HMS SEABOTS

Ranger Team

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Triton II

1. Table of Contents

2. Abstract

We are the HMS SeaBots, a marine robotics company that specializes in manufacturing remotely operated vehicles (ROVs). Our company consists of thirteen first-year Ranger engineers who designed and built *Triton II*, our most innovative ROV to date, ready to tackle 2021's real-world issues.

The MATE Center has issued a request for proposals (RFP) on behalf of the global community to address three needs of concern: (1) plastics in our oceans, (2) the impact of climate change on coral reefs, and (3) maintaining healthy waterways, specifically the Delaware River and Bay.

Triton II is comprised of several special features to enhance its performance. One special feature is a dual manipulator-arm set-up consisting of two grippers, one vertical and one horizontal. These grippers are essential to lift and transport items such as the eel trap in task 3. *Triton II* is equipped with three cameras. The first gives us a view of the grippers. The second provides a downward view for the coral flyover in task 2 and the photomosaic scan in task 3. The third is mounted on a swivel for general navigation. The ROV also has a surface debris retrieval mechanism to collect floating debris in task 1 and a state-of-the-art Micro-ROV capable of retrieving the sediment sample from the drain pipe in task 3. We believe *Triton II* is capable of completing the tasks outlined in the RFP. *Triton II* represents our company's vision: to design and build ROVs and engineer solutions to global problems.

Figure 1. HMS SeaBots Team Photo
Zoom Photo Credit: M. Barrett

3. Teamwork: Project Management

3.1 Company Overview

Our marine robotics company established leadership roles and divisions of labor to optimize our company's time management & productivity.

Chief Executive Officer (CEO) (Matthew & Meghna)	Chief Technology Officer (CTO) (Akshya & Losritha)	Chief Financial Officer (CFO) (Derek & Harry)	Job Safety Officer (JSO) (Vish & John)
- Coordinated and led meetings - Acted as main point of communication between mentors and team	- Collaborated and made documents including the Technical Documentation and Marketing Display. - Organized documents	- Managed the budget and accounting of the company - Gathered, calculated and recorded prices of the various equipment and features of our ROV	- Instituted safety measures for team - Verified ROV is safe, functional and fits the MATE safety requirements - Wrote safety documentation.

Figure 2. Leadership Roles

3.1 Company Overview (cont.)

Mechanical Engineers (MechE) **Shreeya, Adam, Aditya, John, Rishab**	**Motor Control (MC)** **Akshya, Alex, Vish**	**Servo Control (SC)** **Matthew, Derek, Meghna, Losritha, Harry**
- CAD designs - Build ROV frame - Waterproof cameras and servos - Design and 3D print: - thruster guards for T200s - watertight enclosure mounts - motor attachments - servo camera mount - Mount thrusters, cameras, grippers, and enclosure on frame	- Build control box for thrusters - Wire and program the propulsion system - Create SIDs (System Integrations Diagrams) - Build and manage electronics enclosure - Create a software flowchart	- Build grippers - Wire and program gripper system - Create a software flowchart - Build control box for servos

Figure 3. Engineering Cadres and Division of Labor

3.2 Time Management/Schedule

Efficient time management and scheduling methods were crucial. To maintain a project plan, we created a Gantt chart. The chart represents the overall schedule in a neat and orderly manner, and aided our company when manufacturing *Triton II.*

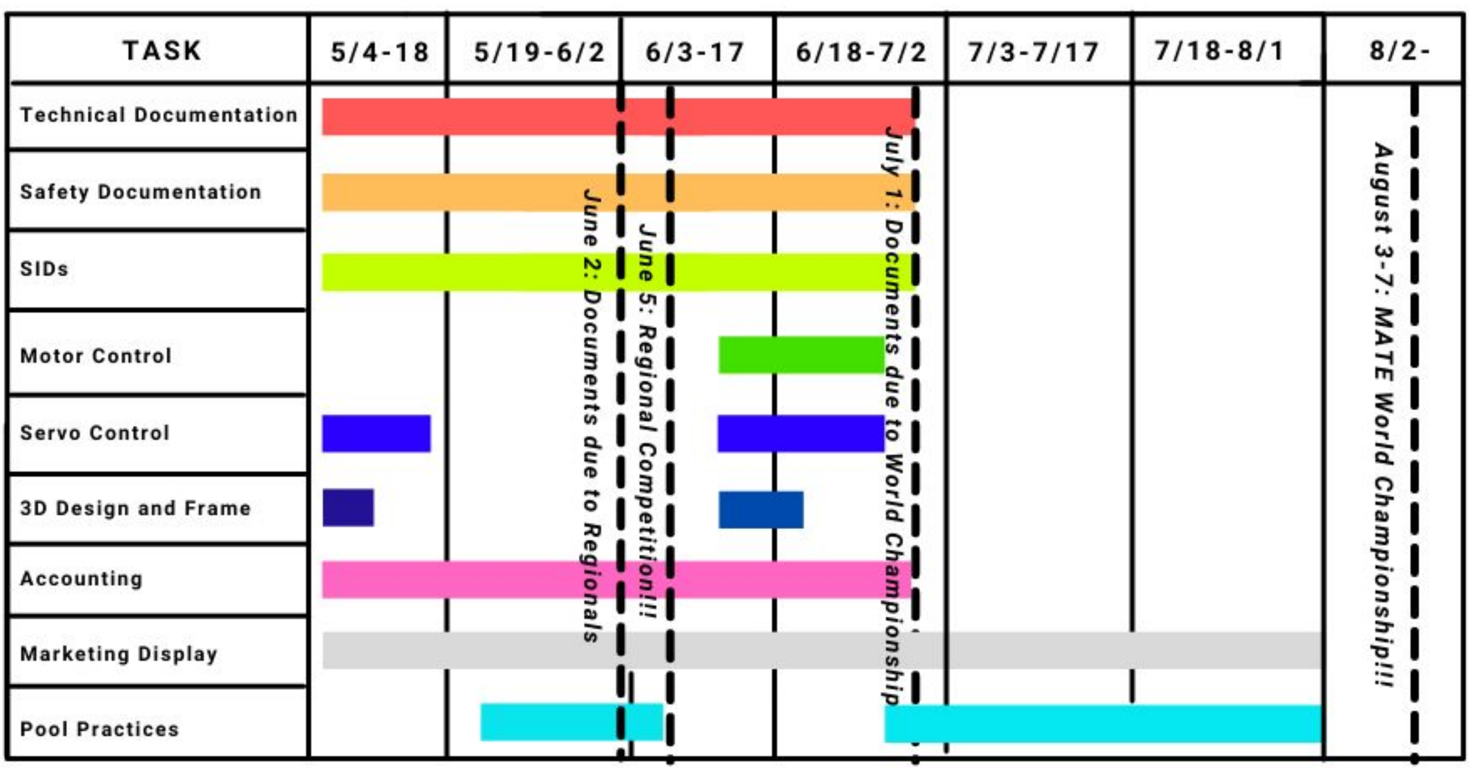


Figure 4. Time Management Schedule Gantt Chart; Created on Canva by V. Jagadeesan

3.3 Organization Methods and Daily Operational Procedures

To keep track of upcoming deadlines and improve our daily productivity, we implemented the following procedures and utilized necessary resources.

- ➔ Developed a detailed documentation plan to delegate duties for company documentation.
- ➔ Created daily agendas to identify daily objectives and assign specific tasks to company employees.
- ➔ Managed a Discord server for virtual communication, such as reminders, plans, Q&A, and additional meetings if required.

One operational problem we encountered was scheduling conflicts. With thirteen people on the team, it was nearly impossible to find times when everyone could meet together. Discord allowed members to join video calls at anytime. Using this feature in Discord, we were able to hold meetings at times that fit better into everyone's schedule. In addition, each engineering cadre had individual meetings via Discord to maximize team efficiency and productivity. Our company also held general meetings with everyone to work on collaborative assignments and discuss overall plans.

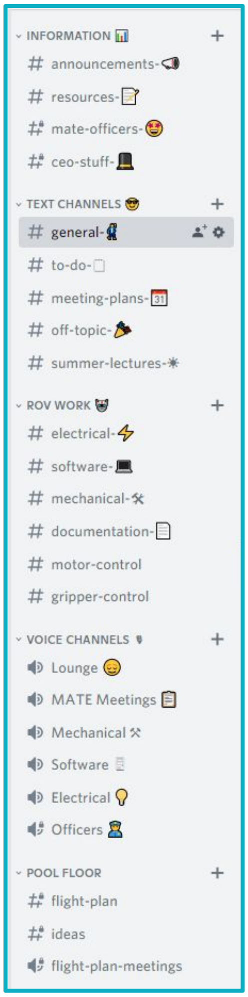


Figure 5. (Right)
Personalized Discord Server Channels
Screenshot Credit: M. Pugh

4. Design Rationale

4.1 Build vs. Buy, New vs. Used

To ensure that our ROV was cost efficient, we developed a set of spending policies that served as general guidelines for new purchases:

1. Reuse as many parts as we can
   - Salvage parts from previous years' ROVs
2. 3D print parts when possible (refer to pages 11-12)
   - While 3D filament still costs money, it is less expensive than buying new parts
3. Use social network to find sponsors or donations
4. Organize fundraising events
   - "Game On!" Arcade night
   - Pancheros Dine-and-Donate
5. Purchase parts when none of the above options are available

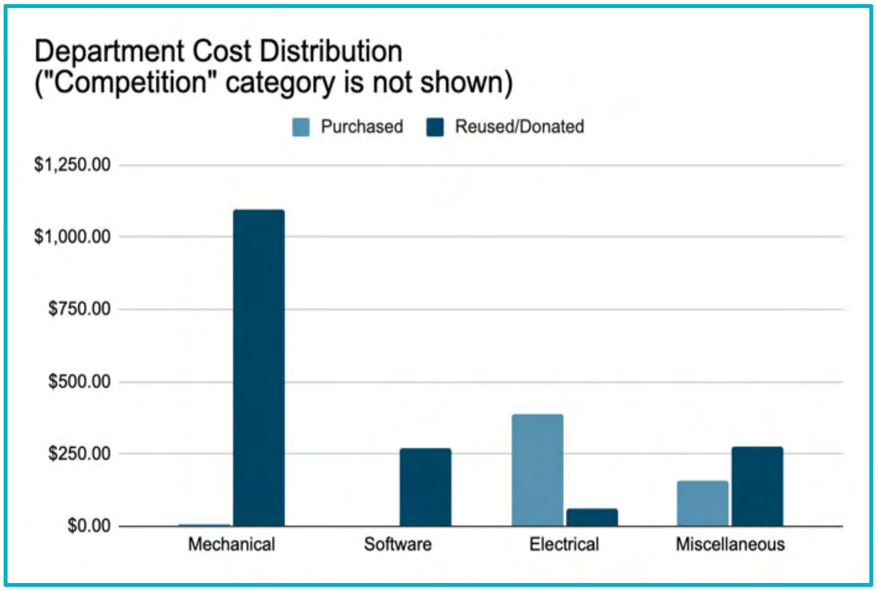


Figure 6. Department Cost Distribution
Chart Created in Google Sheets by H. Southard

4.2 Propulsion System

After the PA Regional Competition, we were not entirely satisfied with the speed of our ROV (*Triton),* so we brainstormed solutions. Subsequently, we discussed totally overhauling *Triton* and designing and building a second ROV (*Triton II).* Our goal was to make *Triton II* faster to complete more tasks. We knew this overhaul would require a lot of problem-solving and innovation, but we were willing to take the risk. After all, our team's tagline is, "Take chances, make mistakes, and get messy!" Below are some of the findings from our propulsion system research:

Brushed vs. Brushless Motors: Unlike the brushed bilge pump motors, Blue Robotics T200 thrusters are brushless. Brushless motors are more energy-efficient as they result in less friction and a higher weight to torque ratio, allowing for improved performance.

Total Thrust Force: Blue Robotics T200 thrusters provides a higher thrust force than bilge pump motors. Please see chart at the bottom of the page (figure 8) for our thruster calculations.

With this knowledge, we developed three potential propulsion systems and evaluated their advantages and disadvantages before making our final decision:

System 1: This propulsion system consists of six bilge pump motors, two positioned vertically and four positioned horizontally. This system would require the least amount of work to prepare for the MATE World Championship. As per figure 8 in our calculation chart below, each bilge pump motor provides 0.83 kilogram force (kgf). The net kgf for this setup is 4.98 kgf, which calculates to 1.66 kgf more than *Triton's* propulsion system.

System 2: The motor placement of this system is similar to *Triton's* system, however the four bilge pump motors are replaced with four Blue Robotics T200 thrusters. While this switching to a Blue Robotics T200 thruster setup appears to be the most promising, doing so would require a great deal of time and energy to learn and implement the system. Each T200 thruster provides 1.2 kgf. The net kgf for this setup is 4.8 kgf. Theoretically, this is a noticeable increase in speed. However, this system would require an electronics enclosure, and the placement of this enclosure would conflict with the vertical motor placement.

System 3: Instead of four T200s, system 3 implements six T200s. As mentioned in the system 2 setup, each T200 provides 1.2 kgf, meaning that this setup has 7.2 kgf in total. This is a significant improvement from the previous two systems, however, we knew switching to this system would require a significant amount of time and effort. Ultimately, the team decided on a six T200 thruster setup. (see figure 7 for diagram)

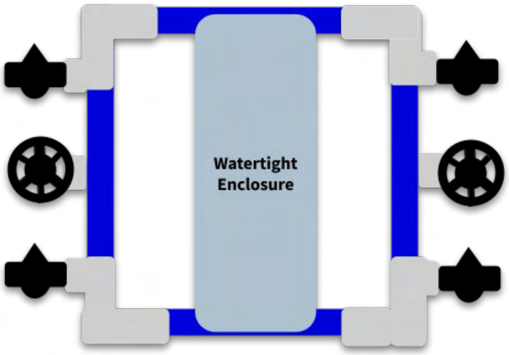


Figure 7. Propulsion System #3 (Above)
Created on Google Drawings by V. Jagadeesan

System 1: Six Johnson bilge pumps	0.83 kgf per motor x 6 = 4.98 total kgf
System 2: Four Blue Robotics T200s	1.2 kgf per motor x 4 = 4.8 total kgf
System 3: Six Blue Robotics T200s	1.2 kgf per motor x 6 = 7.2 total kgf

Figure 8. Systems Thrust Calculations (Left)
Chart Created by A. Sriram and V. Jagadeesan

4.3 ROV Frame & Structure

After deciding to overhaul *Triton*, our mechanical engineers would have to account for the placement of six thrusters, mounting the electronics enclosure, and adding a new servo-camera. We believe that these new innovations would result in higher functionality.

Considering our time constraint, we opted for a simple, rectangular prism frame design, which allowed our engineers to quickly design the frame on TinkerCAD, a collaborative 3D-modeling software. We considered the following options for the frame's material -- PVC, CPVC, PLA, or ABS. We researched each material's weight, ease of fabrication, and the ultimate tensile strength (UTS), which is the maximum stress that a material can withstand before breaking. After extensive research, we decided to construct our frame using PVC. Our findings are below:

Material	PVC (Polyvinyl Chloride)	CPVC (Chlorinated Polyvinyl Chloride)	PLA (Polylactic Acid - 3D Printing Filament)	ABS (Acrylonitrile Butadiene Styrene)
Pros	➔ *Durable material* ➔ *Waterproof* ➔ *Ease of fabrication & modification (i.e. connectors, cuttable)* ➔ *Cost-effective*	➔ *More lightweight than PVC* ➔ *Ease of fabrication & modification (i.e. connectors, cuttable)*	➔ *Lighter in weight than PVC and CPVC* ➔ *More design freedom* ➔ *Adjustable infill density* ➔ *Cost- effective*	➔ *Positively buoyant* ➔ *Ease of fabrication & modification (i.e. connectors, cuttable)* ➔ *Higher UTS than PVC*
Cons	➔ *Negatively buoyant* ➔ *Lack of design freedom vs PLA*	➔ *More expensive than PVC* ➔ *Lack of design freedom vs PLA* ➔ *Negatively buoyant*	➔ *Lower UTS than PVC* ➔ *High machining time* ➔ *May need to be sealed for waterproofing*	➔ *Poor fatigue resistance* ➔ *More expensive than PVC and cPVC* ➔ *Lack of design freedom vs PLA* ➔ *Doesn't come in ½ inch diameter* ➔ *Far more expensive*

Figure 9. Frame Material Analysis; Created by V. Jagadeesan, S. Soma, and A. Freedman

Based off of this research, we decided to make our frame out of PVC. It is the most cost-effective, priced at $1.25 per foot, allowing our ROV to be built at the lowest cost possible. The open design of our PVC frame also provides accessibility for modifications and troubleshooting. PVC is also resistant to corrosion and abrasion, is a safe, non-toxic material, has good mechanical strength, is waterproof, and is a good insulator.

Our frame is designed to house six thrusters, a cylindrical electronics enclosure, two manipulator arms with grippers attached, and three cameras. We had to place the cylindrical electronics enclosure near the top of the frame because of its net positive buoyancy. When designing ROVs, it is optimal to place positively buoyant objects high and negatively buoyant objects low. Even with our new specs after overhauling *Triton, Triton II* still meets the size and weight requirements outlined in the MATE's RFP for maximum points (smaller than 60 cm and weighs under 33 kg).

Triton II ROV

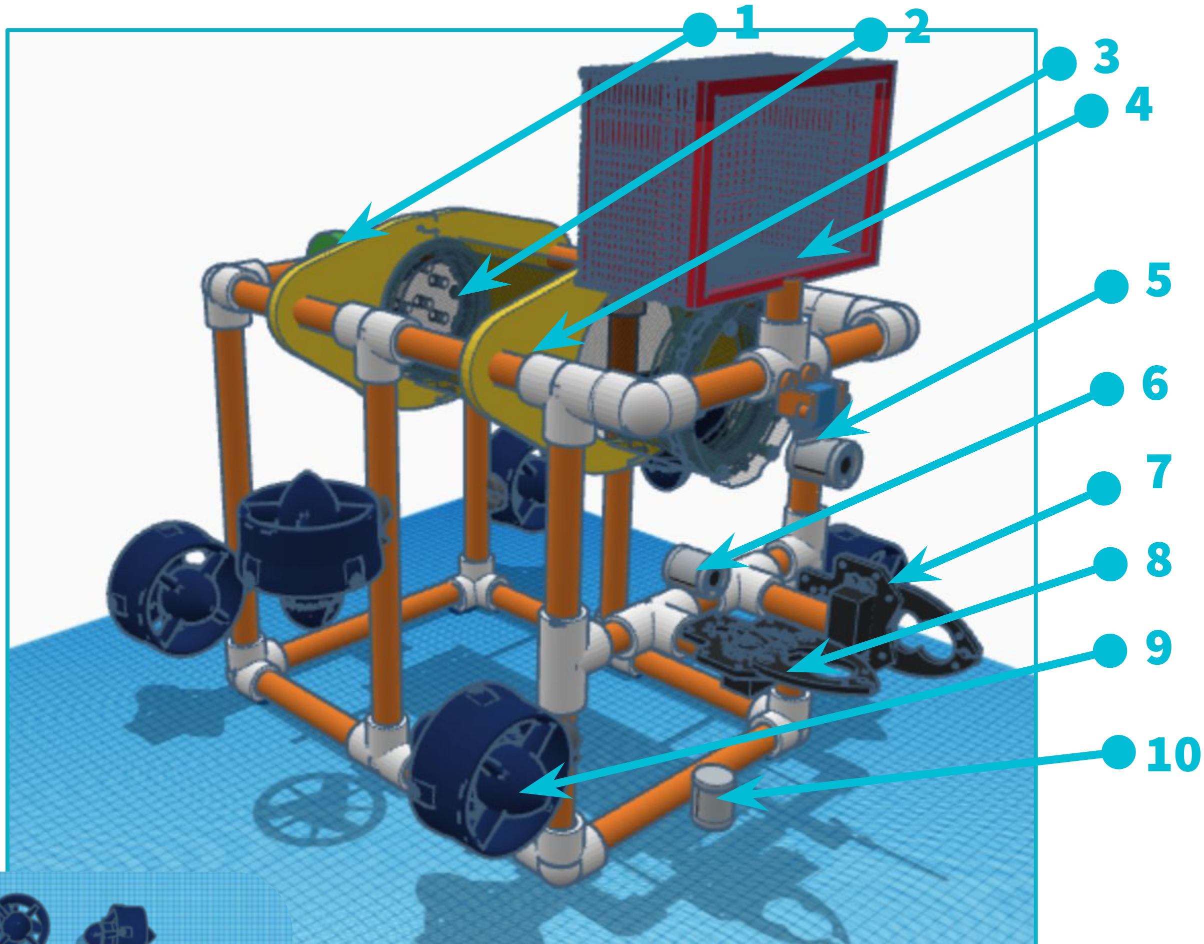


Figure 10. Triton II
Created in TinkerCAD by A. Freedman

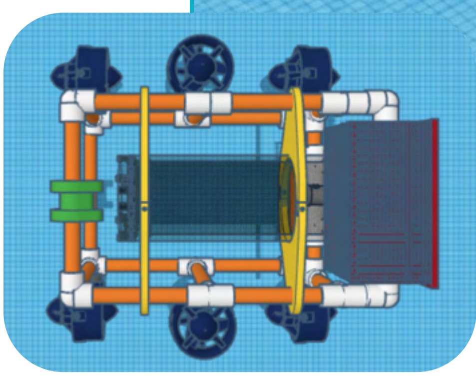


Figure 11. Top View of Triton II
Created in TinkerCAD by A. Freedman

1. Custom 3D tether thimble
2. Electronics enclosure
3. Custom 3D electronics enclosure holder
4. Surface Debris Retrieval Mechanism
5. Servo camera w/custom 3D mount
6. Camera with gripper view
7. Manipulator arm w/vertical gripper
8. Manipulator arm w/horizontal gripper
9. Blue Robotics T200 thruster
10. Camera with pool floor view

Micro ROV Triteia

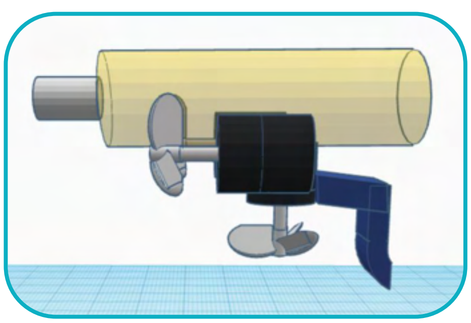


Figure 12. Side View of Micro-ROV: Triteia
Created in TinkerCAD by V. Jagadeesan

4.4 Buoyancy & Ballast System

Considering the tasks outlined in the RFP, our mechanical engineers wanted to make *Triton II* neutrally buoyant. A neutrally buoyant ROV hovers in the middle of the water column, making it more energy efficient and easier to pilot than a positive or negative ROV. An ROV can achieve neutral buoyancy by balancing the buoyant force with the weight force (see figure 14 for diagram). A state of neutral buoyancy ensures *Triton II* would be able to retrieve both the sunken debris from the pool floor and floating surface debris equally with ease.

One big change to *Triton II*'s design was the addition of a watertight electronics enclosure and two additional thrusters. Adding a positively buoyant electronics enclosure, coupled with the addition of additional payload, would make the ROV slightly negatively buoyant. Additionally, we acknowledged that our original flotation system (consisting of pool noodles) would prove ineffective at deeper depths. So we considered options for our flotation system.

As expected, when we placed *Triton II* in the pool, it was negatively buoyant. Our engineers mounted a 1½" ABS buoyancy tube at the back of the ROV to serve as additional flotation and correct its forward pitch. The tube is sealed with end caps and marine epoxy.

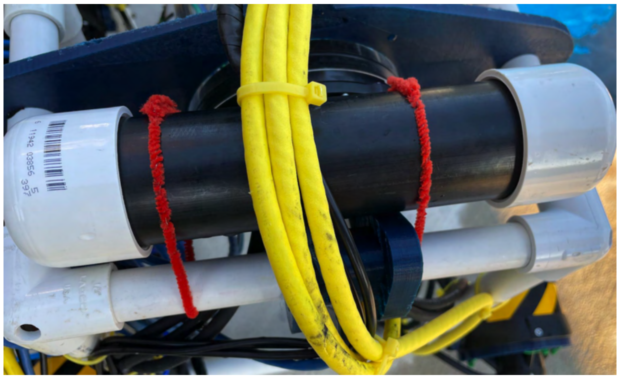


Figure 13. ABS Buoyancy Tube
Photo Credit: V. Jagadeesan

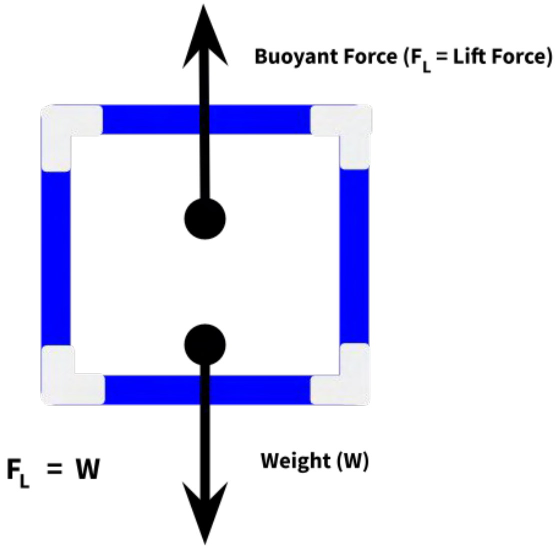


Figure 14. Neutral Buoyancy Diagram
Created on Google Drawings by V. Jagadeesan

4.5 Payload and Tools

Triton II's open frame design allows us to attach the payload and equipment necessary to complete the tasks outlined in the MATE Center's RFP.

4.5.1 Cameras (Purchased)

Triton's camera system incorporates three cameras: two fixed cameras and one camera mounted to a servo motor. The first camera faces forward, the second camera faces our dual manipulator gripper system, and the third faces downwards to observe the coral reef and subway car. The servo camera allows us to rotate the camera angle from 0-180 degrees.

