2022 MATE World Championship

Technical Documentation for *Maui* ROV

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

Photo 1: *Maui* By: Azalea Lurie

2022 PVIT ROV Company:

Sammy Moore:	President, Pilot	4th year	Class of 2022
Jenna Chow:	CEO, Lead Mechanical Engineer	3rd year	Class of 2023
Erika Yiu:	Chief Marketing Officer	3rd year	Class of 2022
Sasha Chehrzadeh:	Chief Technology Officer	3rd year	Class of 2022
Steven Guo:	CFO, Mechanical Engineer	3rd year	Class of 2023
Riko Negishi:	Electrical Engineer	2nd year	Class of 2023
Payton Ahn:	Marketing and Finance	1st year	Class of 2022
Daniel Chu:	Mechanical Engineer	1st year	Class of 2023
Skylor Sun:	Mechanical Engineer	1st year	Class of 2023
Lucia Ruiz:	Mechanical Engineer	1st year	Class of 2023
Kharianna Gracie:	Mechanical Engineer	1st year	Class of 2023
Cynthia Ho:	Design Engineer	1st year	Class of 2023
Lisa Lininger:	CSO, Software Engineer	1st year	Class of 2024
Monica Basha:	Software Engineer	1st year	Class of 2025
Azalea Lurie:	Mechanical Engineer	1st year	Class of 2025
Andrew Moore:	Design Engineer	1st year	Class of 2025
Ben Peters:	Software Engineer	1st year	Class of 2025
Zach Rapoport:	Design Engineer	1st year	Class of 2025
Ethan Sung:	Mechanical Engineer	1st year	Class of 2025
Neil Yeich:	Mechanical Engineer	1st year	Class of 2025
Allison Yu:	Software Engineer	1st year	Class of 2025

Mentors:

Lorraine Loh-Norris: Instructor
Fred and Julie Smalling: Mentor
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 *Maui*, a small, lightweight, low cost, versatile ROV to meet the challenges outlined in the 2022 Marine Advanced Technology Education's (MATE) Request for Proposals (RFP) and to address the needs of the global community. The *Maui* and crew support work to combat climate change, specifically: 1) Help marine renewable energy platforms maintain their equipment such as replacing damaged sections of inter-array cables or replacing damaged buoyancy modules 2) Automate environmental monitoring tasks like inspecting aquaculture nets for structural integrity and removing morts 3) Recover robotic ocean-monitoring floats 4) Map, photograph, and obtain statistics on vessel wrecks.

The *Maui*, a non-corrosive, sturdy, reliable vehicle suitable for harsh environments, is the result of 14 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 21 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: Julie Smalling

Back Row (L→R): Lucia Ruiz, Kharianna Gracie, Neil Yeich, Sammy Moore, Ben Peters, Ethan Sung, Skylor Sun, Steven Guo, Payton Ahn, Jenna Chow, Monica Basha

Front Row (L→R): Daniel Chu, Cynthia Ho, Andrew Moore, Zachary Rapoport, Allison Yu, Lisa Lininger, Sasha Chehrzadeh, Riko Negishi, Erika Yiu, Azalea Lurie

Table of Contents

Project Management

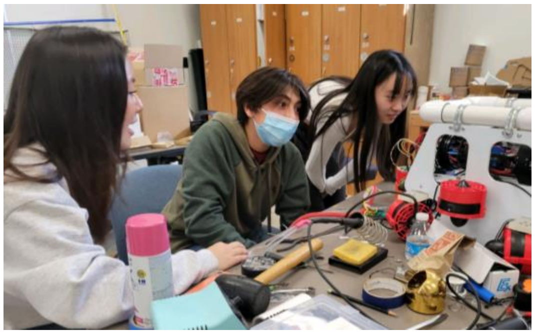


Photo 3: Team working By: Julie Smalling

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 twelve to twenty-one members, with 5 returning and 16 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.) The team members encourage collaboration, respectful interactions, and a supportive learning environment so that the team members and the company can succeed. (See Photo 3.)

Scheduling and Planning: Some of the main PVIT goals this year were to build an ROV using the latest technology, to enable autonomous features with computer vision and to hire new, talented engineers. While planning and scheduling were essential to reach our goals and complete our project on time, it was one of the biggest challenges this year, due to having a large staff. The company had five highly experienced lead engineers and sixteen new hires. Communication, leadership, organization, and mentoring were especially important to outline a plan to stay on track.

Having high expectations, the team called for a large time commitment from every employee. Communication between employees was very important to maintain high attendance and productivity during meetings. We used applications like GroupMe messaging software, Google Calendar, and company emails to communicate and share schedules. Google Drive was an important organizational tool as every single document produced by the company resides on the drive, organized into Design Documents, Photos, Competition Documents, Safety and other categories. Documenting all the company's work was vital to PVIT's success.

The Command & Control team established a project schedule using Jira project management software by Atlassian, while the entire engineering cycle was planned on Google Forms (See Appendix B). Despite our efforts, the team fell behind schedule for various reasons like delays in purchasing, extensive delays in parts delivery, and the software learning curve. In April, deadlines were established for team objectives like finishing props, writing documents, completing payload tools, and fabricating parts. The biggest deadline was "getting into the water" which was pushed back repeatedly. At the end, after many long days, the goals were reached and PVIT produced a state-of-the-art ROV.

Meeting Organization: Over time the meeting schedule increased based on meeting milestones for the pending completion. PVIT ROV started with weekly meetings on Sunday from 2:00 to 4:00 p.m. This evolved in February to adding Saturdays, then extended meeting times from 1:00 to 4:30 p.m. and finally daily after school meetings beginning mid-April to meet deadlines. In addition, employees held small group sessions on Zoom to work on coding. At the beginning of each meeting, the full staff would come together to discuss each group's goal for the meeting and make any other important announcements. Each component that needed completion was evaluated for potential issues, then sub teams would gather to complete their given tasks. More experienced engineers would be assigned to help the new engineers. At the end of the meeting, the staff would once again to discuss their progress, whether or not they reached their goal for the day, and if they encountered any issues.

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.

Design Rationale

The primary consideration for PVIT in designing our new ROV was the customers' requests. The RFP was scrutinized to assess every need, and the specifications were examined to make sure we would be fully compliant. The customers' needs determined our payload tools and the special software applications to be developed. At PVIT, we have many resources which we utilize in the design and manufacture of our ROVs. Our in-house tools, including Markforged and MakerBot 3D printers, a Universal Laser Systems (ULS) laser cutter, Omio CNC machine, soldering irons, and drill press, which provide us with the means to manufacture our ROV and fabricate its payload tools. We use Autodesk Inventor 3D design software, Corel Draw, and MultiSim, to create precise models of parts and components and test circuitry designs. As a result, the *Maui* is our original design, custom-made primarily from base components.

