ROGUE
UNDERWATER SOLUTIONS
Rogue Robotics Club **Holmdel, New Jersey**

NEMO ROV

Technical Documentation

2018 MATE ROV Competition

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1 Introduction

1.1 Abstract

Rogue Underwater Solutions was established in 2017 for the purpose of developing underwater robots to address the challenging marine issues that society faces today. The company is entirely student-run, not affiliated with a school, and is recognized by the IRS as a 501(c)(3) non-profit organization. Competing for the first time in the MATE ROV competition, Rogue Underwater Solutions chose to compete in the Ranger Class division. Although this was the company's first year competing, several members had had prior experience with underwater robotics, including the MATE competition.

The 2018 season competition theme is Jet City: Aircraft Earthquakes and Energy, focusing on the installation and recovery of aircraft and scientific instruments underwater. The company developed its 2018 vehicle, *Nemo*, to allow its clients to carry out the mission tasks in a safe and straightforward manner. *Nemo* features an ABS plastic frame, a custom topside control unit with a built-in monitor, and a powerful control system based on the Arduino Mega microcontroller and the Raspberry Pi 3 single-board computer.

This technical report describes the development process and design details that make *Nemo* the optimal ROV to fully meet the requirements specified in the MATE Center and Applied Physics Laboratory at the University of Washington Request for Proposals (RFP).

Figure 1: *Company photo of Rogue Underwater Solutions. Back Row (left to right): Rishi Salwi, Eric Zheng, Sam Alws, Ananth Koppol. Front row (left to right): Alice Lai, Alisa Lai, Gloria Liu, Sophie Zhang, Bryan Yao.*

2 Description of Project Management

At the beginning of the competition season, the company's senior members came together to discuss the successes and failures of the previous year's MATE ROV competition (as part of a previous organization). The company identified 3 key areas that needed improvement: meeting deadlines, managing tasks, and testing. In order to address these areas of improvement, the company met and developed a document prior to the beginning of the competition season that detailed the terms and conditions with which all company engineers and leaders had to comply. Team leads were also elected to be in charge of the different departments for more organized day-to-day operations: Mechanical, Electrical, Software, and Business. Each company member was assigned to one of these departments based on demonstrated interest and prior technical experience.

In addition, the CEO initially created and shared a Gantt chart in order to facilitate planning and to help the company adhere to long-term goals. To reinforce task responsibility, a Google Group was created. This enabled the CEO to easily send out weekly emails and group texts concerning each individual's task, both for home and for project meetings. A document detailing specific milestones/deadlines was also developed in order to actively track progress. Together, these documents allowed the company to stay organized and develop the *Nemo* ROV in an efficient manner.

2.1 Project Timeline

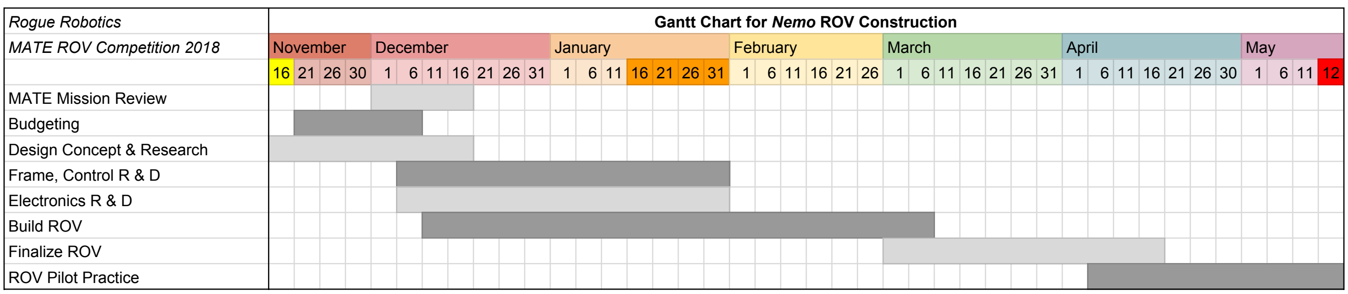


Figure 2: *Company Gantt chart, with important dates (manual release, "cram week," competition date, etc.) indicated*

2.2 Company Assignments

Table 1: *Company structure and responsibilities*

Business	Mechanical	Electrical	Software
Raise money through various fundraisers and public outreach events Keep track of all financial transactions on a company-wide spreadsheet. Manage the company's public relations and online presence through social media.	Design and build an ROV frame capable of completing the tasks needed Research motor placement and find the most optimal location for the motors on the ROV. Create CAD sketches of parts to be 3D printed for the ROV.	Design and construct the control system on both the watertight enclosure and the control box. Waterproof all the electrical connections and seal the electronics enclosure. Ensure that no circuit is being overloaded or shorted. Illustrate the SID.	Develop software to control underwater microcontroller with host computer. Work with electrical and mechanical engineers to integrate sub-systems Develop auto-depth feature to stabilize the ROV for better piloting UX.

3 Design Rationale

The company used a vectored six-thruster configuration as the starting point for the design of *Nemo*. Having a vectored six-thruster configuration allows for additional degrees of freedom, making the ROV movement much more flexible and maneuverable. The company custom-designed the entire frame with Autodesk Inventor, making it as small and hydrodynamic as possible to accommodate the agility and speed of the ROV.

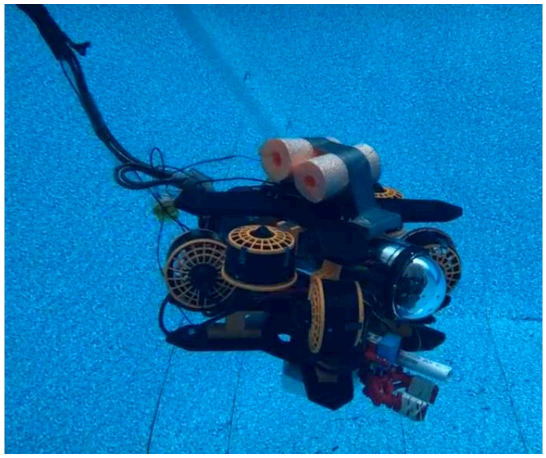


Figure 3: Nemo *ROV*

3.1 Structural Frame and Buoyancy

This year, the company designed and manufactured the ROV frame completely from scratch. The ROV frame was designed toward small size, high strength, and excellent maneuverability. The design process began with detailed CAD modeling and simulation to determine optimal design parameters for the frame. Due to the emphasis on small size and efficiency, the company decided against a traditional PVC box-based frame in favor of a more compact but less easily modifiable design. Because of this, it was imperative that the design was thoroughly and carefully tested before final construction began. A cardboard mockup and 3D printed prototype of the frame design were therefore used to test the design underwater before committing to the production model.

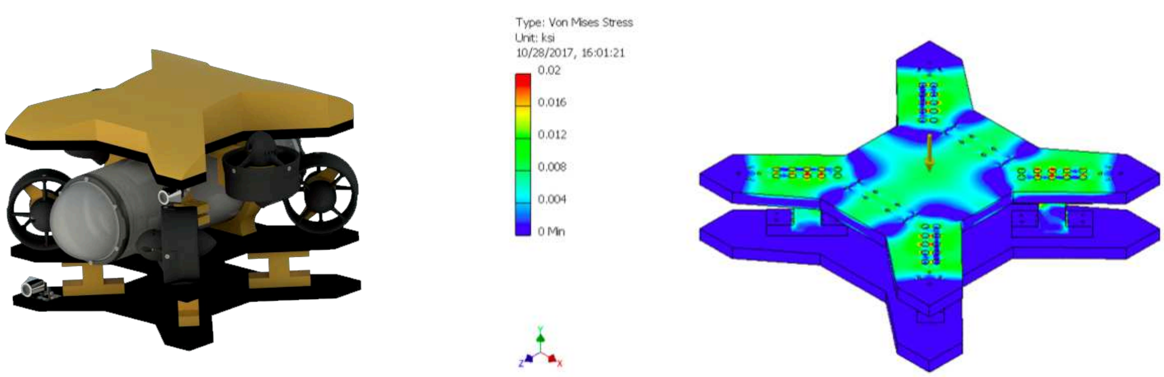


Figure 4: *CAD modeling and FEA simulation of the frame design*

Figure 5: *Prototyping and construction of* Nemo*'s frame*

The frame's design came from careful consideration of several important physical factors. The mission-specific end effectors are housed between two plates on the bottom of the ROV, providing easy access and manipulation when performing tasks. The electronics enclosure and buoyant foam are placed above them, allowing the center of buoyancy to remain above the center of gravity and giving the ROV good stability in the water.