Figure 15. Rear Backup Camera in Fixed Position
Photo Credit: D. Hou

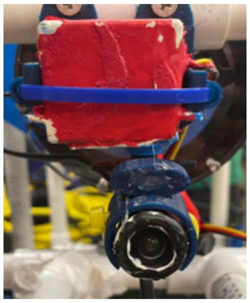


Figure 16. Servo Camera on Custom 3D Mount
Photo Credit: V. Jagadeesan

4.5.1 Cameras (cont.)

This is very helpful for both the coral reef flyover and photomosaic tasks. All three cameras enable the ROV pilot to assess and navigate the terrain while maneuvering underwater to complete the tasks. Rather than purchasing expensive sub-aquatic cameras, we repurposed and waterproofed car backup cameras using marine epoxy and liquid electrical tape.

4.5.2 Grippers (Reused)

Triton II features two adjustable manipulator arms, each with a servo-powered gripper at the end. These grippers are mounted onto adjustable PVC pipes, ensuring that we can change the angle of the grippers to best suit the task at hand. One of these grippers is mounted vertically, while the other is mounted horizontally. The versatility of *Triton II*'s manipulator system makes it well suited to complete the missions outlined in the RFP. For example, our vertical gripper makes it easy to retrieve plastic debris from the seafloor. Meanwhile, our horizontal gripper is used to disconnect and recover the Seabin power plug. *Triton II*'s two-gripper system also makes it easy to lift objects and carry them from place to place, such as the mussel bed quadrat in task 3.

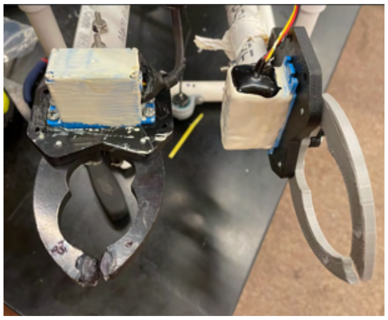


Figure 17. Dual Grippers
Photo Credit: V. Jagadeesan

4.5.3 Watertight Electronics Enclosure (Reused)

Due to using electronic speed controllers (ESCs) to operate brushless thrusters, our engineers recognized the need for a watertight electronics enclosure to house the ESCs. Our engineers chose to purchase a Blue Robotics 4" series watertight enclosure. The model's proven reliability and pressure resistance (up to a 100 meter depth), coupled with its relative cost-efficiency (priced at $67 vs. Robotic OCEANs Underwater Enclosure Plastic priced at $230), made it the most viable option for our company. Previous HMS SeaBots teams have attempted to construct makeshift enclosures to lower costs, but these prototypes could not match the superior waterproofing and pressure resistance of the Blue Robotics model.

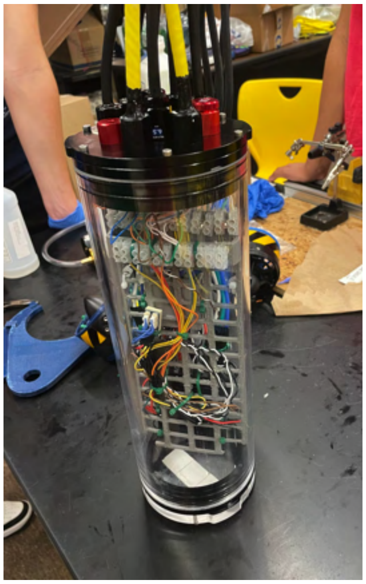


Figure 18. Watertight Enclosure
Photo Credit: V. Jagadeesan

4.6 Mathematical Tools

In Task 3, *Maintaining Healthy Waterways II: Delaware River and Bay,* the MATE Center has outlined a task pertaining to mussels in the Delaware Bay. We had to estimate the number of mussels in a bed using the quadrat method, and then calculate the filtration rate of all the mussels in the bed. To tackle this task, our engineers developed a spreadsheet to take input data to estimate the total number of mussels and their filtration rate (in liters/hour).

MATE Competition 2021 - Math Work for Mussel Bed				
Legend:				
input values in gray boxes				
output value (to submit to judge)				
	Inputs			
# of mussels in the quadrat		mussels		
size of mussel bed		meters times		meters
filtration rate per mussel		liters per hour		
	Outputs			
# of mussels in the whole mussel bed	0			
filtration rate of the whole mussel bed	0			

Figure 19. Mussel Bed Math Spreadsheet
Created in Google Sheets by D. Hou

4.7 Mission Specific Tools

4.7.1 Surface Debris Retrieval Mechanism (Reused)

In Task 1, *The Ubiquitous Problem of Plastic Pollution*, companies are tasked with recovering floating surface debris, represented by six ping pong balls. *Triton II* features a surface debris retrieval mechanism. This mechanism was built using a nylon aquarium net, which is capable of collecting all of the floating surface debris in one run. It is securely mounted to the ROV using a velcro strap but is easily detached when not in use. This mechanism is an example of an innovation resulting in higher functionality at reduced costs.

Figure 20.
Surface Debris Retrieval Mechanism
Photo Credit: A. Freedman

4.7.2 Autonomous Thruster Control

In Task 2, The Catastrophic Impact of Climate Change on Coral Reefs, companies must decide whether to either manually or autonomously fly a transect line over a coral reef to map the points of interest. Our company decided that developing a software program that allowed *Triton II* to fly autonomously over the reef would be advantageous for two reasons: 1) it would give us a new learning experience, and 2) we would earn more points for the task. After the ROV is positioned at a specific height over the coral reef, we begin the autonomous flight. We incorporated a pushbutton in the control box to enter autonomous mode. When flying autonomously, our four horizontal thrusters throttle forward for a fixed amount of seconds, until the *Triton II* has reached the end of the reef.

4.7.3 Image Recognition

In Task 2, our company plans to use image recognition to determine the health of a coral colony by comparing its current condition to past images. While companies were given the opportunity to do this assessment manually, the time saved by using an image recognition algorithm, not to mention the extra points provided, made the effort well worth it. The software was developed using Python and includes the OpenCV library. The program sets the two images to grayscale, then scans for the differences in the images and highlights them.

4.7.4 Micro-ROV: *Triteia*

In Task 3, *Maintaining Healthy Waterways II: Delaware River and Bay,* we are required to retrieve a sediment sample from inside a drain pipe. To complete this task, *Triton II* is equipped with a Micro-ROV (*Triteia*). *Triteia's* size is perfect for accessing the drain pipe, which *Triton II* can't access at all. *Triteia* has a velcro-front to collect the sediment sample inside the drain pipe. When not in use, she is attached to the top right of the main ROV's frame like a piggyback ride, and can be detached when ready to be deployed. Triteia has her own control box and tether. (FYI: in Greek Mythology, *Triteia* is one of *Triton's* daughters)

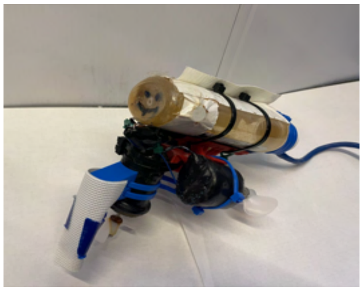


Figure 21. Micro-ROV (Triteia)
Photo Credit: A. Freedman

4.8 Custom 3D Printed Components

Triton II features various custom-designed components. These parts were designed and 3D printed to custom-fit our ROV's specifications. Advantages of 3D printing include reduced costs and improved design freedom. As our first prototypes of several custom components were flawed, we implemented an engineering design process (design, build, test, redesign) to perfect them.

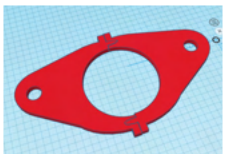
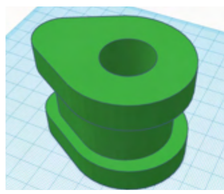
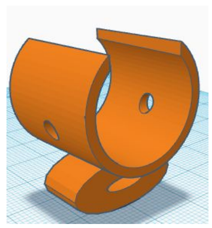
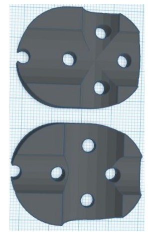
	Watertight Enclosure Holder	Tether Thimble	Servo Camera Holder	Motor Attachment	Joystick Holder
Image					
Purpose	To hold the watertight enclosure in place	To serve as a guide for our ROV tethers	To attach the camera to the servo motor	To attach the T200 thrusters to the PVC pipe frame	To hold the joystick in place on the control box

Figure 22. Custom 3D Parts; Created by A. Freedman and V. Jagadeesan

4.9 Control/Electrical System

4.9.1 Tether Requirements

As per the RFP, *Triton II* had to be capable of operating at a maximum depth of 4 meters (13 feet) and a maximum offshore distance of 10 meters (32 feet). With these numbers, we used simple geometry to determine a minimum tether length. As shown in figure XX, a right triangle is formed from the the depth, offshore distance, and tether length, with the tether length as the hypotenuse. We used the Pythagorean Theorem to calculate the minimum tether length needed to ensure we had enough tether length to complete the task at the furthest distance from the poolside.

