HMS SeaBots: Ranger

Harrington Middle School
514 Mt. Laurel Road, Mount Laurel, NJ, USA

Company Employees

Adithya Selvakumar
CEO, Lead Software Engineer, Mechanical Engineer

Rohan Gawande
CFO, Lead Electrical Engineer

Aayush Talreja
CTO, Lead Mechanical Engineer
PIlot

Saketh Rudraraju
JSO, Mechanical Engineer
Co - Pilot

Numa Wani
Electrical Engineer

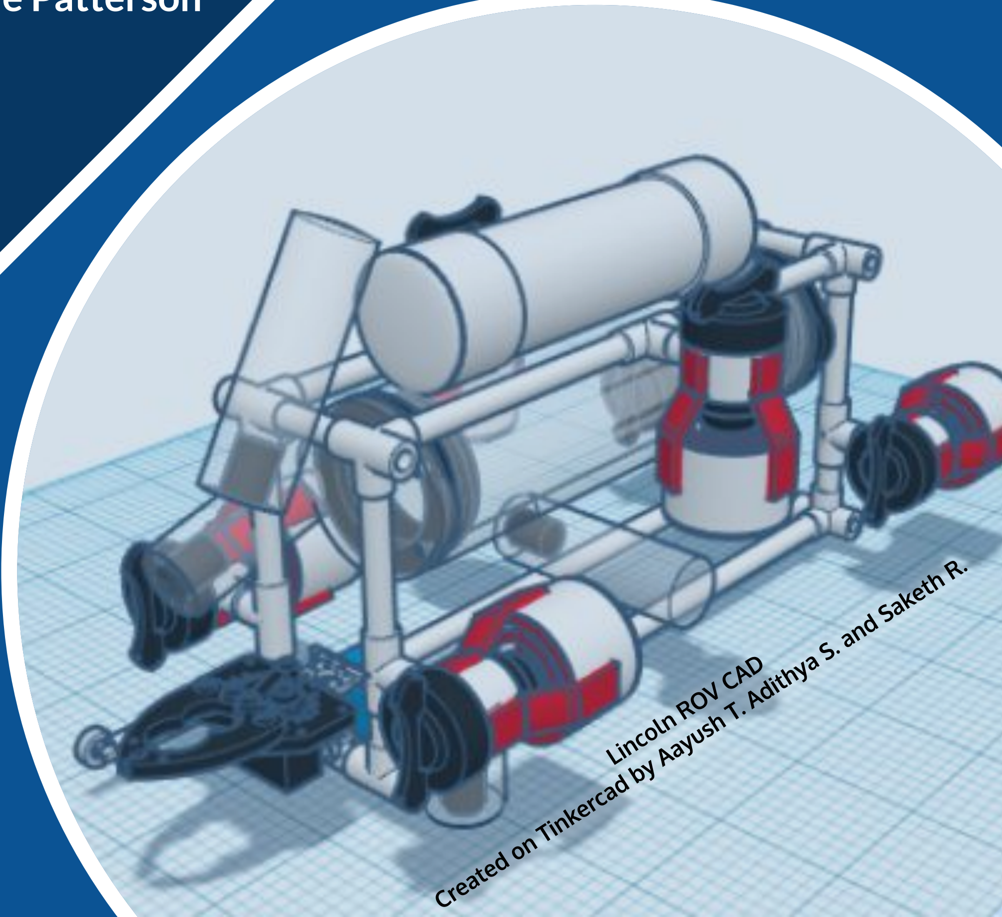
Spoorthy Reddy
Software Engineer

Brael Tagsip
Software Engineer

Mentors

Ms. Maureen Barrett
Head Coach

Ms. Marieve Patterson
Assistant Coach



Lincoln ROV CAD
Created on Tinkercad by Aayush T. Adithya S. and Saketh R.

Table of Contents

Teamwork: Project Management

Design Rationale

- Mission Specific Tools

Safety

Critical Analysis

- Lessons Learned

Accounting

Abstract

We are the HMS SeaBots, a marine robotics company dedicated to the development of remotely operated vehicles (ROVs). Our company consists of seven employees specializing in mechanical, electrical, and/or software engineering. Our latest project is *Lincoln*, an ROV designed for the request for proposals (RFP) issued by Eastman, a global specialty chemical company. The RFP outlines the following three tasks: 1) ensuring public safety, 2) maintaining healthy waterways, and 3) preserving history. With these tasks in mind, *Lincoln* has a minimalistic frame, incorporating many special features. One of these features is a dual action manipulator arm controlled by two Hitec servo motors, allowing us to conduct sensitive operations such as depositing the trout fry and grout in Task 2 of Eastman's RFP: Maintaining Healthy Waterways. Another feature is *Lincoln's* underwater electronics enclosure housing an RS485 module and Arduino microprocessor. This special feature was added to reduce interference and delay to our gripper down a long tether. Our ROV also features image recognition capabilities, designed specifically for identifying the benthic species of Eastern Tennessee waters. Our passionate engineers have answered Eastman's RFP with an ROV capable of completing the competition tasks--and more. With *Lincoln*, our employees look forward to ensuring public safety, maintaining healthy waterways, and preserving history, operating in the freshwater environments of Boone Lake, Boone Dam, and the South Fork of the Holston River for a long time to come.

Figure 1. Company Photo. Photo Credit: Ms. Maureen Barrett
Top Row (Left to Right): Saketh, Aayush, Numa, Rohan; Bottom Row (Left to Right): Adithya, Spoorthy, Brael

Project Management

Time Management

Our team developed a year-long schedule in preparation for the 2019 MATE ROV Competitions. The Gantt chart (see Figure 2 below) helped our company plan meeting agendas and set company deadlines.

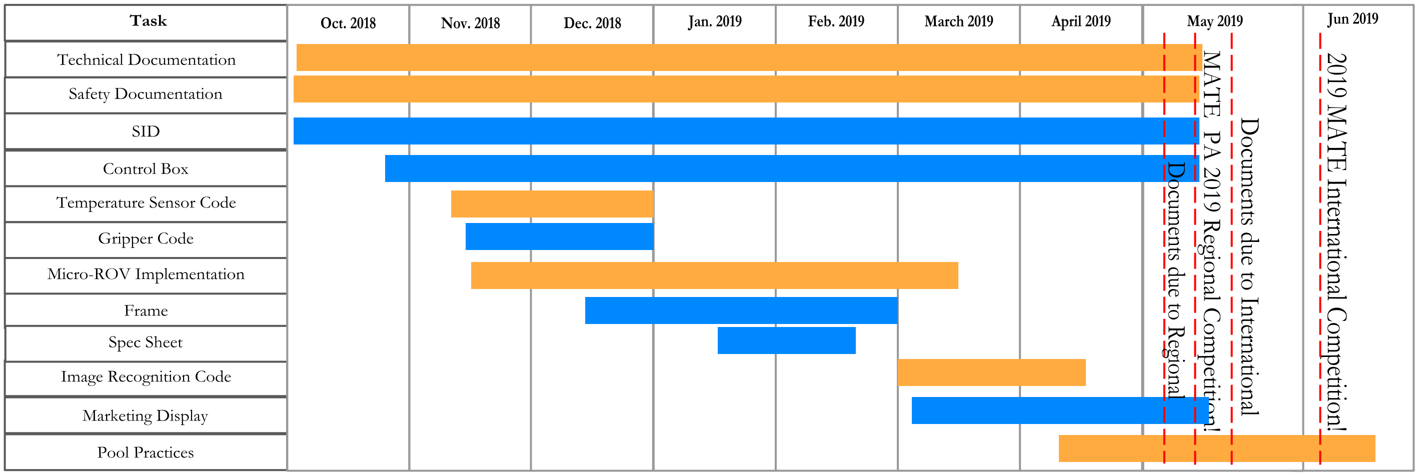


Figure 2. Gantt Chart
Created on Google Drawings by Aayush T.

Project Mgmt. (Cont.)

Organization Methods & Daily Operational Procedures

After developing a schedule, our team decided to implement the Agile methodology, an organizational process typically applied during software development. The Agile methodology requires companies to develop scrum plans - lists of goals that they would like to accomplish within short, two-week periods of time. The scrum plans helped our company leaders plan weekly meeting agendas. Throughout the year, we tracked our progress with a spreadsheet, updating the plans when necessary.

Division of Labor

Since ROVs comprise many interconnected systems such as propulsion, ballast, software, etc., our employees specialize in different engineering divisions: mechanical, electrical, and software engineering (see Figure 3).

Mechanical Engineers	Electrical Engineers	Software Engineers

- CAD Designs
- ROV Frame
- Thruster Guards
- Micro-ROV
- Variable Ballast
	- Control Box which includes:
	  - Propulsion System
	  - Camera System
	- Waterproofed Parts
	- SID (System Integrations Diagram)
		- Program Architecture
		- Servo Grippers
		- Image Recognition
		- Temp. & Leak Sensors
		- Watertight Electronic Enclosure

Figure 3. Division of Labor Chart
Created on Google Slides by Aayush T.

Design Rationale

ROV Frame & Structure

Figure 4. Finished Lincoln ROV; Photo Credit: Saketh R.

The ROV frame that we built last year as a Scout Team worked well for the Applied Physics Laboratory's RFP. However, this year's RFP from Eastman requires more features. Our 2018 frame lacked the following: an electronics enclosure, a micro-ROV docking area, a versatile gripper setup, and room for two additional thrusters to compensate for the weight of all these add-ons. Because the basic frame was not well-suited for our client's needs, we chose to build a totally new ROV frame for Eastman. Our first task was to research possible materials for our ROV frame. Our team debated whether we should 3D print our frame using PLA (polylactic acid) filament. PLA offers a great deal of design freedom, is cost-effective for our client, and is lightweight. Considering the time it would take to fabricate a 3D printed frame, we chose not to do so. Apart from this, PLA has a lower UTS (ultimate tensile strength) than PVC. Its 37 MPa UTS cannot compare to PVC's 52 MPa UTS. It was clear that by using PVC, our company would be able to produce a more robust frame for our client.