Neutral buoyancy is maintained through a combination of buoyant elements (reused water bottles) and ballasts (end effectors and controlled weights). Originally, a syntactic foam buoyant element was designed for the ROV, but the company ultimately preferred a more modular and extensible system. Being able to finely tune and adjust the buoyancy was key; in previous years, team members had implemented this level of adjustment through crude methods such as adding small rocks to a box. This year, the company placed standard weights and conducted extensive pool tests to ensure their proper placement. A careful analysis was performed and weights incrementally adjusted in order to ensure perfect buoyancy.

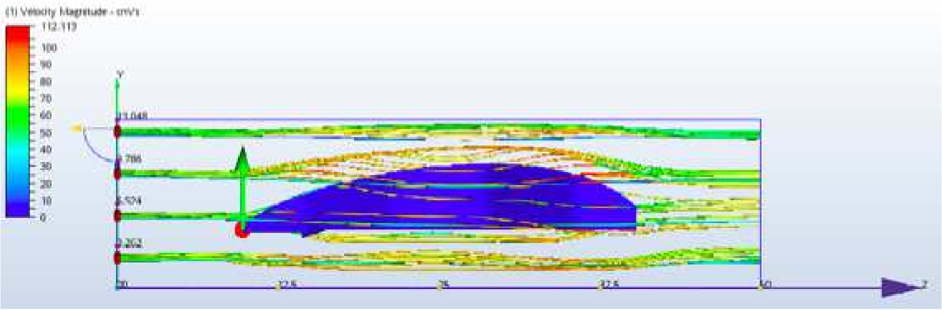


Figure 6: *Design of syntactic foam buoyant element*

Due to the departure from a conventional PVC structure, the company also had to carefully consider the material used for the frame. Balancing items such as cost, strength, and density, the company eventually decided on using ABS plastic for its high strength and low density.

Table 2: *Comparison of frame material candidates*

	Anodized Aluminum	HDPE Plastic	ABS Plastic
Cost ($\$\,kg^{-1}$)	1.98	1.98	3.09
Yield Stress (MPa)	275.8	25.9	43.3
Density ($g\,cm^{-3}$)	2.707	0.958	1.060

3.2 Underwater Electronics Enclosure

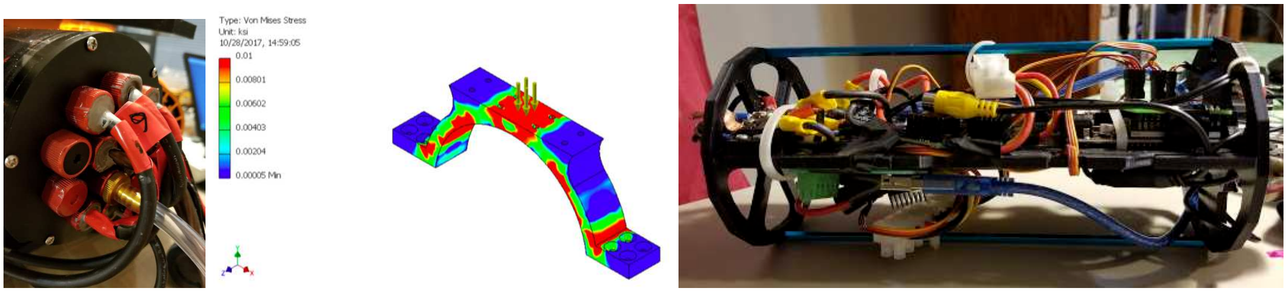


Figure 7: *Crucial electronics enclosure components: (left) aluminum endcap, (center) enclosure clamp, designed to withstand stress during use, and (right) bottomside electronics tray*

Due to historical issues with waterproofing, the company opted to purchase a Blue Robotics underwater enclosure to house bottomside (onboard the ROV) electronics. Early on, there were some minor issues with waterproofing, but these were resolved with a more careful assembly of the tube.

The enclosure itself consists of a cast acrylic tube with an aluminum flange and end cap sealed with a combination of O-rings. Cable penetrators are potted with marine epoxy and sealed to the end cap with O-rings to provide a waterproof yet easily removable connector. This year, the company was able to extensively test the electronics enclosure at pressures far exceeding the MATE competition depth by using a hand-held vacuum pump to create negative pressure in the enclosure, simulating the pressure effects of deep water. Because of this, the company was able to confidently use the enclosure in the MATE competition pool without fear of leakage.

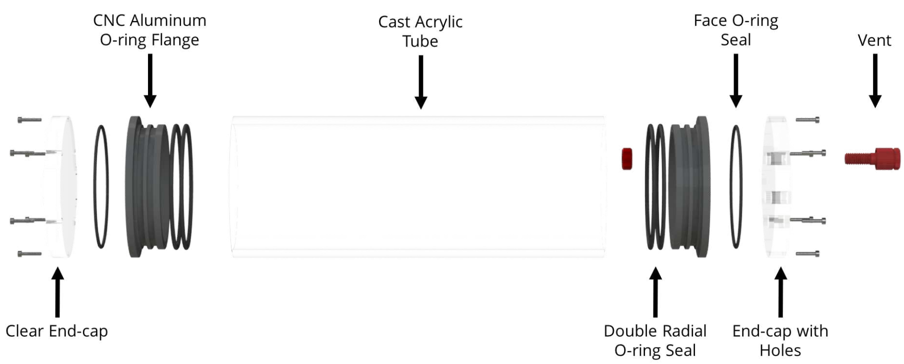


Figure 8: *Blue Robotics electronics enclosure assembly*

To securely fasten the electronics enclosure to the frame, clamps were designed in-house and 3D printed from ABS plastic. The clamps were designed to withstand the stress applied by the structure while still clamping the tube securely. In order to give some tolerance to the clamps for manufacturing, they were intentionally designed to be slightly larger than the outer diameter of the tube and mounted slightly off-center.

Inside the electronics enclosure, power is distributed using 2 eight-screw terminal blocks. 12 V is connected to every other screw and Ground (GND) is connected to rest of the screws. This allows all six of the ESCs to receive power and prevents the wires from tangling. An Arduino microcontroller in the tube sends analog values to the six ESCs to control their speeds.

The team initially tried using an Arduino Uno, but found trouble with the limited amount of I/O pins and susceptibility to voltage spikes. Instead, the Arduino Mega was chosen for its expansive set of digital I/O pins as well as its capability to handle 12 V - 20 V. To keep the data wiring organized, a protoboard was designed for easy connection of motor wires to the Arduino.

A custom camera mount was designed that attaches to a micro-servo motor. The camera mount is based on the Blue Robotics Custom Tilt System and customized for the specific back-up camera that the company used. The entire device allows for up to 45 degrees of rotation for the camera. Since the pilot can rotate the servo to a precise angle, he/she has better visibility. A protoboard with the LM7805 voltage regulator is responsible for stepping down the 12 volts power supplied through the tether to the 6 volts required by the servo motor. This is accomplished using 510 Ω and 75 Ω resistors.