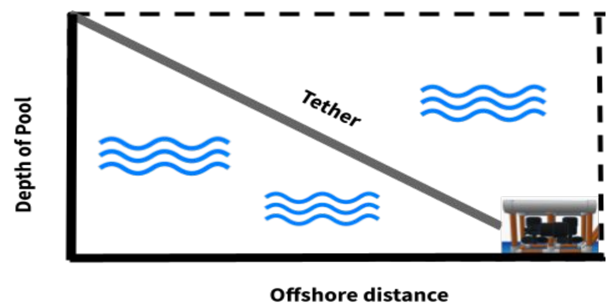


Figure 23. Tether Length Reference Diagram Created on Google Drawings by V. Jagadeesan

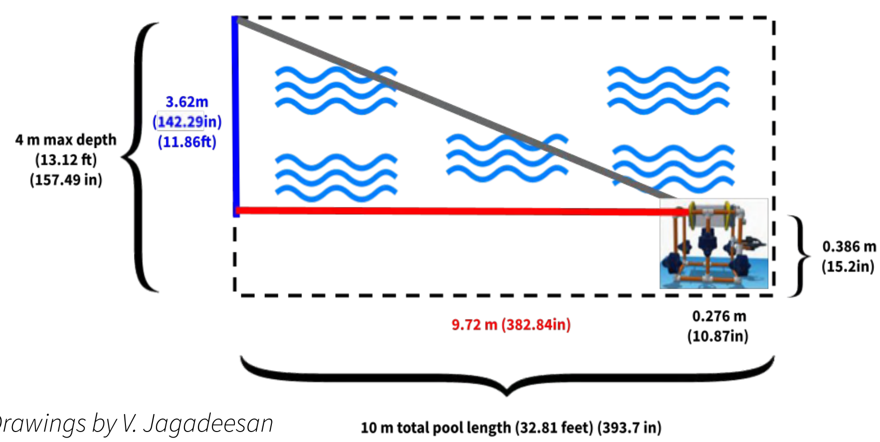


Figure 24. Tether Length Calculations; Created on Google Drawings by V. Jagadeesan

4.9.1 Tether Requirements (cont.)

We considered *Triton II's* dimensions during the calculations, specifically the vertical distance from the frame base to the tether attachment point. After making our calculations, we would need 10.36 meters (approximately 34 feet) of tether to meet the specifications in the RFP. After accounting for factors such as the distance from the pilot's seat to the poolside, additional slack that may be needed and extra maneuverability, our team deduced that *Triton II* should have a 13 meter (or 43 foot) tether.

4.9.2 Voltage Drop

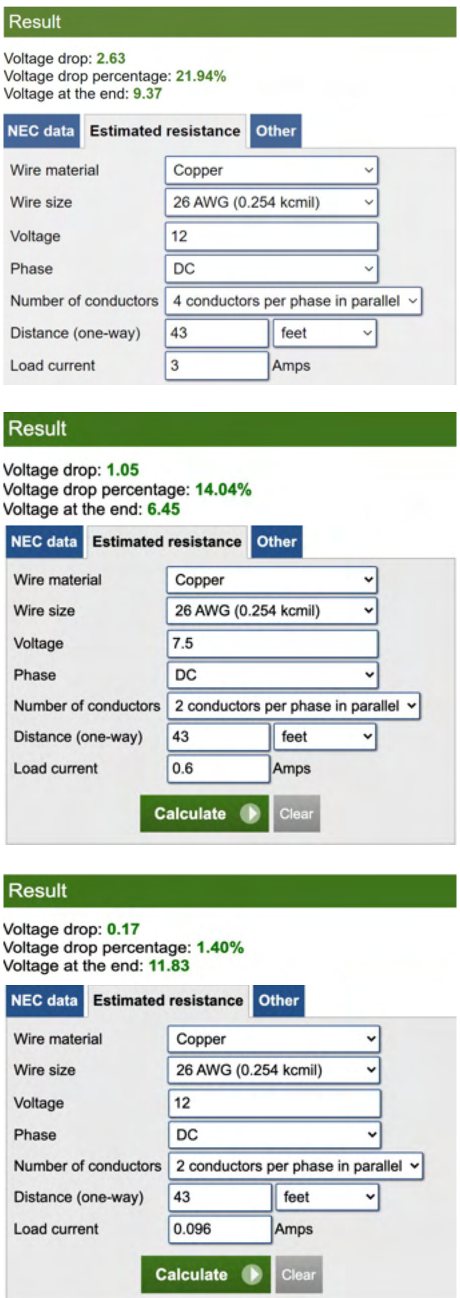


Figure 25. Voltage Drop Calculations by V. Jagadeesan

Voltage drop is the amount of electric potential, or voltage, lost due to electrical resistance. Voltage drop can result in reduced system capabilities, for example, lower the motor thrust or gripper strength. In severe cases, system failure may occur. Listed below are several factors we considered while selecting our tethers and determining the length of our tether.

Material: Metals with better electrical conductivity have lower resistance, and thus result in lower voltage drop. *Triton II*'s tether wires are made of copper, an excellent conductor.

Gauge (diameter): The cables delivering power to *Triton II* 's thrusters are 26 AWG, and a 24 AWG cable is used to power the Micro-ROV. 26 AWG cables were used for gripper power and signal and for the camera power and signal. Through calculations, our employees determined that these wire gauges resulted in minimal voltage drop, while also reducing the tether's weight.

Length: As mentioned previously, we used 43 foot tether lengths to minimize resistance. Longer tether lengths result in more resistance, therefore less voltage is pushing the current through the wire. However, we also considered the factor of extra maneuverability throughout the pool when selecting our tether size

Ampere Capacity: Our team determined the nominal current of each system component using Ohm's law and online voltage drop calculators. We calculated the voltage drop for each of the three subsystems: motors, grippers, and cameras. Each main ROV motor experiences 2.63 V of voltage drop, each micro-ROV motor experiences 0.77 V of voltage drop, each gripper experiences 1.05 V of voltage drop, and each camera experiences 1.68 V of voltage drop. After referring to component documentation and repeated testing, the team determined that the calculated voltage drop for our 43 foot tether had a minimal effect of the ROV's performance.

4.9.3 Tether Design

Seven tethers are implemented into *Triton II's* control system: three for our cameras, one for our servos, two for our thrusters, and one for our micro-ROV.

Like mentioned earlier, our thruster's tethers are 26 AWG, our micro-ROV's tether is 24 AWG, and the tether for our grippers and cameras are 26 AWG. All of our tethers are wrapped together with silicone tape at 1 ft intervals.

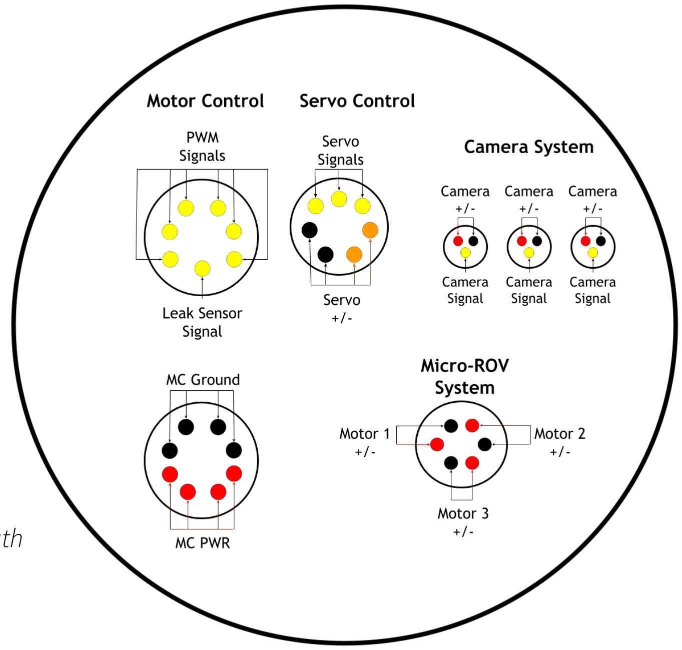


Figure 26. (Right) Tether Cross-Section Created on Google Drawings by A. Amarnath

4.9.4 Tether Management Protocol

Tether management is crucial to keep the ROV in perfect working condition. Our company's JSOs created a tether management protocol checklist:

01 During Deployment

- ❑ **Tether must be properly managed so it does not pose as a tripping hazard for poolside employees.**
- ❑ **Tether manager must be sure to properly control the tether while the pilot is maneuvering *Triton II* in the water.**
- ❑ **Strain reliefs are properly attached to keep our tether secure to the frame.**

02 Workplace Management

- ❑ **Tether must be kept away from sharp tools and objects to prevent nicks or cuts that may cause damage.**
- ❑ **Keep tether neatly coiled so it doesn't get tangled, twisted or knotted**

Figure 27. Tether Management Checklist Created on Google Drawings by A. Amarnath and V. Jagadeesan

5. Software System

5.1 Arduino Software

Triton II's control system features two Arduino microcontrollers. The first runs the ROV propulsion system, while the other controls the gripper system and the servo-camera. Our engineers chose Arduino for its intuitive IDE, wide compatibility, and relative cost efficiency.