Design Rationale (Cont.)

ROV Frame and Structure (Purchased)

Lincoln's frame was designed to house a six thruster setup, a dual action manipulator arm, two standard grippers, a quad camera system, and an electronics enclosure. However, we had to keep in mind our main design constraints: size and weight. We wanted to produce an ROV for Eastman that would fit inside a 60 cm (23.6 in) ring, with a weight under 15 kg (33 lbs.). After completing the building of the Lincoln ROV, we found that it not only was an efficient ROV, it also satisfied both design constraints, fitting in a 60 cm ring (see Figure 5, right), and coming in at a weight at just 5.8 kg. From this we can say that we have produced a small, lightweight and functional ROV for Eastman's RFP.

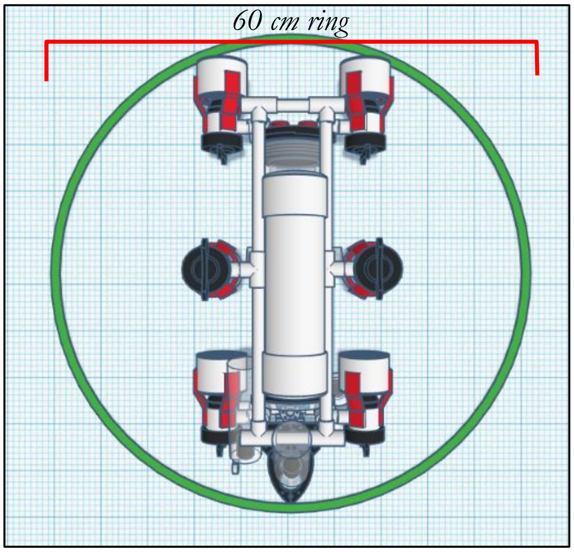


Figure 5. Lincoln inside 60cm ring
Created on TinkerCad by Aayush T., Saketh R. and Adithya S.

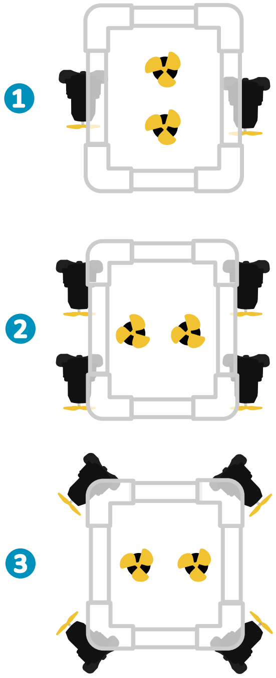


Figure 6. Motor Configurations Diagram
Created on Google Drawings by Aayush T.

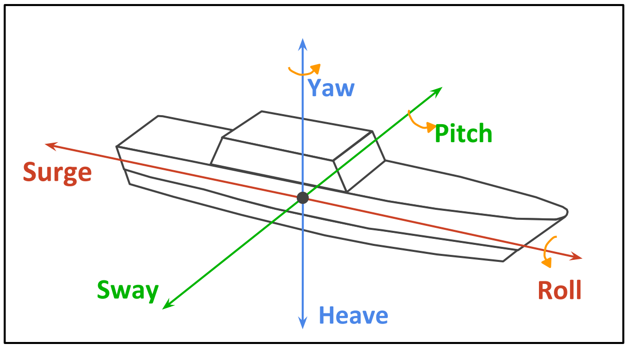


Figure 7. Six Degrees of Freedom Diagram
Created on Google Drawings by Aayush T. and Aditya S.

Propulsion: Six Bilge Pump Thruster Setup (Purchased)

We realized that our various special features would increase our ROV's mass, thereby decreasing our agility significantly. To compensate for this decrease, our engineers decided to implement two additional horizontal thrusters.

The *Lincoln* ROV uses a combination of both 3785.41 liter per hour (1000 gallons per hour) Johnson Bilge Pump Motor Cartridges, as well as 4731.7647 liter per hour motors (1250 gallons per hour). We brainstormed two potential thruster setups to replace our 2018 thruster setup (see Figure 6, Number 1). The first potential setup (see Figure 6, Number 2), simply placed all four horizontal motors facing forward to maximize surge, one of the six degrees of freedom (see Figure 7). Our second potential setup was an omnidirectional thruster setup (see Figure 6, Number 3). This configuration placed *Lincoln's* horizontal motors at 45 degrees from both axes. This weakened each motor's forward thrust by a factor of √2, but it provided *Lincoln* with another degree of freedom: sway. This is because each motor provides an equal amount of lateral thrust and forward thrust. Despite this added advantage, testing proved that the omnidirectional thruster setup did not provide *Lincoln* with enough forward thrust. Therefore, our company decided to forfeit *Lincoln's* ability to sway and chose to implement our first potential thruster setup.

Buoyancy System (Reused)

Rather than purchasing commercial buoyancy foam to maintain the ROV buoyancy, we reused an ABS (Acrylonitrile Butadiene Styrene) tube from last year's robot. The 1½" ABS pipe is sealed with end caps and marine epoxy, leaving it watertight. Our buoyancy tube allows *Lincoln* to maintain an overall density of 1 g/mL, matching the density of water, and making our ROV neutrally buoyant. A neutrally buoyant ROV is more energy efficient and is easier to control as it does not have an tendency to drift upward or downward.

After achieving neutral buoyancy, we assessed the vertical lift capability of our ROV through a Bollard test. A spring scale with a PVC mechanism allowed us to calculate the grams force of the thrusters. According to our test results, our two vertical bilge pump thrusters together provided 664 grams of force. By converting the grams force to kilograms and multiplying this value by 9.807 (gravitational force), we receive 6.51 Newtons, the combined thrust of our vertical motors. Considering that the cannon in Task 3 (Preserving History) could require up to 50 Newtons of force, we determined that *Lincoln* was not efficient at lifting the cannon. In order to upgrade our ROV, we brainstormed a method to increase *Lincoln's* vertical lift capability--a variable ballast system.

Our variable ballast system consists of a punching balloon, ¾ in. (1.91 cm) aquarium tubing, and an Intex hi-output air pump. The balloon's maximum volume is 4849.05 cubic centimeters, and the balloon therefore displaces 4849.05 cubic centimeters of water. The buoyant force exerted by the variable ballast system equals 4849.05 grams, or 47.55 Newtons. When this is added to the upward thrust provided by our motors, our overall upward thrust equals 54.06 Newtons. This would be more than satisfactory when lifting the cannon.

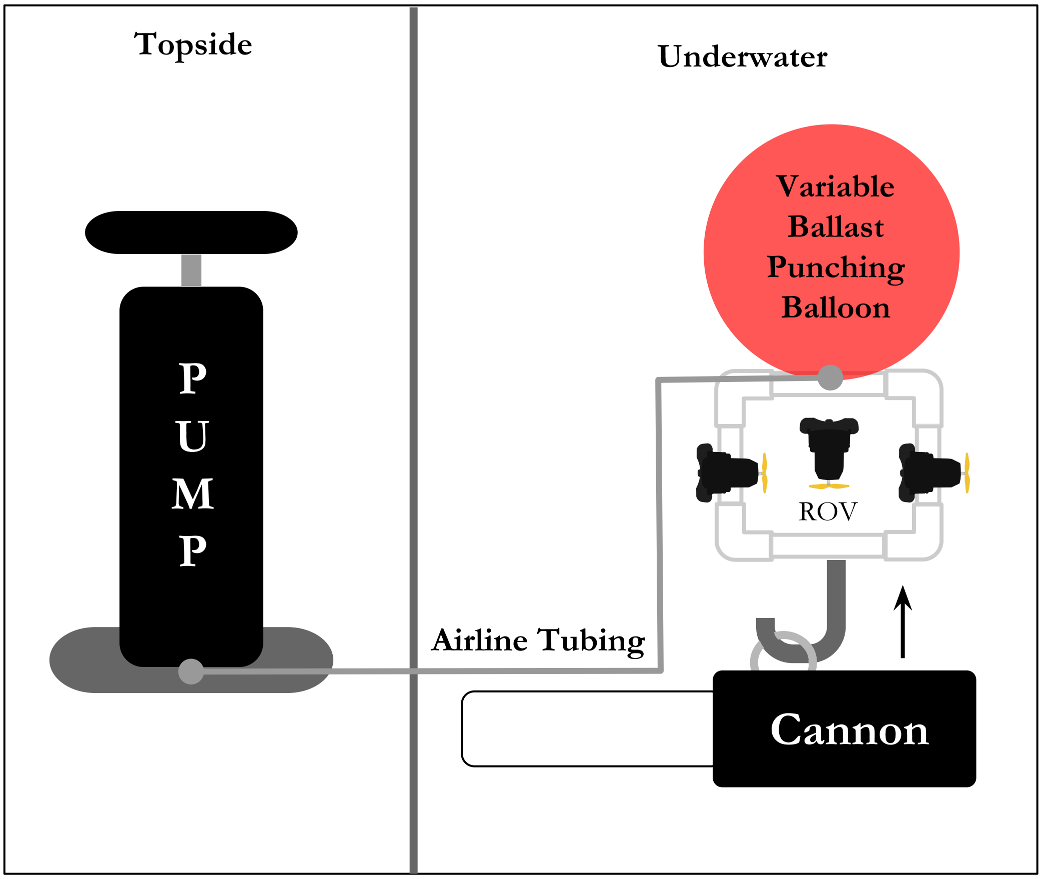


Figure 8. Variable Ballast Diagram
Created on Google Drawings by Aayush T.

Thruster Guards

One of *Lincoln's* prominent safety features is custom built motor shrouds with thruster guards made of PVC pieces and 3D printed parts. A PVC tee connects to a PVC coupling via 3D printed braces. Attached to the coupling are two custom designed 3D printed thruster guards above and below the propellers. Both of these guards are IP 20 rated (ingress protection) which protects any solid objects greater than 12.5 mm in size from damage (see Figure 9). Our custom shrouds protect employees from injury and prevent our propellers from damaging the environment and its inhabitants, such as the trout fry in Task 2 (Maintaining Healthy Waterways).

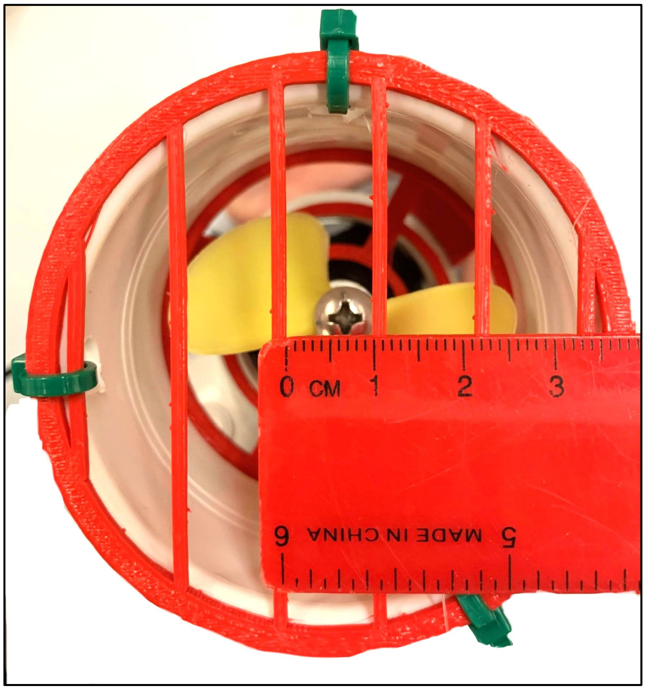


Figure 9. Thruster Guard IP 20 rated
Photo Credit: Saketh R.

Fabrication of Thruster Guards

In order to produce these thruster guards, we debated which material should be used to connect the PVC tee and coupling. We considered using PVC, PLA (a 3D printing filament), aluminum, and ABS. We took four factors into consideration: density, ultimate tensile strength (UTS), ease of fabrication, and cost.

Material	Density g/cm3	UTS	Ease of Fabrication
PVC (Polyvinyl Chloride)	1.38 grams/cm3	52 MPa	Readily available in house with appropriate tools
PLA (Polylactic Acid)	1.25 grams/cm3	37 MPa	Readily available in house, print times can be ~ 10-12 hours/shroud
Aluminum	2.7 grams/cm3	124- 290 MPa	Lack of machinery needed to bend aluminum
ABS (Acrylonitrile butadiene styrene)	1.07g/cm3	27 MPa	Lack of printing machinery, produces toxic fumes

Figure 10. Thruster Guard Material Analysis

After analyzing the four materials in Figure 10, we made the decision to create custom 3D printed braces using PLA to connect the two pieces of PVC. Due to its flexibility in design, we chose to use PLA despite its relatively low UTS and density.

Triggerfish Control System Modifications (Reused)

Our main control box is a MATE Triggerfish Revision 3 Control Box. In order to incorporate our six thruster setup, we had to modify the control system. The standard system relies on two Sabertooth 2x5 electronic speed controllers (ESCs) (see Figure 11) to control four motors through pulse width modulation (PWM). To account for the addition of two motors, we added another ESC and a third joystick in the main control box. Instead of investing in more expensive ESCs that rely on software, we chose to simply reuse extra components that we had available in-house.

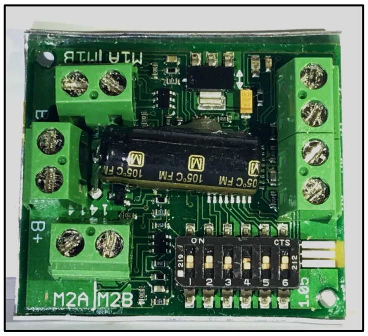


Figure 11. Sabertooth 2x5 ESC
Photo Credit: Saketh R.

Camera System (Reused)

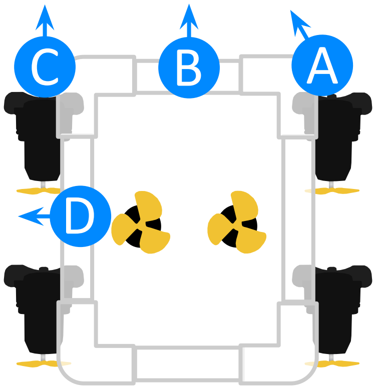


Figure 12.
Camera Configuration Diagram
Created on Google Drawings by Aayush T.

Our ROV features four cameras. Each camera has a unique view of the underwater terrain. The first of these cameras (camera A) points directly ahead of the ROV and at the PVC hook that we use to lift the the cannon in Task 3 (Preserving History). The second camera (camera B) is positioned directly above the manipulator arm, allowing the gripper pilot to pick up objects such as the trash rack in Task 2 (Maintaining Healthy Waterways). The third camera (camera C) is used for image recognition and is oriented downwards, allowing us to identify what benthic species lie on the bed of Boone Lake in Task 2 (Maintaining Healthy Waterways). The final camera (camera D) is pointed towards the port side of the ROV and used to view the transect line of the dam and locate cracks indicating possible dam failure in Task 1 (Dam Inspection and Repair). Two of these cameras (cameras A and D) interface directly with the standard Triggerfish Rev 3 control box through BNC connectors to a monitor inside the control box. The images from the camera above the gripper (camera B) are sent to a second homemade control box. The live feed from camera C (the image recognition camera) is sent to an Elgato Capture Card, via RCA connectors, transferring the signal to a laptop monitor.

All of our cameras have modules that fit perfectly into a 4 cm diameter acrylic tube, allowing the cameras and corresponding connections to be waterproofed. However, the waterproofing process was delicate. It required glueing the camera module to an acrylic faceplate prior to glueing the faceplate to the acrylic tube. If too much glue was used, the glue would smear and obscure the view. After this step, the tube was filled with polyurethane. This process was risky, but well worth the risk because our connectors are now contained within this polyurethane, totally waterproofing the cameras and their connections (Figure 13).

Figure 13. Waterproof Camera Housing
Photo Credit: Saketh R.

Tether (New/Reused)

Lincoln uses eight tethers, each used for transferring power and various signals to/from the ROV (see Figure 14). New tethers are used for the motors and the servo motors, while the camera tethers are reused. A yellow polyester casing keeps all eight of our tether cables neatly bundled and safe from damage. The casing is a flexible material that is easily seen as *Lincoln* descends into Boone Lake.

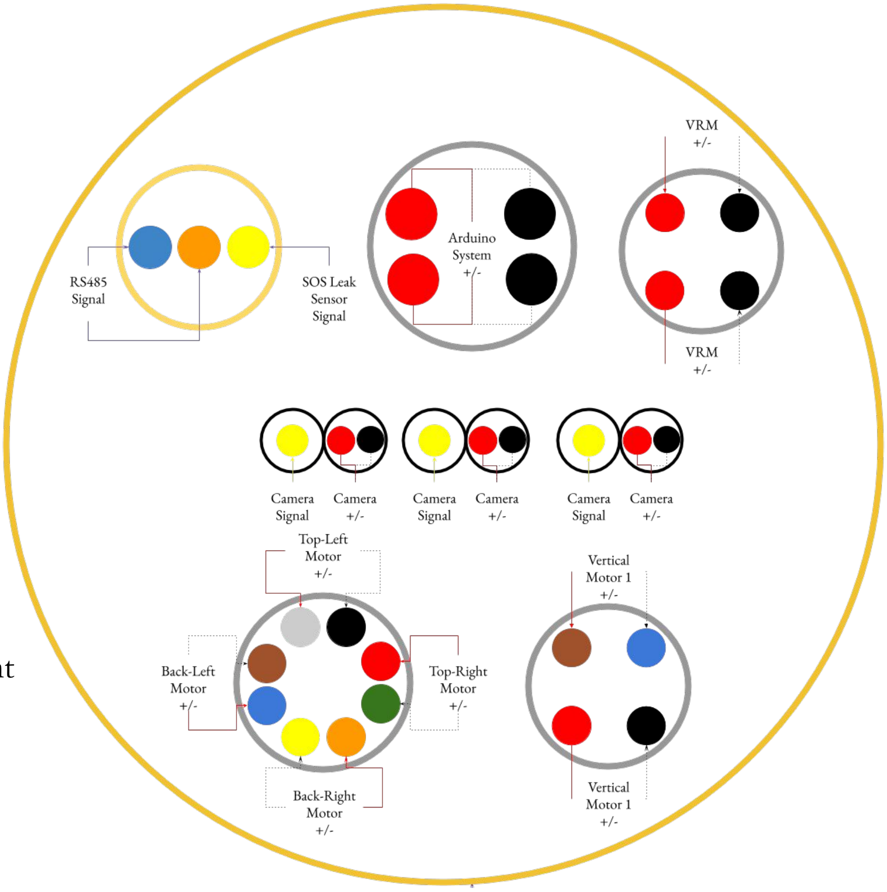


Figure 14. Tether Cross - Section
Created on Google Drawings by Rohan G.

Voltage Drop

Voltage drop and interference were two important concepts we considered because of the 50 foot length of our tether. Voltage can diminish as the conductor length increases. We used the voltage drop formula to find the amount of voltage drop down a tether: $V_{DROP} = IR$, where I is amperage and R is resistance.

