7	14
Tether	8, 14 Gauge Wire	2	14	28
Props			**Subtotal ($)**	**233**
Hardware	PVC Fitting	Various	75	75
Hardware	PVC pipe, white, various sizes	Various	100	100
Hardware	Nuts, bolts, screws	Various	58	58
Other			**Subtotal ($)**	**166**
Power	AC to DC Power Supply Converter	1	166	166
Grand Total				**2732**

Table 4: Purchased Items

PART NAME or DESCRIPTION	**QTY**	**UNIT VALUE ($)**	**TOTAL ($)**
ROV and Float		**SUBTOTAL ($)**	**3690.66**
Modular/Ethernet Connectors	2	80.84	161.68
Ethernet/Networking Cables Flex Conn	2	96.11	192.22
45KG High Torque Servo	1	41.99	41.99
500ml Syringe	1	13.99	13.99
p16-p Linear Actuator	1	90	90
15 PSI Pressure Transducer Sender Sensor	1	15.99	15.99
12V to 5V DC Converter Car Power Voltage	1	8.99	8.99
Fathom-X Tether Interface Board	1	240	240
Cable Connections	1	50	50
Polyethylene Sheets	2	26.99	53.98
10 GA Fuse Holder	2	16.98	33.96

Portenta H7	1	113.9	113.9
Terminal Strip Blocks	1	14.89	14.89
Polypropylene	2	41.74	83.48
12 VDC Linear Actuator	1	260	260
Arduino Mega 2560 REV3	3	48.9	146.7
Acrylic Tube	1	113.7	113.7
Cobalt Series Bulkhead Connector (8-pin)	2	65	130
Cobalt Series Cable, Single-Ended (8-pin)	2	71	142
5V Relay Module	1	12.99	12.99
MAX6675 and Thermocouples	1	11.99	11.99
External RC Control Board	1	20	20
eSUN PLA+	1	24.99	24.99
Expandable Sleeving	1	24.99	24.99
Toggle Switch	1	7.96	7.96
Linear Actuator Control Board	3	30	90
12C Level Converter	1	25	25
Arduino UNO R4 WiFi	1	27.5	27.5
WiFi Antenna	1	25.97	25.97
12v to 3.3 v Converter	1	8.99	8.99
DWE 7-Port Multiplexer/Connector	1	72	72
Panel Mount Housing	5	26.99	134.95
Anderson Battery Connectors	1	20.9	20.9
Bulkhead Connector	1	52	52
Miscellaneous Hardware	1	280.1	280.1
MATE Fluid Power Quiz	1	25	25
MATE Regional Registration	1	250	250
MATE Worlds Registration	1	100	100
PROPS	**61**	**SUBTOTAL ($)**	**7.99**
19 Ounce Bowl	1	7.99	7.99
GRAND TOTAL	**62**		**3130.79**

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Appendix

A: Sub Team Structure

* Denotes Lead

Design	Mechanical	Electrical	Software	Marketing & Information
Gavin*	Ruka*	Andrew*	Ben*	Allison *
Noah	Rayaan	Ben	Michael	Chloe
Allison	Hailey	Michael	Lisa	Eto
Eto	Lucas	Noah	Ryan	Michael
Tim	Ryan	Lisa		
Dean	Payson	Megan		
	Azalea	Azalea		
	Henry			
	Neil			
	Max			