The PVIT ROV team drew inspiration from past designs of our own and from other teams competing in MATE. Learning from other teams at last year's competition, we saw the benefit to implement several more cameras to increase the pilot's visibility and control. In addition, team members collaborated to construct a brand new electronics control system, the "Brain", to use newer, more compact electronics technology that is easier to code with open source libraries, to incorporate Raspberry Pi and Arduino microprocessors, and to implement the Python programming language for machine learning of the autonomous tasks.

Overall Vehicle Design & Systems Approach: The driving factor in the design of the vehicle was simplicity: reducing the parts of the ROV to yield optimal efficiency and reliability. The overall design of *Maui* was strategically built in Inventor to plan its size and layout where we designed and assembled the major components of the ROV including the Brain, thrusters, side frames, and crosspieces. 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, which is a new feature incorporated this year to make the vehicle more compact and hydrodynamic. We created a fully functioning ROV that will meet the size goal as well as be maneuverable to accomplish the demanding tasks that are set before us by MATE. (See Figure 1.)

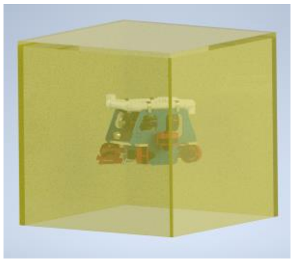


Figure 1: ROV Design with Size Constraint
By: Cynthia Ho

Figure 2: Main Assembly
By: Cynthia Ho

We completely customized our side frames to reduce water resistance by narrowing the side frames in the front and back of the ROV and incorporating cut-outs. The thrusters are oriented in a vectored array of 30 degrees angled toward the interior of the ROV in order to provide significant maneuverability in the horizontal plane 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. In addition, the thrusters are securely attached to the underside of existing cross pieces to simplifying the design. (See Figure 2.)

All Brain input connections are on the endcap of the enclosure to streamline the vehicle for better flying, minimize size and weight, and improve access for repairs if necessary. On the other end, the Brain has a clear dome with a camera. There are two other waterproof cameras facing forward and one facing downward for maximum visibility so that the pilot can complete tasks such as inspecting an offshore aquaculture fish pen and mapping the *Endurance* shipwreck. We mounted our claw assembly on a single mounting plate which can be removed to reduce vehicle size and allow servicing. The claw is in the center to facilitate clear viewing for the pilot while grasping objects such as morts and seagrass. The electromagnet device is mounted at the front left of *Maui* to facilitate removing the damaged inter-array power cable and retrieving a ghost net. Careful consideration was given to every detail of designing and building *Maui*. Nothing is placed randomly; everything is considered for performance outcome and effect.

Innovation: Due to its innovative rotation feature, the claw is highly capable and can easily perform most of the customer's requested tasks. The hook mounted on the left side frame is extremely cost-effective with high functionality at a reduced cost and weight. While the hook was laser cut from cast acrylic and took less than two hours to make from start to finish, it allows the ROV be efficient and carry multiple items at once, such as in the power array in task 1.1 and ghost net in task 1.3.

Mechanical Design and Fabrication

Vehicle Structure: The ROV has a very simple structure which consists of side frames and cross pieces. Its dimensions are 52 cm in height, 38 cm in length, and 51 cm in width. The side frames are 0.635 cm thick and are made from polypropylene because it is lightweight and durable, and the cross pieces are made from nylon. There are six cross pieces in total, four of them have a 29 cm length, 5 cm width and 1.25 cm thickness and the other two have a 40.5 cm length, 5 cm width and 1.25 cm thickness. These chosen materials made it very easy to construct the ROV as both materials are very machinable and non-corrosive. The ROV this year has a weight of 12.5 kilograms. Overall, it is still compact, allowing faster movement with enough room for payload tools.

	Nylon	Polypropylene
Density	1.135 g/cm^3	0.9134 g/cm^3
Impact Strength	32- 75 ft. (J/m).	48 - 101 (J/m)
Flexibility	Semi-Rigid	Semi-Rigid
Cost	$ 0.044 per cm^3	$ 0.026 per cm^3

Table 1: Vehicle Structure By: Ben Peters

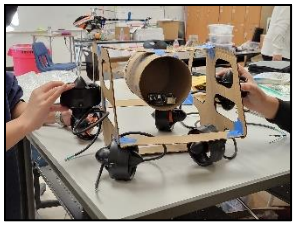


Photo 4: Cardboard Frame
By: Sammy Moore

After carefully scaled measurements made in CAD, each component was precisely cut using a laser cutter in our lab. The side frames were cut from polypropylene; a material we chose because it is strong, lightweight, non-brittle, and machinable. Before we laser cut the polypropylene sheets, we prototyped the designs with cardboard sheets as a way to test many different designs without wasting premium materials. (See Photo 4.) There were multiple redesigns to fit our claw and crosspieces. Once we were set on the design of the prototype, we cut our final design in the polypropylene. These components were then assembled according to the Autodesk CAD ROV design. (See Figure 3.)

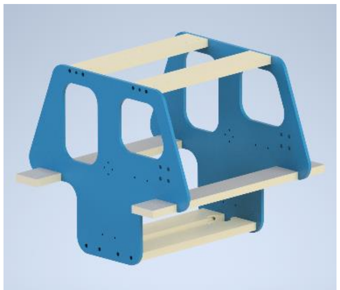


Figure 3: Polypropylene Frame
By: Cynthia Ho

Propulsion: The *Maui* utilizes six BlueRobotics T-200 thrusters, chosen for their cost and availability after our SeaBotics thrusters reached the end of their service life. BlueRobotics generously donated eight T-200s thrusters. The thrusters are controlled by BlueRobotics ESCs and the code restricts the six motors to draw no more than 16 amps total at the same time. The motors are also surrounded by custom designed and fabricated red 3-D printed shrouds (See Figure 4.) to make sure that no propellers are exposed and are easily recognized as areas of potential danger. (See Photo 5.) Two of the thrusters are positioned vertically on the outer middle area of the frame to make sure that the ROV can stay stable while moving vertically as well as to make room in the center of the ROV for the claw, cameras and Brain. The other four thrusters are positioned in a vectored format on the outside corners of the frame. This allows *Maui* to have unlimited maneuverability in the horizontal plane which is crucial for task 1.1, inspecting power cables and task 3.2, finding and mapping shipwrecks.