Lincoln requires 12 volts of power. If 12 volts do not reach the ROV, there may be problems with the electronic components. A lower voltage can prevent the motors from running at their fullest potential and may also reduce camera quality. A longer tether will lead to an increase in voltage drop. For instance, a 25 ft. tether with 16 AWG wires having 12.6 volts sent from a battery will have 12.4 volts at the other end. The same tether with a length of 50 ft will have 12.2 volts going to the submerged ROV components.

Another factor that influences voltage drop is the gauge of the wire through which power is being sent. A lower gauge wire--one with a larger diameter--will have a lower voltage drop than that of one with a higher gauge. If we send 12.6 volts of power through a 50 ft, 16 AWG tether, the resulting voltage would be 12.2 volts. In the same situation but using an 18 AWG cable, there will be only 11.96 volts for the motors and other submerged ROV components.

The amperage sent down the tether also has an effect on how much voltage drop is present. All the above examples were with 1 amp sent, leading to a final voltage of 12.2 volts. With 5 amps sent, there is a final voltage of 9.99 volts.

All of these factors were considered when selecting our tethers. We used lower gauge wires for sending power to the motors, the software system, and the camera in order to combat voltage drop down a 50 foot tether. While a shorter length tether would have decreased the voltage drop, a longer tether allows us to properly traverse the depth of Boone Lake required in Eastman's RFP.

Arduino Software

Our engineers incorporated an Arduino based program in order to serve as a communication medium to receive and process data from the pool deck as well as onboard the ROV. Our company chose to incorporate this open-source platform for multiple reasons: Arduino boards are relatively inexpensive, have a simple and clear programming environment (the Arduino IDE), and are versatile with other components through PWM-capable I/O pins. These features help distinguish the Arduino platform from competitors such as the Raspberry Pi.

Figure 15. Arduino Logo
Credit: arduino.cc

Software Architecture

Before writing our software program, our company developed a plan detailing when and how we would complete software tasks. We began by dividing our program into various modules: gripper control, temperature reading, SOS leak prevention, and RS485 transmission. The initial stage was to develop the network protocol. This protocol essentially consists of two steps--request and response. We developed an architecture plan describing each individual request and response. Request commands include receiving signals from push buttons and sensors. Response commands include sending signals to components such as the LCD display, servo motors, and LEDs.

Gripper Control

In order to complete the tasks detailed in Eastman's RFP, we preferred to incorporate a versatile gripper system. Our initial thought was to reuse a single gripper from our 2018 ROV. That gripper consisted of a commercial gripper kit mounted to a Hitec D646WP digital servo motor. Though the single gripper was satisfactory for last year's RFP, it had some flaws: a lack of versatility (could only open and close), servo jitters, and the inability to retrieve multiple items at once.

To have a more maneuverable gripper setup, our company decided to develop a gripper that could open both horizontally and vertically--a dual action manipulator arm. Our company knew that another servo would be required, but we were unsure as to how we would mount it. Our initial thought was to 3D print an attachment between the motors, but after conducting research, we discovered ServoCity's Standard Hub Shaft ServoBlock Kit (see Figure 16). Our company chose to purchase this kit instead of building any 3D printed attachment, as it saved time. In addition to saving time, the aluminum framework of the ServoBlock Kit is stronger than PLA, as aluminum has a higher UTS then PLA (see Figure 10 on Page 7). Our company recognizes that manufacturing a PLA attachment could be more cost effective for the client, but we believe that a stronger attachment ready in a fraction of the time far outweighs any cons, especially for such a vital component of our ROV.

Figure 16. ServoBlock Kit
Image Credit: servocity.com

Design Rationale (Cont.)

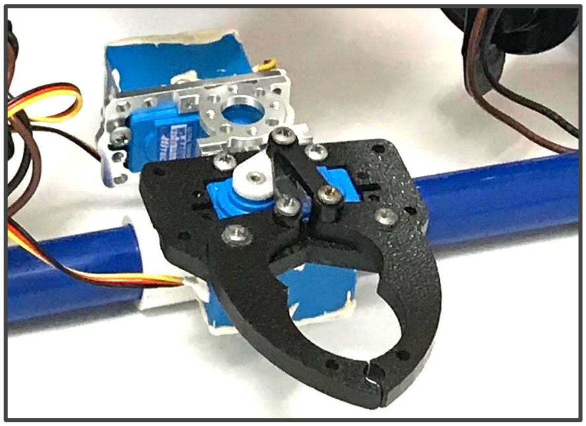


Figure 17. Lincoln's Dual Action Manipulator Arm
Photo Credit: Saketh R.

After purchasing the Servo Block Kit, our company began to build the new manipulator arm. We installed the first servo in the block kit but then immediately noticed that there was no way to mount the Standard Gripper Kit A directly to the hub shaft of the kit. In order to resolve this issue, our engineers decided to attach an additional Side Tapped Pattern Mount (from another kit) to the hub shaft, and then fasten the Standard Gripper Kit A to the pattern mount (see Figure 17). Along with the dual action manipulator arm, our company built two additional grippers consisting of the Standard Gripper Kit A and a servo motor. This provided *Lincoln* with the ability to retrieve multiple items at once.

Lincoln's new manipulator arm provided a great deal of versatility, but it still didn't solve the servo jitter issue that we experienced as a Scout company the previous year. Upon conducting research, we found two potential causes of the servo jitters: potentiometer signal and signal interference. This caused us to question the reliability of potentiometers, so we began research another possible option: push buttons. We compared the two to see which device would be more reliable.

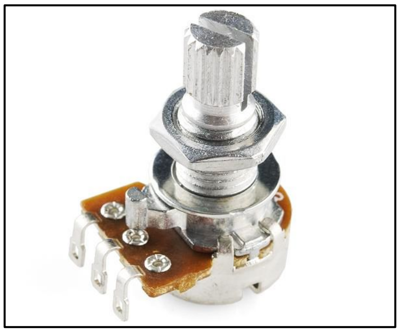


Figure 18. 10K Ohm Potentiometer
Image Credit: www.sparkfun.com

We previously controlled our single gripper with a 10K Ohm potentiometer (see Figure 18). As our employees sought to solve the servo jitter concern, we noticed via Arduino Serial Monitor that the potentiometer sent conflicting signals to our servo motor, leading it to glitch. After further research, we first tried using potentiometers of various resistances, but this did not solve the problem. Our engineers proceeded to combat the issue using rounding formulas in the Arduino program. However, this also proved unsuccessful. We soon realized that the tasks detailed in the RFP did not require 180 degrees of movement from our gripper. We could use a gripper that merely opened and closed. As for the servo that rotated the gripper, it, too, required just two modes. Because the gripper only needed to be turned vertically and horizontally, we decided to use push buttons.

When our company tested our gripper control using the push buttons, we ultimately noticed another issue. The push buttons available were momentary switches, meaning they needed to be held down to maintain their position--an inconvenience for the product demonstration team. Nevertheless, our engineers were able to find a way around the problem by developing a software library that allowed us to control each servo by clicking push buttons, rather than holding them in place. When testing our new program with push buttons, we were glad to see that most of the servo jitter had disappeared.

Figure 19. Momentary Push Button
Image Credit: www.adafruit.com

However, another issue presented itself: occasionally, all four servos would move to a random position without a pilot even touching the push buttons. Our software engineers attributed this to signal interference. We could identify the issue; we did not know how to solve it. We tried grounding both servos to different components and considered using ferrite cores.

Figure 20. Hitec HS646WP Servo
Image Credit: www.hitecrcd.com

When these solutions proved fruitless, we considered using a servo motor aside from the Hitec D646WP digital servo. Through research, our engineers learned that there were two types of servo motors: analog and digital. While analog servos regulate the speed of the motors by simply sending on/off pulses, digital servos send pulse signals differently. This leads to digital servos having better speeds, accelerations, and torque than analog servos. A concern is that digital servos can produce some noise when in neutral mode due to the rapid voltage adjustment occurring inside the motor. We realized that this was what was causing the glitches. Using an analog servo was the better choice for two reasons: (a) we had no need for an extremely strong or fast servo motor and (b) we did not have the need to update the servo motor every fraction of a second. Therefore, our company chose to use the HS646WP analog servo because it was more effective as well as less expensive for our client.

RS485 (Purchased)

Our company integrated two RS485 serial modules into our ROV. These components allow our control system to seamlessly transmit and receive signals along a single pair of wires, helping to avoid noise/interference over our 50 foot tether. The RS485 protocol is a half-duplex system based on Universal Asynchronous Receiver/Transmitter (UART) communication.

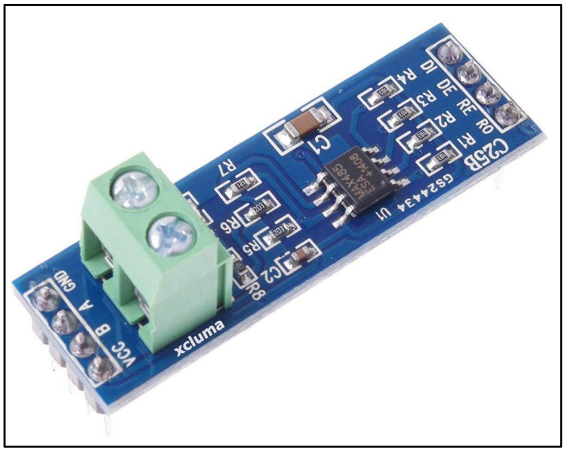


Figure 21. RS485 Module
Image Credit: www.amazon.com

In UART communication, two UART devices communicate directly with each other. The transmitting UART converts parallel data from a processor such as an Arduino board into serial form and transmits it in serial form to the receiving UART which then converts the serial data back into parallel data for the receiving device, whether it be a motor, display, or another processor.

The challenge of incorporating the RS485 modules into our Arduino programs was alleviated by the Arduino SoftwareSerial library. Our master Arduino program put both servo values in a buffer and sent them to the topside RS485 module. This module communicated with its onboard ROV counterpart, which sent the buffer to the remote Arduino to be decoded and sent to the servo motors. The remote Arduino program can send temperature sensor values directly to the onboard ROV RS485 module. This sends the signal through the tether to the topside module, which sends the signal in turn to the master Arduino.

Watertight Enclosure (New)

The structure of our program and the use of RS485 modules meant that our company was required to use a watertight enclosure onboard the ROV. Our company initially considered developing an electronics enclosure rather than buying one--addressing the individual needs of and saving money for our client. We tested various containers underwater, ranging from sandwich containers to Pelican boxes. Though they were marketed as "waterproof," they could not withstand high levels of pressure, rendering them useless. Therefore, we chose to incorporate a Blue Robotics enclosure, as a professional watertight enclosure would be a more reliable and safe option. The enclosure is rated to depths of 1000 meters, offering a great deal of versatility to our client.

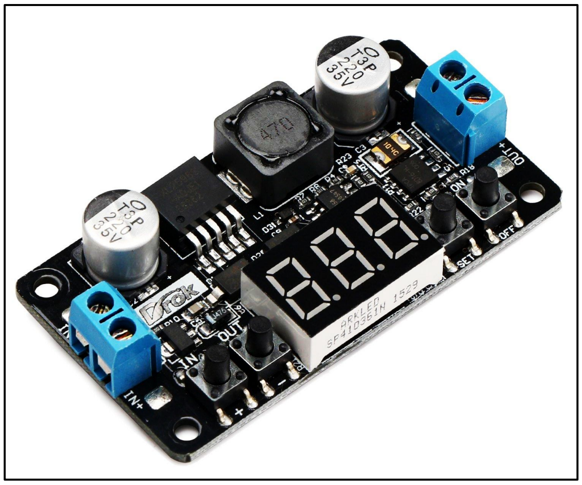


Figure 22. Drok LM2596 VRM
Image Credit: www.amazon.com

Lincoln's underwater electronic components comprise an Arduino Uno microcontroller, an RS485 module, SOS leak sensors, and a VRM (voltage regulator module). The purpose of the VRM is to reduce voltage drop over our 50 foot tether--a consideration of the potential depth requested by Eastman. We used a Drok LM2596 VRM (see Figure 22 above).

After deciding to use a Blue Robotics acrylic watertight enclosure (see Figure 23), we had to place and organize our electronics. Rather than purchasing electronics trays, we used 3D printed trays. These were designed to not only fit our various electronic components, but also easily organize our wiring. After placing the trays, our engineers began the waterproofing process. Our tether wires were potted in Blue Robotics cable penetrators using the WetLink Thixotropic Potting Compound. The O-rings were greased and placed into grooves on our CNC aluminum flange. The cable penetrators were then attached to the end caps, the end caps to the flange, and the flange to the enclosure itself. After pressure testing, the enclosure was mounted to the ROV using PVC piping, screws, velcro, and pipe strapping.

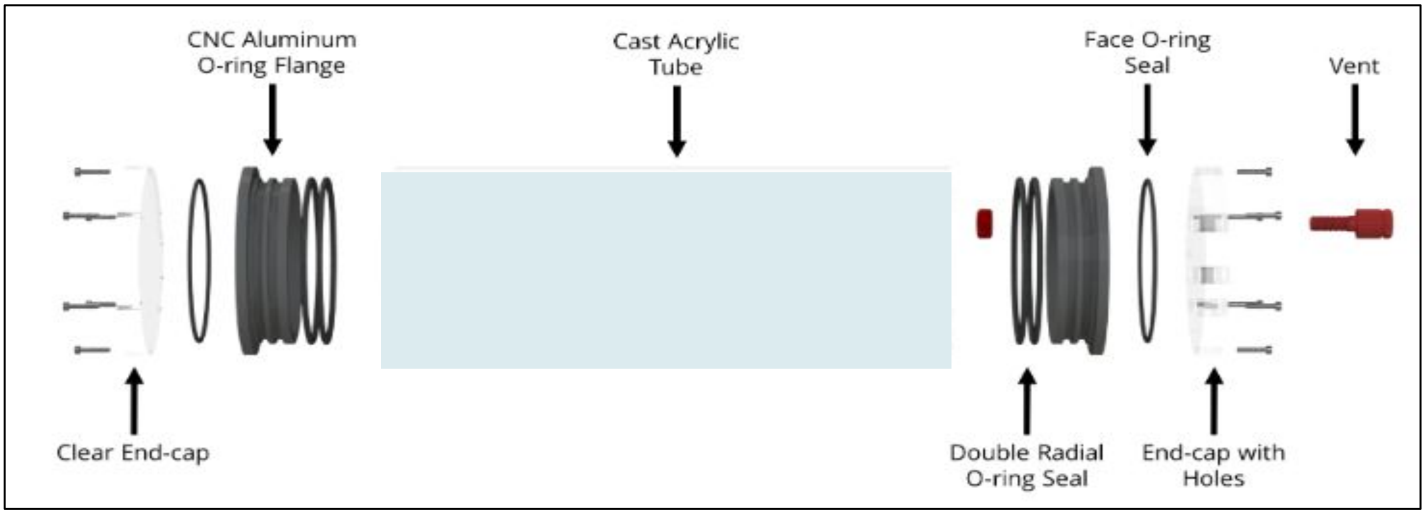


Figure 23. Enclosure Diagram;
Image Credit: www.bluerobotics.com

SOS Leak Sensor (New)

Inside the electronics enclosure, we strategically placed leak sensors, a major safety feature that allows us to detect enclosure breaches. The leak sensors are connected to the master Arduino directly through the tether. The SOS leak sensor has four sponge probes. If a sponge gets wet, water will complete a circuit, allowing a signal to be sent to our master Arduino and illuminate an LED in our control box.

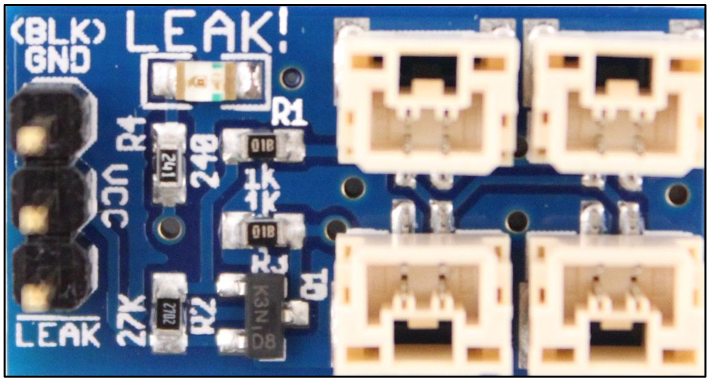


Figure 24. SOS Leak Sensor
Image Credit: www.bluerobotics.com

Servo Waterproofing

Our servo motors are IP67 rated, meaning the servo can function in one meter depth of water for 30 minutes. This is not acceptable by our company's high standards nor would the servos operate properly in 12+ feet of water. We researched several different methods of waterproofing servos and tested the following products and procedures.

Methods	Procedures	Advantages	Disadvantages
Marine Grease	1. Disassemble servo 2. Insert marine grease into servo 3. Reassemble servo	- Prevents further damage to servo even if water enters	- Doesn't effectively prevent water from entering the servo - May cause servo to overheat
Marine Epoxy	1. Squeeze out marine epoxy 2. Mix the two substances thoroughly 3. Using popsicle sticks, spread epoxy on all seams 4. Squeeze out more solution where needed and continue to apply 5. When finished, ensure that all seams are covered	- Prevents water from entering and damaging the servo - Proven in previous years to work very well in the pool	- Waterproofing process takes 12+ hours - The dried epoxy can easily crack if not handled properly - The solution is thick, so application process can be tedious
Plasti Dip	1. Spray or dip servo with PlastiDip 2. Wait for coating to dry 3. Apply another coating 4. When finished, ensure that all surfaces are covered	- Covers entire servo - Prevents water from entering and damaging the servo	- Coating peels after minimal use - May caused servo to overheat

Figure 25. Servo Waterproofing Analysis

After analyzing these methodologies, our company chose not to use marine grease for waterproofing as it doesn't cover the external seams of the servo motor. Between the two remaining methods, PlastiDip seemed like the more reliable option, but it also caused our servos to heat up and sometimes even led the servo motors to burn out. The only remaining option was Marine Epoxy, and its effectiveness was proven in the pool during testing.

Mission Specifics:

Micro-ROV

The second task for Eastman, Dam Inspection and Repair, requires a secondary ROV to inspect a 6-inch pipe for leaks. As a result, our company built a micro-ROV that detaches from the primary ROV. We 3D printed the micro-ROV frame, measuring 12.5 cm across (see Figure 26). Our micro-ROV is equipped to house three DC motors as well as a Tiker 8 LED vehicle backup camera.

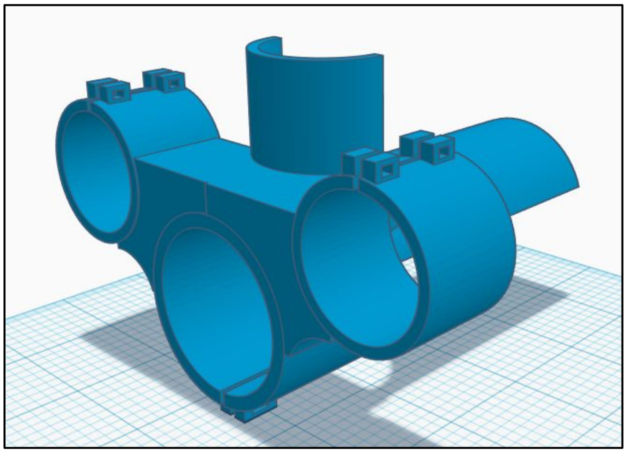


Figure 26. Micro - ROV frame
Created on TinkerCad by Aayush T. and Saketh R.