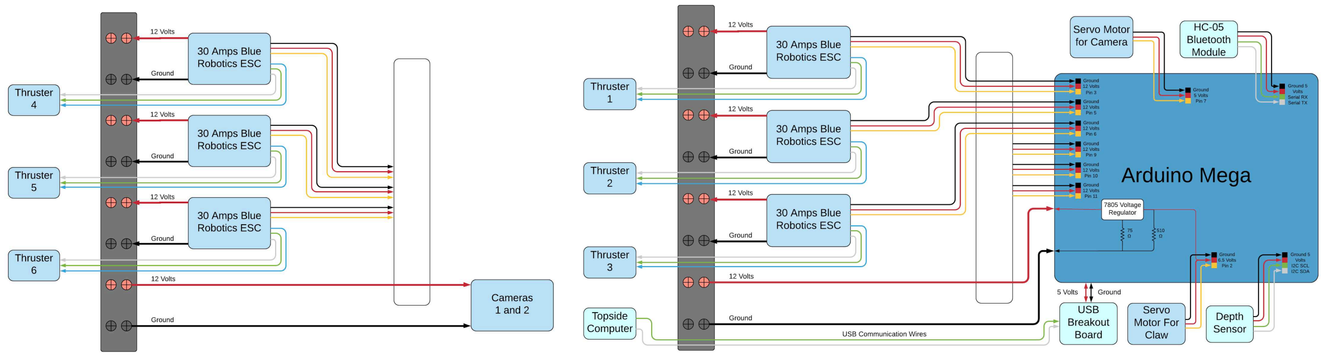


Figure 9: *Bottomside electronics layout, including (left) top view and (right) bottom view*

The company designed the tether to be as minimalist and compact as possible, minimizing the impact of drag from the tether on the ROV's movements. The tether consists of two 8 AWG wires for 12 V and GND to minimize voltage drop across 15 m, a USB cable for communication, two RCA cables for camera feeds, and one piece of PVC tubing for the lift bag mission task. The tether has polyethylene foam wrapped around it at various intervals so that it is positively buoyant. Thus, it does not weigh down the ROV during operations. The tether's connections to the electronics enclosure are also strain relieved using an apparatus consisting of a piece of acrylic and tennis string.

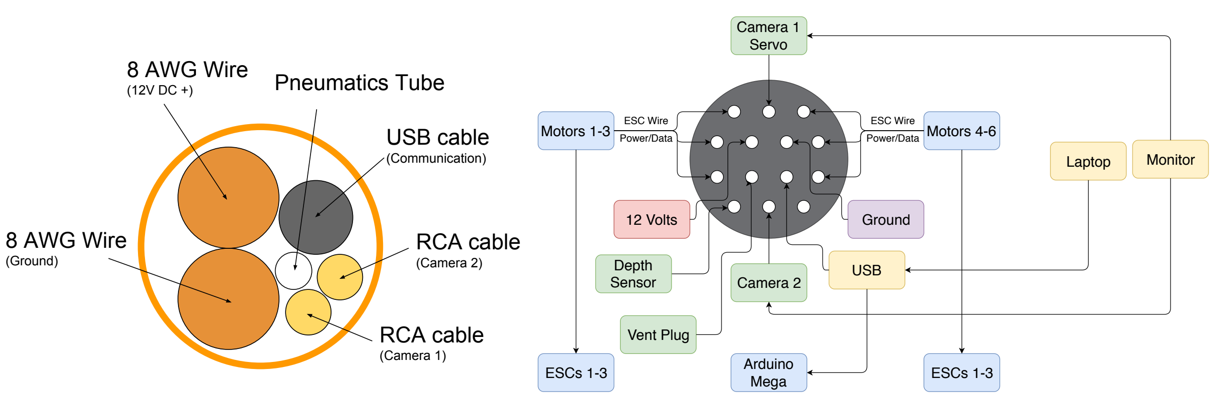


Figure 10: Nemo*'s tether, showing: (left) cross section and (right) endcap connection layout*

3.3 Topside Control Unit (TCU)

The topside control unit (TCU) is a hub for power, communications, and video for the *Nemo* ROV system, and is also a key component of the safety subsystem. Designed to be durable and easily portable, it is very easy to both mobilize and demobilize the *Nemo* ROV's topside control unit during set-up as well as clean-up. The pilot can use the TCU to monitor vehicle status, get sensor data, and aid with shore-side mission tasks such as calculating vectors for aircraft in Task 1.

Figure 11: *The* Nemo *topside control unit, including: (left) repurposed monitor and (right) electronics*

As outlined in the SID (System Integration Diagram), 12 VDC power supplied by MATE first enters through a 25 A in-line fuse and through a strain relief cable gland on the top right of the TCU's base. The 12 V and GND wires pass through a kill switch, located to the left of the TCU, allowing the pilot to easily shut down the ROV system in case of electronics tube leaks or any other emergency. The wires then go through a watt meter, another safety component which allows the pilot to monitor the current draw of the ROV and its components in real-time. Power finally is sent through the tether via a pair of robust Anderson Powerpole connectors, as shown in Figure 12.

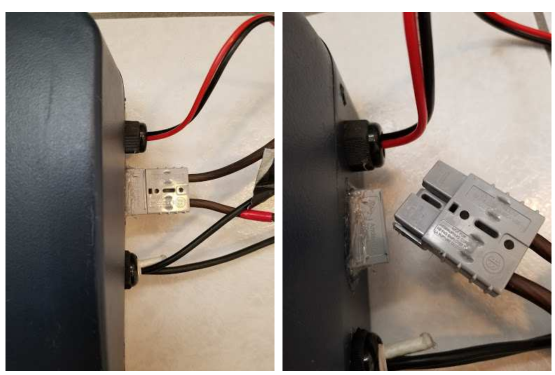


Figure 12: *TCU tether connections, with Anderson Powerpole connection in center*

For communication, a 15 meter long USB cable is used to connect the host Raspberry Pi computer and the Arduino Mega microcontroller. This USB cable is used to send the joystick inputs from the XBOX 360 wireless controller received by the USB wireless receiver plugged into the Raspberry Pi down to the Arduino. Since MATE rules dictate that any ROV electronics can only be powered through the MATE-supplied power supply, a USB Type A breakout board is used to help only distribute the “data” signal of the USB, with the +5 V wire of the USB cable manually removed.

To view the camera feeds, the two RCA cables from the tether are connected two USB capture cards, which plug into the Raspberry Pi and convert the RCA data signals to USB.To display the two ROV camera feeds, an LCD monitor is connected to the Raspberry Pi via an HDMI cable. For cost efficiency, the LCD monitor was stripped off of an old laptop and refitted with standard universal video controller board.

3.4 Propulsion (Thrusters)

The Blue Robotics T100 thrusters are an upgrade from previous propulsion systems. They are cost-efficient and powerful, outputting up to 23.13 N of thrust at full throttle. Six Electronic Speed Controllers (ESCs) are used to provide three-phase AC power and control the speed of these thrusters from the Arduino Mega microcontroller. Because there is a 25 A power limit, the company decided to only run the motors at 50% thrust. Despite the limitation, the Blue Robotics T100 thrusters are still powerful enough to effectively maneuver the ROV.

Rather than a classical orthogonal thruster placement, the *Nemo* ROV utilizes a six-thruster vectored configuration to improve ROV maneuverability. This priority on maneuverability improves the ROV’s ability to perform the MATE mission tasks involving, for instance, attaching a lift bag to subaquatic debris.