Photo 5:
Thrusters with Shroud
By: Allison Yu

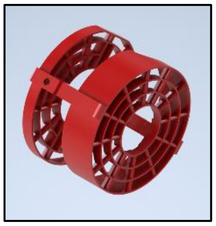


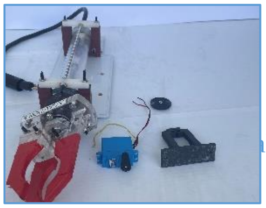
Figure 4: CAD Shrouds
By: Cynthia Ho

Buoyancy & Ballast: The buoyancy and ballast on our ROV is carefully designed for optimization. The *Maui* is guaranteed to be stable and fly horizontally with even weight distribution. Our vehicle is designed to have our payloads near the bottom in order for the center of mass to be near the bottom. By placing the center of mass central and low to the craft we do not need to add any ballast. The buoyancy of our ROV is placed on top of the craft for better stability. We use a variable buoyancy system made of PVC pipe configured in a rectangle and a manual bike pump with an air tube running into the pipe, allowing our deck crew to pump in air when needed. A PVC cap that can be taken out at the surface to allow the pipe to be flooded with water so the *Maui* 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. Additional foam pieces are attached to achieve the precise buoyancy desired when submerged.

Cameras: The *Maui* features four brand new exploreHD 2.0 Underwater ROV/AUV USB Cameras purchased from Deep Water Exploration which come with auto color correction and fisheye correction technology. We replaced the two GoPro cameras from last year's ROV that were housed inside the waterproof enclosure. These new exploreHD cameras are waterproof, which allows us to mount the cameras externally on the ROV frame. One camera is placed inside the dome of the waterproof enclosure, facing downwards at an angle so that it faces the claw. Of the three remaining cameras, one faces directly downwards and two face directly forward to work in unison. By employing a machine learning computer vision system, OpenCV libraries, the two forward-facing cameras are able to triangulate distance using stereo vision. The two forward-facing cameras can also merge their two images together to provide a wider field of view.

Underwater Measuring & Photomosaic Technology: The *Maui's* exploreHD cameras produce all the necessary data to provide to G-Streamer, an open source video streaming platform that powers the camera view. G-streamer utilizes H.264 encryption to turn the camera stream into an mp4 format, then compresses the streams and turns them into a generic mp4 format that is piped over to OpenCV. As the ROV's two front cameras are synchronized, their video streams are submitted to OpenCV to be stitched together. This stitched image provides the front-facing, wide-angle view for the pilot. All subsequent cameras are run as single view sources, running in separate streaming threads and thus, are processed in parallel.

Manipulator: The ROV's manipulator, fondly called the "claw," consists of three fingers that are configured similar to the shape of a hawk's claw. In the final claw design, we chose to sacrifice the ability to pick up very small items


l Parts

with the claw, such as pins, and instead use an electromagnet to pick up small things. The claw's 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 6.) This design adaptation gives the claw a 12 Newton grabbing force at 12V. The fingers open wide and are interlocked in their fully closed position, allowing gripping of items ranging in size from less than 1cm to 10cm. The fingers are wrapped with colorful tape for safety, visibility and grip. The claw is held together by a custom mount comprised of two custom bushings made of a very light, slick material, (polypropylene or nylon). The center point of the actuator end cap is attached to a servo with 90-degree rotation. (See Photo 7.) This year, the company made a carbon-fiber, 3D-printed custom mount for the servo. The single 3D-printed piece with a little flexibility designed into the spacing is a big improvement over last year's multi-piece acrylic mount that broke on numerous occasions. Turning the servo rotates the claw, which provides the ability to pick up a variety of objects positioned either horizontally, vertically, or in 2 midway positions and complete other tasks such as releasing the clamp on the failed buoyancy module. 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. Note that the claw is completely custom made. We custom cut the claw fingers, acrylic mounts, backplate and numerous linkage pieces using our company's laser cutter, and the bushings are custom fabricated on a lathe. The servo is a waterproof motor purchased from BlueRobotics, and electrical connections were made and waterproofed by our electrical engineers. This year, we only made slight modifications to our previous manipulator; we replaced water-damaged hardware and did general maintenance to preserve the capability of the manipulator.

Electromagnet: We chose an electromagnet for the tasks requiring pulling magnetic pins because of its automatic and quick function, whereas a claw's manual manipulation requires attention and time. (See Photo 8.) The electromagnet device is attached on an original mount 3D printed with carbon fiber, a strong material adept at supporting the device. The electromagnet is positioned on the front left of *Maui* to facilitate removing the damaged inter-array power cable and retrieving a ghost net.

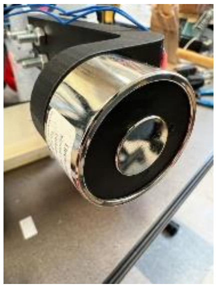


Photo 8: Electromagnet
By: Allison Yu


Photo 9: *Molokini* Float
By: Azalea Lurie

Float: Our float, fondly named the *Molokini*, is comprised of a thruster connected to an acrylic tube. Inside the waterproof tube is an Arduino Mega and eight C-cell batteries which start up when a BlueRobotics switch is turned on by our deck crew. The Arduino Mega is coded to automate multiple timers. The first timer starts as soon as the switch is activated and gives the ROV sufficient time to deploy the *Molokini* through the PVC frame. A new timer starts immediately after, causing the thruster to engage and begin its descent, followed by another timer, giving the *Molokini* time to surface. The *Molokini* is slightly positively buoyant, allowing for it to passively float to the surface. The last two timers will repeat, so as to complete two full cycles. (See Photo 9.)

Tether: The tether has 3 wires encased in an expandable mesh sleeve. It is constructed using one Ethernet cable and a pair of 10-gauge wires. The wires supply 12-volt power and ground to the remotely operated vehicle. We chose 10-gauge over 12-gauge for less voltage drop across the tether's 15 meters. The Ethernet cable, which is CAT 6a and shielded, carries serial communications, video signal, and video ground.

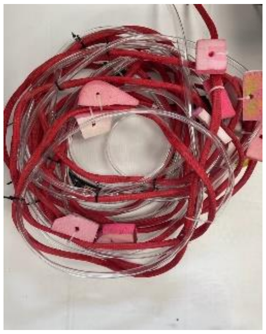


Photo 10: Tether
By: Azalea Lurie

We chose CAT6a over CAT5 for less signal degradation. We also have terminal connectors that are heat shrinked to the power and the ground of the tether. Exterior to the mesh holding the wires, an air hose is attached to the tether with zip ties. (See Photo 10.) 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 air line. The tether is 15 meters long and has stress relief devices that attach it to the *Maui* and to the control box to prevent damage to its connectors are pulled. We require buoyancy for the tether so that it floats on or close to the surface of the water and does not sink or disrupt the environment by dragging on the bottom. Buoyancy is achieved by attaching small pieces of foam at 1-meter intervals. Tether management is an important aspect of flying the *Maui*, and we adhere to the Tether Protocol when operating the ROV (see safety section).