Tether Recoil Device (TRD)

To deploy the onboard micro-ROV, we needed a way to manage its CAT5e tether cable. We decided on a tether recoil device (TRD). To create this device, we used a discarded Makerbot filament roller from our in-house 3D printer. In order to rotate the TRD, we used a 15 RPM (Rotations Per Minute) stepper motor. Given the relationship between torque, speed (RPM), and horsepower (HP), a low RPM motor has a high torque (see Figure 27). A DPDT (double pole double throw) toggle switch was added to the side of our control box to control the TRD mechanism.

$$\boxed{Torque = \frac{HP \times 5252}{RPM}}$$

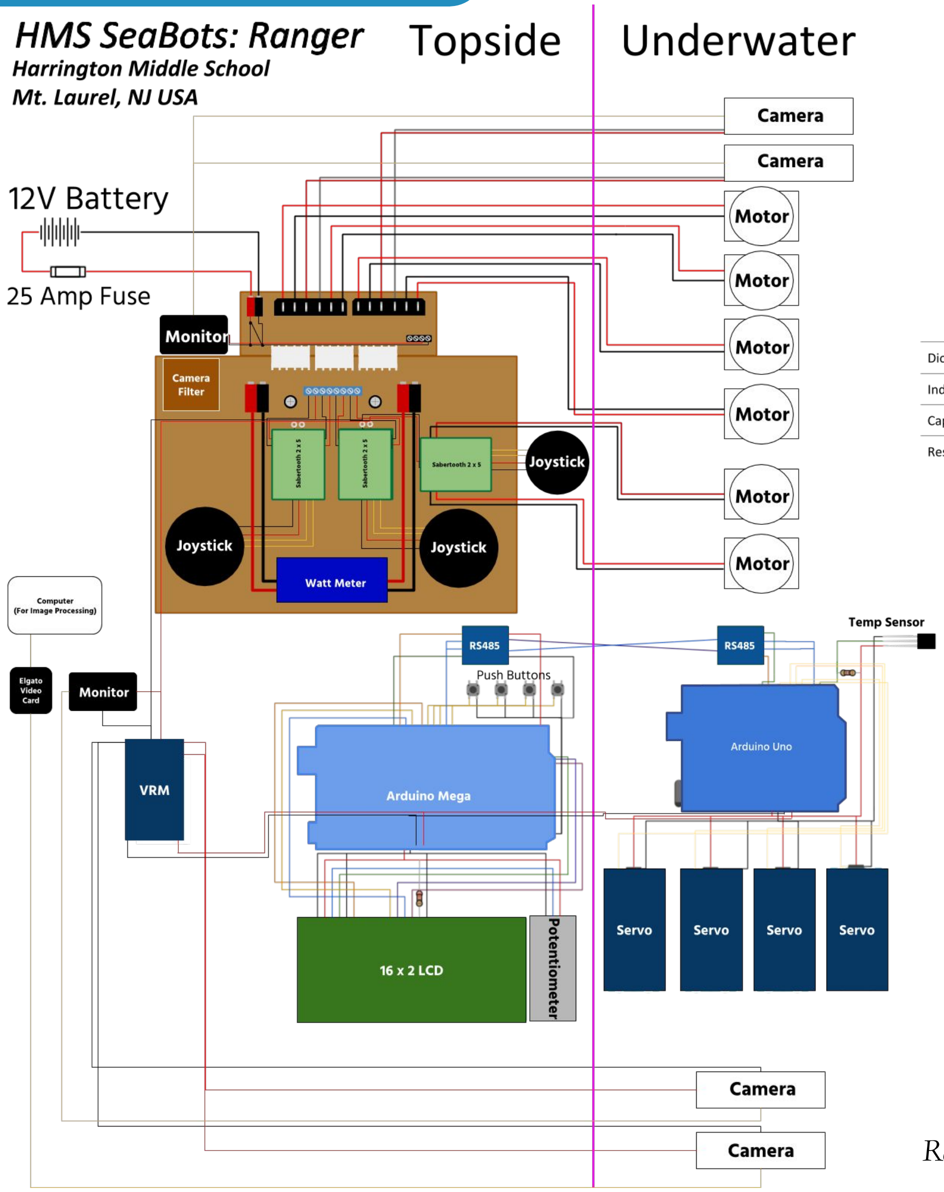
Figure 27. Torque and RPM Relationship Equation

Temperature Sensor (Purchased)

Our company used the DS18B20 temperature sensor, using the 1-wire interface. This interface allowed us to receive signal through a set of only two wires, ground and signal. The use of this sensor required us to include two additional libraries to our program: DallasTemperature and OneWire. Our temperature reading is displayed on a 16x2 LCD display. A temperature reading is necessary for Task 2: Maintaining Healthy Waterways.

Image Recognition Software

Our software engineers developed an image recognition program capable of recognizing the benthic species for Task 2 (Maintaining Healthy Waterways) of the RFP. The program was developed using Python and makes use of two libraries: *cv2* for image processing and *numpy* for calculations. Our program reads an image from our camera and converts the image to grayscale. The program detects shapes by drawing contours on the received image. Shapes with three sides are classified as triangles, and non-applicable shapes are classified as circles. Shapes with four sides are further inspected. We observed that while both squares and rectangles have four sides, the squares all had greater areas than the rectangles. Therefore, shapes with a larger area are classified as squares, while the shapes with smaller areas are classified as rectangles. After determining how many of each shape were present, the program printed the values onto the format provided by MATE.



Micro-ROV SID included on Design Document

Fluid Power not used on ROV

AC Power not used on ROV

Legend

Diode	▮
Inductor	●
Capacitor	○
Resistor	▭

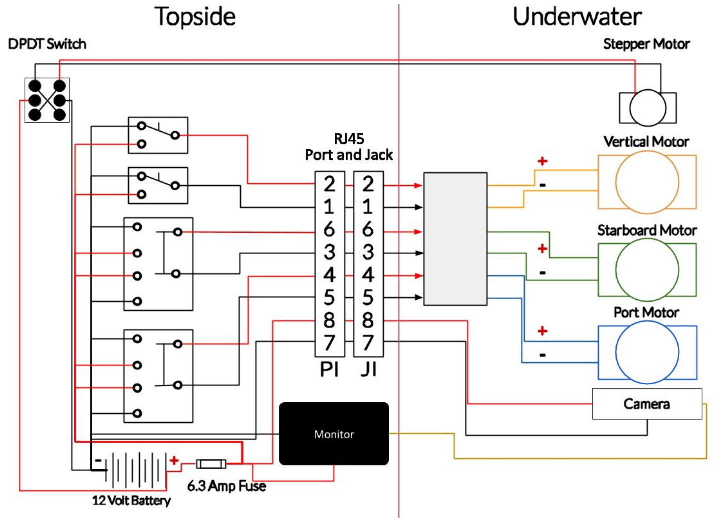
Overcurrent Calculations

Six Bilge Pump Motor Cartridges
(two 1000 gph, two 1250 gph)
14.6 Amps
Three Cameras
0.26 Amps
Monitors
0.46 Amps
Two Servos
0.96 Amps Total
LCD Display
0.16 Amps
Temp Sensor
0.15 Amps
SOS Leak Sensor
0.02 Amps
Arduino Uno
0.045 Amps
Arduino Mega
0.2 Amps
= 16.855
16.855 x 1.5
=25.2825

The ROV utilizes 25 amp fuse

Figure 28. SID
Created on Google Drawings by Rohan G. Adithya S. and Numa W.

Micro-ROV SID



Overcurrent Calculations

Three Motors
1.5 Amps
Camera
0.9 Amps
Monitor
0.23 Amps
Stepper Motor
1.1 Amps
= 3.73
3.73*150%=5.595

The Micro-ROV utilizes 6.3 Amp Fuse

Figure 29. Micro-ROV SID
Created on Google Drawings by Rohan G. Aayush T. and Adithya S.

HMS SeaBots: Ranger
Harrington Middle School
Mt. Laurel, NJ USA

Micro-ROV SID

Safety

Safety Philosophy

Our company holds safety in the highest regard. Whether on the poolside or in the workplace, we strive to maintain the safety of our employees, equipment, and work environment. To insure this, we appointed a Job Safety Office (JSO) who instituted numerous safety procedures to minimize accidents in the workplace.

Safety Checklists and Protocols:

Tool	Safety Procedure
Drill	☐ The JSO must be on-site to supervise/assist ☐ Drill location must be marked ☐ Goggles must be worn to prevent debris from entering the eye ☐ Object being drilled must be secured tightly via table vice ☐ Drill bits must be tightly secured in drill
Soldering Iron	☐ JSO must be overseeing while any employee who is actively soldering ☐ Soldering space must be clutter-free ☐ Soldering iron filter must be powered on to limit toxic fumes ☐ Safety goggles must be worn at all times ☐ Soldering iron must be in the stand if not it is being actively used ☐ Soldering iron must be turned off and unplugged after use
Heat/Hot Glue Gun	☐ JSO must be on-site ☐ Gloves must be worn to prevent burns ☐ No other employees should be within five feet of the area ☐ Heat gun/ Hot glue gun ☐ Gun must be turned off after use

3D printer	☐ During Print:
	    ☐ Employees must not lean over or go near the 3D printer without consent of the JSO
	    ☐ Employees must stay clear of the extruder while it is active
	    ☐ Employees must remain outside the caution line
	☐ After Print:
	    ☐ Wait 5 minutes for the print to cool down before removing it from the printer
	    ☐ While removing print from plate, be cautious if using any sharp removal tool

Miter Saw	☐ JSO must be on-site while cutting ☐ Sawing location must be neatly marked on object ☐ Proper training is required prior to use ☐ Employees must wear goggles to prevent debris from entering eye area

Figure 30. Tool Safety Protocols/Procedures Checklist

Safety (Cont.)

