2021 MATE World Championship

Technical Documentation for *Mamba* ROV

Palos Verdes Institute of Technology (PVIT)

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

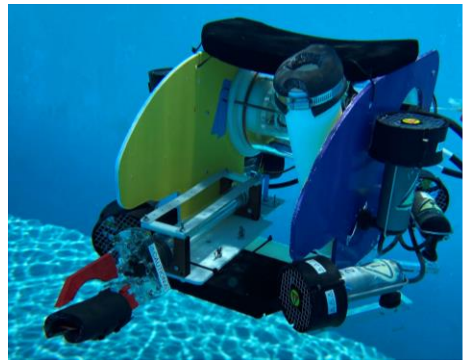

Photo 1: *Mamba*
By: Sammy Moore

2021 PVIT ROV Company:

Dara Chidi:	President	4th year	Class of 2021
Armaan Jhangiani:	Lead Electrical Engineer	3rd year	Class of 2021
Sammy Moore:	CEO, Lead Design Engineer, Pilot	3rd year	Class of 2022
Sasha Chehrzadeh	Lead Programmer	2nd year	Class of 2022
Erika Yiu:	CSO, Mechanical Engineer	2nd year	Class of 2022
Jenna Chow:	CFO, Lead Mechanical Engineer	2nd year	Class of 2023
Natalie Hong:	Mechanical Engineer	2nd year	Class of 2023
Zusan Hu:	Mechanical Engineer	2nd year	Class of 2023
Steven Guo:	Mechanical Engineer	2nd year	Class of 2023
Matthew Smalling	Mechanical Engineer	5th year	Class of 2020
Fransisco Moore	Design Engineer	5th year	Class of 2020
Erin Magid	Electrical Engineer	5th year	Class of 2020

Mentors:

Lorraine Loh-Norris: Instructor
James Warren: Instructor
Fred Smalling: Mentor
Julie Smalling: Mentor
Kraig Kreiner: 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 *Mamba*, a small, lightweight, low cost, versatile ROV to meet the challenges outlined in the 2020 Marine Advanced Technology Education's (MATE)[1] Request for Proposals (RFP) to address the needs of the global community. The *Mamba* and crew can operate to aid in both the removal of plastics from waterways and in the preservation of marine life. Specifically, it can: 1. Remove plastic pollutants with our debris collector and through support of the Seabin 2. Monitor coral reef colonies and assess damages utilizing our two cameras for downward and forwards sight and photography 3. Inspect and sample pipeways with our micro ROV, collect and replace flora, fauna and manmade materials with a manipulator that can rotate to change functionality. The *Mamba* is the result of 13 years of successful engineering in creating ROVs that have met past MATE challenges through our original designs. The *Mamba* is a non-corrosive, sturdy, reliable vehicle suitable for harsh environments. PVIT has strict adherence to safety. Custom fabricated shrouds, rounded edges and warning labels have been integrated to the *Mamba* to prevent harm to personnel. The ROV team consists of 12 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: Cheryl Oshiro

Back Row (L→R): Matthew Smalling, Francisco Moore, Sammy Moore, Steven Guo, Zusan Hu, Armaan Jhangiani, Natalie Hong.
Front Row (L→R): Dara Chidi, Riko Negishi, Erika Yiu, Jenna Chow, Erin Magid, Sasha Chehrzadeh

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Product & Service Overview

With pollution and other factors quickly deteriorating the health of our planet, it is essential to monitor and sustain healthy waterways. The Delaware Bay is an important area for freshwater marine life. The Delaware River is also a hotspot for different species because of its marshes and diverse ecosystem. With this in consideration, it is imperative that an effort is made to maintain the conditions for the local ecosystems. Underwater ROV's are an effective means of examining and maintaining the river and bay. Our company has optimized our own underwater ROV, the *Mamba,* to accomplish this goal and completely satisfy all tasks outlined by MATE for the benefit of the global community. PVIT has made great strides in video quality including use of a high-definition internet protocol (IP) video camera which can be used to better identify changes in coral colonies and observe plastic pollution. To recover plastic debris from the surface of the water, the *Mamba* is equipped with a powerful bilge pump and holding container. The *Mamba* also hosts a rotating claw which functions much like your own hand and wrist allowing for endless underwater manipulations. Along with our excellent ROV, PVIT provides expert piloting, data retrieval and analysis.

Photo 3: Delaware River
Credit: American Rivers[2]

Project Management

The PVIT ROV company is comprised of twelve members, some experienced members and others that are new to the team. Our company has a management system with established leadership positions and specialized teams comprised of individuals skilled and/or interested in specific areas of expertise. See Appendix A. The sub teams created division of labor but also accountability and feedback to the larger team. Since over half of our company is new, training and communication were a high priority, including a transfer of general knowledge of all ROV matters. During the months of team member isolation due to Covid, each member was tasked with building a simple "personal ROV" at home. Kits were delivered instruction was provided through online meetings and videos. This activity provided new (and returning) team members a chance to learn the fundamentals of ROV's from design through operation, encompassing electrical, control, and structural concepts. Back in the team facility, employees were cross-trained so that if someone couldn't be at a meeting, work could continue on their part of the project, keeping us all on schedule. In October 2019, we submitted a budget request, which was granted. See Appendix B. We follow a purchasing procedure that entails a team member making an email request, which includes item details, to the head of the PVIT program. With the head's approval, the order is placed by the school district purchasing department. To manage our goals and deadlines we created a detailed list of all the tasks required generated through a team brainstorming session of the tasks needed to compete. The three lists (ROV, Non-ROV, and Props) were printed large and posted on the workroom wall. See Appendix C. Although more rudimentary than previous electronic systems we've used (Microsoft Project), this simple, highly visible system worked well for us. Throughout the year and even daily we referred to the project checklist and continued to keep track of deadlines and completed tasks. This management system was friendly for new members and proved to help keep people on track and effectively using their time. The company's inability to meet in person due to Covid required us to abandon this project management method and increase digital communication and hold virtual meetings to organize and facilitate individual work on the ROV from our homes.

Design Rationale

At PVIT, we have many resources which we utilize in the design and manufacture of our ROV's. Our in-house tools, including 3D printers, soldering irons, drill press, laser cutter, and CNC machine, provide us with the means to manufacture our ROV and fabricate its payload tools. Additionally, access to design software, namely Autodesk Inventor, Corel Draw and MultiSim, allow us to create precise models of parts and components and test circuitry designs. As a result, the *Mamba* is our original design custom made primarily from base components.

Overall Vehicle Design & Systems Approach:

Our company first identified the payload tools we would be utilizing and where they would be positioned on the ROV, along with the thrusters, and designed our ROV in accordance. The driving factor in the layout of the vehicle was the 60-centimeter size constraint, which was our biggest design challenge. The overall design of the *Mamba* was strategically built in 3D CAD software from Autodesk in order to optimize its size and layout. In the software, we designed and assembled the major components of the ROV including the "Brain" of the ROV, thruster mounts, side frames, and crosspieces. The design also includes the most essential tool on the ROV, the manipulator. See Figure 1. 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 2.

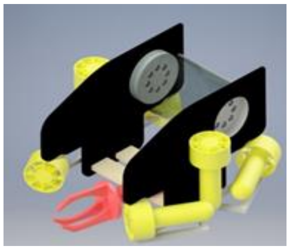

Fig. 1: *Mamba* Design
By: Frankie Moore

After careful scaled measurements, each component was precisely cut using a laser cutter in our lab. The side frames are cut from polypropylene; a material we chose because it is strong, lightweight, non-brittle, and machinable. Polypropylene can also be painted, so naturally the *Mamba* is purple and gold[3]. Before we laser cut the polypropylene sheets, we cut the designs onto cardboard sheets as a prototype. See Photo 4. This way, we were able to test many different designs without wasting premium materials. Once we were pleased with the design of the prototypes, we cut our final design onto the polypropylene. These components were then assembled according to the Autodesk CAD ROV design. See Photo 5.