B: Project Schedule

*This is a 5 week representation of our schedule, not the entire schedule

DATE		TASK
1/21		
	CLAW	Everyone working on different claw pieces, identify any issues that may change schedule
	DESIGN	Constrain all parts in main assembly, finalize idea for thruster mounts, assign payload tools, laser cut & model cardboard ROV
	FLOAT	Draw Float frames on CAD
	MARKETING/DOCUMENTS	start writing, more photos, work on formatting
	PROPS	Recovery float, milk crate assembly
	CONTROL BOX	Design Layout
	TETHER	Find Materials with correct Specs and Order
	SOFTWARE	
	PAYLOADS	Temp sensor: Order parts
1/28		
	CLAW	Servo pieces CAD finished, Claw fingers printed (housing and interface)
	DESIGN	Understand frame attatchment positionings and implement spaces for hydrodynamicism, refine fingers, find/cut replacement parts for all claw pieces
	FLOAT	Design/Draw electronic SID
	MARKETING/DOCUMENTS	start looking at other documents (spec sheet, safety, etc)
	PROPS	Recovery line, Waypoint 1
	CONTROL BOX	Find Parts and Materials
	TETHER	Find Materials with correct Specs and Order
	SOFTWARE	
	PAYLOADS	Temp sensor: if parts arrived, put parts together. if parts not arrived, work on code
2/4		
	CLAW	Servo pieces printed and put together, Conector between linear actuator and claw piece with fingers,CAD done, test servo
	DESIGN	Understand frame attatchment positionings and implement spaces for hydrodynamicism, refine fingers, find/cut replacement parts for all claw pieces
	FLOAT	Make order list for needed parts
	MARKETING/DOCUMENTS	EVERYONE WRITES THEIR SECTION OF TECH DOC (and allison edits)
	PROPS	Waypoint 2, Waypoint 3, seamount
	CONTROL BOX	Find Parts and Materials
	TETHER	Assemble Tether
	SOFTWARE	
	PAYLOADS	Temp sensor: if parts arrived, put parts together. if parts not arrived, work on code
2/11		
	CLAW	Conector between linear actuator and claw piece with fingers (piece name unknown?!) printed
	DESIGN	Cut acrylic side frames and crosspieces, create holes for allthread attachment, check all payload/attatchment designs
	FLOAT	Adjust CAD drawing to the ordered specific parts
	MARKETING/DOCUMENTS	EVERYONE WRITES THEIR SECTION OF TECH DOC (and allison edits)
	PROPS	SMART cable repeater, SMART Cable designated area
	CONTROL BOX	Ask for Donation
	TETHER	Add Bouyancy
	SOFTWARE	
	PAYLOADS	test temp sensor
2/18		
	CLAW	claw completly put together,CAD assembly done!!!, test claw
	DESIGN	Refine and design and print...
	FLOAT	Estimate total cost
	MARKETING/DOCUMENTS	EVERYONE WRITES THEIR SECTION OF TECH DOC (and allison edits)
	PROPS	AUV docking station power connector, Platform for AUV docking station power connector
	CONTROL BOX	Prototype Scissor Lift and Mounting Plates
	TETHER	
	SOFTWARE	

C: PVIT 2024 Budget

Item	Qty	Unit Value ($)	Total ($)
Regional Budget		**Subtotal ($)**	**5876**
Actuator (claw)	2	155	310
Servo (claw)	2	55	110
Enclosure (float)	1	55	55
Actuator (float)	2	260	520
Syringe (float)	2	35	70
Depth Sensor (float)	2	20	40
Battery Pack (float)	2	8	16
Portenta (float)	1	105	105
Control Box	1	810	810
Control Box Internals	1	300	300
Bulgin Connectors	12	90	1080
Acrylic Pipes (4 inch)	2	70	140
heatshrink, various	1	100	100
Blue Rob. Thrusters	2	210	420
Polypropelene Sheets (1x2 ft)	3	55	165
3D Filament (Carbon Spool)	2	50	100
3D Filament (PLA Spool)	2	25	50
Website Fees	1	35	35
Competition Registration	1	250	250
Fluid Power Quiz	1	25	25
Outreach	1	50	50
Anderson Powerpole connecters	1	25	25
ESC's	6	30	180
Enclosure	1	70	70
acrylic dome	2	50	100
ethernet cable	1	20	20
expendable sleeve	1	20	20
computer fan covers	6	10	60
o-rings	6	15	90
end caps	2	30	60
Props & Hardware	1	500	500
Worlds Budget		**Subtotal ($)**	**1760**
brochure	30	1	30
poster	80	1	80
Teacher Hotel and Food	750	1	750
Teacher Airfare	400	1	400
ROV Transportation	500	1	500
GRAND TOTAL			**7636**

D: PVIT 2024 Job Safety Analysis (JSA) for Deck Ops/Launch and Recovery

ENTERING AND 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 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 2 meters 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.
		Secure loose clothing
		Tie back long hair
		Remove all jewelry
		Wear safety glasses at all times
	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.
Control 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)	
Linear Actuator (claw)	846 grams	
End cap #1 (4 connectors and vent bolt)	873 grams	
End Cap #2 (no connectors)	697 grams	
1 Thruster	385 grams	
Tube	807 grams	
Camera	101 grams	
Female Seacon connector	40 grams	
‘Brain’ (endcaps + tube + 8 Seacons)	2669 grams	
Brain camera mount	89 grams	
Brain electronics on mount	713 grams	

F: List of Tables and Figures

Acknowledgments

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Additionally, we acknowledge: