2017 MATE International ROV Competition

Technical Documentation for *Nemesis* ROV

Palos Verdes Institute of Technology

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

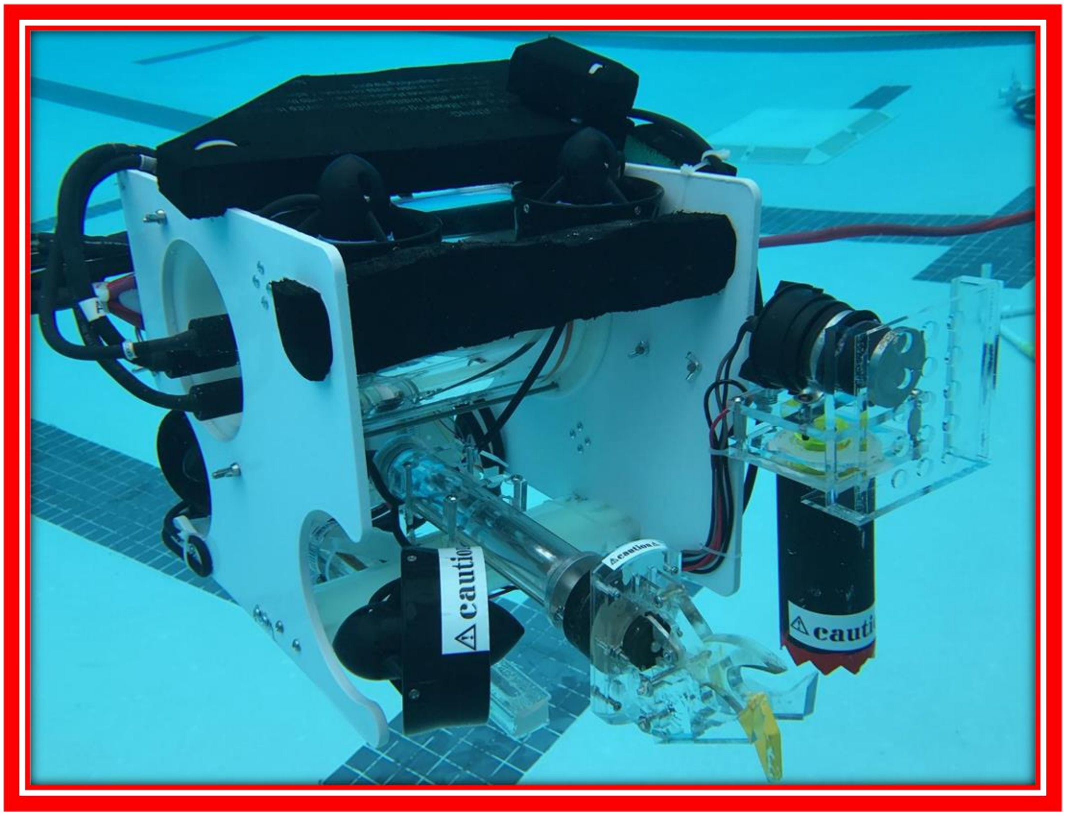

Fig. 1: *Nemesis* ROV
By: Nicolas Kalem

2017 PVIT Ranger Company

JOSHUA MAGID: President, 4th year, Class of 2017
BRIAN SMALLING: Chief Executive Officer, Pilot, 3rd year, Class of 2018
JORDAN EWALD: Chief Engineer, 2nd year, Class of 2018
JEFFERY HAAG: Research and Development, 2nd year, Class of 2018
GARRETT SMITH: Mechanical Engineer, 2nd year, Class of 2018
JOSEPH ARRIOLA: Mission Specialist, 2nd year, Class of 2018
NICOLAS KALEM: Chief Safety Officer, Director of Regulatory Affairs, 2nd year, Class of 2019
ERIK VAUGHN: Electrical Engineer, 2nd year, Class of 2019
BRIAN HOM: Mechanical Engineer, 1st year, Class of 2018
LAURA GONG: Chief Financial Officer, 1st year, Class of 2019
TED ZHANG**:** Programmer, Control systems, 1st year, Class of 2019
BLAKE CARPENTER: Mechanical Engineer, 1st year, Class of 2020
MATTHEW SMALLING: Design Engineer, 1st year, Class of 2020
FRANKIE MOORE: Outreach Liaison, Mechanical Engineer, 1st year, Class of 2020
ERIN MAGID: Electrical Engineer, 1st year Class of 2020
DANIEL ARRIOLA: Mechanical Engineer, 1st year Class of 2020

Mentors:

LORRAINE LOH-NORRIS: Instructor.
FRED SMALLING & JULIE SMALLING: Mentors

Abstract

Palos Verdes Institute of Technology's (PVIT) underwater Remotely Operated Vehicle (ROV) division presents the *Nemesis*, a product with ten years of engineering experience behind it. In the previous four years, PVIT has been a consistent top performer for MATE. The *Nemesis* is designed to operate quickly and efficiently in the Port of Long Beach. The *Nemesis* features customized tools to perform underwater construction and maintenance, quickly retrieve environmental samples, and search and identify potential hazards in the Port of Long Beach. The *Nemesis* was designed and developed with customer satisfaction and cost efficiency in mind. Before the fabrication of each component, prototypes are created on CAD programs like Autodesk Inventor and Corel Draw. PVIT then fabricates customized parts utilizing laser cutters, 3D printers, and Computer Numeric Control (CNC) machines located in our facility. The *Nemesis* is the product of nine months of diligent work, resulting in a small, lightweight, maneuverable, and effective ROV. The *Nemesis*'s frame is made of durable polypropylene, and it is driven by five brushless Blue Robotics thrusters. The payload tools are designed to perform specific mission tasks effectively. The following pages detail the preparation and engineering that went into producing the *Nemesis*, while maintaining a strict focus on safe work practices and inherently safe design. The *Nemesis* is able and ready to respond to Marine Advanced Technology Education's (MATE) Request for Proposal (RFP)[1] and is the best ROV for the job.

Fig. 2: Team Photo   By: Julie Smalling

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Mission Theme

Being one of the world's largest, most profitable, and busiest ports, the Long Beach Harbor is a hub of commercial activity. The bustling nature of the port makes ongoing maintenance a challenge. In addition, upgrades to facilities are necessary to maintain a competitive shipping business. Furthermore, with all the shipping traffic, there is considerable potential for environmental damage. Keeping the waterways clean is a massive task. Finally, the port is a major tourist attraction, and many people visit the port to see the ships in action and enjoy local attractions. Remotely Operated Vehicles are machines capable of addressing all of these problems. ROVs are a safe and cost effective option and can access hard to reach places where divers and ships cannot go. The *Nemesis* will deliver all the capability you deserve when it comes to your underwater missions.

Fig. 3: Long Beach Harbor By: Google

Project Management

To build the *Nemesis*, the company worked together in all aspects to ensure good build quality, speedy production and involvement by every team member. By working closely together, communication was easy, and everyone knew their job. Mini teams were established for each payload tool, command & control, and for props. Additional key roles were Safety, Finance, Outreach, and Photographer. If anyone was struggling, it was easy to get an older member of the team to help the inexperienced workers. In fact, training new members was critical since 50% of our company was new and only two members had more than one year of experience. Those two experienced members, the CEO and the President, led the team in design and fabrication, giving a more structured approach to building an ROV, and ensuring that the work of the mini teams came together successfully. A schedule was used to keep the project and workers on track.

Safety

Safety Overview: Due to our delicate and hazardous work building the Nemesis, we make it our priority to ensure everyone's safety. Since we had to create an ROV designed to thrive and be the best at what it does, we incorporated various tools and electronics for it to be functional and complete all of its missions. However, the devices utilized in our ROV do pose potential dangers to the people around it. To compensate for this, we integrated various safety practices necessary to establish everybody's safety.

Safety Program of Conduct: In order for us to successfully work on our vehicle, it was necessary for us to establish a safe and effective working environment. Our employees have been informed about the general Environmental Health and Safety (EHS) guidelines. We also make sure that our employees follow and are aware of our Job Safety Analysis (JSA) guidelines, which can be found in the appendix. This includes keeping passageways free of slipping or tripping hazards and properly handling dangerous tools, such as cutters, 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 all wear close-toed shoes and safety glasses at all times in order to eliminate the dangers of debris hitting the eyes and feet.

ROV Safeguards: Since some of the tools and electronics pose potential dangers to the divers working with the Nemesis, we developed multiple methods to ensure the divers' safety. In order to prevent the entanglement of divers in our tether, we have someone standing by, constantly regulating the length of the tether. This role also serves the purpose of preventing the tether from getting snared on any objects underwater. We painted the tips of our claw's fingers yellow, the tips of our valve turner red, and the tips on the sediment collecting tool (agar sampler) canister red in order to alert the divers or people working around the ROV of the sharp or moving edges. To also protect our divers and employees, we created a box that would encase the rapidly spinning weight attached to the motor used in our sediment collecting tool. We attached warning labels and made sure that our motors are shrouded in order to prevent divers from further injuring themselves.

Keeping the electronics dry is an important safety issue. We keep the electronics on our ROV compacted in an acrylic tube called the Brain. We keep this dry by placing O-rings on the endcaps to prevent any water from leaking in and damaging or 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 25 amp fuse installed between the power supply and the control box.

Checklists: Below are our company's safety and operational checklists. We implement these processes while operating or working around the ROV in order reduce any dangers that threaten the safety of our employees, ROV, or others.

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

Pre-Run Checklist:
1. Ensure control station/table is dry.
2. Ensure the power connection and controller is connected before powering on the control box.
3. Check all the electrical power connections.
4. Dry run to check that cameras are working properly.
5. Check to ensure that all waterproof seals are secure.
6. Check the thrusters to see if they are working and are clear of obstructions.
7. Check the claw, fork, and sampler to see if properly functioning.

Tether Protocol:
1. Unroll the tether.
2. Safely plug the tether into the control box.
3. Secure the tether 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. Safely unplug and disconnect the tether from the control box.
6. Roll up the tether.

On Deck Checklist:
1. Proceed with the tether protocol.
2. Check all the connections.
3. Power up the *Nemesis*.
4. Test the thrusters, claw, fork, LED lights and agar sampler a second time.
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!"

Post-Run Checklist:

1. Disconnect the tether from the ROV.
2. Follow the tether protocol.
3. Disconnect all electronic connections.
4. Dry the ROV and set it safely on the cart.

Project Schedule

A project schedule was made in September, 2016, upon the formation of the 2017 PVIT Ranger Company. It was updated periodically. The company had difficulties keeping to the schedule but it was a valuable tool in keeping us aware of impending deadlines. We increased the number and durations of meetings in April and May in order to meet final deadlines for competition.

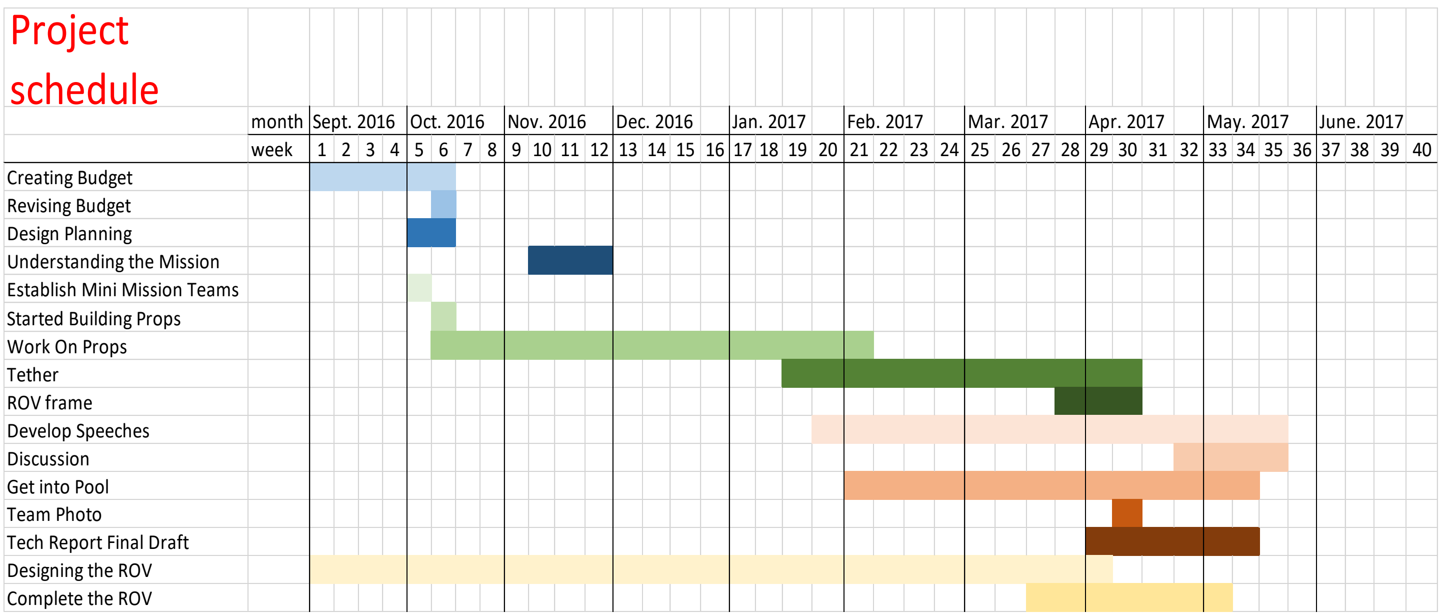


Table 1: Project Schedule By: Laura Gong

Command, Control, and Communications (C3) Diagrams

Pictorial Block Diagram:

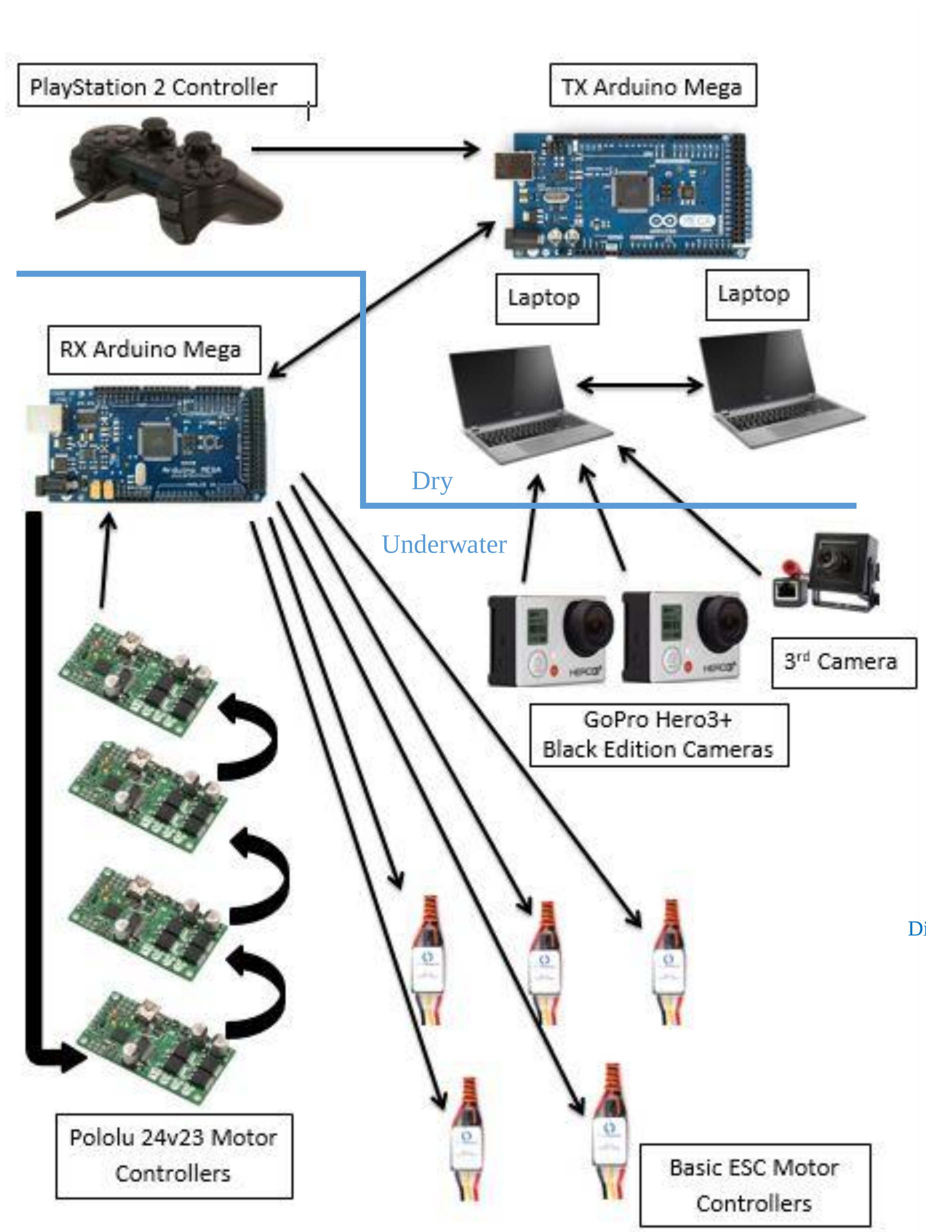
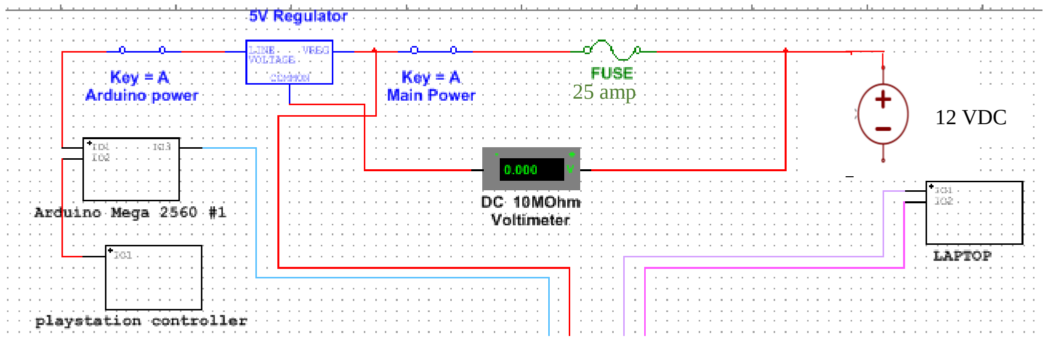


Diagram 1: Block Diagram
By: Brian Smalling

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 and ESCs, one Pololu for each motor, and one ESC per thruster. Images from on-board cameras are transmitted to on-deck laptop. Laptops communicate via Wi-Fi.

Systems Integration Diagram (SID):

Surface



Tether

Diagram 2: Dry SID
By: Eric Vaughn

Tether

Underwater

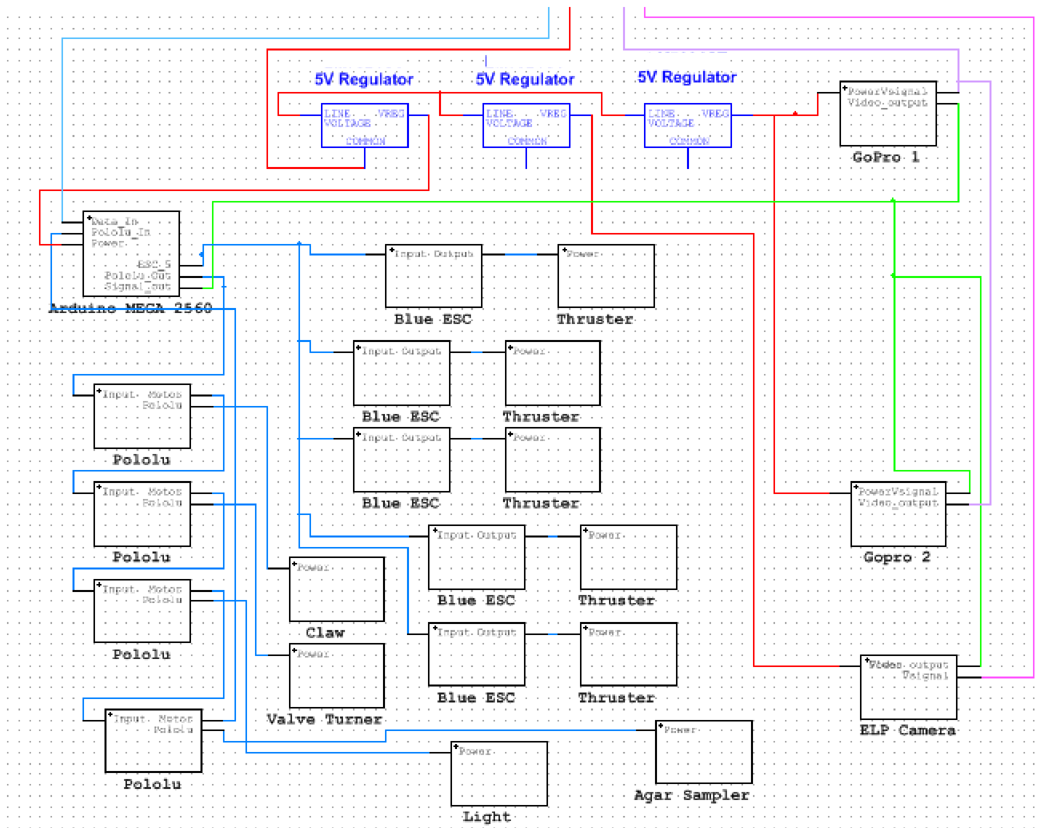


Diagram 3: Underwater SID
By: Brian Smalling

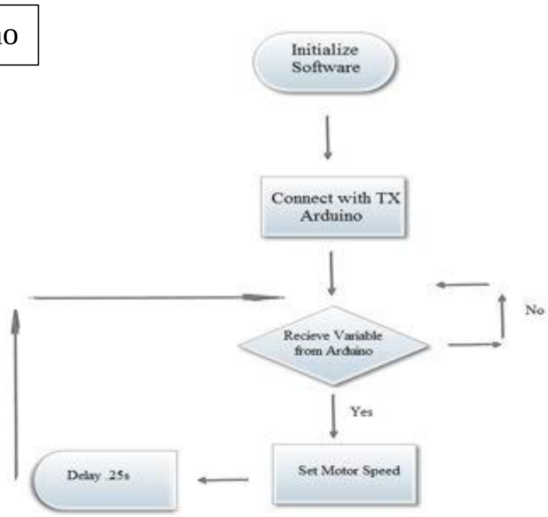
Fuse Calculation:
Overcurrent Protection = ROV Full Load Current * 150%

Fuse Rating = [(5*Blue Robotics Motor Rating) + (Linear Actuator Rating) + (Valve Turner Rating) + (Sampler Rating)] * 150%

Fuse Rating = [(5*2.4 Amps) + (0.22 Amps) + (2.0 Amps) + (2.0 Amps)] * 150% = 24.33 Amps = Fuse of 25 Amps

Software Flowcharts:

Underwater Arduino



Above-Ground Arduino

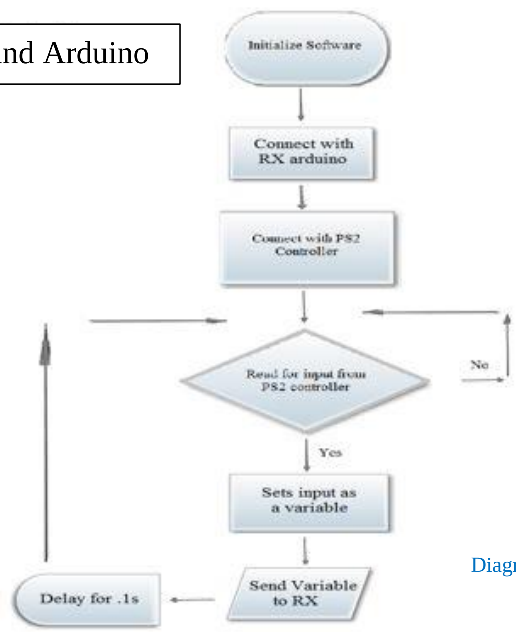


Diagram 4: Software Flowcharts
By: Brian Smalling

Design Rational

Nemesis is designed for optimal performance in underwater conditions to meet the customer's unique demands. Payload tools are original designs fabricated in-house by the PVIT company. The frame and control system are also original and custom fabricated. Only the Arduino's, Pololu's, cameras, thrusters, and SEACON waterproof connectors are off-the-shelf items; everything else being assembled from basic components or fabricated from stock materials. Fabrication equipment includes a MakerBot 3D printer, VERSALaser laser cutter, CNC mill, and lathe.

Fig. 4: Building the Brain By: Laura Gong

Command & Control: The Command and Control System on the *Nemesis* is a master–slave configuration between two Arduino Mega 2560 micro controllers. The master is the on–deck Arduino and the on–board Arduino is the slave of the configuration. The Master-Slave configuration allows for fine tuning of control of the vehicle via the on–deck Arduino without having to open the vehicle and should reduce downtime of the vehicle. We utilize the open source Easy Transfer and PlayStation 2x libraries[2]. The Easy Transfer library facilitates the communication between the Arduino, while the PS2x library allows for integration with a Play Station 2 controller.

The on-deck Arduino reads the analog values from the PS2 controller and sends the information down the tether to the on–board Arduino. The on-board Arduino communicates with four Pololu Motor controllers which control: a brushed bilge pump motor on the valve turner, an LED light string, a linear actuator (powering the claw), and a second bilge pump motor that spins a weight as part of the agar sampler. The on–board Arduino also sends information to five ESCs (Electronic Speed Controllers), which control the brushless Blue Robotics thrusters. Because of our special motor arrangement, we have a program that integrates three horizontal thruster inputs into a singular channel output.

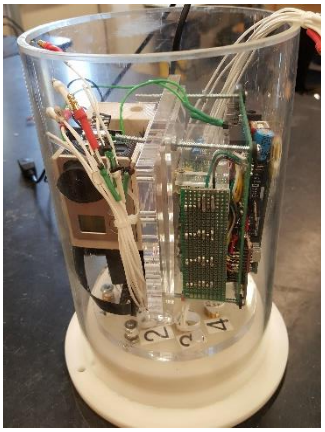


Fig. 5: Brain By: Brian Smalling

To ensure that the brain is organized, all electronics are securely fastened onto a custom made acrylic mount, ensuring untangled wires and easy maintenance. The entire control system is custom designed and built in house from basic components. See figure 4, of one of our workers creating the brain and figure 5, the brain.

Cameras: A noteworthy advancement with the *Nemesis* is the utilization of high definition video. PVIT has been developing the ability to get an HD signal from the onboard cameras for the last two years. This year, we are using three cameras on the *Nemesis*. We use two GoPro Hero 3+ Black Editions as our main cameras. These are very small, reliable, have a wide viewing angle and they can provide full HD video. We have placed one facing forward as our main camera. This is what we use to drive, and it is able to see two of the payload tools. The second GoPro Hero camera is looking backward to make sure that the tether does not get tangled and to view the valve

Fig. 6: Camera Mount By: Brian Smalling

turner. The final camera also provides HD video. It is a compact camera purchased from elpcctv.com. The third camera is pointed downward to view objects on the sea floor. This camera will be used to help locate, identify and map lost shipping containers and to evaluate environmental samples for contaminants.

To power the two GoPro cameras, we use breakout boards that supply power directly to the cameras. There are no batteries, and the cameras automatically turn on with the ROV. The third camera also does not have a battery; it can only be powered from an external source which is the ROV. The GoPro cameras are mounted in custom designed housings that are 3D printed by PVIT. See figure 6, our 3D printed camera case for easy, accurate mounting in the brain.

Underwater Measuring Technology: Our measuring technique for the *Nemesis* uses software called Analyzing Digital Images[3]. This software uses pictures from the cameras located on the ROV and a known dimension so that it can accurately measure anything seen on the screen. It uses pixel scaling in the images and ratios to find any dimension.

PVIT decided to use Analyzing Digital Images, a free non-commercial software developed by John Pickle (Concord Academy; formerly, Museum of Science, Boston) and updated by Dan Gullage (STEM Education Institute, University of Massachusetts Amherst), to find specific distances in various missions. The program uses a digital image taken by a GoPro Camera and a specified length to determine an undetermined length.

Prior to choosing Analyzing Digital Images, PVIT researched utilization of laser sensor technology to determine needed distances. Per the time-of-flight principle, sensors can report distance measurements efficiently and incredibly fast. Using this initial distance received by the principal and trigonometric calculations, other values of distance can be obtained. We explored many different types of lasers and laser configurations throughout our research. However, several roadblocks were encountered regarding powering the laser system and placement which resulted in the determination that a laser system was not feasible this year. We at PVIT are determined to explore and utilize laser sensor technology in the future.

Vehicle Layout and Frame: For our layout, we decided to create our ideas on a 3D sketching system called Autodesk Inventor Pro (CAD). Before designing the whole ROV, we first discussed what the ROV needed in terms of the tasks that needed to be completed for this year's competition. During these discussions, we shared ideas, compared those ideas to past years, and chose which ideas would best suit our ROV. A big topic of these discussions was to figure out the size of the brain. Based on the conclusions of our team, we came up with a rough estimate of how big the brain would be. From there, we built other parts around the brain to achieve the most efficient layout.

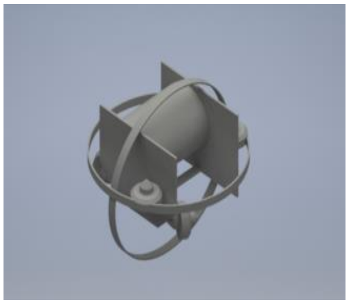


Fig. 7: ROV Autodesk drawing with size constraints
By: Erin Magid

One challenge this year was to create a more diverse design for the ROV from prior years. We also had to make the ROV much more compact and lightweight. A new feature to our ROV this year is the orientation of the motors. We came up with a "Y" shape, and created a conceptual layout of the thrusters to ensure functionality. After hand drawing

sketches, we transferred them into CAD software. Each individual part of the ROV was drawn and later brought together in an assembly drawing, with 48cm rings to verify size restrictions given by the client. See our CAD mockup of the ROV in figure 7.
After creating all the tools, we designed a frame that holds all the parts of the vehicle together while still being compact. Consideration had to be given to camera location and "line of sight" for the pilot to see the tools. The "Y" thruster configuration further limited the positioning of payload tools. Using CAD software helped give everyone a visual and it helped us edit anything that we thought needed to be added or removed. Following the design step, we continued the process of fabrication by prototyping with laser cut cardboard parts. We modified and cut 5 sets of cardboard side frames before arriving at our final design. A drawing of the side frame can be seen in figure 8.

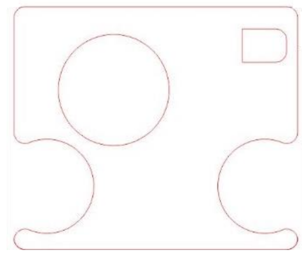


Fig. 8: Autodesk frame drawing
By: Frankie Moore

Thrusters: For this year's new ROV, we made a significant investment in brand new T-100 Blue Robotics brushless thrusters. This decision was made after a cost-benefit and weight-benefit analysis was made between the SeaBotix thrusters we have used in the past and the possible new Blue Robotics thrusters. There was a difference of approximately 400 grams per thruster and we could also conserve space within our brain with the smaller ESCs. The cost savings between Blue Robotics and SeaBotix was a significant $3480 for 6 thrusters. Once we decided on purchasing thrusters from Blue Robotics, we turned to Autodesk Inventor to create a virtual diagram of the potential layout. The thrusters on the Y- frame are deployed in a vectored configuration to allow for better maneuverability than a conventional orthogonal layout.

Fig. 9: Y Frame with Thrusters
By: Joseph Arriola

The thruster configuration for horizontal movement of the *Nemesis* is with three thrusters in a vectored arrangement. This layout was prototyped and programmed on a land vehicle by our company programmer to test viability. As a final product, we came to a design called the "Y-Frame". With this layout, each thruster is positioned with a 120° angle between them and equal distance from a center point. Our Y Frame can be seen in figure 9. Through this motor configuration, the ROV now has exceptional movement in any direction in the horizontal plane and a higher rotational speed. In regards to our vertical movement, two additional thrusters are used in unison for ascending and descending to the sea floor. The vertical thrusters receive the same control signal through individual ESCs. Each thruster produces approximately 33.4 Newtons of thrust. To maintain safety procedures, we chose thrusters that have proper shrouds on both sides of the propeller. To comply with maximum power limitations set by the customer, the thruster output is reduced to 40% of manufactured capability.

Payload Tools:

Claw: *Nemesis* features a custom designed and fabricated claw. The claw, seen in figure 10, has two fingers that are located directly across from a third finger, all of which operate together in a pinching fashion. This setup and the shape of the fingers was designed to maximize the ability to grab PVC and pretty much anything that can fit between the fingers, including ropes, lines, handles, fountain parts and clams. The top finger has a notch feature for catching lines without opening the fingers. The original concept featured three fingers equally spaced in a radial pattern on a circular base. We scrapped the old design because it was extremely difficult for the pilot and it couldn't do all the tasks we needed it to do. We then considered a rack and pinion design to close the fingers linearly. We researched this extensively and even prototyped it but decided it wouldn't be able to grab everything we needed it to, including clams. We decided on the current design which involves a linear actuator closing the fingers towards the center.

Fig. 10: Claw By: Laura Gong

We decided on two fingers moving towards the middle instead of a claw machine type claw where you have three fingers moving towards each other. This makes it easier on the driver because instead of needing to get the object he needs to pick up directly in the center, it just needs to be positioned in between the two fingers. Our custom designed claw is ideal for the tasks laid out for us by the customer,

Agar Sampler: The Agar Sampler is a tool that can extract agar from an ordinary plastic cup. The agar represents sediment from a contaminated area. The completed agar sampler is in figure 11. The body of the Agar Sampler is made from acrylic that has been designed and precision cut by a laser cutter. The multiple pieces are held together with screws and acrylic glue. The bottle, which extends below the housing to extract the sediment, is a cylindrical aluminum bottle that has been serrated and glued to hold it in place. The serrated edge allows for easy penetration of sediment. To extract the sediment, we use a one-way valve from a snorkel inserted in a hole cut at the top of the bottle with a watertight seal. The snorkel valve allows water to escape the sample chamber while it is filling and then holds a vacuum. We also implemented a motor from a bilge pump into our tool. Attached to the motor's shaft, we have an offset circular stainless steel weight. When the motor is turned on, it shakes the Agar Sampler making a "thumping" action which further optimizes the sampler's ability to puncture and extract the agar from the cup. The whole tool is suspended from the ROV using springs so the motor on the tool doesn't shake the entire vehicle.

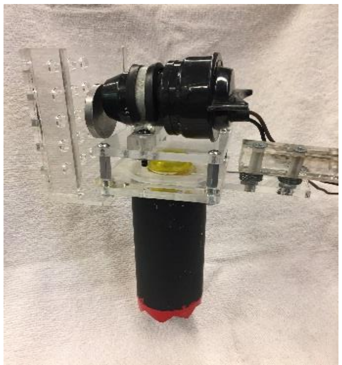


Fig. 11: Agar Sampler Housing
By: Nicolas Kalem

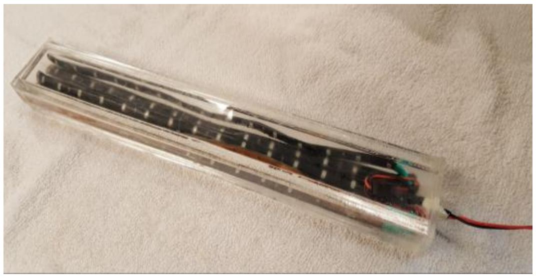


Fig. 12: Light By: Nicolas Kalem

Light: To satisfy the (simulated) task of analyzing the agar sample for contaminants, we at PVIT created our light to be lightweight and effective in completing the mission at hand. Our light "sensor" consists of 5 parallel strings of 50 green LED's and is encased in a protective acrylic housing. The initial design was comprised of a single string of 50 green LEDs which proved to be too weak to light up the target sample. The lights we chose are marketed to the automotive industry and are waterproof. We enclosed the lights to ensure waterproofing at the depths the *Nemesis* will operate. The light is switched on and off with the ROV controls utilizing a Pololu. With our improved light, we are easily able to identify the targeted agar sample. Our waterproof light is in figure 12.

As we were investigating lasers for use as a measurement technology we also evaluated them for use as the agar analyzing device but decided to defer that to future designs.

Valve-Turner: The *Nemesis* features a unique and custom designed valve turner which we have named the Timmie Turner[4]. The valve turner has two prongs that are set across from each other and that spin. This setup is designed to make it easier to engage the valve to spin it. The tips of the forks are colored red for safety reasons and better visibility. We have connected Timmie Turner to a geared bilge pump motor. Our motor controller (Pololu 24v23) is programed to turn the motor at a slower speed to reduce the need for gearing and thus reduce weight. The control of the valve-turner is especially important for success with turning off and later turning on the water valve on the light show fountain in the Port of Long Beach. The valve turner can be seen in figure 13.

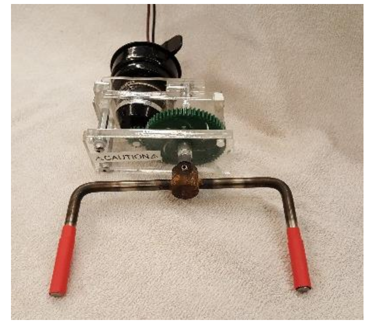


Fig. 13: Valve Turner By: Nicolas Kalem

Tether: The tether is constructed of two Ethernet cables and a set of 12-gauge speaker wires. The speaker wires are used to supply 12-volt power and ground to the remotely operated vehicle. The first Ethernet cable provides wires for serial communications, video signal, and video ground. The second Ethernet cable transports video signal for our bottom facing HD camera. Both Ethernet cables are CAT6a and shielded. In order to protect the tether, we wrap all cables in a protective plastic sheathing. This stops abrasion and keeps the cables from breaking. We attach small pieces of foam along the finished tether to make it buoyant. By keeping the tether on the surface, it remains clear of underwater hazards including divers. This helps prevents getting tangled in foreign objects. We use high quality, waterproof SEACON connectors to attach the ROV to the brain, ensuring a proper connection without any water entering the brain. The tether is approximately 18 meters long and has a stress relief device that attaches it to the *Nemesis* to prevent damage to its connectors if it is pulled. There is also a strain relief connection at the control box on deck. To further ensure safety, we always utilize a tether protocol, which keeps workers safe and the tether in good condition. The spooled tether is in figure 14.

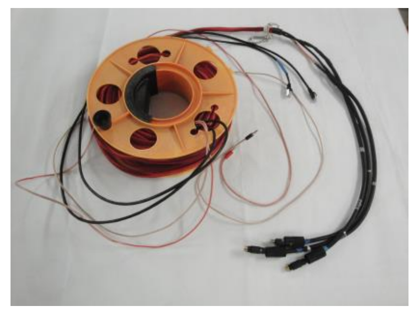


Fig. 14: Tether By: Brian Smalling

Project Costing

In September 2016, the PVIT ROV team developed a prediction for spending in the form of a budget. The final budget prediction was $7,942, mostly from SeaBotix BTD-150 thrusters, SEACON connectors, and GoPro cameras. The ROV division of PVIT submitted this budget request to the PVIT company. However, the budget allocated to ROV was less than the requested amount. This caused us to scrutinize and revise which products were purchased. Instead of buying the SeaBotix BTD-150 thrusters, which would have cost $4,200, the team switched to Blue-Robotics T-100 Thrusters that cost $714. This reduced our budget by $3,486. Additionally, the team switched from buying the Go-Pro Hero 4+ to buying the GoPro Hero 3+ cameras, reducing the budget by $215. The final purchasing record is $3,234. The ROV team received a gracious donation from Pelican Products, a 1500 Medium Protector Case, which is our Control Box, and the 1690 Transport Case, utilized for the ROV. PVIT ROV has the unique opportunity to have direct contact with both Pelican and Blue Robotics companies which are headquartered within 15 miles of our location. We did not budget for any travel expenses this year because the international competition is being held locally for us.

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 $40,000 to PVIT's annual budget. The Palos Verdes High School Booster Club funds another $10,000. Parent contributions fund approximately $7500. The total PVIT budget of $60,000 supports 150 students in 14 different teams. The ROV team is one of those teams. To offset the funding shortfall this year, ROV participated in five local fundraisers. ROV also worked diligently to monitor spending and finish under budget.

PVIT ROV Budget, Established September 2016

Item	Quantity	Price Each ($)	Price Total ($)
SeaBotix BTD-150 Thruster	6	700	4200
Aluminum End Caps	2	200	400
Kickboard	2	0	0
Connectors	10	167	1670
Go-Pro Hero 4 Black	2	430	860
Claw	1	100	100
Tether	1	100	100
Control Box	1	50	50
Pololus	8	16	128
Arduino Mega 2560	2	40	80
5V Regulators	4	1	4
Capacitor	1	0	0
Props	1	150	150
MATE Registration	1	100	100
Gas	1	20	20
Poster Board	1	80	80
Total $:			**7,942**

Table 2: Budget By: Laura Gong

Project Costing Summary

Table 3: Spending Summary By: Brian Smalling

Total ROV Cost (Value of the *Nemesis*)	**$2890**
Total Value (ROV + Control Box + Tether + Props + Other)	**$3649**
Total Value Reused	**$663**
Final 2017 Spending	**$2986**

Purchase Record

Date	Type	Category	Expense	Description	Source/notes	Quantity	Unit Price	Supplier	Total Price ($)
ROV									**Total: $2,890**
11/6/16	Purchased	Electronics	Motor Controller	Pololu 24 v 23	Used for brushed motors	8	$55	Robotshop.com	$440
11/13/16	Purchased	Electronics	Connections	Heat Shrink Tubing	Used for protection of connections	1	$11	Amazon	$11
11/13/16	Purchased	Electronics	Connections	Wires	Used for electrical connections	1	$21	Amazon	$21
11/13/16	Purchased	Electronics	Pins	Male and female pins	Used for electrical connections	various	$26	Amazon	$26
11/20/16	Purchased	Electronics	Regulator	5V, 5-pack	Supplies power to cameras and arduinos	1	$5	Digikey	$5
11/20/16	Purchased	Electronics	PCB	Smaller(6x8 cm), Larger(8x12cm)	Used for electrical connections	various	$15	Amazon	$15
11/22/16	Purchased	Electronics	Arduino	Mega 2560 micro-controllers	Used as connection with the coputer	1	$10	Amazon	$24
12/4/16	Purchased	Electronics	Blue Robotics T-100 Thruster	Propeller and nozzle provides thrust	Used for ROV movement	6	$119	Blue Robotics	$714
12/8/16	Purchased	Electronics	Electronic Speed		Used for motor controller	6	$25	Blue Robotics	$150
2/21/17	Purchased	Electronics	MicroHDMI to		Used for the brain	1	$19	Amazon	$19
2/24/17	Purchased	Electronics	HDMI to Ethernet, and vice-versa	HD Video over Tether	Used for cameras	1	$30	Amazon	$30
2/24/17	Purchased	Electronics	Interface Board	Fathom-X Thether (2 pack)	Provides video connections	1	$160	Blue Robotics	$160
3/4/17	Purchased	Electronics	Electronic connectors		Used for connections for various reasons	Various	$36	Radioshack	$36.00
3/7/17	Purchased	Electronics	SEACON water tight connectors	Under water connections	Protects electrical connections	1	$182	Amron Inc.	$182.00
4/20/17	Purchased	Electronics	HDMI cable	Micro to Standard Interface		1	$17		$17.00
12/7/15	Re-used	Sensors	Cameras	Go Pro Hero 3+ Black Edition Cameras	Reused to produce images	3	$215	Amazon	$645
11/13/16	Purchased	Sensors	Cameras	Craze Pony 700 TVL Camera 3.6 mm	Produces images	2	$20	Amazon	$40
1/11/15	Re-Used	Hardware	Bilge Pump	500 GPH	Used to run Agar Sampler	1	$18	Myboatsupply	$18
11/28/16	Purchased	Hardware	End Cap	Delrin rounds, 2" x 7" dia	Used for ROV structure	4	$80	McMaster Carr	$320
4/16/17	Purchased	Hardware	Polypropylene	White, 12x24x1/4 in	Used for the side structures of ROV	2	$30		$60.00
Control Box									**Total: $151**
12/8/16	Purchased	Electronics	Extender Cable	PS2	Used with the cable box	1	$3	Amazon	$3
11/22/16	Purchased	Electronics	Arduino	Mega 2560 micro-controllers	Used in Control Box	1	$10	Amazon	$10.00
12/13/16	Purchased	Electronics	Digital Voltimiter	DC voltage: 200, AC voltage:200/600V	Checks electronic connections	2	$13	Amazon	$26
1/11/17	Purchased	Electronics	Monitor	7 in. 480p	Used to see images	1	$27	Amazon	$27
2/12/17	Purchased	Electronics	Female Ethernet	10 pack	Used for props	1	$12	Amazon	$12
2/17/17	Purchased	Electronics	Banana plugs	Female and male banana plugs	Used for electrical connections	1	$22	Amazon	$22
2/19/17	Purchased	Electronics	Bus	Bus #1 and Bus #2	Used for the control box	1	$17	Amazon	$17
2/17/17	Purchased	Electronics	Fuse	25A	Used for safety props	1	$7	Amazon	$7
4/21/17	Purchased	Sensors	Wifi Router		Used for cameras	1	$27	Radioshack	$27
Props									**Total: $340**
2/12/17	Purchased	Electronics	Connector End		Used for safety props	1	$10	Amazon	$10
2/12/17	Purchased	Electronics	Magnetic Reed Swiches and Magnets	10 pack	Used for safety props	1	$18	Amazon	$18
2/12/17	Purchased	Electronics	CAT5 cable with ends		Used for safety props	1	$18	Amazon	$18
2/12/17	Purchased	Electronics	Buzzers	5pack	Used for safety props	1	$5	Amazon	$5
2/12/17	Purchased	Electronics	Switches		Used for props	2	$6	Amazon	$12
12/3/16	Purchased	Hardware	Agar Powder		Tests props	3	$7	Amazon	$21
1/11/17	Purchased	Hardware	PVC	White, various sizes	Used for various props	1	$57	Home Depot	$57
2/3/17	Purchased	Hardware	PVC Prop supplies	Pipes, T's, coupling	Used for props	1	$50	Home Depot	$98
2/27/17	Purchased	Hardware	Hardware	Ex. shrink tube, nuts and bolts	Used for various reasons(ex. ROV build)	Various	$58	Various	$58.00
3/8/17	Purchased	Hardware	HS-646WP	Standard size		1	$43	Blue Robotics	$43
Tether									**Total: $63**
3/15/17	Purchased	Electronics	Plastic Sleeving	Plastic Tether Wrap	Protects Tether	1	$8.00	McMaster Carr	$8.00
4/20/17	Purchased	Electronics	CAT6a Ethernet	Flat Copper Network Cable -		2	$20	Amazon	$40.00
3/15/17	Purchased	Electronics	12 AWG Speaker	Power through Tether - 100ft	Power and Ground Bundle	1	$15	Amazon	$15.00
Other									**Total: $215**
10/19/16	Donation	Hardware	Protector Cases	1500 and 1690 case	Donated by Pelican Products	2	$0.00	Pelican	$0.00
3/5/17	Purchased	General	MATE Registeration Fee	Competition requirement	Used for MATE competition entry	1	$150	MATE	$150.00
3/5/17	Puchased	General	MATE fee	Fluid power quiz	Checks pressure and equipments	1	$15	MATE	$15.00
Anticipated	Purchased	General	Poster Printing			1	$50	makesigns.com	$50.00
			Total Value						$3,649
			Total Value Reused						$663.00
			Final Balance Spent in						$2,986.00

Table 4: Spending By: Laura Gong

Troubleshooting

Operational troubleshooting on the *Nemesis* has improved over previous PVIT ROV models. We test every connection after we complete it to make sure that there is no bridging and that everything is properly connected. However, if the *Nemesis* is not functioning, the trouble-shooting begins in one of three areas: the craft, 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 *Nemesis* is ready to launch, otherwise, we repeat the troubleshooting process.

Another way that we reduce problems is to cut all components of our ROV out of cardboard before we cut the pieces out of necessary materials. This assures that we can have a working ROV the first time we cut it out. It also prevents the waste of hard to get materials, so we don't have to wait for a shipment to build the ROV.

Challenges

While building the ROV, we faced many challenges, many of which we overcame and learned valuable lessons from. One very difficult technical challenge that we faced was making the ROV fit in the 48-centimeter ring. We spent many hours designing and redesigning the ROV to fit the thrusters and endplates inside the ring. We did manage to finally succeed in this task by using design software to map out our ROV. Using this software was a very difficult challenge. Every part of the ROV had to be designed using CAD software, and in many instances the part was too complex for the non-user friendly program to handle. In many cases, perfectly dimensioned parts became too big or too small when putting them in drawings with other parts. All this work on this program led to an organizational challenge of making time management extremely difficult, as many team members spent all their time during the four-hour meetings working on computers to make the parts fit. This caused our team to become rushed as the competition was nearing to get the ROV in the water. Daily meetings were needed to solve the time crunch. Once constructed, we were further challenged to give the pilot "line of sight" to all the payload tools. Although they all fit on the craft, it was hard for the pilot to see and operate successfully.

Another organizational challenge that affected our ability to have a working ROV was a new purchasing system put in place by the school district. This year, we had to verify every purchase we made with an attendant at the district office to get it accepted. This made it very difficult for us to get our parts in time for the competition.

One final technical challenge that we faced was to get the ROV under the weight requirement for the competition. Several trade-offs were made, such as the move from aluminum to Delrin® for the Brain endcaps. The Weight Chart found in the appendix illustrates some of the research and tradeoffs made for weight. Nevertheless, due to heavy payload tools, we were unable to meet the lightest requirement, but during our tests we can make it under the heaviest requirement. We made our ROV out of lighter material to achieve this goal.

Lessons and Skills Learned

A new skill that I acquired while working on the ROV this year was learning how to operate the 3D printer. When I first joined the ROV team, I had no idea how to operate the 3D printer. However, through working with parts, such as a waterproof box for a motor, I learned how to transfer an Inventor design into a design compatible with the printer by using the MakerBot software and printing it. A lesson I learned while using the 3D printer is to double check the measurements on the piece so as not to waste materials, because the MakerBot and the Inventor run on different measurement systems. This skill will greatly help us later because we will be able to build our own unique parts instead of buying them. **Daniel Arriola, Mechanical Engineer, 1st year.**

Future Improvements

Future modifications planned for the *Nemesis* include two technical advances we researched this year. First we will pursue the thruster control to use feedback from a gyroscope. The PID part of the program takes in the information from a gyroscope on the ROV, does calculations to give feedback and then fixes the direction and position error from the water currents. Finally, the program mixes all the commands from both driver and PID auto stabilizer program. The gyroscope is currently mounted on the *Nemesis* and our programmer wrote the code and successfully prototyped it on a land vehicle, but we did not have the time to make it functional on the ROV.

The second technology researched but not integrated is a new laser system for taking measurements. We researched many technologies this year, but did not reached a definitive conclusion before we ran out of time. In the future, we would like to use this research to update our measurement system, and install a laser measuring device.

Another improvement we have in mind is to design and build an articulating claw with rotating wrist action. We have used a fixed wrist claw successfully, however, having a more versatile instrument would enable us to accomplish multiple tasks with fewer tools onboard. This would enable our company to respond to some of our more demanding customer requests. This feature will require additional ROV programming, but we are up for the design challenge.

Finally, the PVIT ROV team would like an improved flotation system for the ROV; a foam flotation device coated with fiber glass to maximize buoyancy. Since foam deteriorates over time, fiberglass would be more durable. In addition, a fiberglass coating would make our ROV more aesthetically pleasing and would allow us to paint our company colors and logo on the ROV. More importantly, we believe, fiberglass will improve the hydrodynamics and mobility of the ROV in tight spaces.

Reflections

With three years of experience at the MATE competition, I have had the chance to do things that are unique to the program. Learning how to fully build a robot has been one of the best experiences of my life, but traveling to all the fantastic locations for competition has been one of my favorite aspects of the program. When we went to St. John's my first year, that was one of the best areas I've visited so far. Last year in Houston, visiting the Johnson Space Center and the

Neutral Buoyancy Lab was an amazing experience. Even going to Alpena as a spectator was great fun. Now that the competition is in Long Beach, a short drive from home, the competition will be different. A huge part of the international competition was the travel, and seeing places I would have ignored otherwise. Hopefully, next year I will get to visit another great area of the world for my last MATE International competition.
Brian Smalling, CEO, Pilot, 3rd year.

Appendix

PVIT 2017 Job Safety Analysis (JSA)

HOUSEKEEPING

TASK	HAZARD	PROTOCOL
Machining	Contact with body Dangerous debris	Follow safety checklist, use personal protection equipment (PPE)
Mission Runs	Leaking and breaching of electrical systems	Perform pre-run checklist,
General Shop work	Stepping on sharp items and tools	Putting all items back where they belong Wear close toed shoes
Electrical Power Tool (soldering iron)	Unsafe contact with skin or clothing flying debris	Properly hold tools Keep all people not involved at a safe distance

HAND SAFETY

TASK	HAZARD	PROTOCOL
Laser Cutter	Contact with fingers	Keep lid closed, watch for sharp edges.
Drilling	Contact with fingers	Wear work gloves, Keep hand clear of drill bit.
Soldering	The use and contact of hot objects	Keep clear of hot surfaces, notify others of hot surfaces, stow hot iron in designated areas.
Drill Press	Hitting fingers	Use designated clamps. Keep hands clear.

PERSONAL PROTECTIVE EQUIPMENT

TASK	HAZARD	PROTOCOL
Power tools	Puncturing of skin Debris	Eye protection, gloves, close toed shoes.
Metal Machining (Lathe)	Debris in eyes	Face protection, gloves, close toed shoes, goggles.
ROV operation	Injuring of body parts	Eye protection, close toed shoes.

LIFTING & BACK SAFETY

TASK	HAZARD	PROTOCOL
Moving the ROV	Heavy lifting Dropping heavy objects on self	Lift with the knees.
Launch/Recovery of ROV	Heavy lifting, awkward position.	Kneel on deck, use caution, and don't fall 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.

TOOL SAFETY

TASK	HAZARD	PROTOCOL
Drill Press	Damage to skin Crushing of fingers	Safety Glasses, Gloves, Close Toed Shoes
Dremel	Breaking of skin	Safety Glasses, Gloves, Close Toed Shoes
Soldering Iron	Serious burning of skin	Safety Glasses, Close Toed Shoes, Hot tip holder/cleaner
PVC cutter	Cutting of fingers	Safety Glasses, Close Toed Shoes

ELECTRICAL SAFETY

TASK	HAZARD	PROTOCOL
ROV Operation	Electrical shock	Follow all checklists, keep extension cord dry.
Troubleshooting ROV Control System	Shock	Power Off.
ROV Electrical Design & Fabrication	Electrical systems failure	Use fuse, diodes, comply with MATE regulations. No power supply in water.

Implementation & Enforcement:
Employee Observation Program
Utilize Safety Task Analysis Cards (STAC).

Weight Chart

Item:	Quantity	Weight (grams)	Total
Aluminum end cap	0	1122	0
Delrin® end cap	2	675	1350
Thruster Blue Robotix	5	387	1935
Thruster SeaBotix	0	700	0
Cylinder, 13cm dia. Weight in g/cm	0	14.59	0
Cylinder, 24cm dia. Weight in g/cm	23.5	25.25	593
Aluminum disc large	0	46	0
Aluminum disc small	0	10	0
Steel thin disc	0	46	0
Steel thick disc	0	90	0
Steel disc medium	1	61	61
Fork large gear box and mount	0	519	0
Fork small gear box and mount	1	311	311
Fork motor and connect	1	328	328
Fork only, metal	1	158	158
Fork only, polypropylene	0	30	0
Agar sampler	0	475	0
Claw	1	709	709
Stepper motor	0	332	0
Old brain circutirty	0	242	0
New brain circutirty + acrylic mount	1	508	508
Cross pieces	3	70	210
Agar sampler complete + connector	1	774	774
Timmie Turner, no connector or mount	0	588	0
Side frame left	1	436	436
Side frame right	1	334	334
TOTAL			7707

Table 5: Weight Chart   By: Daniel Arriola

List of Tables and Figures

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