Figure 13: *Thruster placement was carefully considered to afford the ROV five principal degrees of freedom: surge/sway/heave (violet), roll (red), and yaw (blue)*

3.5 Camera Sensors

When designing the ROV, the company gave special focus to the camera type and layout. The company understood the importance of having a proper view of the robot’s surroundings and therefore decided on having two cameras—specifically waterproof backup car cameras. The team decided to repurpose car backup cameras because they have wide angle lenses, they’re lightweight, and they only require a thin RCA cable to carry camera signals in the tether. The first, primary camera is located in the waterproof enclosure and is mounted so that its angle may be adjusted with a servo motor. This camera provides the most informative view, but is supplemented by an auxiliary camera mounted on the top-left of the robot.

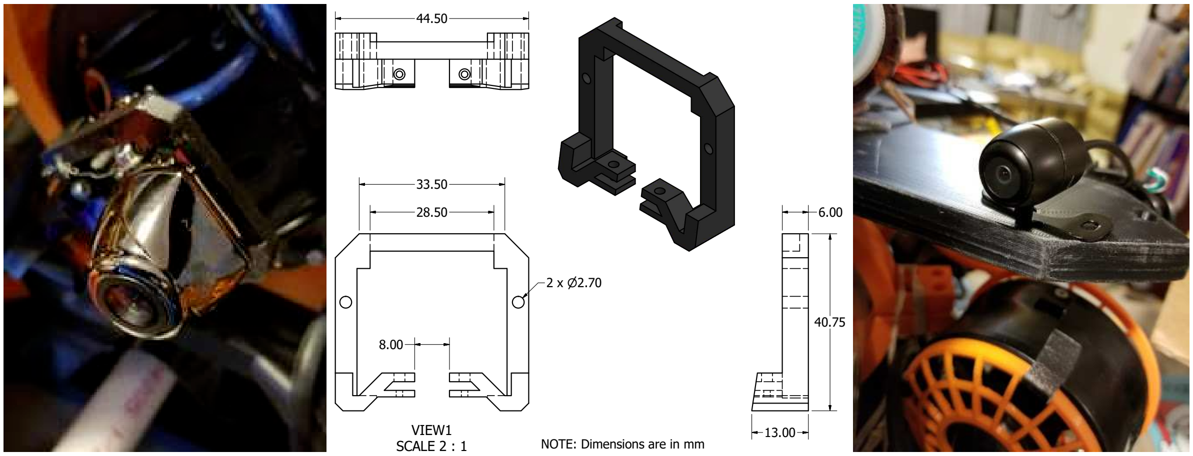


Figure 14: Nemo *camera system, including (left) primary camera, (center) custom camera mount, and (right) auxiliary camera*

3.6 Payload Tools

3.6.1 Primary Gripper

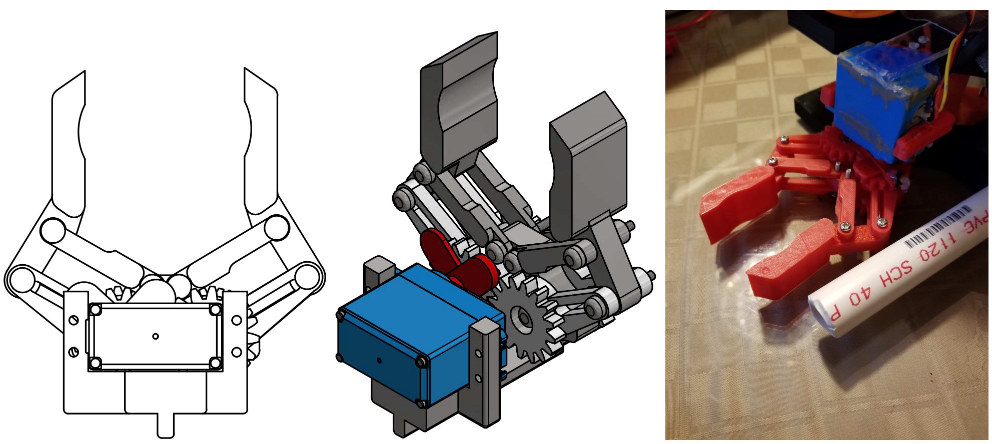


Figure 15: *CAD drawing and assembled model of* Nemo*'s primary gripper*

Nemo's primary end effector is a custom 3D printed parallel gripper actuated by a waterproof servo motor and assembled using M3 bolts. The design features two symmetric parallelogram linkages connected by meshing spur gears, one of which is attached to the servo for precise position control. The gripper is designed to open up to 5.6 cm, sufficient for accomplishing all of the mission tasks requested by the client. For additional grasp strength, a surface like rubber bands can be wrapped around the jaws to provide more friction.

3.6.2 Lift Bag Inflation Apparatus

Nemo also features an inflation mechanism for the lift bag missions in Task 1. A 15 m long PVC tubing provides air to the inflating apparatus from topside to bottomside, supplied by a manually-powered bike pump. Hot melt adhesive (HMA) is used to create a watertight seal between the tubing and the PVC end of the lift bag inflating apparatus. The apparatus itself consists of a short PVC segment that can direct the air supply into the lift bag. The PVC segment is visible in Figure 15.

3.6.3 Depth Sensor

Nemo's Blue Robotics Bar30 depth sensor adds another layer of spatial awareness for the pilot. This waterproof sensor determines the depth of the ROV by measuring the pressure. It fits into one of the penetration holes on the endcap. The depth sensor is visible in the endcap in Figure 7.

3.6.4 Bluetooth Sensor

To communicate with the OBS, a Bluetooth shield was placed inside the ROV's waterproof enclosure. When the pilot wants the OBS to be released, he/she can use the Bluetooth shield to send the signal to a corresponding shield in the OBS's release circuit.

3.7 Software

In previous years, the company often had a sophisticated and yet overly complex software system, and it was very difficult to complete the code well before the competition. This year, the company decided to develop its entire software system in Python. Targeting a high-level Python interface dramatically decreased the implementation time required, allowed for more rapid and frequent testing, and allowed for more engineers to thoroughly understand the control system.

The company first decided to utilize the Python client of the Firmata communication protocol to communicate between the Raspberry Pi computer and the Arduino Mega on bottomside. Although the company's software engineers initially had trouble with integrating other electronics components with the PyMata library, over time the engineers learned how PyMata worked and were even able to write custom libraries for electronics components to integrate with PyMata.

4 System Decisions

4.1 Power System

- 8 AWG wires (New/Commercial)

Power management was critical to the bottomside electronics. It was of great importance that most of the power supplied by MATE be used for the T100 thrusters so that the ROV could move quickly. Thus, two 8 AWG wires were implemented to minimize voltage drop as much as possible across the 15 meter tether.

- 7 V LM7805 Regulator (New/Commercial)

It was essential that the servo motor which controlled the claw received the correct voltage so that it did not stall or use too much current. Therefore, a voltage divider was used to supply 7 volts to the servo motor.

4.2 Control System

- Raspberry Pi 3 Model B Single-Board Computer (New/Original)

Nemo runs off of a Raspberry Pi 3 single-board computer. The Raspberry Pi was chosen for its availability and easy integration with other components.

- Laptop LCD Monitor (Reused/Original)

The company decided to repurpose a used laptop LCD monitor to serve as the primary display for *Nemo*'s navigation and status.

- 15 m USB cable and USB Type A Breakout (New/Commercial)

This year, the company decided to purchase a 15 meter USB cable and USB Type A breakout as its primary serial interface between topside and bottomside electronics. The USB breakout board is used to prevent the laptop from supplying 5 V to the Arduino as the MATE rules dictate. The 15 meter USB cable is implemented because it represents a much more reliable and efficient method of communication than a custom-built or general purpose cable.

- 2 USB Capture Cards (Reused/Commercial)

The two RCA cables that carry the two camera feeds are fed into USB capture cards that convert the RCA signal into USB. Then, the pilot can run the Python script using the PyGame module to view the camera feed on the monitor.

- Arduino Mega 2560 Microcontroller (Reused/Original)

Bottomside electronics components are controlled with a central Arduino Mega 2560 microcontroller. The team already had several Arduino Mega microcontrollers available and had extensive experience utilizing the Arduino platform, so the company decided to opt for Arduino-controlled electronics.

- XBOX 360 Gamepad Controller (Reused/Original)

The XBOX 360 Gamepad Controller is an intuitive user interface for the pilot. Since the pilot was already familiar with the controller, the pilot did not have to learn an entirely new control scheme to control the ROV. In addition, a company member already owned an XBOX 360 controller, so repurposing the controller made financial sense.

4.3 Propulsion System

- BlueRobotics T100 Thrusters and Afro Electronic Speed Controllers (6 New/Commercial)

Nemo's propulsion system features six Blue Robotics T100 thrusters, four of which are mounted in a vectored configuration and two of which are mounted vertically. Based on members' previous experience with bilge pump systems, the company opted to purchase the more expensive T100 thrusters for their superior power efficiency and force characteristics. Better power efficiency enables *Nemo* to utilize its available power more effectively on other end effectors and subsystems, and increased force output enables more rapid movement and greater lifting capabilities. These thrusters represent a significant investment of resources, but the company is confident that, in the context of the challenges faced by *Nemo* and future generations of its ROVs, the gains in performance are significant enough to outweigh the cost.

4.4 Primary Gripper

The *Nemo* ROV's main gripper is actuated by an IP67-rated HS-646WP servo motor further protected by a robust layer of marine epoxy. The gripper's main components are 3D printed from PLA plastic and fastened with M3 machine screws. The company chose to manufacture the claw in-house because this afforded the greatest opportunity to iteratively customize the design for the tasks at hand.

The design chosen was a modification on a commercially available claw with which several members had experience. The company chose this design as a base model due to its reliability and strength but ended up modifying it to accommodate the specific requirements of the *Nemo* ROV. In particular, the original commercial claw was created from machined aluminum; the company had to extensively reinforce the design before 3D printing and assembly from PLA plastic.

4.5 Frame Components

In previous years, company members had had experience with PVC-based frames. While these designs were easily modifiable, they were also bulky and unwieldy. This year, the frame structure was entirely redesigned by company members and was 3D printed using ABS plastic. Rather than purchase an expensive commercial frame, the company chose to design a custom frame to better suit the specific needs of the *Nemo* ROV, particularly with respect to thruster placement and end effector mounting.

The only part of the frame system that was commercially purchased was the Blue Robotics electronics enclosure, which serves to house the ROV's electrical components. The company opted to purchase a commercially available electronics enclosure for superior reliability and performance at great depths, allowing the company to focus design efforts on components directly related to the mission tasks.

4.6 Camera Systems

Table 3: *Comparison of camera systems*

	Arducam and Raspberry Pi	2 Car Backup Cameras (RCA)	4 Car Backup Cameras (multiplexed)
Current Draw (A)	0.07	1.0	2.0
Waterproof Rating*	1	3	5
Tether Size Increase (cm)	0.0	1.27	0.5

*the difficulty in establishing and maintaining the integrity of a watertight pressure seal was assessed on a scale of 1-5, with 5 being the most difficult

After comparing the above three choices for camera systems, the electrical engineers opted for the 2 car backup cameras for their relatively low power draw and ready integration into the current electrical system. The central forward-facing camera is mounted on a micro-servo inside of the electronics enclosure, ensuring waterproof integrity and allowing for a wide effective viewing angle. The second camera is placed on the outside of the tube, directed toward the end effector to ensure high precision in task completion.

5 Systems Integration Diagram (SID)

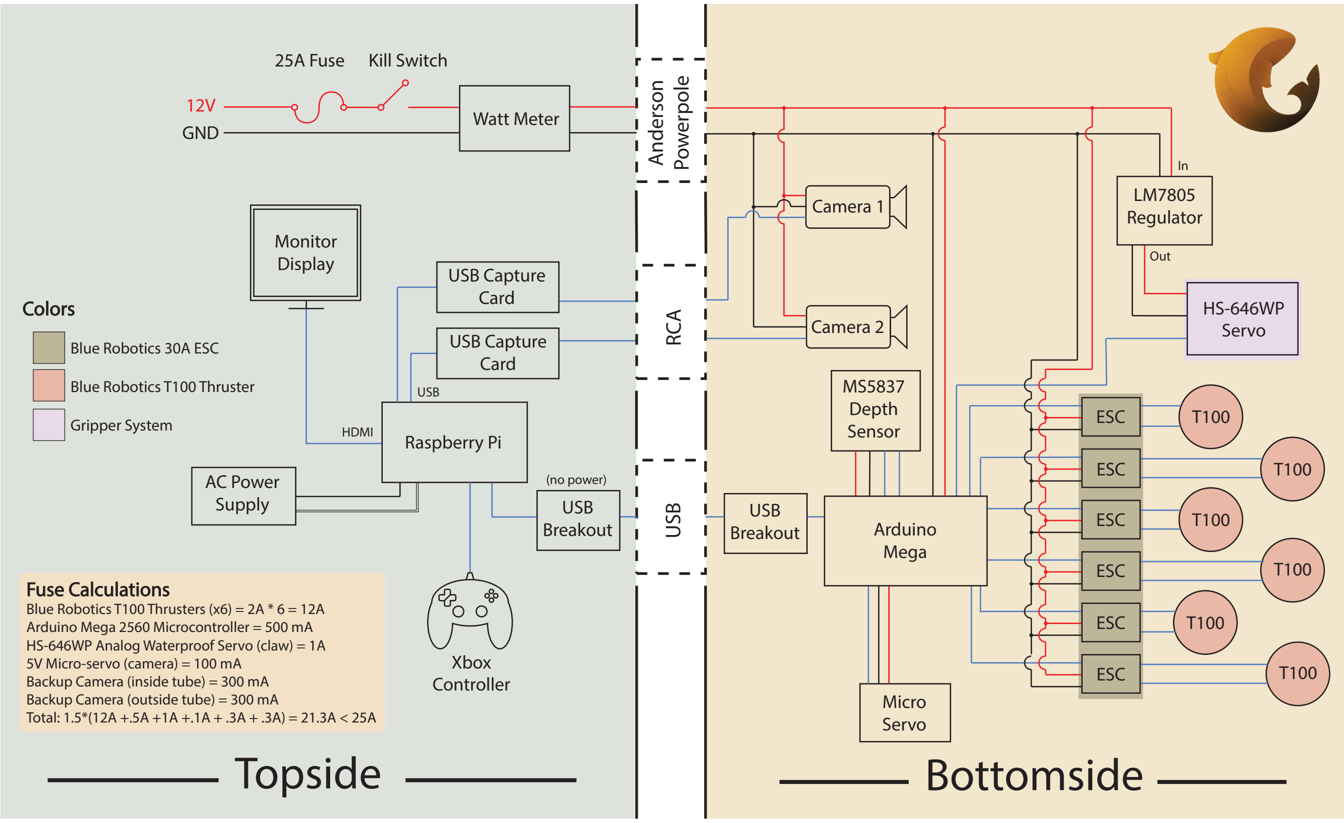


Figure 16: Nemo *ROV systems integration diagram (SID)*

6 Technical Flowcharts

6.1 Hardware Flowchart

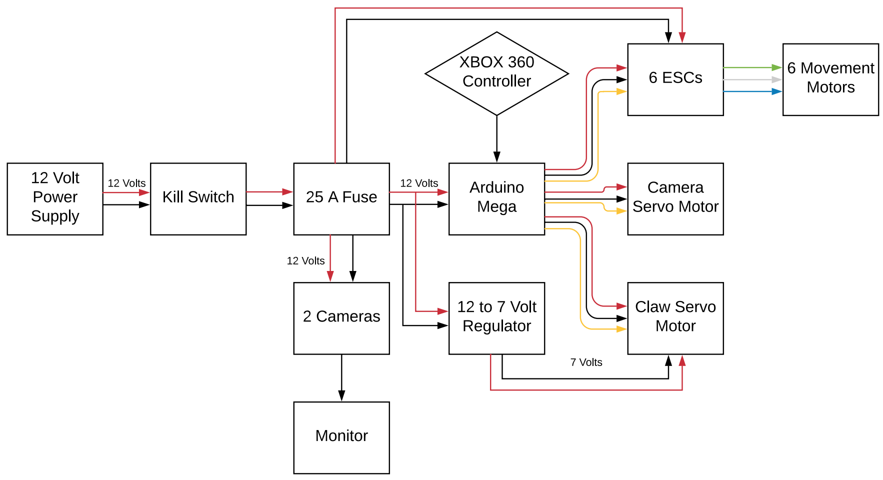


Figure 17: Nemo *ROV hardware flowchart*

6.2 Software Flowchart

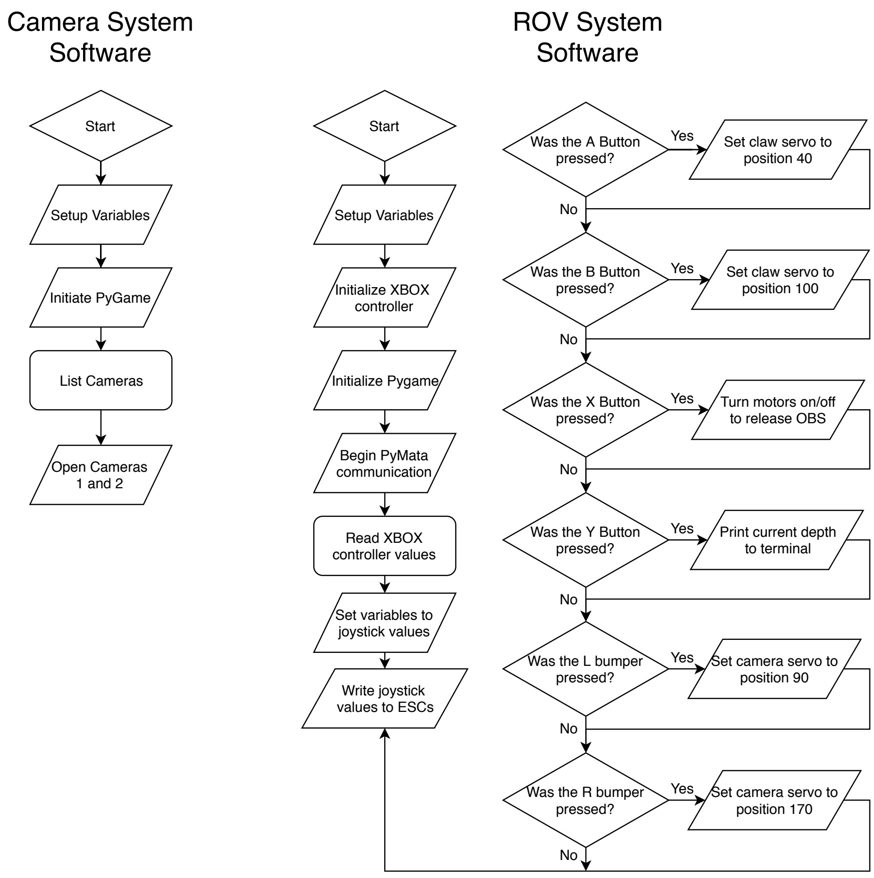
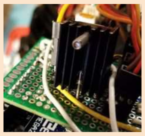
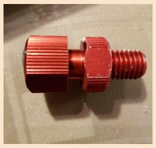
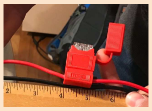


Figure 18: Nemo *software flowchart*

7 Safety Features and Philosophy

Nemo has several key safety features to protect company members and the ROV itself. The company's safety philosophy is to prevent accidents from happening at all, and if they happen, to curtail the problems as soon as possible. To make each run-through safer with less work, several precautionary features have been added to the ROV to make safety easier to uphold and maintain the quality of the vehicle itself:

Table 4: Nemo *ROV safety features*

Feature	**Description**	**Picture**
Tether Strain Relief	The tether was routed through a loop of tennis string secured by a rectangular piece of acrylic at the top of the ROV frame. This ensured that if the tether were pulled, the force would be redirected to the ROV frame, preserving the electronic connections. Attaching and detaching from the topside box allows easier transport of all the wires and the vehicle.	
Motor Intake Guards	The company mounted the thrusters on top of 3D printed shields. This provided two benefits: it ensured that any personnel handling the ROV would not suffer injury due to contact with exposed thruster blades, and it ensured that the thrusters would not become damaged by floating debris. They are within IP 20 standards as required.	
Safety Labels	Safety labels are placed in the topside box and around the ROV, so that everyone knows to be careful around it.	
Kill Switch	The company uses a purple switch on top side box to immediately shut off all power in the case of an emergency and for ease of access to turn of power at any time.	
Heat Sink	To protect the electronics, a heat sink is used to prevent overheating of the voltage regulator. It also helps the effectiveness of the system.	
Watt Meter	The watt meter provides an additional insurance that everything is running smoothly. If a number is not what it is supposed to be, the crew can determine there is a problem quickly and fix it.	
Cable Penetrators	To ensure that the ROV is waterproof, every opening to the electronics housing is secured with marine epoxy and cable penetrators and pressure tested to ensure that is it secure. In addition, a pressure sensor has been repurposed as a leak sensor to detect leaks as soon as possible to fix the problem quickly. It triggers a signal back to the pilots so that they can cut off power before more damage is done.	
Fuse	Fuses are essential for safety of the ROV. Circuits shorting and other situations will blow the fuse. Blowing the fuse will mitigate some of the damage of the electronics that would have existed had there not been a fuse. The company uses a 25 A fuse, and under normal conditions, it will not blow because the total current is 21.0 A.	

7.1 Safety Protocol/Checklist

The following checklists are used before testing the ROV or working on the vehicle.

Table 5: *Construction Safety Protocol (Build Phase)*

Check	Requisite
	ROV Protection
☐	Tether, control box, and ROV are arranged in a stable and safe manner before work is done on them.
☐	Thrusters are off above water.
	Member Safety
☐	Members are dressed appropriately (safety goggles, closed-toed shoes, hair tied back, etc.) before any operation of any cutting equipment.
☐	Member warns others before working with a hazardous device.
☐	Members have displayed aptitude and understanding of a tool's function before usage.
☐	Members are fully informed about all emergency procedures regarding tools.
☐	There is a readily accessible first-aid kit.
☐	There is at least one adult supervisor at any meeting.

Table 6: *Operation Safety Protocol (Pool Phase)*

Check	Requisite
	ROV Protection
☐	All ROV components are secured and there are no cracks or broken pieces.
☐	All sharp edges and objects are covered.
☐	Wires are not exposed or tangled and in their places.
☐	Shrouds of ROV thrusters are securely attached by screws.
☐	The electronics box is pressure tested to ensure waterproofing.
☐	ROV transport carried out by at last 2 company members for safe handling. One member holds the topside box while the other holds the ROV.
☐	The tether is placed in a safe way, untangled, with all strain relief functional.
☐	Ensure watt meter, fuse, and are present and secure before testing or working.
☐	A member is monitoring the safety features of the ROV at all times while working or testing, particularly the fuse, the leak sensor, and watt meter.
☐	The kill switch is easily within reach for the pilot.
	Member Safety
☐	Members are wearing life jackets.
☐	The environment is safe for operation: weather acceptable, launch platform is stable and dry, no other hazards present
☐	There is at least one adult supervisor at any testing.
☐	There is a readily accessible first-aid kit.
☐	Members are fully informed about all emergency procedures regarding the ROV.