Software and Electronics

Photo 11: Brain inside Tube
By: Jenna Chow

Command and Control: The “Brain” is carefully structured to fit into a waterproof acrylic tube where the electronics are highly organized and compact without hindering the vision of the cameras. (See Photo 11.) An 8-pin Ethernet cable carries all signals between on-deck and on-board. PVIT programmers wrote original code to provide the best control of the *Maui* based on input from our pilot through a PlayStation 4 DualShock Bluetooth controller. ‘The code was fully renovated from previous ROVs and was rewritten in the Python programming language. Two Raspberry Pi computers and an Arduino microcontroller within the ROV brain handle a host of new services including a modularized thruster control module, an electromagnet control module, a rotating and opening claw module, and an HD camera module. (See Photo 12.)We have utilized OpenCV libraries to allow the ROV to autonomously recognize objects, obstacles, and distances and send feedback to the operator. The on-deck command system, the “Commander”, has also been redesigned to host all new software systems. This updated controller module, which integrates the PlayStation 4 controller, can switch between manual mode, to manually drive the ROV, and any of the autonomous running modes. The *Maui* employs autonomous modules based on OpenCV, to classify objects, recognize terrains, automate ROV movements, and calculate distances. A novel ROV diagnostic module displays relayed real-time information from the ROV itself. Finally, a distributed video streaming system based on the industry standard GStreamer library is deployed across multiple laptop displays.

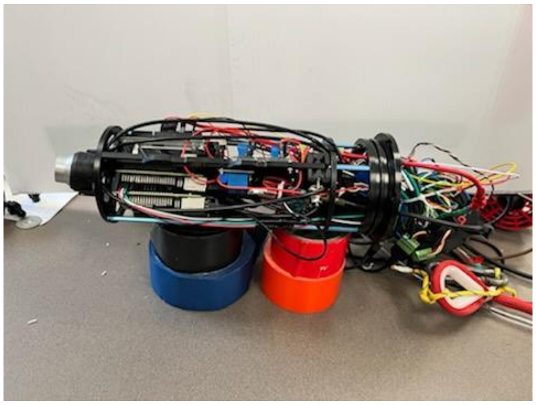


Photo 12: Brain   By: Jenna Chow

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

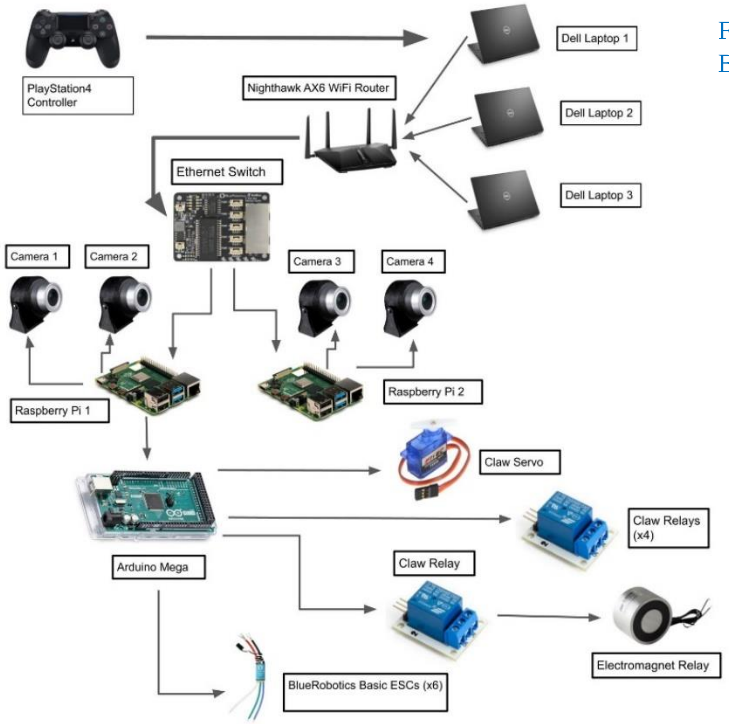


Figure 5: Pictorial Block Diagram
By: Allison Yu

KEY

➡ = Data Flow

Illustration of electronic command and control system (arrows depict electronic signals): Pilot delivers commands with the PS4 controller to the commander Python application in the on-deck laptop. Commander application sends the commands via an HTTP API call to the brain Python application in the ROV Raspberry Pi. Commands are then deciphered and sent to the thruster module to control the BlueRobotics thrusters, electromagnet, and the claw. Video cameras stream through the Raspberry Pi's to a network IP and port. These streams are then captured by on-deck laptops. Laptops communicate through either ethernet wires or Wi-Fi.

Systems Integration Diagram (SID) for Float Device:

Legend: Red=5v, Blue=12v, Green=Signal

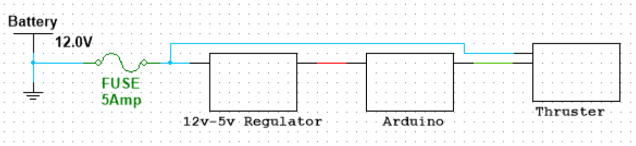
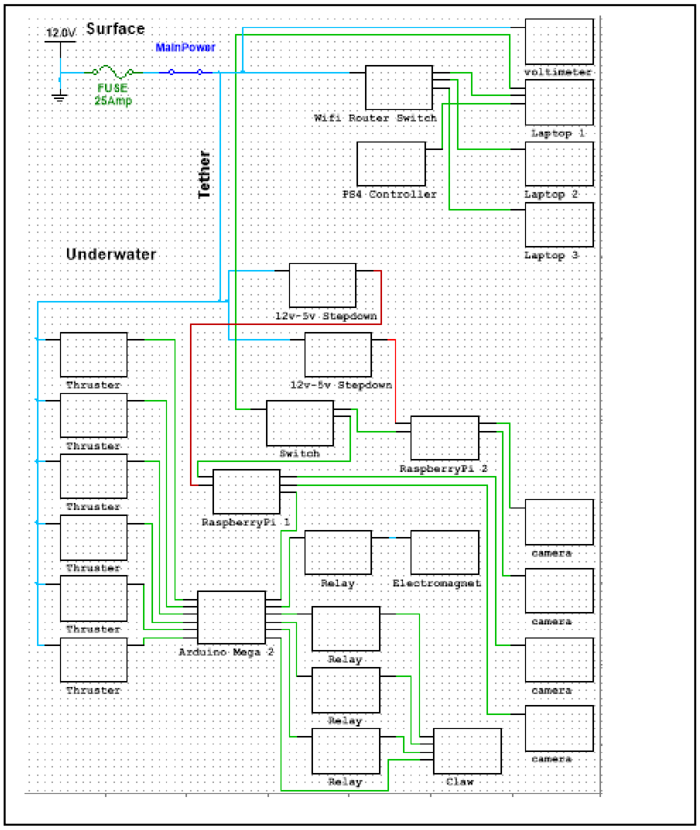


Figure 6: SID for Float
By: Lisa Lininger

Fuse Calculation:

Overcurrent Protection= Float Device Full Load Current * 150%
Fuse Rating = BlueRobotics Thrusters Rtg *150
Fuse Rating = 4 Amps*150% = 6
Maximum Fuse Rating = 6 Amps
Note: a 5 Amp fuse is used due to availability and the thruster is appropriately limited by software.