Launch Checklist:

Below is a checklist used when deploying the *Lincoln ROV:*

Before:

- ☐ Securely connect all plugs/electrical connections
- ☐ Test that all ROV components (e.g. thrusters, gripper, camera) are functional properly
- ☐ Verify all ROV components are firmly secured to frame
- ☐ Check for any sharp edges and handle them appropriately
- ☐ Ensure that tether is managed and isn't tangled on ROV or employees

During:

- ☐ Place ROV in water gently and keep clear of dropzone
- ☐ Ensure the enclosure and other watertight components are secure
- ☐ Test all ROV functions (e.g. thrust, gripper, camera) before beginning missions
- ☐ Immediately return the ROV to the surface if any malfunctions occur
- ☐ Handle all tools for repair appropriately
- ☐ Ensure that tools do not get wet unless necessary to prevent rusting

After

- ☐ Power off the ROV
- ☐ Bring ROV to surface and dry off all parts thoroughly
- ☐ Leave all parts to dry to prevent molding
- ☐ Properly store the tether, ROV, and control box into the ROV storage container

Safety Features

Although the workplace has many potential hazards, the ROV also has equally dangerous components. Our team has instituted numerous safety features for *Lincoln* in order to ensure employee safety. We have listed a few of the most important safety features incorporated in *Lincoln* in the table below.

Feature	Purpose
Thruster Guards	3D printed guards are IP 20 rated to eliminate any chance of harming employees and/or the environment while operating the ROV.
Fuse	This safety feature protects our circuit from being damaged, for example, if the ROV were to draw too many amps. The fuse will blow and break the circuit stopping the flow of power, protecting our electrical system.
Kill Switch	Power for the control system runs through the kill switch. In the event of an emergency, employees can manually shut off the flow of power to the ROV.

Warning Tape on Thruster Guards	OSHA certified black/yellow caution tape is wrapped around the top portion of our thruster guards and warns employees of the high-risk physical hazard lying beneath.
SOS Leak Sensor	A set of four probes placed inside the watertight enclosure will alert us of any leaks via an LED in our project box. From there we can rescue the components inside our enclosure before they get damaged or destroyed.
Strain Reliefs	Clamp strain reliefs secure our tethers to our frame. In the event the tether gets pulled, the tether will pull on the frame rather than our soldered enclosure connections.
Voltage Regulators	Multiple voltage regulators are placed throughout the ROV system, preventing damage to the electronics, both in the control box and onboard the ROV.

Figure 31. Safety Features

Critical Analysis

Testing and Troubleshooting

Using the Agile method, we were able to test the ROV systems separately. Each engineering division faced problems through *Lincoln's* fabrication process. However, the Agile methodology and our weekly scrum plan updates allowed our engineers to communicate with each other and share ideas. Troubleshooting the various ROV systems throughout the year provided us with more knowledge in regard to our ROV. As we troubleshooted, our engineers learned certain strategies to use in the event of system failure.

Perhaps the biggest electrical malfunction that occurred as we built our main control box was the incorporation of our two cameras. Though the cameras were obviously wired correctly, our monitor was not receiving camera signal. Our strategy in this scenario was to isolate the problem. After testing each component separately, our engineers discovered that there was a faulty connection in the backplane board. We were finally able to successfully replace the board and receive signal from our cameras.

Our software engineers spent time discovering a method to combat servo jitter after merging the software system with the main electrical system. Though our push buttons and analog servos were still in use, the jitter had returned. Our strategy here was to use prior electrical knowledge. Our engineers thought to perhaps ground the servo motors to a different location, away from the other components in our electrical system. This proved to be an effective strategy, eliminating the servo jitter issue.

A mechanical problem our engineers attempted to solve was our ROV's lack of speed. Our strategy for this was to simply brainstorm various solutions and test them. We first wondered whether our shrouds were preventing our motors from providing full thrust. We saw that this was not the case after we tested our ROV without its shrouds. We then realized that our ROV was lacking waterflow and proceeded to drill holes in our frame. This solution increased our ROV's speed.

Technical Challenges

As we built *Lincoln,* we faced many technical challenges. One of the most prominent challenges we faced was combatting servo jitter, which we addressed previously on page 11. But it was not only the software division that faced these technical challenges; the fabrication process also brought mechanical challenges, where we struggled with assembling our shrouds with thruster guards.

One of our shroud/thruster guard design consisted of PLA cylinders and aluminum bars. The *Lincoln* prototypes were constructed on our 3D printer purely of PLA, but this caused several breakage issues (see Figure 32) due to the relatively low UTS (Ultimate Tensile Strength) of PLA, at just 37 MPa, as mentioned in figure 10 on page 7. This explained why our shrouds were breaking. The PLA that we were using was unable to sustain pressure and stress for elongated periods of time. Although PLA is a good material for larger structures, we found that it isn't extremely useful for heavy duty operations such as housing a motor. In comparison to the other materials that we tested (PVC, ABS and aluminum), PLA was not the right fit for our shrouds.

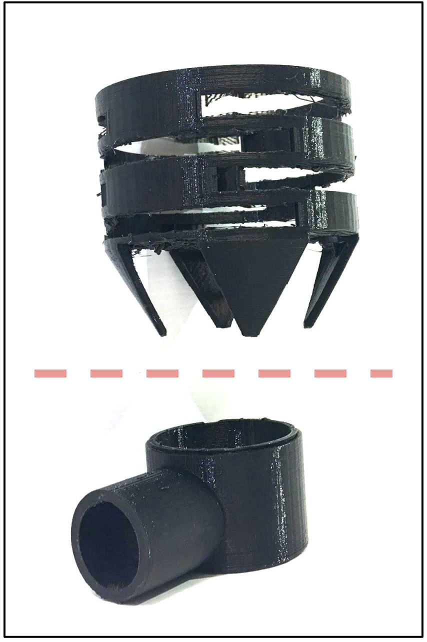


Figure 32. Broken Shroud
Photo Credit: Saketh R.

Interpersonal Challenges

One of the major decisions that our company was faced with was deciding whether or not we should design and build a micro-ROV. A micro-ROV would allow us to inspect the drain pipe in Task 1 (Dam Inspection and Repair). While some members of our team believed that the micro-ROV would give us a greater chance of being awarded Eastman's contract, while others argued it would consume too much time. Both sides had pros and cons. When it was time to put the casing on all the tethers to secure them together, again we debated about whether or not to include a tether for the micro-ROV in the casing. Some company members argued that there would be no harm in putting the tether in the casing. Others voiced that there was not enough time remaining to demonstrate a fully functional micro-ROV, so the tether was not necessary. A four to three vote was the deciding factor in favor of a micro-ROV.

Technical Lessons Learned

One of the main problems that constantly showed up in the building of the control and software systems was interference--specifically the camera and Arduino signals. The monitor would not show an accurate image, making it hard for our pilot to view the missions in front of them. Using the same tether for signal and power also had an adverse effect on the signals sent through the RS485 communication standard. The servo signals sent through the RS485 could have been affected by nearby power wires, causing a jitter. The primary cause for this is a type of interference is called crosstalk. This occurs when wires close by each other have signals that "bleed" into each other, causing them to interfere. Our team ultimately rewired signal and power into separate tethers. The signal that had "leaked" out from the power would not be able to affect the signal of others. After making this change, both the camera and software systems worked.

Critical Analysis (Cont.)

Interpersonal Lessons Learned

Through all of our company's challenges, we learned a great deal. These lessons do not merely consist of mechanical, electrical, and software related information; we also learned more about project management. Despite having prior experience as a Scout company, we encountered various issues, perhaps the most prominent being our time management. As the competition neared, our company realized that we were not on track to complete the remaining tasks. Our engineers were unable to complete the planned assignments in the past two scrums. Our engineers had been updating the scrum plans, postponing the uncompleted jobs to later scrums. But about three weeks before the competition, our company couldn't postpone any longer. The next days were stressful, as we worked long nights to get back on track. The central lesson that we learned from this was to allocate time for troubleshooting while planning. Oftentimes, systems do not work the first time they are tested. Our company's flaw was the lack of accounting for the amount of time that might be spent troubleshooting. Perhaps, if we had realized this earlier, we may have had more ROV practice time. Nevertheless, we learned the lesson in the end, and if we are ever to compete again, we will keep this in mind while planning.

Development of Skills

Our middle school MATE program consists of both 7th grade students (Scout) and 8th grade students (Ranger). The Ranger team includes students who are returning for a second year or 8th graders new to the program, while all the Scout members are new to MATE. It is typically the responsibility of Ranger members to educate their juniors. As a Scout team last year, many of us learned the basics of underwater robotics from our seniors, such as CAD design, Arduino programming, and use of tools. As senior members this year, we continued to develop these technical skills and many more. Each of our own engineering fields required us to test, troubleshoot, and learn throughout the year. We will never stop learning and developing these skills that are sure to help us through high school, college, and careers.

Future Improvements

Our ROV has many special features that make it unique. Nevertheless, we are aware that there are still improvements that can be made to improve the functionality of *Lincoln*. First, *Lincoln's* propulsion system might be more than satisfactory to complete Eastman's tasks outlined in their RFP, but we believe investing in higher RPM thrusters, such as Blue Robotics T100s or SeaBotix thrusters, would decrease our time in the water. This would not only increase *Lincoln's* efficiency, it would grant us more time to complete other jobs for the client. Second, when our company read Eastman's RFP for the first time, we brainstormed two methods of completing the transect line mission (Task 1: Ensuring Public Safety), each with its own merits. The first method was an omnidirectional motor configuration, which provided our ROV with additional maneuverability but weakened our forward thrust. However, we decided against this thruster setup because it hindered our surging (our forward and backmovent movement). In the future to compensate for the loss of sway movement, we could incorporate a servo controlled camera. This camera would be able to rotate, giving us a view not only of the front of the ROV, but its port and starboard sides, providing our demo team with additional visibility to complete Eastman's tasks.