8 Critical Analysis

8.1 Testing

Testing the ROV was done systematically. First, prototypes were made and tested to examine their plausible functionality. Then, the individual parts were constructed and tested, before being combined into the ROV. Once the vehicle was complete, it was also thoroughly tested before conducting tests in the pool. Since the ROV is tested before moving on to each step, it allows the company to troubleshoot and discuss design options for every step of the way.

Prototyping the mechanics of the ROV involved building mock-up models of the planned ROV and all its end effectors to see if it was feasible, and any potential problems. The mechanics were then tested for proper functionality. This included running the motors and operating the payload tools independently of the other components to check to see if they are working as intended. For example, through this testing we found out that our original claw was not as strong as it needed to be, and this led to discussion on design options. The mechanical engineers also used a vacuum pump to test waterproofness to ensure that the O-ring seals and marine epoxy on the electronics housing cap effectively created an airtight enclosure to prevent leakage. Before putting the ROV in a pool, our company tested it in a member's bathtub for final testing of the thruster mount configuration and waterproofing.

The electronics were tested in a similar way, with prototyping done by breadboarding all components to ensure they were functional before combining them together. For example, the Bluetooth release mechanism for the ocean bottom seismometer (OBS) was first tested on breadboards before moving to solder our own custom circuit boards. The company also used multimeters to ensure all electronics were integrated properly and there were no shorts in the electrical system circuit.

8.2 Troubleshooting Techniques

When troubleshooting the ROV, the team used a systematic process that consisted of the steps: identify the problem, analyze and figure out why it is not working, isolate the source of the problem, develop a solution, construct and test the solution. When problems were discovered through testing, the team always referenced this troubleshooting process.

For example, if there were any electrical shorts, the electrical engineers systematically isolated electronic components and wires to determine the location of the short relative to the circuit. This process of systematic isolation often led to quick and easy analysis of the problem within 10 minutes. If there were any problems in the software, the software engineers determined the faulty lines of code via unit testing and continuous integration. This troubleshooting process was applied to most problems found during testing, and improved the ROV to where it is today.

8.3 Technical Challenges

Early on, the company had challenges with the electronics tray layout and the Blue Robotics ESCs. The various electronics components and ESCs frequently had connection issues due to poor organization and management. Exposed wires from power and ground were frequently close to each other, and this was often solved by using hot glue. However, after extensive research, the team discovered organizational devices such as such as screw terminals and electrical crimp connectors. By using these components, the team was able to successfully and safely complete electronics work in the underwater electronics enclosure.

Building the simulated ocean bottom seismometer also provided a host of technical challenges. The team was inexperienced with Bluetooth communication as well as the selected 2-pin waterproof buttons, and frequently experienced connection issues. To solve this, the company decided to concurrently work on a short-term "side-project" in order to gain practical experience with Bluetooth as well as the waterproof buttons.

8.4 Non-Technical Challenges

Since Rogue Underwater Solutions was founded recently, many challenges had to be overcome in order to make the company operational and efficient. The company first had to register as a 501(c)(3) nonprofit in order to become tax-exempt. New company rules also had to be written and put in place. Other challenges for Rogue Underwater Solutions included setting up a meeting schedule and universal form of communication; in the end, Google Hangouts and email were decided upon for communication, and Google Drive was decided upon for sharing files among members.

8.5 Technical Lessons Learned

Since the many props and components were built from scratch, members had to cut large PVC tubes, acrylic sheets, and expensive materials. Because many times there is only "one chance" to get the cut correct, the company has learned to adopt a measure twice, cut once method. It is easier to do it right the first time than to redo it. Along this line, company members have learned to be careful and neat with their overall work. This applies to the electronics tray especially, since a neater tray would have made identifying problems less of a hassle, and the probability of a problem occurring lessened. Drilling holes and soldering goes along this principle. Company members check twice, and confirm with other members, before doing something that is irreversible like soldering. It is easier to do something right the first time than to do it over.

In addition to being neat and careful, the club prioritizes safety. When actions are performed in a safe manner, less work needs to be done in the future. Examples of this are hot gluing the solder and then using electrical tape to prevent the ground and power wires from touching after soldering.

8.6 Interpersonal Lessons Learned

- Learning to voice ideas and concerns

To build a functioning ROV from scratch, Rogue Underwater Solutions company members learned to take initiative in speaking out about possible improvements and problems. Company members learned to speak up any ideas they have, to contribute to a common goal of the pursuit of excellence. Taking initiative to pursue a common goal was found to effectively encourage members.

- Learning to split up and share work

Company members each had their own role, but an interdisciplinary approach was used to help everyone understand what was going on and provide insight about all areas of the ROV. When members responsible for a particular component explain its functionality, it helps practice for the actual demonstration on site as well.

- Learning to communicate respectfully

We learned that an interdisciplinary approach improves communication. Interpersonal skills of being courteous and speaking with passion were also learned when members communicated with sponsors. As a first year company, everyone had to contribute in finding any and all possible sponsors.

8.7 Development of Skills

Company members developed the technical skills necessary to build the ROV through meetings held over the summer. Experienced team members introduced the first year members to the competition as well as tasks the ROV was required to accomplish in past seasons. New members began by learning 3D CAD modeling in Autodesk Inventor through online tutorials and teammates' guidance. Company members then designed various frames using the software prior to constructing actual prototypes with PVC tubing. The team practiced safely using tools required for ROV construction, such as the soldering iron, wire stripper, and heat gun, by building electronic subassemblies from a TriggerFish ROV kit.

One company member did not have access to a computer science or electronics education at her school, so she developed basic programming skills and electronics concepts through Rogue Underwater Solutions. Working on the *Volturnus* ROV over the summer helped prepare her for the *Nemo* ROV, since by then everyone was already familiar with software like Inventor, and how to program an Arduino.

Company members also developed skills by reaching out to the community. Over the summer and the beginning of the school year, the team reached out to professors and specialists in the fields of electronic and mechanical engineering. This way, throughout the season, the team had access to expert opinions and could ask for advice. In addition, reaching out for support helped members develop communication skills. Company members frequently sent emails, made phone calls, and set up meetings with potential sponsors at the beginning of the season so that they could focus more of technical challenges and less on financial challenges as the competition approached.

9 Future Improvements

9.1 Reflections

- **Alice Lai** - As CEO, I managed company member assignments as well as deadlines. The biggest improvement this year was the communication within the company. Weekly emails were sent out detailing specific company engineer assignments and deadlines, resulting in a more efficient workflow between team leads and the engineers. Having spent all four years of high school participating in the MATE ROV competition, the skills that I've gained will help as I continue my education at Cornell University next year.