Systems Integration Diagram (SID) for ROV:



Legend:
Red = 5v
Blue = 12v
Green = Signal

Figure 7: SID for ROV
By: Lisa Lininger

Fuse Calculation:
Overcurrent Protection= ROV Full Load Current * 150%
Fuse Rating = [(Linear Actuator Rtg) + (BlueRobotics Thrusters Rtg) + (Electromagnet)] *150
Fuse Rating A (horizontal thrusters) = [(0.22 Amps) + (4*4.0 Amps) + (0.3 Amps)]*150% = 24.78
Fuse Rating B (vertical thrusters) = [(0.22 Amps)+ (2*4.0 Amps)) + (0.3 Amps)] *150% = 12.78
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 *Maui'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 *Maui* 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 PS4 controller or other UI controls. Based on these messages, the Commander either forwards the data to the Brain or operates the different command system modules.

Autonomous Module: Autonomous mode on the ROV is implemented through separate modules for each function. The current set of features includes 1) Autonomously docking of the ROV into the "resident ROV" docking station in task 1.4, 2) Autonomously flying a transect line to inspect and identify damaged areas in task 2.1, 3). Differentiating "morts" from live fish in task 2.2, and 4) Autonomously creating a photomosaic of the Endurance wreck in task 3.2. For tasks which require ROV movement, images are used to programmatically calculate the directions necessary to move the ROV, then movements are determined incrementally based on a continuous stream of image calculations. Determining morts from live fish is a computer vision machine learning exercise which requires advanced training which was accomplished with images of live fish, dead fish, and images with no fish. Creating a photomosaic of the Endurance wreck involves a process which applies computer vision image stitching to methodically assemble the 4x2 photo grid. This process involves stitching a 2x1 section of the grid four times, then assembling the four 2x1 sections into two 2x2 sections, and then a final assembly of the two 2x2 sections into a 4x2 photomosaic. All of the stitching can be done by simply starting the autonomous process and cycling through the 8 images. The on-deck autonomous controller coordinates the stitching automatically and presents the final image on the main display.

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 PS4 controller 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 PS4 controller. The PS4 controller communicates via hardware device driver open source library known as Pygame*.

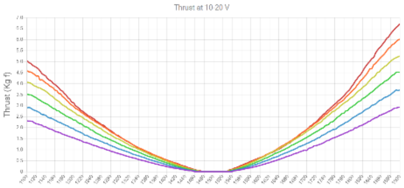
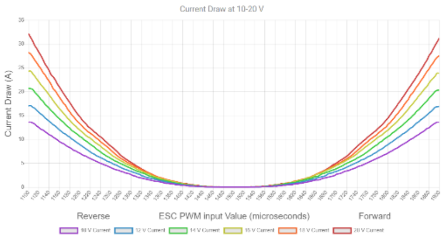


Figure 8: Thrust vs. ESC PWM Input Value
By: Ben Peters

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. (See Figure 8.) As the signals get farther from the 0 value, the thrust increases significantly, but this



causes the thrusters to draw more amps. The ROV is using a 12V current and when the thrusters run on the max signal, they pull 17 amps each, which far exceeds the 25 amp fuse limitation. To make sure we don’t blow a fuse, we set up a couple safety features within the program. First, we make sure we are never running more than four thrusters. Secondly, we set the maximum signals for clockwise rotation and counterclockwise rotation to 1250 and 1750. (See Figure 9.) This makes sure that the four motors can pull only 16 amps. These features mean we get less thrust, but it also means we are safe when controlling the ROV.

PS4 Module: The PS4 controller of the ROV uses Pygame* to capture and convert the button and trigger actions into events. (See Figure 10.) Specifically, the ROV is controlled by the joystick module of the Python library. The PS4 controller module runs within the main controller module and the events are either forwarded to the Brain or used in the command system to switch from manual mode to one of the autonomous modes. Each action event generated by the PS4 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. Most PS4 controller actions consist of a single button or trigger action, however, there may be actions that require two buttons to be pressed simultaneously. Besides capturing the button and trigger actions, the PS4 module normalizes the data coming from the button actions. For example, when a left analog stick change registers both the up/down and left/right values as .9 and .1 respectively, the controller determines that the value of the up/down change is the most relevant and registers the change as up/down (.9) and left/right (0).

Figure 10: PS4 Diagram
By: Allison Yu

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 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 such as in task 3.2, Measuring *Endurance* from bow to stern, to highlight over the edges and be displayed to the user. The model information is then sent to the autonomous module for automating the ROV. OpenCV can also stitch together two images. Given two side-by-side images, it stitches them together to create one merged image such as in task 3.2, Creating a Photomosaic, and at the same time, enables us to calculate distances through triangulation.

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 and tools we have, we typically build it, as PVIT's first preference is always to custom build to meet our customer’s specs. However, our company also considers cost, time, and manpower, as well as whether or not we have the option to buy. 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 new Markforged Onyx 3D Printer, which uses carbon fiber filament, was used to retrofit our reused electromagnet with a custom mount attached directly to the port sideframe. PVIT’s Makerbot Replicator 3D printer, which uses PLA material, was used for the light-service thruster shrouds. We use our ULS laser cutter to fabricate various thicknesses of acrylic and polypropylene for planar pieces. (See Table 2.)