5.2 Software Architecture

Before writing our code, our company developed software architecture which served as a blueprint, ensuring that our program fulfilled the requirements. This architecture outlines program algorithms and highlights major components, such as thrusters and servos. Through developing this architecture, we used strategies such as writing pseudocode, creating flowcharts, etc.

5.3 Motor Control

Triton II's propulsion system consists of six Blue Robotics T200 thrusters. As the motors are brushless, our engineers programmed six ESCs to operate the thrusters using pulse-width modulation (PWM) input. An Arduino Mega, located topside, reads and processes joystick input and signals the ESCs to operate the motors accordingly. An overview of the MC system is below (red indicates namespace, blue indicates setup, green indicates loop):

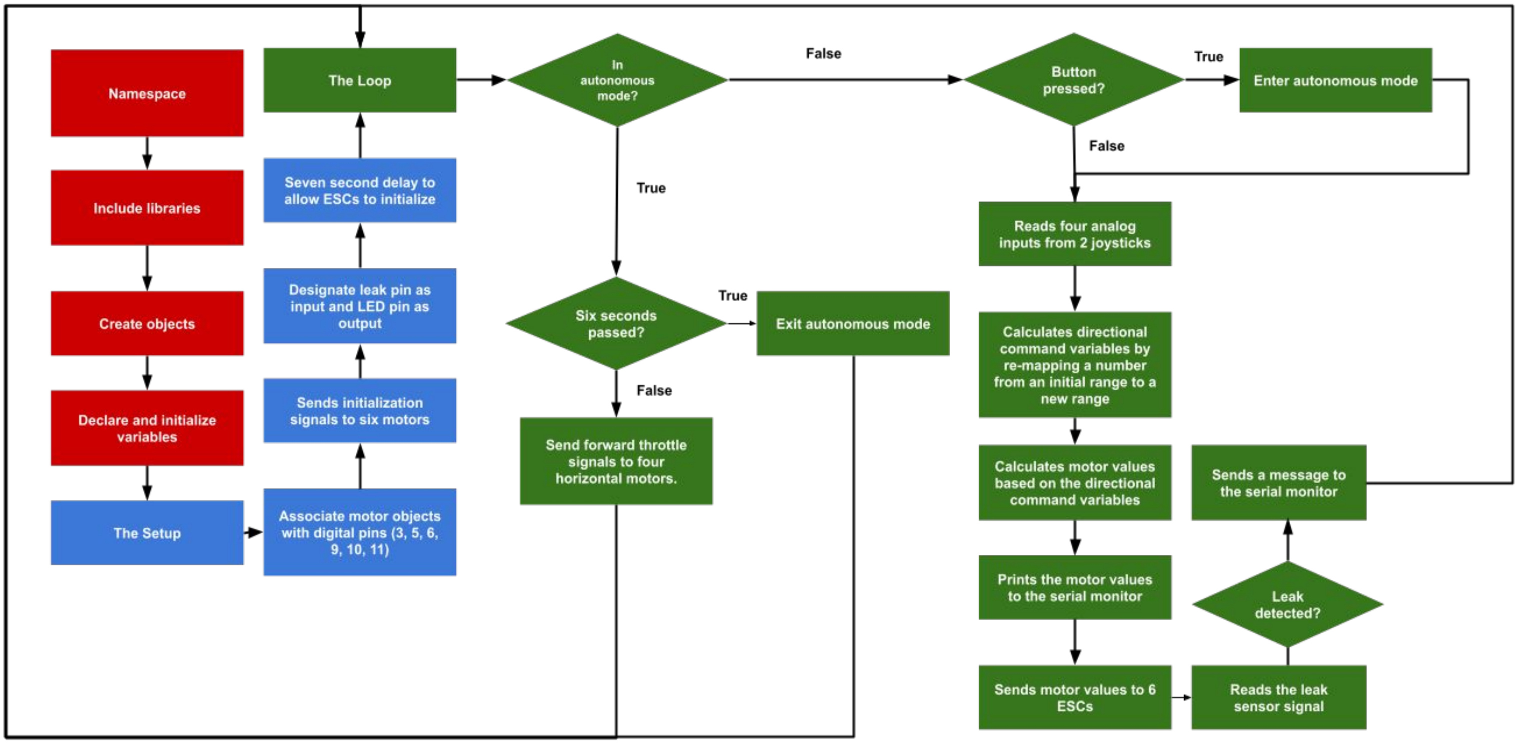


Figure 28. Flowchart for Motor Control
Designed in Drawings by V. Jagadeesan and A. Tornese

5.4 Servo Control

Triton II features an additional Arduino microprocessor that operates its gripper system and the servo-camera. The gripper system consists of two manipulator arms, each built from a Standard Gripper Kit A and a Hitec HS-646WP servo motor. The grippers are operated using pushbuttons. The servo-camera is operated using a potentiometer located topside. An overview of the SC system is below (red indicates namespace, blue indicates setup, green indicates loop):

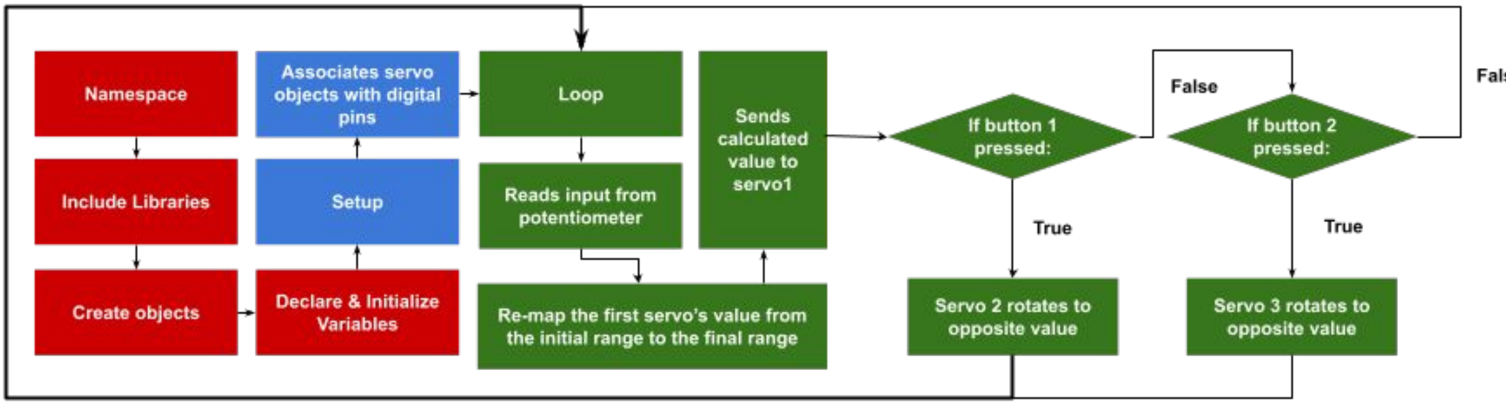


Figure 29. Flowchart for Servo Control
Designed in Drawings by V. Jagadeesan and A. Tornese