Fig. 2: ROV Design with Size Constraint
By: Frankie Moore

Photo 4: Cardboard Frame
By: Frankie Moore

The thrusters are oriented in a vectored array of 30 degrees angled toward the interior of the ROV in order to provide complete maneuverability in the horizontal plane. The reason 30 degrees was chosen as the angle was to facilitate the coding process and thruster calculations as well as provide optimal maneuverability for the *Mamba*. The thrusters were placed outside the frame in order to provide the pilot with maximum visibility so that he can complete tasks such as mapping the coral reef.

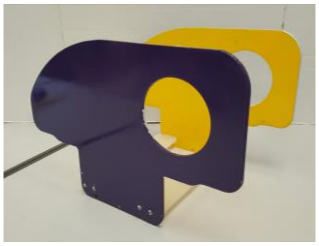

Photo 5: Polypropylene Frame
By: Frankie Moore

Methods of wire organization were taken while designing the ROV to streamline the vehicle for better flying, minimize size and weight, and improve access for repairs if necessary. All Brain input connections are on the port side and output connections are on the starboard. The Brain is strategically placed near the rear of the ROV so that the forward-facing camera has a clear view of all payload tools while operating underwater. Aboard the ROV, we achieved a simple and efficient system that can easily be adjusted and controlled for changing environments and function demands. Key to this flexibility is mounting our entire claw assembly on a single mounting plate. It is quickly and easily removed to reduce vehicle size and allow servicing. We can also change the mounting position as needed. The claw has been placed at a slight angle to the vehicle and to the side near the bottom, to facilitate clear viewing for the pilot while grasping objects such as coral fragments and garbage debris. The suction collection device is positioned at the top of the *Mamba* to facilitate colleting floating debris. It is positioned to the side of the *Mamba* for better visibility for the pilot. Careful consideration has been given to every detail of designing and building the *Mamba.* Nothing is placed randomly; everything is considered for performance outcome and effect.

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 speaker wires. See Photo 6. We chose 10-gauge instead of 12 and upgraded our waterproof bulkhead connectors from 2-pin to 3-pin for less voltage drop across the tether's 15 meters. The speaker wires supply 12-volt power and ground to the remotely operated vehicle. The Ethernet cable provides wires for serial communications, video signal, and video ground. The Ethernet cable is CAT 6a and shielded. We chose CAT6a instead of CAT5 for less signal degradation. The tether is 15 meters long and has stress relief devices that attach it to the *Mamba* and to the control box to prevent damage to its connectors if it is pulled. We require buoyancy for the tether so it does not sink and disrupt the environment by dragging bottom, but rather floats on or close to the surface of the water. Buoyancy is achieved by attaching small pieces of foam at 1-meter intervals. We adhere to the Tether Protocol when operating the ROV (see safety section).

Photo 6: Tether
By: Dara Chidi

Propulsion: The *Mamba* is propelled by six thrusters – two for vertical movement and four in a vectored array for horizontal movement. PVIT has experience with both Blue Robotics T100 motors and SeaBotix BTD-150. The *Mamba* uses only SeaBotix thrusters as they have proven to be more efficient than Blue Robotics thrusters. While SeaBotix thrusters add some additional weight, they also produce significantly more thrust (29N)[4] than Blue Robotics thrusters (23.1N)[5] with the same power input. See Figure 3. To save money, we continue to use the SeaBotix motors we purchased eight years ago. See Photo 7. The price for new SeaBotix thrusters has more than doubled in that time and we pride ourselves on performing annual maintenance on our thrusters and maximizing our investment. For maximum speed and maneuverability, our thrusters are vectored at a 30-degree angle relative to the side frames. This enables 15% faster speeds than previously delivered and allows for an extremely small turning radius. With four vectored thrusters, *Mamba* has the forward and backward thrust of 3.46 motors and a sideways thrust of 2 motors, along with capability to move at any angle in the horizontal plane. With an extra boost in the forward-backward directions we can move at top speeds of 0.8 m/s for faster service. This minimizes our customer's costs since "time is money." Although the thrusters are purchased items, we customize the shrouds to meet rigorous safety protocols. We have used three different original shroud designs and believe the current design maximizes performance while ensuring safety. Two designs involved 3D printed shrouds, but impeded water flow and subsequently thruster output beyond

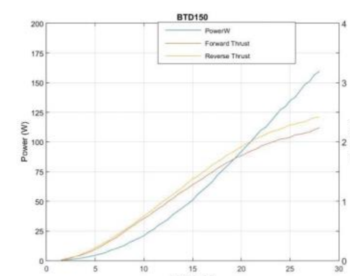

Fig 3: Seabotix BDT-150 Power Curve
By: Research Gate[11]

Photo 7: SeaBotix Thruster with Shroud
By: Riko Negishi

acceptable limits. Our best design is adding custom trimmed metal screen to both the intake and outflow of the stock shrouds. See Photo 7. Fitting the screens is a painstaking effort but ensures safety.

Buoyancy & Ballast: On the *Mamba* we consider every detail in order to have the most stable, functional ROV. We ensure a stable vehicle, one that flies horizontally straight with even weight distribution. To increase stability, we arrange our payload tools and distribute our weight to make the center of mass near the bottom of the ROV and centered front to back and left to right. We also place our buoyancy near the top of the ROV in order to eliminate the chance of the craft flipping and to keep the ROV stable. Our buoyancy material is a repurposed swimming kickboard which we custom cut for our specific need. Ballast is extra weight added for stability. We do not use any ballast on our ROV since the ROV is negatively buoyant to start with and we make every attempt to make the craft more buoyant. A perfectly neutrally buoyant craft is optimal; however, we build our craft slightly positively buoyant so that in the case of craft failure, it will slowly float to the surface for easy recovery. This is one of many precautions we take with the ROV. We have optimized our vehicles fluid dynamics by placing our kickboards parallel along the frames of our ROV instead of horizontally across the top, allowing for unobstructed water flow through the vehicle.

Cameras: The *Mamba* features two high-definition cameras, mounted in the waterproof Brain housing, to display all useful viewing angles from the ROV. Both cameras have been reused from previous years for their reliability and cost saving measures. Our primary camera, a GoPro Hero 3+ Black Edition, serves as a forward-facing camera. It was selected for quality image, wide angle view, and non-battery power option. Our pilot uses this as a main camera to navigate throughout the water and use the payload tools. A custom 3D printed mount allows us to mount the GoPro in the Brain for optimal viewing. We have a second camera purchased from elpcctv.com[6]. This camera is our downward facing camera which allows the pilot to traverse the sea floor, transect a reef, and identify points of interest. By having forward and downward facing cameras on our ROV, the pilot has multiple viewing angles for accurate and precise operations.

Underwater Measuring & Photomosaic Technology: Our technique for taking underwater measurements uses software called PixelZoomer[7] to briskly recognize colors and measure distances in real life through snapshots of the live feed coming from the ROV. The user selects a portion of the screen in which they want to measure a feature and the software counts the number of pixels in the selected region, and measures the width and height of the pixels. It then uses scaling and proportions to produce accurate values that represent the dimensions of underwater features and objects being measured. To combine colorful images captured by our high-resolution cameras in a single photomosaic we use Microsoft's *Paint 3D* software[8]. Our skilled technicians can quickly and accurately create the image the customer desires from any combination of underwater views the *Mamba* makes.