Table 2: Build vs. Buy, New vs. Reused
By: Zach Rapoport

Purchased / New	**Build / New**	**Used / Reused**	**In House Customization**
	Side frames		Designed and laser cut
		Cross pieces	Hand cut
		Tether	ROV solder connections, air line addition
		Claw parts	Servo mount, fingers, bushings, connecting pieces
BR** Wetlink Penetrators			16 bulkhead penetrations soldered & connected
		Electromagnet	Design and 3D print mount
BR T-200 thrusters			Design and 3D print shrouds
Brain components* & tube	Mounting plates, Brain assembly	5V relays	Design & print electronics mount, solder & wire connection
Cameras			Design & print mounts
		Control Box	Rewired for new components
PS4 Controller			Configured buttons for piloting

*Arduino, Raspberry Pi, BR ESC's
** BR = BlueRobotics

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 *Maui*, we tested our payload tools and other devices multiple times to optimize our design and performance. To troubleshoot design flaws, we first cut prototypes using cardboard for every laser cut piece. This includes structural components of the vehicle and many parts of the claw. This allows us to see if our design is precise and optimal as well as if and how we should redesign them before creating the final product. 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 motors 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 *Maui*, it is first tested in the lab where each operational function (thrusters, claw, electromagnet) is tested. After passing the dry test, the *Maui* 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 *Maui* 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 *Maui* 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) and our team's Job Safety Analysis (JSA). Employees worked in pairs or small groups so that no one was using 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 *Maui* 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, and the thrusters are shrouded with MATE compliant custom-made 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 BlueRobotics Wetlink 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. To ensure everyone is safe in the pool area, pool covers are removed before we work with the ROV, eliminating the possibility of team members becoming trapped underneath. We also make sure 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 in order 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.
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 air line to the ROV.
6. Connect air to the supply (bicycle pump).
7. Connect the strain relief to the ROV.

Disconnect:

1. Safely unplug and disconnect the tether from the control box.
2. Disconnect the air line from air supply and ROV.
3. Roll up the tether neatly.

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.

Project Costing, Budget and Funding

Budget: Our Budget was created by estimating costs based on anticipated needs and historical purchasing experience. The budget was submitted for approval in October 2021.The approved 2022 budget of our ROV company, granted by PVIT, was $11,745. This consists of new parts, materials, and technologies to bolster the performance of our ROV.

Funding: Most PVIT funding comes from the Peninsula Education Foundation (PEF), which raises money for PVPUSD's entire STEM program. PEF contributes two thirds of PVIT's annual budget. The Palos Verdes High School Booster Club and parent contributions supply the balance.

Spending: Our total spending for the MATE regional competition was $2880. The company used purchased, donated, and reused items to construct a capable ROV below budget. Emphasis was placed on building an original ROV from purchased or fabricated components. Reused items were limited to cl electronics (wires, 5v regulators), hardware fasteners (screws, bolts), tether components, fittings for props. The unexpected and generous donation of thrusters from BlueRobotics from Bob Waters contributed to a large portion of the below budget savings. Another savings was using materials that PVIT ROV already had in inventory, like acrylic and polypropylene.

Table 3: Costing Summary
By: Payton Ahn

Costing Summary:

ROV Value (vehicle, tether and control box only):

Purchased	$2806
Donated	$2013
Reused	$ 748
TOTAL	$5567

Total Valuation:

(ROV, control box, tether, props, fees):

Purchased	$3079
Donated	$2013
Reused	$ 748
TOTAL	$5840

Table 4: Reused Items
By: Payton Ahn

Reused Items:

CATEGORY	ITEM	QTY	UNIT VALUE ($)	TOTAL ($)
ROV				
Electronics	Wires	Various	21	21
Electronics	5 5V Relay Module	1	9	9
Claw	Linear Actuator	1	70	70
Claw	Bushings	2	50	100
Claw	Acrylic tube	1	20	20
			Subtotal ($)	**220**
Command & Control				
Electronics	Arduino Mega 2560 micro-controllers	1	38	38
Electronics	Female Ethernet, 10 pack	1	12	12
Electronics	Anderson Power Pole connectors	1	22	22
Electronics	Fuses, 25A, 5A	2	7	14
Power	AC to DC Power Supply Converter	1	166	166
Tether	12 gauge wire	2	14	28
Tether	Mesh sleeve	1	15	15
			Subtotal ($)	**295**
Props				
Hardware	PVC Fitting	Various	75	75
Hardware	PVC Pipe, White, Various sizes	1	100	100
Hardware	Nuts, bolts, stock	1	58	58
			Subtotal ($)	**233**
GRAND TOTAL			**Total ($)**	**748**

Donated Items:

Table 5: Donated Items
By: Payton Ahn

ITEM	QTY	DONOR	UNIT VALUE ($)	TOTAL ($)
Motor controllers	8	Bob Waters	30	240
5-volt valve	3	Bob Waters	17	24
stepper motor	1	Bob Waters	25	25
DC motor	1	Bob Waters	10	10
32pc compact splicing connector asst kit	1	Bob Waters	30	30
micro controller boards	2	Bob Waters	27	54
silicone conformal coating	1	Bob Waters	30	30
T200 thrusters	8	BlueRobotics	200	1600
GRAND TOTAL:	**27**		**$ 369**	**$ 2013**

Purchased Items:

Table 6: Purchased Items
By: Payton Ahn

PART NAME or DESCRIPTION	QTY	PRICE (each) ($)	TOTAL ($)
ROV			
Four Inch Series Cast Acrylic Tube & dome end cap	1	125	125
Four inch Series Aluminum end cap with 18 holes	1	48	48
Four inch Series enclosure clamp, O-Ring Flange, Spare	1	145	145
Four inch series Electronics Tray	1	52	52
M10 Enclosure Vent and Plug	2	9	18
M10 WetLink Blank	2	6	12
M10 WetLink Penetrators	16	48	192
WetLink Penetrator Spare Seals	4	72	72
Spare Bulkhead O-Ring Set M10	1	2	2
Power bus	1	31	31
Saw	1	119	119
Ethernet switch	1	175	175
Depth/pressure sensor	1	75	75
ExploreHD 2.0 Underwater ROV/AUV USB Camera	6	250	1500
HDcam HD USB Camera	2	120	240
		Subtotal ($)	**2806**
Props and Other			
Pink String	1	10	10
Plastic Mesh	1	27	27
Metal tent stakes	1	11	11
Registration	1	200	200
Fluid power quiz	1	25	25
		Subtotal ($)	**273**
GRAND TOTAL			**3079**