- **Eric Zheng** - While our frame was very successful, there were several improvements that could be made. In particular, the frame is not very modular: thruster configurations, end effector mounting, and camera angles are all fairly rigid. Ideally, next year's design should feature swappable components that would allow the ROV to adapt to new environments.
- **Rishi Salwi** - The Blue Robotics T100 thrusters and ESCs were great investments that will serve the company well for many years to come. One improvement for next year would be to mount the ESCs directly onto the ROV to allow for better cooling of the electronics.
- **Sophie Zhang** - Although I had prior robotics experience, this was my first year with the MATE ROV competition. As business lead, I was responsible for managing public relations, fundraising, and online presence through social media. Being the business lead taught me to write effective emails and developed my artistic ability through marketing design.
- **Sam Alws** - As one of the software engineers, I developed the Python software for the Nemo ROV. I really liked how the code was easier to write this year, and that there was a backup communication protocol in case of tether failure. In the future, I'd like to try to use the ROS framework, which has an internal Gazebo simulation for virtual piloting practice.
- **Bryan Yao** - The electronics box was very compact and contained a lot of electronics. I liked how the company dedicated a Raspberry Pi and a monitor to the box, so that the company didn't depend on the software engineers' personal laptops to run the code. In the future, it would be great to develop a co-pilot interface to help the pilot control the ROV.
- **Ananth Koppol** - This was my first year involved with the MATE ROV competition. I had a great experience learning to collaborate with company engineers working on different ROV sub-systems. Some changes that could be made to our ROV would be to use a fiber optic cable for communication and to use IP cameras instead of analog ones.
- **Gloria Liu** - I had no prior experience with robotics, so everything was completely new to me in the beginning. However, Rogue Robotics significantly helped me learn all the basics of engineering for robotics. All the members were supportive and much more than just knowledge, I got confidence that I too could make a positive contribution to the company.
- **Alisa Lai** - Besides being student-run, I like how this club is centered around building something useful completely from scratch, placing parts together that are not made to exist together. For me, having this experience that simulates the real world is extremely meaningful, and is something that I will always treasure as I continue my education at Cornell University next year.

10 Accounting

10.1 Budget

A balanced budget is necessary to provide the team with a solid foundation and the ability to explore creative robot designs. Because Rogue Underwater Solutions is not affiliated with an organization or institution that can regularly give financial support, the company must be cautious and discuss all major purchases. In addition, this year's budgeted expenditures is greatly inflated due to the nature of the company being a 1st year participant in the MATE ROV competition; a significant amount of equipment and components are investments that can be reused for future competitions. Purchased robotics equipment, which primarily consists of the electronics enclosure, total to approximately $2500. Logistics costs include the standard registration fee of $200 and expenses for transportation to competitions. At the international level, cost of flight to competition for nine company members is approximately $4500, and cost of a three day hotel stay is approximately $2000. This totals to $6500.

To obtain the money for all expenses, the company fundraised by showcasing the ROV at community events, such as at a demonstration booth at a local Telugu school. The supportive parents of each member of the team donated 250 dollars for startup costs. The team applied for and obtained 501(c)(3) status, which enabled us to find local sponsors. The team is especially grateful to the generosity of the companies etherFAX, Eastern Automation Systems, 3D Solutech, Pierce Professional Resources, and Dosil's Scuba, Swim and Surf who have provided us with materials and funding.

10.2 Cost Accounting

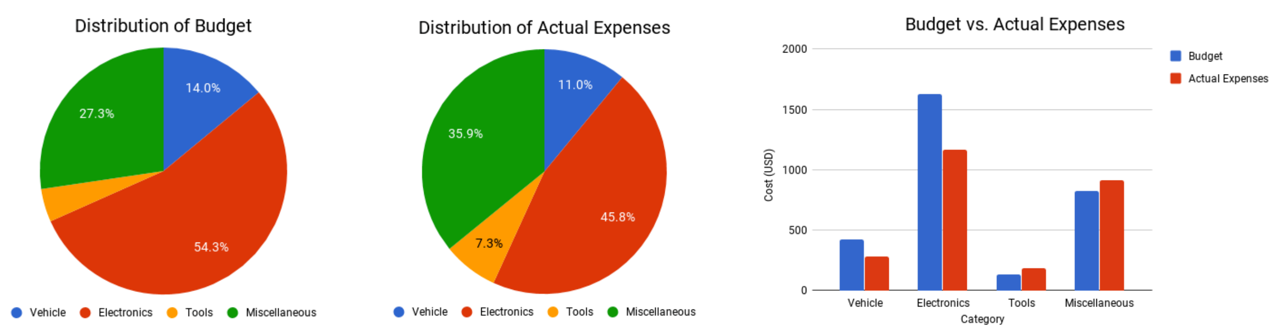


Figure 19: *Rogue Robotics budget distribution*

Table 7: *Rogue Underwater Solutions 2018 financial summary*

CATEGORY	SOURCE	BUDGET	COST	FAIR-MARKET VALUE	VARIANCE
Vehicle					
Frame Material (ABS Plastic)	Donated	200	0	22	200
Blue Robotics Electronics Enclosure Tube	Purchased	200	250	250	-50
Endcap Plates	Purchased	20	30	30	-10
SUBTOTAL		420	280	302	140
Electronics					
Joysticks	Donated	0	0	40	0
Raspberry Pi 3 Kit	Purchased	70	70	70	0
USB Host Shield	Purchased	50	40	40	10
Tether Cables and Wires	Purchased	50	60	60	-10
Video Capture Equipment	Purchased	100	60	60	40
Waterproof Servo	Reused	40	0	40	40
Depth Sensor	Purchased	50	70	70	-20
Kit of Fuses	Reused	0	0	10	0
Video Controller Board	Purchased	50	30	30	20
USB Cables and Connectors	Purchased	100	70	70	30
USB Breakout Boards	Purchased	50	24	24	26
Terminal Blocks and Connectors	Purchased	50	30	30	20
I^2C Level Converter	Purchased	20	14	14	6
Blue Robotics Basic 30A ESCs	Purchased	100	75	75	25
Blue Robotics T100 Thrusters	Purchased	800	560	560	240
NATIKA Car Backup Camera	Purchased	50	50	50	0
NOAUKA Waterproof IP68 Camera	Purchased	50	16	16	34
SUBTOTAL		1630	1169	1259	461
Tools					
Fasteners	Purchased	20	25	25	-5
Marine Epoxy	Purchased	10	18	18	-8
Hand Operated Vacuum Pump	Reused	0	0	20	0
FatMax Container	Purchased	20	35	35	-15
Blue Robotics Penetrators	Purchased	50	100	100	-50
Clamps	Reused	20	0	20	20
Voltage Regulator	Purchased	10	8	8	2
SUBTOTAL		130	186	226	-56
Miscellaneous					
Blue Robotics Shipping Fees	Purchased	20	30	30	-10
Mission Props	Reused	100	110	110	-10
Application for 501(c)(3) Status	Purchased	200	275	275	-75
Customink Polos	Purchased	200	225	225	-25
Registration Fee	Purchased	200	200	200	0
Hourly Pool Rental	Purchased	100	75	75	25
SUBTOTAL		820	915	915	-95
TOTAL		3000	2550	2702	450

11 References and Acknowledgements

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11.2 Sponsors

The club’s progress this year would not have been possible without the sponsorship of several companies and the advice of several individuals:

- **MATE Center and Marine Technology Society** - Sponsoring this year’s competition
- **MATE Pennsylvania** - Organizing the 2018 MATE Pennsylvania Regional Competition
- **Vanessa Morris** - Coordinating the MATE Pennsylvania Regional competition
- **National Science Foundation** - Funding of the MATE competition
- **Weyerhaeuser King County Aquatic Center** - Hosting the MATE Competition
- **Villanova University** - Hosting MATE Pennsylvania Regional Competition
- **Oceaneering International** - Supporting the MATE competition
- **Yung-Hui Lai, Mentor** - Providing his time, creativity, knowledge, and guidance for his first year participating in the MATE competition
- **Ulric Gordon-Lewis, Mentor** - Providing extensive engineering advice and 3D-printing services
- **Professor Jim Nickels of Monmouth University** - Providing pools for ROV testing
- **Add-On Pools** - Providing pools for ROV testing
- **3D SoluTech** - Providing $100 worth of ABS filament
- **Eastern Automation Systems, Etherfax, Pierce Professional Resources** - Providing generous monetary donations
- **GitLab** - Providing web-based Git-repository management
- **GrabCAD** - Providing Workbench CAD version control software
- **Company Members’ Families** - Supporting and encouraging company members

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