Accounting

Build/Buy/Reused/Purchased

When creating our ROV, we had many options of how we decided upon obtaining different parts. Below are three examples of these decisions.

Component	Build/Buy/ Reused/Purchased	Why?
Enclosure	Reused	Our company decided upon using the Blue Robotics 3” Watertight Enclosure to hold components of our Arduino System. We decided upon using this enclosure due to its proven reliability. Instead of purchasing one, we decided to utilize an enclosure from a previous year’s ROV. This enclosure was close to mint condition, with no possible chance of failure.
Cameras	Purchased	New cameras were incorporated in our control system. While there were older cameras that could have been reused, the quality of their waterproofing was not up to par. Instead of having a possibility of compromising the visuals, we decided to use new cameras and waterproof them to the highest standards.
Shrouds	Build	Rather than purchasing commercial shrouds, our company decided to manufacture our own custom designed shrouds as these would be just as effective as any commercial shroud for a fraction of the cost.

Figure 33. Build/Buy/Reused/Purchased

Budget

School:	Harrington Middle School		
Instructor:	Maureen Barrett		
Reporting Period:	October 23, 2018 - June 2019		
Team Name:	HMS SeaBots		
Income:	**Mt. Laurel Education Fund**		**$1,000.00**
	Mt. Laurel Schools		**$2,000.00**
	Sparkfun Grant		**$400.00**
	Hi-Tec Grant		**$700.00**
Total Income:	**$4,100.00**		
Expenses:	Purchased/Reused/Donated	Projected Cost:	Budgeted Cost:
Power and Control	**Purchased/Reused**	**$1,250.00**	**$1,250.00**
Arduino Systems	**Purchased/Reused**	**$1,250.00**	**$1,250.00**
ROV Frame	**Reused**	**$250.00**	**$250.00**
Tools	**Reused/Donated**	**$200.00**	**$200.00**
Mission Components	**Purchased/Reused**	**$750.00**	**$750.00**
Miscellaneous	**Purchased/Reused/Donated/**	**$400.00**	**$400.00**
Conclusions			
Total Income:	**$4,100.00**		
Total Value of ROV and other Components:	**$2,604.92**		
Total Income Spent:	**$2538.65**		

Figure 34. Budget

Cost Accounting

New	Amount	Notes	New/Reused/Donated/Discounted/On Sale	Amount spent($)	Market Value($)	Total
Power and Control						$1,318.75
Triggerfish ROV Rev 3 Kit	1		New	$700.00	$700.00	
Sabretooth 2 x 5	1		Reused	$0.00	$60.00	
Adafruit Mini Joystick-10k	1		Reused	$0.00	$19.95	
18AWG, 8 Wire Cable	3		Reused	$0.00	$58.50	
SeaMATE Camera Add-On Kit	1		New	$65.00	$65.00	
SeaMATE Camera Waterproofing Kit	1		New	$20.00	$20.00	
Kenwood Vehicle Backup Camera	1		New	$150.00	$150.00	
Vehicle Backup Camera w/ Guidelines	3		New	$47.97	$47.97	
VideoRay Neutral Buoyancy Tether	1		Donated	$50.00	$50.00	
7" TFT Monitor	1		New	$42.99	$42.99	
Elgato Video Capture Card	1		Donated	$84.95	$84.95	
RCA Male to Male Wire	1		Reused	$0.00	$8.95	
BNC Female to RCA Male Adaptor	1		Donated(Chirip)	$0.00	$1.95	
BNC Splitter to Dual BNC	1		New	$8.49	$8.49	
Arduino Systems						$534.77
Arduino Mega	1		New	$38.50	$38.50	
Arduino Uno	1		New	$22.00	$22.00	
Waterproof Temp Sensor	1		New	$19.52	$19.52	
HiTec D646WP Servo	2		New	$70.00	$70.00	
Standard Gripper Kit A	1		New	$9.95	$9.95	
Voltage Regulator w/ Display	4		New	$31.96	$31.56	
Voltage Regulator	2		New	$15.98	$15.98	
RS-485 Board	2		New	$14.38	$14.38	
25 Tooth ServoBlock	1		New	$26.99	$26.99	
Pelican 1150 Box	1		New	$36.99	$36.99	
Clear Acrylic Plate	1	21.5 cm x 16 cm	New	$3.23	$3.23	
Dupont Wire	1	Pack	New	$17.99	$17.99	
16 x 2 LCD Display	1		New	$9.95	$9.95	
Through-Hole LED	2		New	$0.74	$0.74	
Cast Acrylic Tube - 11.75", 298mm (3" Series)	1		New/Discounted	$41.39	$46.00	
O-Ring Flange (3" Series)	2		New/Discounted	$43.20	$48.00	
Aluminum End Cap with 4 holes (3" Series)	1		New/Discounted	$10.80	$12.00	
Enclosure Vent and Plug	1		New/Discounted	$7.20	$8.00	
6mm Penetrators	11		New/Discounted	$39.60	$44.00	

Accounting (Cont.)

Cost Accounting (Cont.)

No Hole Penetrators	3		New/Discounted	$10.20	$12.00	
8mm Penetrators	8		New/Discounted	$36.00	$40.00	
Potentiometer	1	1	New	$6.99	$6.99	
ROV Frame						$35.54
ABS Pipe	1		Reused	$0.00	$1.85	
Blue and Yellow 1/2" PVC (Schedule 40)	10	Feet	Reused	$10.99	$10.99	
1/2" PVC Three-Way	8		Reused	$0.00	$15.98	
1/2" PVC Elbows	12		Reused	$0.00	$4.44	
1/2" PVC Tees	12		Reused	$0.00	$2.28	
Tools						$24.14
Hot Glue	50		Donated	$0.00	$12.00	
Electrical Tape	2		Donated	$0.00	$6.00	
Loctite Marine Epoxy	1		Donated	$0.00	$0.14	
Heat Shrink	1	Roll	Donated	$0.00	$2.00	
Cable Penetrator Potting Kit	1		Donated	$4.00	$4.00	
Mission Components						$691.72
Dell Inspiron 5000 (I7-8550U)	1		Donated(Talreja)	$0.00	$679.00	
Punching Balloons	1	Pack	Donated(Rudraraju)	$6.00	$6.00	
Intex Double Quick III S Hand Pump, 14.5"	1		Donated(Barrett)	$6.72	$6.72	
Misc.						$4,068.98
Team Uniforms	10		Donated (Team Members Parents)	$0.00	$385.00	
Registration Fee	N/A		N/A	$200.00	$200.00	
Pool Rental	N/A		N/A	$300.00	$300.00	
PLA Filament Spools	0		New	$192.00	$288.00	
MakerBot Replicator 5th Generation Build Tape	1		New	$9.99	$9.99	
Marketing Display	1		New	$95.00	$95.00	
Business Cards	500		New	$15.99	$15.99	
Fluid Power Quiz Fee	N/A		N/A	$15.00	$15.00	
Travel Expenses to Regionals by School Bus	N/A		N/A	$0.00	$0.00	
Travel Expenses to International	N/A	Hotel	N/A	$760.00	$760.00	
Travel Expenses to International	N/A	Flights/Gas	N/A	$2,000.00	$2,000.00	
TOTAL AMOUNT SPENT/TOTAL MARKET VALUE				**$5,298.65**	**$6,673.90**	
AMOUNT OF MONEY SPENT ON ROV				**$1,710.67**		
TOTAL ROV VALUE				**$2,604.92**		

Figure 35. Cost Accounting

Acknowledgements and Sponsors

The journey that we have taken this year has been quite amazing, but none of this would have occurred if not for a few select organizations and individuals that guided us along the way. We would like to begin by thanking our mentors, Ms. Maureen Barrett and Ms. Marieve Patterson, who helped us overcome many of the challenges that we encountered. Thank you to Ms. V. Vanessa Morris and Ms. Jane White, for organizing the 2019 PA Competition and to Villanova University for hosting it. Thank you to Ms. Jill Zande, Mr. Matt Gardner, and all the MATE Center staff, volunteers, and judges for making the 2019 MATE International ROV Competition in Kingsport, Tennessee possible. We would also like to thank the many organizations that funded our journey to build *Lincoln* to fulfill the RFP from Eastman (see Figure 36 below). This program has enriched our lives. We have overcome engineering, leadership, and work ethic challenges while simulating the environmentally conscious company that we strive to become.

Figure 36. Sponsor Logos

References

1. "3d Filament Spools." ™ *"3d Filament Spools" Keyword Found Websites Listing | Keyword Suggestions*, www.keyword-suggest-tool.com/search/3d+filament+spools/.
2. "Acrylonitrile Butadiene Styrene." *Wikipedia*, Wikimedia Foundation, 29 Apr. 2019, en.wikipedia.org/wiki/Acrylonitrile_butadiene_styrene.
3. "Knowledge Base." *3D Hubs*, www.3dhubs.com/knowledge-base/pla-vs-abs-whats-difference.
4. "Marine Advanced Technology Education :: Home." *MATE*, www.marinetech.org/.
5. "PVC Properties." *Vinidex*, www.vinidex.com.au/technical/material-properties/pvc-properties/.
6. Tyson, Ed. "What To Do With Empty Filament Spools? Here Are Our 6 Favourite Ideas." *Rigid.ink*, Rigid.ink, 6 Feb. 2017, rigid.ink/blogs/news/what-to-do-with-empty-filament-spools-heres-our-6-favorite-ideas.
7. "Water Treatment Solutions." *Lenntech Water Treatment & Purification*, www.lenntech.com/polyvinyl-chloride-pvc.html.