6. System Interconnections Diagrams (SIDs)

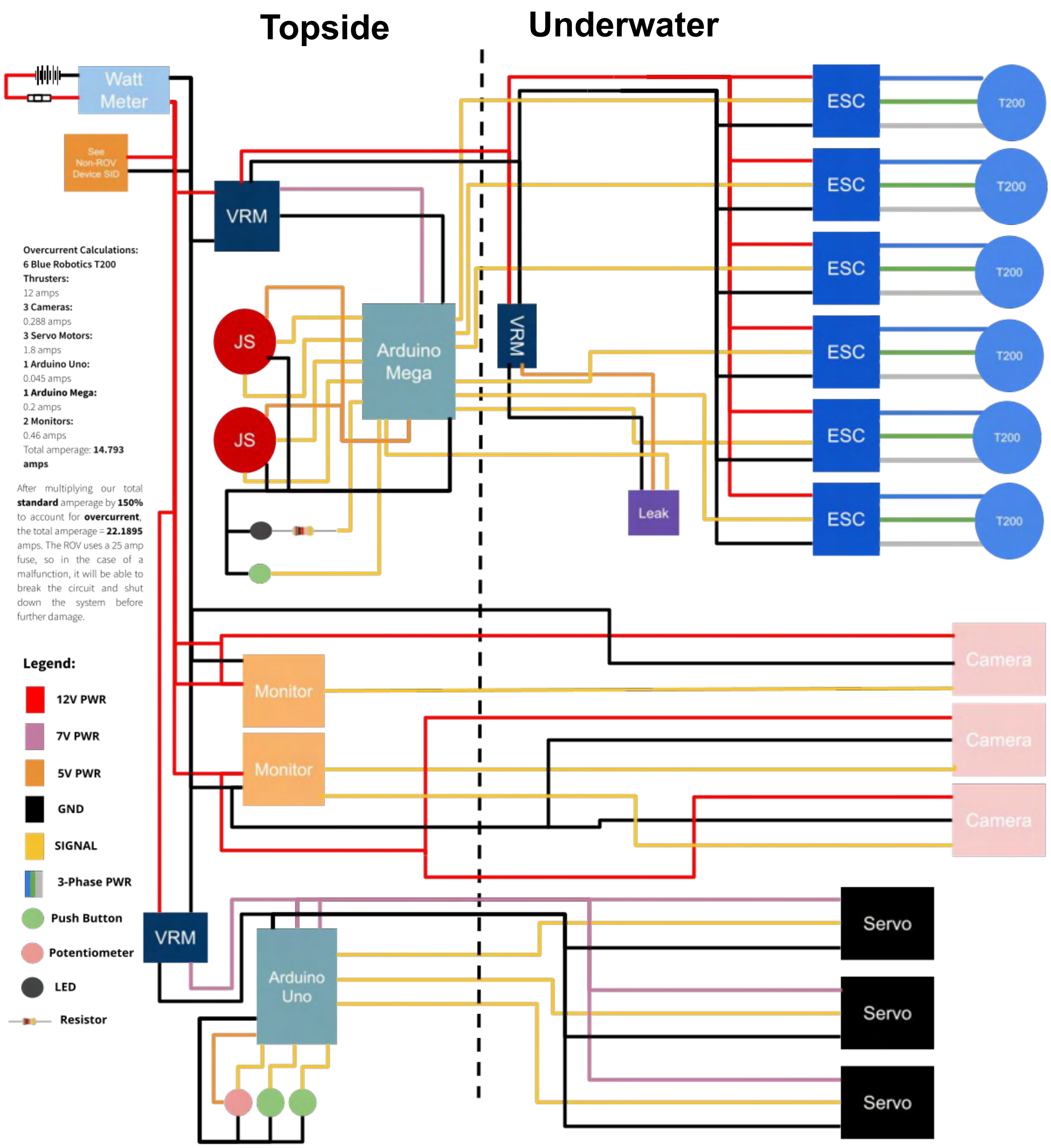
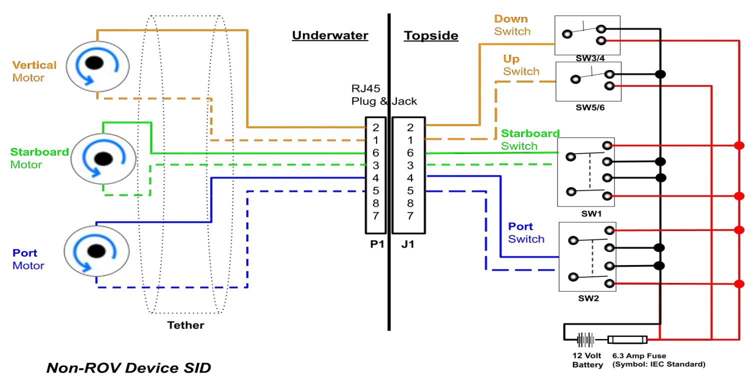


Figure 30 (Above). SID
Created on Google Drawings by V. Jagadeesan and A. Amarnath

Figure 31 (Right). Micro-ROV SID
Created on Google Drawings by A. Amarnath



7. Safety

7.1 Safety Philosophy

Our company prioritizes the safety and protection of our employees, as the process of building an ROV requires a lot of hands-on work. Our Job Safety Officers (JSOs) implemented several safety measures for the team. This ensured the maximum safety of the company's employees, whether on the poolside or in the workplace.

7.2 Safety Procedures: ROV Construction

During the process of constructing *Triton II*, we worked with potentially dangerous tools. The safety protocols we followed while construction *Triton II* are as follows:

Safety Checklist (ROV Construction)
✓ Workplace must be organized before starting a certain task.
✓ Tools, such as the soldering iron and drill, must be handled safely and properly.
✓ A JSO must supervise and assist when using these potentially dangerous tools.
✓ Goggles must be worn while soldering, drilling, and/or cutting PVC to prevent debris from entering eyes.
✓ Nitrile gloves must be worn when waterproofing and/or handling chemicals to prevent skin exposure.
✓ Two people should be always be present when doing tasks such as soldering, cutting, or drilling: one person uses the tool, while the other person stabilizes the item under construction.
✓ After completing a task, the workplace must be cleaned.
✓ Unplug any power tools or equipment when they are not in use.

Figure 32. Construction Safety Principles
Created by V. Jagadeesan

7.3 Safety Procedures: Operation of ROV

We recognized that there are several potential hazards before deploying the ROV. Below is the launch checklist to ensure safety when operating *Triton II*:

Launch Checklist (Operation of ROV)

Before Launch:

- ✓ Plug ROV into 12V battery.
- ✓ Verify that all components of the ROV are functioning properly and are firmly attached (i.e. ESCs are properly working when power is connected, enclosure is tightly secured to frame, etc.).
- ✓ Tethers should be managed properly and not be tangled.
- ✓ Make sure pool props are placed on the pool floor according to the MATE Manual Product Demonstration Setup map.

During Launch:

- ✓ Gently place the ROV into the water.
- ✓ In the case of an emergency or malfunction, immediately return the ROV to the surface and remove it from the pool for inspection.

After Launch:

- ✓ Return ROV to the surface side of the pool and power off the ROV.
- ✓ Dry off the ROV, and open the enclosure to let out any condensation that may have accumulated.
- ✓ Properly store away the ROV, tether, and control boxes.
- ✓ Make repairs for the next launch if necessary.

Figure 33. Launch Safety Principles
Created by V. Jagadeesan

7.4 Safety Features

Triton II is equipped with various safety features. These features are to protect the company members and the ROV from potential dangers. We have listed these safety features below:

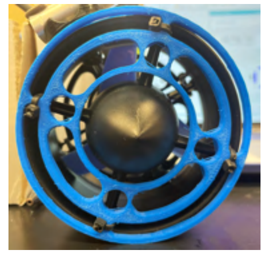
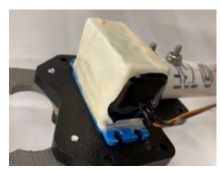
Feature	Purpose	Image
In-Line Fuse	The fuse will blow and break the circuit when the current exceeds 25 amps (the fuse size for the Ranger class). This immediately stops the flow of power and protects our electrical system from any damage.	
Motor Shrouds w/Thruster Guards	Our custom 3D-printed thruster guards protect employees from the ROV thrusters and block large debris from getting into the motors. The holes on the thruster guards meet IP20* standards. The motor shrouds are wrapped with yellow/black caution tape to warn employees to be cautious around the motors. *The Ingress Protection (IP) Code, is defined by the International Electrotechnical Commission who rate the degree of protection of waterproofing.	
Kill Switch	In the event of a malfunction, employees operating the control box can manually shut down the control system's power via a kill switch, which immediately shuts down the power to prevent further damage.	
Strain Relief	Strain reliefs prevent cables and connections from experiencing stress. They are used on every cable coming from our control boxes.	
Voltage Regulators	Voltage regulators ensure a steady, constant voltage supply to our electrical components. The regulators also adjust the input voltage for components requiring less than 12V.	
Waterproofing	In order to prevent water damage which can short circuit the control system, the cameras, servo motors and wire connections were waterproofed with a variety of methods including heat shrink, hot glue, splicing tape, liquid electrical tape and marine epoxy.	 
SOS Leak Sensor	The SOS leak sensor is housed in the watertight electronics enclosure. It will notify the operators if there is a water leak in the watertight enclosure.	

Figure 34. Safety Features Table
Photo Credit: V. Jagadeesan and D. Hou

8. Critical Analysis

8.1 Prototyping

Considering our time constraint, prototyping techniques helped our engineers develop intricate systems in a step-by-step manner. For example, our Motor Control (MC) engineers developed several prototypes before finalizing the complete system. Before interfacing our motors and joysticks, they wrote programs to test joystick input and thruster output. Software engineers proceeded to develop an initial prototype using a single thruster, ESC, potentiometer, and microcontroller to verify program algorithms before scaling to a larger system. Likewise, our Servo Control (SC) engineers built a preliminary prototype consisting of a single button, servo, and microcontroller to verify the control algorithms. Such prototypes ensured the SC engineers could perfect the software without consideration of extraneous system factors such as voltage drop.

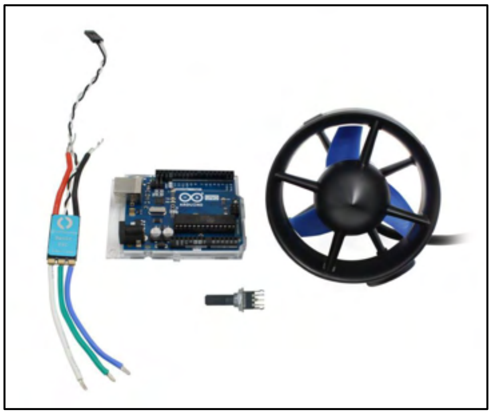


Figure 35. Representation of Our Initial Prototype
Image Credit: bluerobotics.com

8.2 Testing

Testing is a necessary aspect of system design, and thus each engineering cadre had significant experience with the testing process.