Manipulator: The *Mamba's* manipulator, fondly called the "claw," consists of three fingers that are configured in a way that is similar to the shape of a hawk's claw. These fingers open using a single Firgelli L12 electrical linear actuator, 50:1 gear ratio with limit switches, which is waterproofed by an acrylic tube, O-rings, and custom fabricated endcaps. See Photo 8. This design adaptation gives the claw a 12 Newton grabbing force at 12V. The fingers open wide and are interlocked when in their fully closed position allowing grip of items ranging in size from less than 1cm to 10cm. For gripping items less than 2cm in size, we slip on a thick, padded, custom "mitten". We wrap the fingers with colorful tape for visibility and grip. The claw is held together by a newly designed custom mount comprised of two custom bushings that are made of a very light, slick material, (polypropylene or nylon). The center point of the actuator endcap is attached to a servo with a 90-degree rotation. Turning the servo rotates the claw. A rotating claw provides the ability to pick up a variety of objects positioned either horizontally, vertically, or 2 midway positions and complete other tasks such as turning a valve. 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 *Mamba* in any desired position. The claw is custom made from base components. We custom designed the claw fingers, acrylic mounts, backplate and numerous linkage pieces and cut them out of acrylic sheets with our company's own laser cutter. The bushings are custom fabricated in a lathe. The servo is a waterproof motor purchased from Blue Robotics[4]. Electrical connections are made and waterproofed by our electrical engineers.

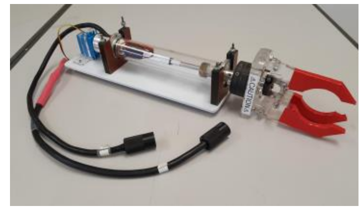
Photo 8: Claw By: Erin Magid

Suction & Collection Device: The company has created an innovative suction and collection device comprised of a bilge pump, PVC fittings, a 3d-fabricated collection tube, and mesh wiring to remove plastic debris (ping pong balls) from the surface of the water. See Photo 9. An 18cm long, 8cm diameter, custom 3D printed cylindrical tube is attached to a bilge pump that sucks water into it so that ping pong balls on the surface of the water are pulled into and caught in the tube. In the first test, the device could only collect 1 or 2 ping pong balls because they would cover the suction point and block the flow of water then nearly float out due to their buoyancy. We improved the design by placing a mesh screen inside the tube, offset 3cm above the point of suction to allow multiple ping pong balls to get sucked into the tube with minimal water flow blockage. The device is mounted at an upward angle of 15 degrees relative to the horizontal to increase speed and ease of debris collection and prevent the ping pong balls from floating out of the tube.


Photo 9: Collection Device By: Dara Chidi

Micro ROV: The micro ROV consists of four elements: the thruster, the camera, the chassis/sample collector, and the tether. Several designs for the chassis were evaluated. Considerations were 1) securely holding the camera, 2) camera view, 3) clean water flow for the thruster, 4) size, 5) functionality of the sample collector, and 6) wheels for a good fit and smooth ride in the drainpipe. The final design of the chassis satisfies all these requirements. The chassis has four wheels and a deck that holds the camera and thruster and a front plate covered with Velcro to retrieve samples. See Photo 10. Previously, the micro ROV chassis did not have wheels. It was a disc-shaped guide with an acrylic camera tube on it. Underneath the guide was a blue robotics thruster which controlled the movement of the micro ROV. This design was functional for viewing a screen at the end of


Photo 10: Micro ROV (Side) By: Sammy Moore

the pipe. However, now that the micro ROV must collect a sample, the buoyancy will change, and wheels are required to travel back out of the pipe. Other flaws with the first prototype include the excessive size of the camera tube and Blue Robotics thruster compared to the current camera and bilge pump.

The thruster is an in-line bilge pump that allows for linear, forward, and back movement. The camera is mounted directly onto the front of the chassis next to the bilge pump. The chassis is custom designed and 3D printed in-house. The wheels and camera are both waterproof. The whole device is made slightly negatively buoyant through the addition of rigid foam.

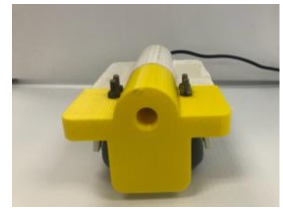

Photo 11: Micro ROV (Front)
By: Sammy Moore

The Micro ROV is controlled by its own small control box which consists of a toggle switch, a rocker switch, and a 7.5 Amp fuse. The thruster is controlled either forward or reverse. The camera has infrared lighting for excellent viewing in the dark environments of pipes. 12V power comes directly from the surface through its own tether. The tether is a four strand single cable running from the surface control box to the micro ROV. The Micro ROV is a stand-alone device and is transported by the *Mamba's* claw and deployed from the claw. When the Micro ROV service is completed, it is returned to the surface by the main ROV.

Command and Control:

Table 1 lists the components of the on-board command and control system. We have named this the "Brain." The Brain is carefully structured to fit into the 25cm tube without hindering the vision of the cameras. It is highly organized and compact. See Photo 12&13. The end caps' pin count was done to ensure enough pins are insulated by SEACON connectors. The endcap on one side of the tube has incoming wires, and the other side has output wires to reduce junction and tangling. An 8-pin Ethernet cable carries all signals between on-deck and on-board.

Part	**Qty**	**Description**	**Function**
Pololu	6	DC voltage controller	SeaBotix thrusters: 4 horizontal, 2 vertical synced; linear actuator
Wire		24-gauge wire throughout	Reduce resistance
Relay	2	Electronic switch with standard PCB pin connection	Servo, suction bilge pump
Camera	2	GoPro Hero 3+ Black Edition, IP	Forward, Downward Pilot view
Acrylic tube	1	14 cm dia., 25 cm long	Housing, clear, waterproof
Endcap	2	Custom machined from Delrin®	O-ring, waterproof seal, wire bulkhead
SEACON	3, 8	Waterproof connection for wires into/out of endcaps.	3 for Power, Ground, Signal; 8 for thrusters, payload tools
Fuse	2	25Amp, 7.5Amp	Protect Main ROV from MicroROV failure. Protect personnel and system from main failure
Arduino	2	TX – on deck, RX – on board, PS2X Library, EasyTransfer Library.	Executes control program written in Arduino language

Table 1: 3C Components By: Sasha Chehrzadeh

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

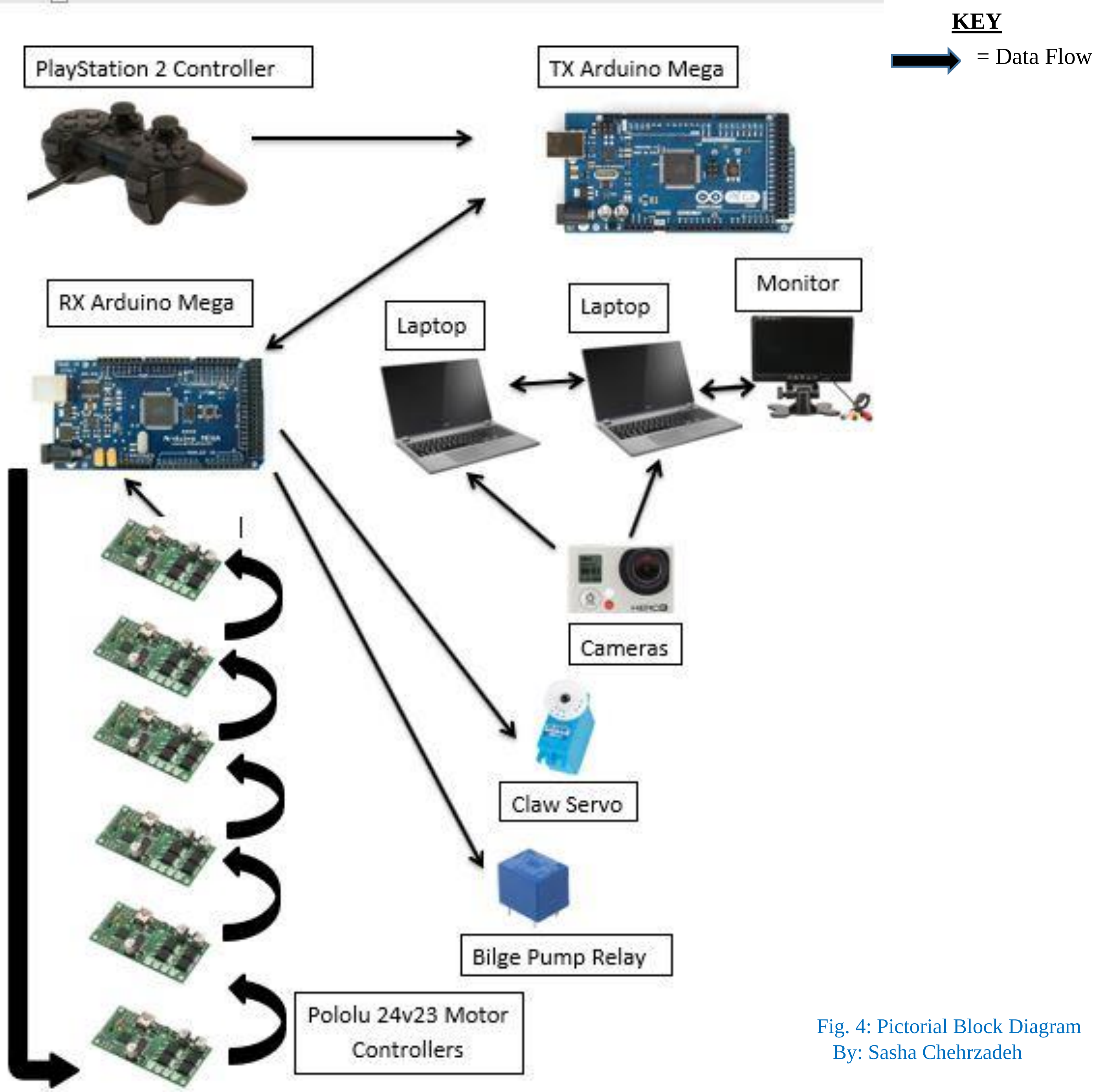

Fig. 4: Pictorial Block Diagram
By: Sasha Chehrzadeh

Illustration of electronic command and control system (arrows depict electronic signals): Pilot delivers commands with the Ps2 controller to the TX Arduino in the on-deck control box. Electronic signals are translated and transmitted to the RX Arduino underwater. RX Arduino sends commands to individual Pololus for SeaBotix thruster control and claw control. Images from on-board cameras are transmitted to on-deck laptops or monitor. Laptops communicate with Wi-Fi.

Integration Diagram (SID), Main ROV:

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

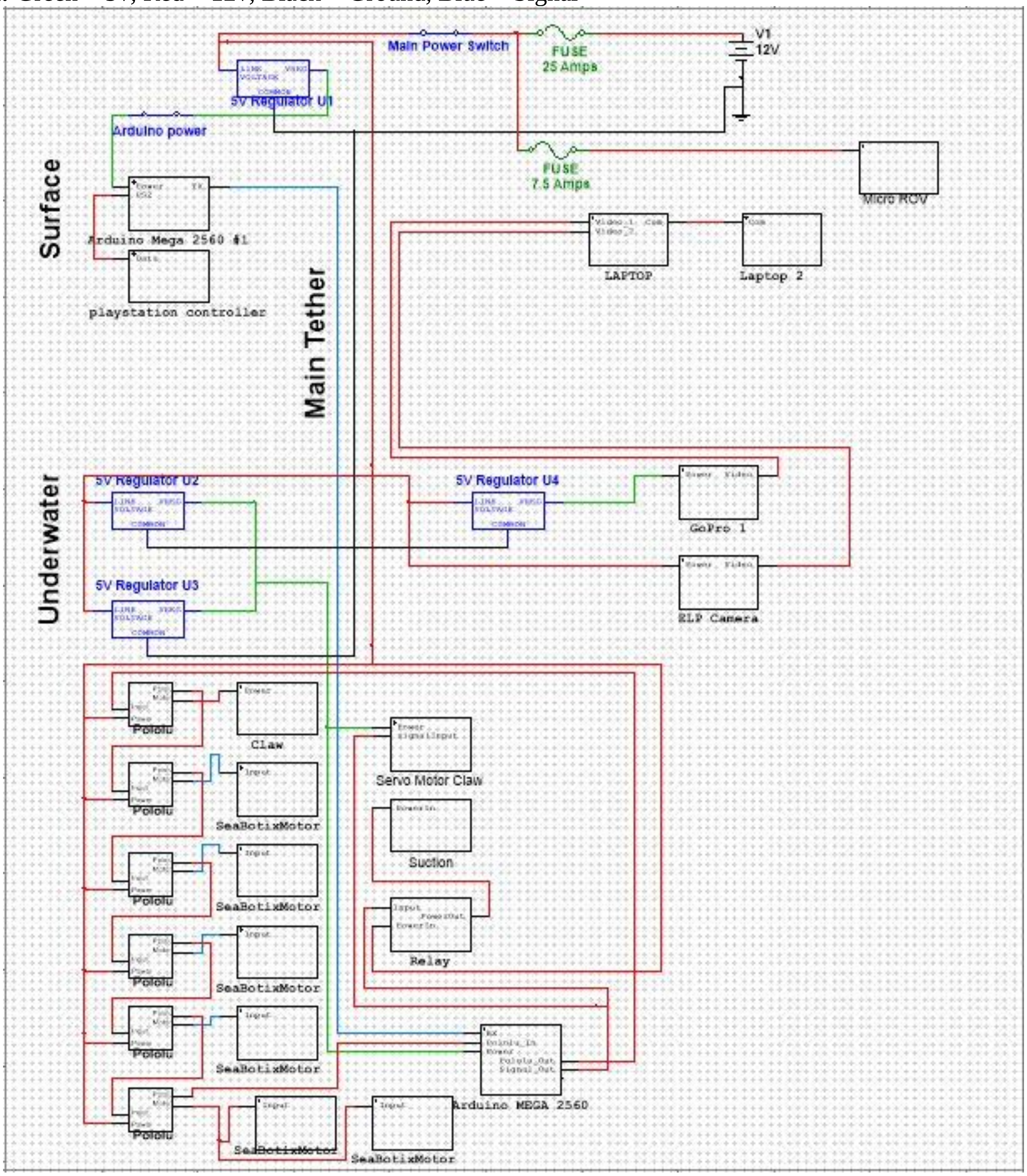

Fig. 5: SID, Main ROV
By: Sasha Chehrzadeh

Fuse Calculation:

Overcurrent Protection= ROV Full Load Current * 150%

Fuse Rating = [(Linear Actuator Rtg) + (SeaBotix Thrusters Rtg) + (Bilge Pump)] *150

Fuse Rating A (horizontal thrusters) = [(0.22 Amps) + (4*3.5 Amps) + (3 Amps)]*150% = 25.8 A

Fuse Rating B (vertical thrusters) = [(0.22 Amps)+ (2*4 Amps)) + (3 Amps)] *150% = 15.3 A

Maximum Fuse Rating = 25 Amps

Nota bene: Our program control logic prevents simultaneous horizontal and vertical movement.

Systems Integration Diagram (SID), Micro ROV:

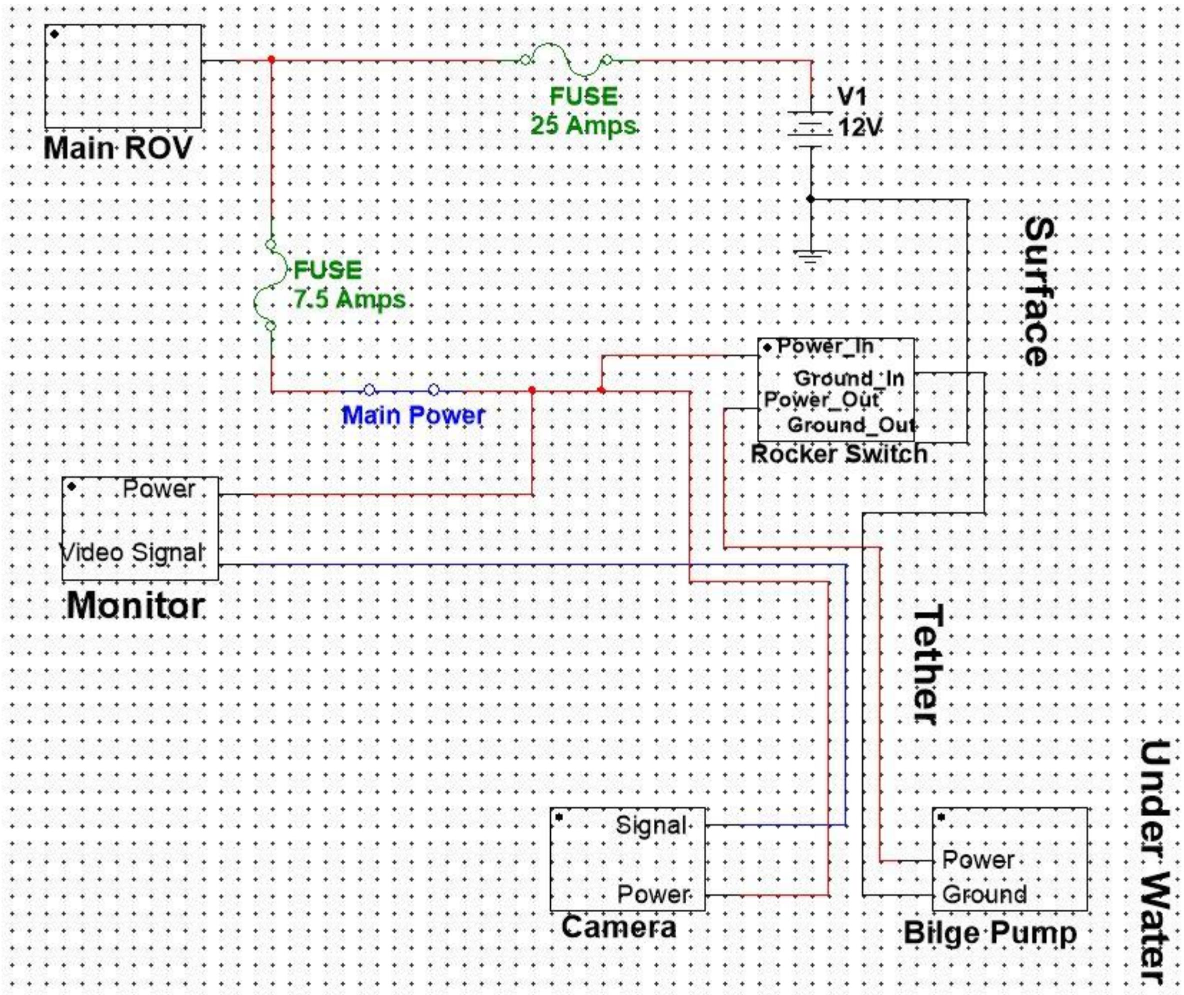

Fig. 6: SID, Micro ROV
By: Sasha Chehrzadeh

Legend:
Red = 12v   Black = Ground   Blue = Signal

Fuse Calculation:
Overcurrent Protection= Micro ROV Full Load Current * 150%
Fuse Rating = [(Bilge Pump)] *150
Fuse Rating = [(3 Amps)] *150 = 4.5 Amps
Maximum Fuse Rating = 7.5 Amps

PVIT programmers wrote an original program to provide the best control of the *Mamba* considering input from our pilot. The program has two parts, the TX and the RX programs. Each of them is installed and executed in the corresponding Arduino. Each time a key is pressed on the PS2 Controller, the TX Arduino receives it and stores it as a variable to send to the RX Arduino[9]. The RX Arduino takes in the variable and accordingly, executes a different action on the ROV. The TX Arduino updates the RX Arduino every tenth of a second while the RX Arduino updates the ROV every hundredth of a second[10]. This ensures that the RX Arduino does not miss any change in signals from the TX Arduino and it minimizes the control-response lag. The horizontal thrusters' variables are controlled via joysticks and are stored as integers to provide variable thrust, and this gives *Mamba* precise controllability. To avoid high current draw from the 6 SeaBotix thrusters, we implemented a restriction function in the program. When the current draw exceeds the equivalent of four full thrusters' maximum usage, we scale every thrusters' draw down by a factor which results in the total draw equal to that of four thrusters. There are two electronic relays in the Brain. One controls the power to the claw rotation servo; the second relay controls the power to the suction device bilge pump. This executes on a Boolean variable which changes every time the designated key is pressed, turning the controller key into a toggle switch to power the suction device.

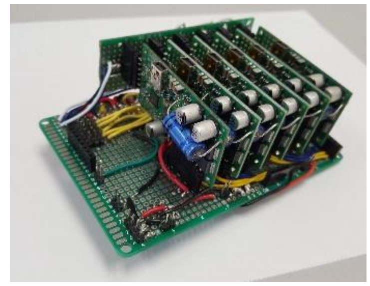

Photo 12: Brain Motherboard and Pololus
By: Armaan Jhangiani

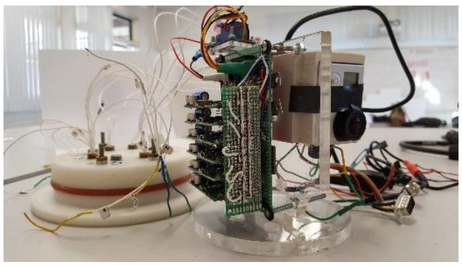

Photo 13: Brain
By: Armaan Jhangiani

Innovation

We have a number of innovations incorporated into our ROV. Omnidirectional movement is now possible for the *Mamba*, with our new vectored thruster design. Another innovation is our improved thruster shrouding. This year, we are using thin metal wire gauze that increases waterflow, speed, and energy efficiency while still protecting ocean life. Our company tried using custom 3d printed motor shrouds, but water flow through the shrouds was not optimal. The task of removing pollution from the surface of the water required innovative thinking. Instead of using the ROV's claw to remove debris, which would be more complicated than needed, we decided to utilize a pump that sucks water into a 3d printed tube, pulling the balls into it. After running into the problem of the ping pong balls escaping from the tube due to buoyancy, we situated the tube at an angle and added a one-way foam flap across the opening. For the first time, our company has had to employ a mini ROV. It features 4 wheels, a forwards/reverse thruster, and a camera. The simplicity of a rolling vehicle is low cost and efficient. Perhaps our most significant innovation is adding a rotating wrist to our claw which allows the *Mamba* to grab objects in any orientation and perform complex operations. We were innovative with our choice of materials for the Brain endcaps. After extensive research of materials, we selected Delrin®[11], which is noncorrosive, lightweight, and machinable. Additionally, in our program, we have a limitation on total thrust so that it does not exceed the power of 4 thrusters and trigger a power problem,

Testing and Troubleshooting

In manufacturing the *Mamba*, we had to test our payload tools and other devices multiple times to develop an optimal design. 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.