References

1. Mate ROV Competition Website https://www.materovcompetition.org/
2. BlueRobotics Website https://bluerobotics.com/learn/voltage-drop-calculator/
3. Microsoft Paint 3D Website https://www.microsoft.com/en-us/p/paint-3d/9nblggh5fv99?activetab=pivot:overviewtab/
4. BlueRobotics T200 Thruster, https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/
5. BlueRobotics Basic Electronic Speed Controller, https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/
6. BlueRobotics 4” Watertight Enclosure, https://bluerobotics.com/store/watertight-enclosures/4-series/wte4-asm-r1/
7. BlueRobotics 4” Electronics Tray, https://bluerobotics.com/store/watertight-enclosures/4-series/wte4-etray-r1/
8. BlueRobotics 10m Depth/Pressure Sensor, https://bluerobotics.com/store/sensors-sonars-cameras/sensors/bar02-sensor-r1-rp/
9. BlueRobotics Ethernet Switch, https://bluerobotics.com/store/comm-control-power/tether-interface/ethswitch/
10. BlueRobotics Switch, https://bluerobotics.com/store/comm-control-power/switch/switch-10-5a-r1/
11. DeepWater Exploration exploreHD 2.0 Underwater ROV/AUV USB Camera, https://exploredeepwater.com/products/explorehd-rov-auv-usb-camera
12. Netgear Nighthawk AX5400 WiFi Router, https://www.netgear.com/home/wifi/routers/rax50/
13. Raspberry Pi 4, https://www.raspberrypi.com/products/raspberry-pi-4-model-b/
14. Arduino Mega 2560 Rev3, https://store-usa.arduino.cc/products/arduino-mega-2560-rev3?selectedStore=us
15. Delrin®, High-Performance Acetal Resin, https://www.dupont.com/brands/delrin.html
16. Nylon Reference: https://www.mcmaster.com/8539K38/
17. Polypropylene Reference: https://www.mcmaster.com/8742K237/
18. OpenCV Computer Vision Library, https://github.com/opencv
19. Compiling OpenCV from scratch: https://github.com/opencv/opencv/issues/21389
20. OpenCV for image stitching: https://github.com/opencv/opencv/blob/4.x/samples/python/stitching.py
21. Displaying multiple images in OpenCV: https://www.geeksforgeeks.org/how-to-display-multiple-images-in-one-window-using-opencv-python/
22. Distance calculations using stereo cameras in OpenCV: https://www.youtube.com/watch?v=sW4CVI51jDY
23. GStreamer Video Streaming Library, https://gstreamer.freedesktop.org/
24. Custom OpenCV with GStreamer Build: https://github.com/sayakpaul/portfolio/issues/7
25. PyFirmata and Firmata Reference - Microcontroller communications protocol: https://roboticsbackend.com/control-arduino-with-python-and-pyfirmata-from-raspberry-pi/
26. Pygame PS4 Controller Library: https://www.pygame.org/
27. How to use Pygame joysticks: https://github.com/ChristianD37/YoutubeTutorials/tree/master/PS4%20Controller
28. BlueRobotics Depth Sensor Python Library: https://github.com/bluerobotics/ms5837-python

Appendix

A: Sub Team Structure

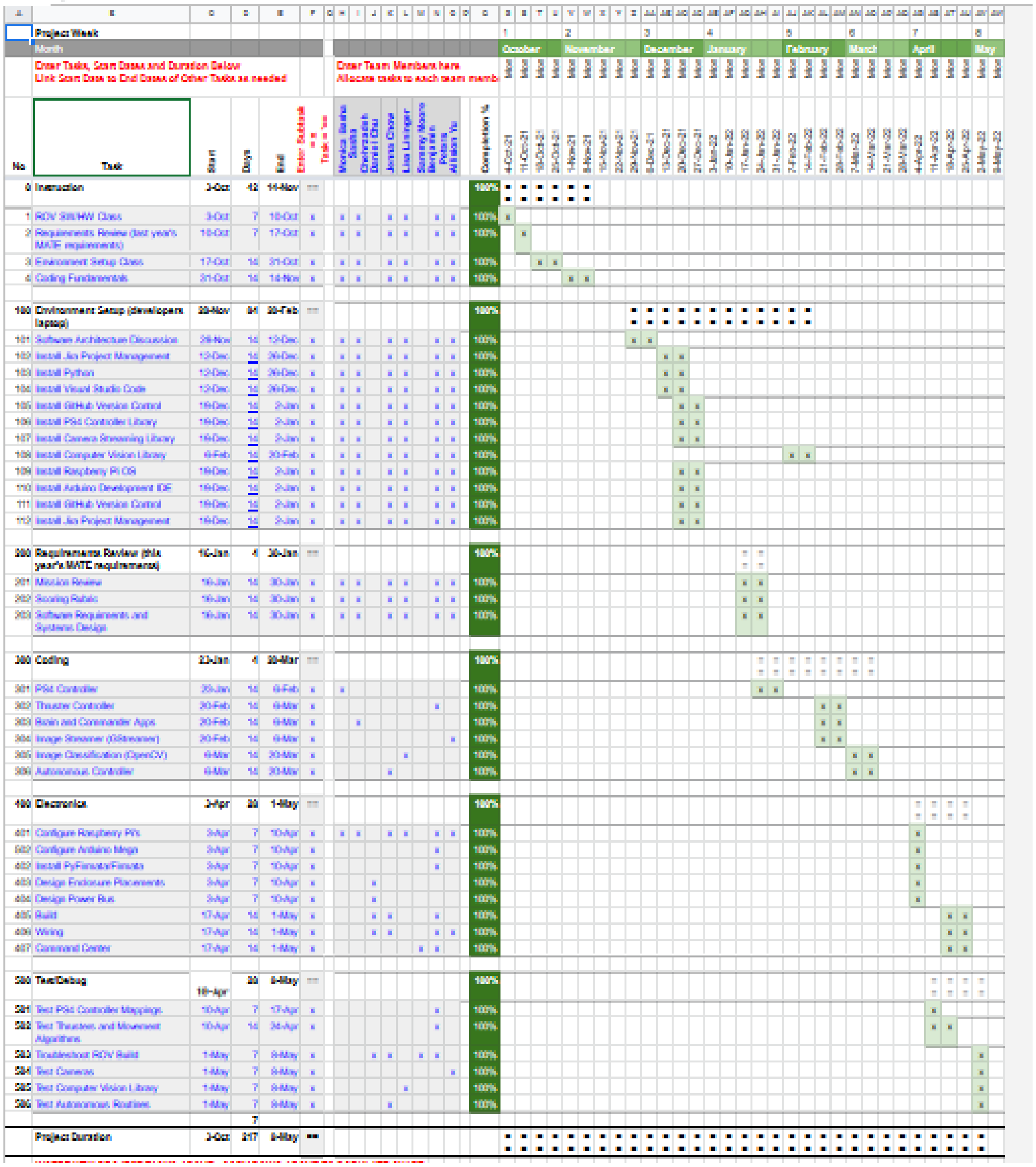
By: Erika Yiu

Design	Mechanical		Software & Electronics	Marketing & Information
Sammy*	Jenna*	Sammy*	Jenna*	Erika*
Cynthia	Steven	Daniel	Ben	Lisa
Ben	Cynthia	Zach	Allison	Steven
Andrew	Riko	Ethan	Lisa	Skylor
Daniel	Allison	Lucia	Sasha	Payton
	Azalea	Kharianna	Monica	

*Lead

B: Project Schedule (excerpt)

By: Jenna Chow



Project Week

Month

Enter Tasks, Start Dates and Duration Below
Link Start Dates to End Dates of Other Tasks as needed