In regard to electrical work, we test every connection after we complete it to make sure that there is no bridging and that everything is properly soldered. However, if the *Mamba* is not functioning, the troubleshooting begins in one of three areas: the craft/Brain, the tether, or the surface control box. The first step is to check that power is reaching all elements, looking for unplugged or loose connections. Next, using a multimeter, we test the continuity of the electrical system in each of the three areas to determine where any problem lies. Based on continuity, we start testing 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 systems successfully function, 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 *Mamba* is ready to launch; otherwise, we repeat the troubleshooting process

Upon completion of the *Mamba*, it was first tested in the lab. Each operational function (thrusters, claw, suction, micro ROV) was tested. After passing the dry test, the *Mamba* was tested against the customer's needs, which were simulated in a 2.1-meter-deep pool environment using company-built props and tools, resulting in continuous fine-tuning for perfect field operation.

Our rigorous manufacturing practices, developed over the last decade, have resulted in a very reliable product. Although we have operational troubleshooting procedures, we seldom use them due to the quality our product.

Safety

Safety Overview: Due to our delicate and sometimes hazardous work on our ROV, we make it our priority to ensure our employees' safety. Since many of our employees are new to our company, we've established an orientation system that protects everyone's safety. Once a month we have a meeting on a certain safety topic. Some meeting topics have been hand safety, eye safety, proper work clothing, power tool safety, solder safety, and general electrical safety. Our employees have been educated on how to safely handle and operate our ROV in order to eliminate any potential accidents to themselves or the ROV.

Safety Program of Conduct: To safely work on our vehicle, it is necessary to establish a safe and effective working environment. Our employees have been informed about the general Environmental Health and Safety (EHS) guidelines. We created a Job Safety Analysis (JSA) that notifies workers of potential hazards and how to properly eliminate workplace dangers. See Appendix D. This includes keeping passageways free of slipping or tripping hazards and properly handling dangerous tools, such as saws, soldering irons, and drills. If we notice any potential dangers, we immediately work to get rid of any hazards and re-establish a safe working environment. To also ensure the protection of our employees, it is required that we wear close-toed shoes and safety glasses when working, as well as tying back long hair and removing loose jewelry and clothing.

ROV Safeguards: We developed multiple methods to ensure personnel safety since some of the payload tools we made, necessary to complete the missions, pose potential dangers to divers or others working with our ROV. 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. To also protect personnel from the thrusters on our ROV, we made sure that they were shrouded with MATE compliant custom-made shrouds based on MATE specification MECH-006. Warning labels are located on the motors to further ensure safety and awareness of the hazards of the thrusters to divers and people working on the ROV. Keeping the electronics dry is an important safety issue. The electronics on our ROV are housed in an acrylic tube called the Brain. The Brain is sealed by placing O-rings in radial compression on the endcaps to prevent any water from leaking in and short-circuiting the electronics. We use SEACON waterproof connectors for all wiring coming in and out of the endcaps of the Brain. To further protect the electronics and those working around the vehicle, we have a 25amp fuse installed between the power supply and the control box. See DOC-005, Company Safety Review for proof of compliance to MATE protocol.

Pool Safety: During competition practice we utilize the pool at our PVIT facility. We always consider safety when we work with and around the ROV, and the pool is no exception. We ensure that at least one adult and three students are present at the pool, and we treat the pool area with respect. We always remove all the pool covers before we work with the ROV to eliminate the possibility of workers becoming trapped underneath. We make sure that workers never run on the pool deck and that electrical power supply lines are kept away from water.

Safety Procedure: Below are our company's safety checklists. We refer to these checklists while operating or working around the ROV in order reduce any dangers that threaten the safety of our employees or ROV.

General Safety Checklist:

___ Establish communication with co-workers.
___ Ensure everyone has hair tied up, sleeves rolled up, and earphones and 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 is 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 or workers from stepping on the tether by ensuring they're aware of it.
5. Connect tether to ROV
6. Connect strain relief to ROV

Disconnect:

7. Safely unplug and disconnect the tether from the control box.
8. Roll up the tether.

On Deck Checklist:

1. Proceed with the tether protocol.
2. Check all the connections.
3. Power up the ROV.
4. Test the thrusters and claw
5. Gently place the ROV in the water.
6. Release any trapped air pockets.
7. Deck crew gives the "ready" signal.
8. 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.
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, first turn off main power, then Arduino power, then ROV power.

2. Follow the tether protocol.
3. Disconnect all electronic connections.
4. Dry the ROV and set it safely on the cart.
5. Clean up 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. Travel is estimated by researching hotel rates and airfare. The approved 2020 budget of our ROV company, granted by PVIT, was $2505. Another $2220 was approved for company use by PVIT, contingent on participation in the international MATE competition held in East Tennessee University, Tennessee. These additional funds are to be used for teacher airfare and transportation of the ROV, pursuant to Palos Verdes Peninsula Unified School District's (PVPUSD) policies on travel. Company employees are required to pay their own airfare and food and lodging costs. This brings the total budget request to $4725. See Appendix B.

Funding: The ROV company is a subdivision of PVIT and receives its operating income from PVIT, an organization which has had level funding for several years despite its significant growth, placing PVIT ROV under continued pressure to manage costs. Funding for PVIT comes primarily from the Peninsula Education Foundation (PEF), who annually raise money to fund the entire STEM program in the Palos Verdes Peninsula Unified School District. 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 $1002. The company used purchased, donated, and reused items to construct a capable ROV within budget. Emphasis was placed on building an original ROV from purchased or fabricated components. Some components of previous ROVs and props have been reused for cost-saving purposes. Items reused include thrusters, cameras, electrical components, and a large supply of PVC fittings. Six SeaBotix BTD-150 thrusters were purchased in 2011 for $450 each. Today, they are priced at $1000 each. This makes it challenging to value our ROV in today's dollars. However, we continue to maintain and use these SeaBotix thrusters as they have proven to be some of the most reliable and efficient on the market.

Costing Summary

ROV Value (vehicle & tether only):

Purchased	$574.47
Donated	$43.00
Reused (Thrusters valued at $450 ea.)	$5,393.00
TOTAL	$6,010.47

Total Valuation (including ROV, control box, tether, props, and fees):

Purchased	$1,001.91
Donated	$863.00
Reused	$5,937.00
TOTAL	7,801.91

Table 2: Costing Summary By: Jenna Chow

Reused Items:

	Expense	Notes	Quantity	Unit Value	Total
ROV + C&C				**Total**	**$ 5,685 .00**
ROV				**Total**	**$ 5,393.00**
Thruster	SeaBotix BTD 150	Purchased at $450 ea	6	$ 2700.00	$ 2,700.00
Sensors	Elpcctv.com IP Camera		1	$ 70.00	$ 70.00
Electronics	Seacon Connectors		10	$ 167.00	$ 1,670.00
Electronics	Wires		Various	$ 21.00	$ 21.00
Electronics	Male and Female Pins		Various	$ 26.00	$ 26.00
Electronics	HDMI Cable	Micro to Standard	1	$ 17.00	$ 17.00
Electronics	Fantom-X-Tether		1	$ 160.00	$ 160.00
Electronics	Perforated Printed Circuit Boards		1	$ 14.00	$ 14.00
Electronics	5 5V Relay Module		1	$ 9.00	$ 9.00
Electronics	Pololu motor controllers		6	$ 37.00	$ 222.00
Sensors	Go Pro Hero 3+		1	$ 225.00	$ 225.00
Hardware	HDMI to ethernet, vice-versa		1	$ 30.00	$ 30.00
Hardware	End Cap, Delrin®		2	$ 80.00	$ 160.00
Hardware	72in All-thread		1	$ 17.00	$ 17.00
Hardware	Steel Hex Nuts		2	$ 7.00	$ 14.00
Hardware	Acrylic Sheet		2	$ 19.00	$ 38.00
Command & Control				**Total**	**$ 292.00**
Electronics	Extender Cable	PS2	1	$ 3.00	$ 3.00
Electronics	Arduino Mega 2560 micro-controllers		1	$ 38.00	$ 38.00
Electronics	Female Ethernet	10-pack	1	$ 12.00	$ 12.00
Electronics	Banana Plugs	Female & Male	1	$ 22.00	$ 22.00
Electronics	Bus	Bus #1, Bus#2	1	$ 17.00	$ 17.00
Electronics	Fuse	25A, Safety Prop	1	$ 7.00	$ 7.00
Sensors	Wifi Router	Used for cameras	1	$ 27.00	$ 27.00
Power	AC to DC Power Supply Converter		1	$ 166.00	$ 166.00
Props				**Total**	**$ 252.00**
Hardware	PVC Fitting		Various	Various	$ 75.00
Hardware	6in corrugated drain pipe		1	$ 14.00	$ 14.00
Hardware	PVC Pipe, White, Various sizes		1	$ 57.00	$ 100.00
Hardware	Nuts, bolts, stock		1	$ 58.00	$ 58.00
Hardware	Home Depot Bucket		1	$ 4.00	$ 4.00
Weights	Brick		2	$ 0.50	$ 1.00
GRAND TOTAL REUSED		Thrusters valued at $450 each		**Total**	**$ 5,937.00**

Table 3: Reused Items By: Jenna Chow

Donated Items:

Category	Description	Donator/Notes	Quantity	Unit Value	Total Value
Non-ROV	1690 Protector Case	Pelican, ROV transportation	2	$350.00	$700.00
Non-ROV	1500 Protector Case	Pelican, Control Box	1	$120.00	$120.00
ROV Claw	Waterproof servo	Blue Robotics, HS-646WP	1	$43.00	$43.00
Total					**$863.00**

Table 4: Donated Items By: Jenna Chow

Purchased Items:

Category	Expense	Unit Cost	Qty	Total Item Cost	Category Total
Tether				**Total**	**$178.81**
Tether	10 Gauge Easy-ID Low-Voltage Cable, 100 ft. Length	$140.00	1	$140.00	
Tether	Expandable Polyester Sleeving, 1/2" ID, 50' Long Spool, Red	$18.82	1	$18.82	
Tether	Cable Matters Snagless Cat 6a Ethernet Cable in Black 75 Feet	$19.99	1	$19.99	
ROV				**Total**	**$395.66**
ROV	Acrylic Sheet 12in. x 24in. x 1/2in.	$55.73	2	$111.46	
ROV	Polypropylene Sheet – White – 12in x 24in x 1/8in Thick	$14.96	4	$59.84	
ROV	Polypropylene Sheet, 12in x 24in x 3/16in, opaque white	$13.41	1	$13.41	
ROV	Micro ROV Camera	$9.95	1	$9.95	
ROV	Clear Cast Acrylic Tube, 1-1/2in OD x 1-1/4 ID, 1 ft long	$52.00	1	$52.00	
ROV	VELCRO Brand Industrial Strength Fasteners, 6 x 4in strips, 3 sets, titanium	$10.25	2	$20.50	
ROV	Stainless Steel Wire Cloth, Sheets, 4 x 4 Mesh, 0.22in Opening, 2ft x 2ft	$39.38	1	$39.38	
ROV	Hardware (nuts, bolts, screws)	various	various	$20.00	
ROV	Plumber's tape	$7.00	1	$7.00	
Micro-ROV	Water-Resistant Rubber Wheel with Ball Bearing, 2-1/2 Diameter x 1-3/8 Wide	$7.41	4	$29.64	
Micro-ROV	Water-Resistant Rubber Wheel with Sleeve Bearing, Gray, Soft, 2-1/2 Diameter	$8.12	4	$32.48	
Props				**Total**	**$227.44**
Props	White Corrugated Plastic Sheet	$21.88	1	$21.88	
Props	Various PVC Pipe and Fittings for Props	$30.44	1	$30.44	
Props	Kiefer Ankle/Wrist Weights (1 Pair)	$21.89	8	$175.12	
Registration				**Total**	**$200.00**
Registration	MATE Worlds Registration	$200.00	1	$200.00	
TOTAL				**Total**	**$1,001.91**

Table 5: Purchased Items By: Jenna Chow

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2) American Rivers Website https://www.americanrivers.org/
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9) Bill Porter, *PlayStation 2 Controller Arduino Library v1.0,* http://www.billporter.info/2010/06/05/playstation-2-controller-arduino-library-v1-0/
10) Bill Porter, *The Engineer's Guide to DIY Computer Controlled Holiday Lights* http://www.billporter.info/2011/06/30/easytransfer-2-controller-arduino-library/
11) Delrin®, High-Performance Acetal Resin https://www.dupont.com/brands/delrin.html

Appendix

A: Sub Team Structure

Table 6: Sub Team Structure By: Dara Chidi

Design	Software	Electrical	Mechanical		Micro ROV
*Frankie	*Sasha	*Armaan	*Jenna		Sammy
Sammy	Matthew S.	Erika	Dara		Sasha
Dara	Erika	Jenna	Erika	Steven	
Sasha	Erin	Riko	Natalie	Zusan	
	Armaan	Natalie	Riko	Sammy	