Enter Team Members here
Allocate tasks to each team memb

No	Task	Start	Days	End	Completion %
0	Instruction	3-Oct	42	14-Nov	100%
1	ROV SW/HW Class	3-Oct	7	10-Oct	100%
2	Requirements Review (last year's MATE requirements)	10-Oct	7	17-Oct	100%
3	Environment Setup Class	17-Oct	14	31-Oct	100%
4	Coding Fundamentals	31-Oct	14	14-Nov	100%
100	Environment Setup (developers laptop)	28-Nov	84	20-Feb	100%
101	Software Architecture Discussion	28-Nov	14	12-Dec	100%
102	Install Jira Project Management	12-Dec	14	26-Dec	100%
103	Install Python	12-Dec	14	26-Dec	100%
104	Install Visual Studio Code	12-Dec	14	26-Dec	100%
105	Install GitHub Version Control	19-Dec	14	2-Jan	100%
106	Install PS4 Controller Library	19-Dec	14	2-Jan	100%
107	Install Camera Streaming Library	19-Dec	14	2-Jan	100%
108	Install Computer Vision Library	6-Feb	14	20-Feb	100%
109	Install Raspberry Pi OS	19-Dec	14	2-Jan	100%
110	Install Arduino Development IDE	19-Dec	14	2-Jan	100%
111	Install GitHub Version Control	19-Dec	14	2-Jan	100%
112	Install Jira Project Management	19-Dec	14	2-Jan	100%
200	Requirements Review (this year's MATE requirements)	16-Jan	4	30-Jan	100%
201	Mission Review	16-Jan	14	30-Jan	100%
202	Scoring Rubric	16-Jan	14	30-Jan	100%
203	Software Requirements and Systems Design	16-Jan	14	30-Jan	100%
300	Coding	23-Jan	4	20-Mar	100%
301	PS4 Controller	23-Jan	14	6-Feb	100%
302	Thruster Controller	20-Feb	14	6-Mar	100%
303	Brain and Commander Apps	20-Feb	14	6-Mar	100%
304	Image Streamer (GStreamer)	20-Feb	14	6-Mar	100%
305	Image Classification (OpenCV)	6-Mar	14	20-Mar	100%
306	Autonomous Controller	6-Mar	14	20-Mar	100%
400	Electronics	3-Apr	28	1-May	100%
401	Configure Raspberry Pi's	3-Apr	7	10-Apr	100%
402	Configure Arduino Mega	3-Apr	7	10-Apr	100%
402	Install PyFirmata/Firmata	3-Apr	7	10-Apr	100%
403	Design Enclosure Placements	3-Apr	7	10-Apr	100%
404	Design Power Bus	3-Apr	7	10-Apr	100%
405	Build	17-Apr	14	1-May	100%
406	Wiring	17-Apr	14	1-May	100%
407	Command Center	17-Apr	14	1-May	100%
500	Test/Debug	10-Apr	28	8-May	100%
501	Test PS4 Controller Mappings	10-Apr	7	17-Apr	100%
502	Test Thrusters and Movement Algorithms	10-Apr	14	24-Apr	100%
503	Troubleshoot ROV Build	1-May	7	8-May	100%
504	Test Cameras	1-May	7	8-May	100%
505	Test Computer Vision Library	1-May	7	8-May	100%
506	Test Autonomous Routines	1-May	7	8-May	100%
			7		
	Project Duration	3-Oct	217	8-May	

C: PVIT 2022 Budget

By: Steven Guo

ITEM	**COST ($)**
Buoyancy System and foam	300
Pump, pressure relief valve, depth sensor	81
Blue Robotics vent, penetrators, O-rings	208
Ardinos Mega 2560 Rev 3 & Arduino Portenta H7	814
ESC	240
Fabrication material – acrylic, polypropylene, 3D filament	130
Electronics - wiring, USB cables, heat shrink, misc	815
BlueRobotics T200	1432
T200 Propeller Set, Thruster Guards, Thruster command units	752
Explore HD Camera	1500
Raspberry Pi 4 Rev B	300
BlueRobotics watertight enclosure	100
Tether	100
Miscellaneous hardware	378
Regionals registration	250
Fluid power quiz	15
Regionals Total	**7415**
World Competition	
Marketing display and pamplets	120
Miniature ROV models	105
Display table handouts	200
Banner	200
ROV equipment freight	1600
Teacher’s airfare	500
Teacher’s hotel and expenses	1000
Worlds Total	3725
Grand Total	**11,140**

D: PVIT 2022 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.

SYSTEM SET UP

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

POWER UP CHECKS

TASK	HAZARD	PROTOCOL
Product Demo (the ROV run in pool)	Leaking and breaching of electrical system	Perform the pre-run checklist before 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 secured.
Troubleshooting control system	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 communications with all employees.
	Electrical shock	Follow all checklists.
		Keep the extension cord dry.
	Falling in water	Kneel on deck when placing the ROV in the water.
		Always walk, never run in the pool area.
Control deck operation	Shorting of electronics	Ensure that the control deck remains dry at all times.
Supplying props to the ROV	Hands/Fingers caught in claw fingers	Place the prop in between claw fingers, proceed to hold it in place, make sure to avoid hand/fingers getting crushed by the claw fingers as it grips, let go of 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.
Clean the area	Tripping	Remove all props, materials, supplies, and trash

E: List of Tables and Figures

Acknowledgments

We would like to thank the following individuals and organizations for their support:

·Mrs. Loh-Norris, PVIT instructor.

·Mr. Warren, Physics teacher and PVIT instructor.

·Mentors Mrs. Julie Smalling and Mr. Fred Smalling.

·Mentors Mrs. Isabel Moore and Mr. Greg Moore

·Mr. Fred Chow, Software Team Mentor

·Mrs. Cheryl Oshiro, organizing many aspects of the PVIT Team

·Mr. Yutai Liu, additional technical help

·Bob Waters, professional ROV pilot for Bob Ballard, for his expertise and donations

·BlueRobotics, for their great factory tour and generous thruster donations

·Palos Verdes High School Booster Club for supporting the Science Technology Engineering & Math (STEM) program.

·Peninsula Education Foundation for their generous financial support of PVIT.

·Boeing Corporation for their continuing financial support.

·Pelican Inc. for the donation of two large transport cases (2012) and another large and small transport case (2016).

·A special thanks goes to Palos Verdes High School and Patty Camp for the use of the heavily utilized swimming pool for hours of testing and practice.

We thank our MATE Regional Coordinator, Mr. Fraser, for his continued support. We thank Jill Zande and Matthew Gardner and the team of volunteers and judges for arranging the MATE Worlds Competition and answering all our questions. Additionally, we acknowledge:

BOEING

NAUTILUS LIVE
OCEAN EXPLORATION TRUST

MATE ROV
COMPETITION

DeepWater Exploration Inc.

BlueRobotics