*Lead

President: Dara
CEO: Sammy
CFO: Jenna
Chief Safety Officer: Erika
Pilot: Sammy

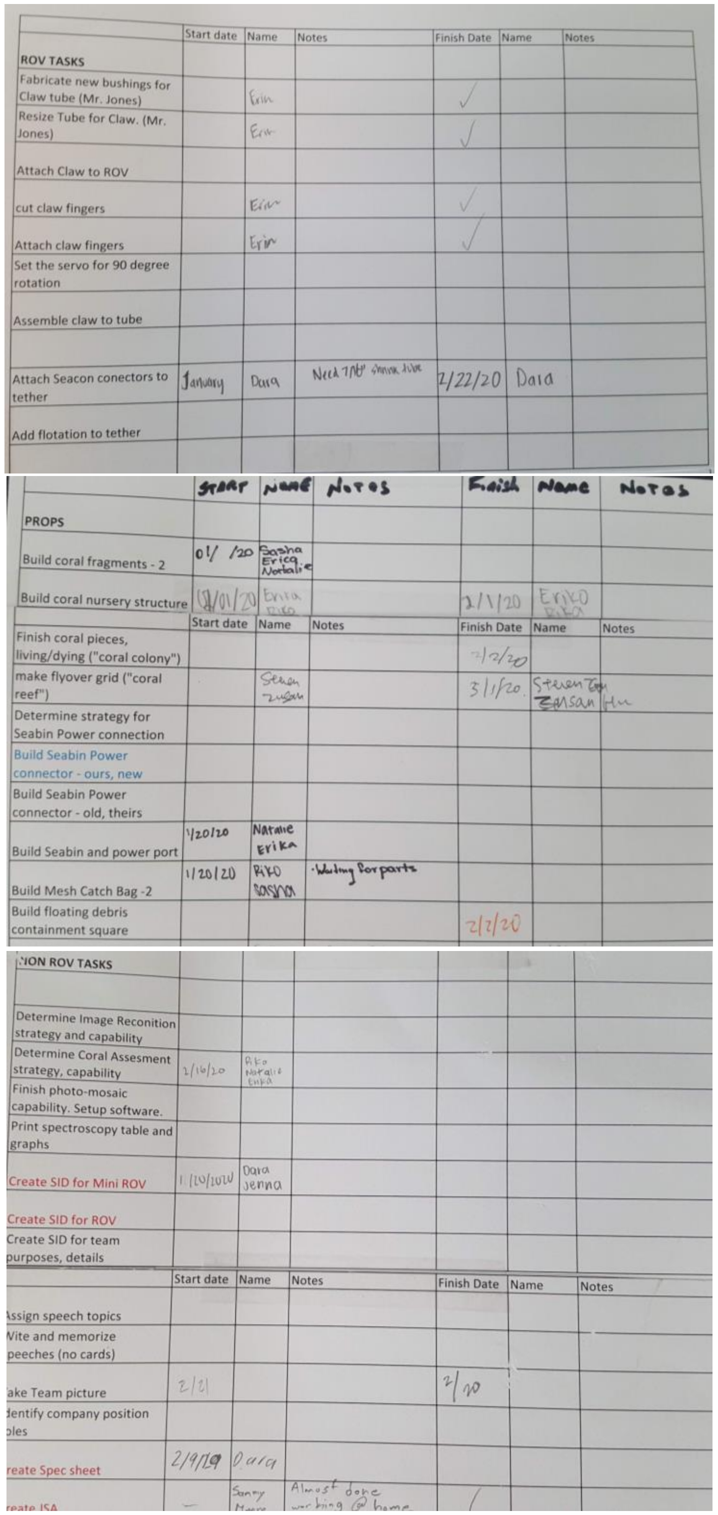
B: PVIT 2020 Budget

Item	Quantity	Unit Cost ($)	Cost ($)
Regional Competition			
acrylic sheets 1/3rd inch	4	13	52
acrylic sheets 1/2 inch	4	20	80
3D printer filament	3	30	90
1/2inch pvc	10	3	25
pvc fittings, large		50	50
pvc fittings, small		50	50
Velcro		10	10
registration	1	250	250
fluid power quiz	1	15	15
Stainless Steel Hardware		50	50
Pololus	5	18	90
SeaBotix thruster or shroud		500	500
Micro Rov Tether		100	100
Micro Rov		100	100
All Thread	1	100	100
Seacon connectors	3	100	300
acrylic tube claw	1	20	20
soldering tips	6	2	14
mesh screen	1	20	20
Payload tools		400	400
Plastic sheeting		25	25
Miscellaneous electronics		75	75
adhesive Heatshrink	1	75	75
10 AWG 50 ft clear speaker wire	1	14	14
International Competition			
Teacher airfare	1	500	500
Teacher hotel and food	4	230	920
ROV shipping, Pelican case	2	400	800
Total Cost for Regionals			**2505**
Total Cost for International			**2220**
GRAND TOTAL			**4725**

Table 7: Budget   By: Jenna Chow

C: Project Schedule

Figure 7: Project Schedule By: Dara Chidi



	Start date	Name	Notes	Finish Date	Name	Notes
ROV TASKS						
Fabricate new bushings for Claw tube (Mr. Jones)		Erin		✓		
Resize Tube for Claw. (Mr. Jones)		Erin		✓		
Attach Claw to ROV						
cut claw fingers		Erin		✓		
Attach claw fingers		Erin		✓		
Set the servo for 90 degree rotation						
Assemble claw to tube						
Attach Seacon conectors to tether	January	Dara	Need TNT [illegible]	2/22/20	Dara	
Add flotation to tether						

	START	NAME	NOTES	Finish	Name	Notes
PROPS						
Build coral fragments - 2	01/ /20	Sasha Erica Natalie				
Build coral nursery structure	01/01/20	Erika Riko		2/1/20	Eriko Riko	
	Start date	Name	Notes	Finish Date	Name	Notes
Finish coral pieces, living/dying ("coral colony")				2/2/20		
make flyover grid ("coral reef")		Steven Zusan		3/1/20	Steven Zou Zansan Hu	
Determine strategy for Seabin Power connection						
Build Seabin Power connector - ours, new						
Build Seabin Power connector - old, theirs						
Build Seabin and power port	1/20/20	Natalie Erika				
Build Mesh Catch Bag -2	1/20/20	Riko Sasha	Waiting for parts			
Build floating debris containment square				2/2/20		

NON ROV TASKS						
Determine Image Reconition strategy and capability						
Determine Coral Assesment strategy, capability	1/16/20	Riko Natalie Erika				
Finish photo-mosaic capability. Setup software.						
Print spectroscopy table and graphs						
Create SID for Mini ROV	1/20/2020	Dara Jenna				
Create SID for ROV						
Create SID for team purposes, details						
	Start date	Name	Notes	Finish Date	Name	Notes
ssign speech topics						
Vite and memorize peeches (no cards)						
ake Team picture	2/21			2/20		
dentify company position oles						
reate Spec sheet	2/19/20	Dara				
reate ISA	—	Sonny Moore	Almost done working @ home	/		

D: PVIT 2021 Job Safety Analysis (JSA) for Deck Ops/Launch and Recovery

HOUSEKEEPING

TASK	HAZARD	PROTOCOL
Product Demo	Leaking and breaching of electrical systems	Perform pre-run checklist, waterproof electronics.
Product Demo	Tripping	Manage tether position, props, and support items on deck.

HAND SAFETY

TASK	HAZARD	PROTOCOL
Launch/Recovery of ROV	Crushing Fingers Hands caught on equipment	Kneel on deck, use caution, and avoid falling in the water.
Supplying Props to ROV	Hands/fingers caught in claw fingers	Place prop in between claw fingers, hold in place, keep fingers out of claw grip, let go and give thumbs up.

ELECTRICAL SAFETY

TASK	HAZARD	PROTOCOL
ROV Operation	Electrical shock	Follow all checklists, keep extension cord dry, waterproof electronics.
Troubleshooting ROV Control System	Shock	Power Off.
Pool Side Operation	Shorting electronics	Keep control desk at least 6 feet from the pool

LIFTING & BACK SAFETY

TASK	HAZARD	PROTOCOL
Moving the ROV	Heavy lifting Dropping heavy objects on self	Lift with the knees. Communicate and synchronize with lifting partner.
Launch/Recovery of ROV	Heavy lifting, awkward position.	Kneel on deck, use caution, and avoid falling in the water.
ROV supply boxes	Heavy lifting Crushing fingers	Lift with the knees, use handholds, keep the load close
Moving Pelican Cases	Heavy lifting	Use wheels when possible, ONLY lift in pairs
Local transport of ROV	Heavy weight on body	Use rolling cart.

PERSONAL PROTECTIVE EQUIPMENT

TASK	HAZARD	PROTOCOL
ROV operation	Injuring of body parts Claw and hand injury	Eye protection, close-toe shoes. Alert pilot when hands are near the claw.

PANDEMIC SAFETY

TASK	HAZARD	PROTOCOL
Group Meetings	Inhalation of COVID particles	Keep 6 feet away from members. Wear mask at all times. Meet in small groups of 3 to 4 people.
Outdoor Meetings	Inhalation of COVID particles Transfer of COVID particles	Keep 6 feet away from members. Wear mask at all times. Wipe down used tools.

E: List of Tables and Figures

Acknowledgments

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- ·Mentors Mrs. Julie Smalling and Mr. Fred Smalling.
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- ·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 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 International Competition and answering all our questions. Additionally, we acknowledge:

PVIT especially honors the memory of Kobe Bryant, who's *Mamba Mentality*, *"just trying to get better every day,"* inspires us.