Through poolside testing, we gauged *Triton II's* initial buoyancy. As expected, the ROV was net negatively buoyant. Through repeated experimenting and adjustment, our team made *Triton II* neutrally buoyant by adding a buoyancy tube (See section 4.4 Buoyancy/Ballast System, for the reasoning behind a neutrally buoyant ROV).

Additionally, through frequent vehicle testing, we perfected *Triton II*'s ability to autonomously fly over the transect line in Task 2. Through trial and error, we calculated and hardcoded the time it would take the ROV to complete the flyover, ensuring we accounted for extraneous variables such as system voltage and amp draw. During these time trials, the ROV pilot also determined the optimal starting position for the autonomous flyover.

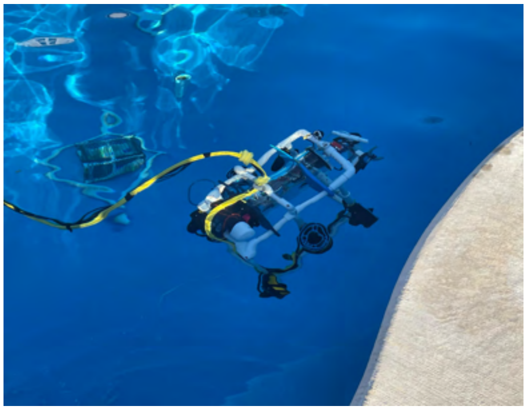


Figure 36. Poolside Testing
Photo Credit: V. Jagadeesan

Figure 37. Engineers Testing and Troubleshooting Triton II
Photo Credit: M. Barrett

8.3 Troubleshooting

As we built *Triton II*, our engineering departments had to overcome many challenges. In response, our engineers troubleshot these subsystems extensively, which allowed our company members to become more knowledgeable about the systems. Listed below are some of the issues our company had faced and the troubleshooting methodologies used to tackle them:

8.3.1 Mechanical & Servo Control Troubleshooting

Custom 3D prints: Our mechanical engineers used troubleshooting techniques while 3D printing custom parts. Initial attempts would often result in failed prints due to incorrect measurements, requiring multiple redesigns and reprints. What didn't help was that reprinting a single component often took several hours. After reprinting several pieces, we learned the philosophy of "measure twice, cut once" to prevent further errors.

Gripper issues: A problem that we encountered with our grippers was that they opened too wide (at an angle of 180 degrees). We corrected this error by reprogramming the gripper servo to only open at 120 degrees.

Servo Jitter: After programming and testing our servo grippers, we observed significant servo jitter. We traced the cause of this jitter to the source of our input, which comes from the potentiometers. Our software engineers decided to implement two push buttons as input. Repeated testing showed a significant decrease in servo jitter allowing us to complete the tasks more efficiently and effectively.

Gripper placement: Our original plan for the dual gripper system was to attach the grippers directly to the main body of the frame. However, the initial design was not versatile because the grippers were fixed and the angle could not be adjusted for different tasks. To solve this problem, we mounted both grippers on adjustable arms built from PVC tee connectors and 4 inches of ½" PVC pipe. This allowed us to reach items such as the eel trap that would have been out of reach had the grippers been attached directly to the frame.

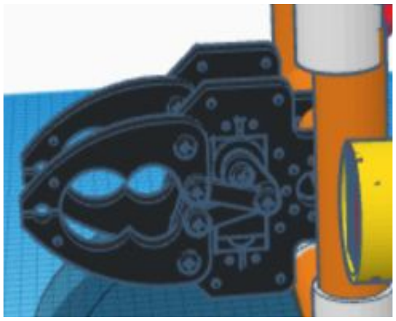


Figure 38. Former Gripper Placement
Photo credit: V. Jagadeesan

8.3.2 Motor Control Troubleshooting

When developing our program to control six thrusters, we recognized that some thrusters experienced jitter, while some did not operate at all. We recognized that the analog signals from the joysticks were not being received properly by the Arduino Uno through our tether, especially when the motors were run at high speeds. Our engineers proposed theories as to what may be the cause of the jitter:

ESC Functionality: First, we realized that two of our ESCs were not receiving PWM signals. We received new ESCs from Blue Robotics and replaced the dysfunctional ESCs. After integrating these new ESCs into the enclosure tray, all thrusters began functioning, but we still observed jitter from certain motors.

Microcontroller/Board Switch & Motor Calibration: Next, our engineers decided to replace the Arduino Uno board itself with an Arduino Mega as we thought changing the microcontroller might assist with the issue. Although it helped slightly, we still observed significant jitter. To combat this, we calibrated our motors, by fine-tuning our joystick data in the program. This was a noticeable improvement, but the motors still exhibited jitter, especially when run at higher speeds.

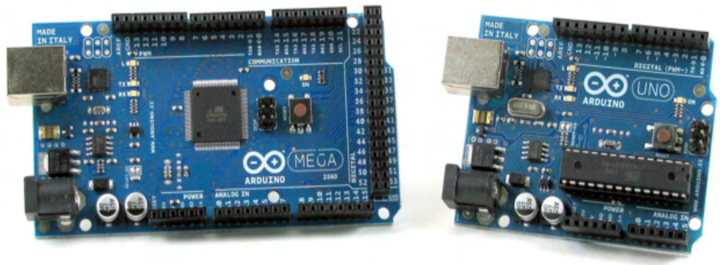


Figure 39. Arduino Mega vs. Uno (left to right);
Image Credit: robotshop.com

8.3.2 Motor Control Troubleshooting (cont.)

Program Review: Our engineers observed that when the motors were run at high throttles, joystick signals deviated from the standard range. To eliminate any abnormal joystick values greater than 631 - 639 PWM or less than 377 - 385 PWM, we included conditional statements to keep joystick inputs in check. While this resulted in being able to run the thrusters at higher speeds, the issue persisted.

Analog Signal Interference: Through extensive troubleshooting, our team deduced that analog signals could not transmit effectively in the presence of excessive amperage draw. At a specific amp draw, the motors would jitter. In theory (see graph below), a T200 operating at about 1692 PWM should draw 3 amps. However, with a six thruster configuration, each thruster could only operate at 1580 PWM without experiencing jitter. To operate the thrusters properly, our engineers had two options: either lower each motor's speed or decrease the number of motors. Both solutions would result in a significant loss of net thrust. Through research and testing, we recognized that the control system was capable of running the motors at higher speeds, if not for the analog signals experiencing impedance.

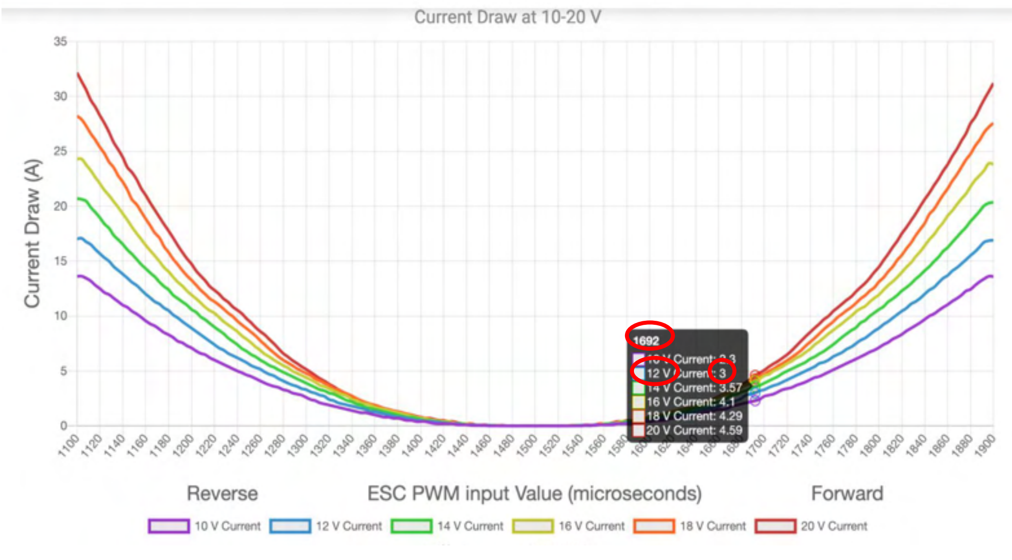


Figure 40. T200 PWM to Amp Draw Graph ; *Image Credit: bluerobotics.com*

PWM: After research, our MC engineers proposed a solution: instead of sending analog inputs through the ROV tether, we transmitted the PWM signals (from the Arduino microcontroller to the ESCs) through the tether instead. The team moved the Arduino to the control box (topside), and sent ESC-bound PWM signals through to the watertight enclosure. Through testing, our team recognized that increasing the number of thrusters and/or running the motors at high speeds did not negatively impact the signal transmissions, in contrast to the impedance observed with the analog joystick signals. In the four-step motor algorithm (detailed below), our original prototype placed our tether at point A. Our final system has the tether at point B.

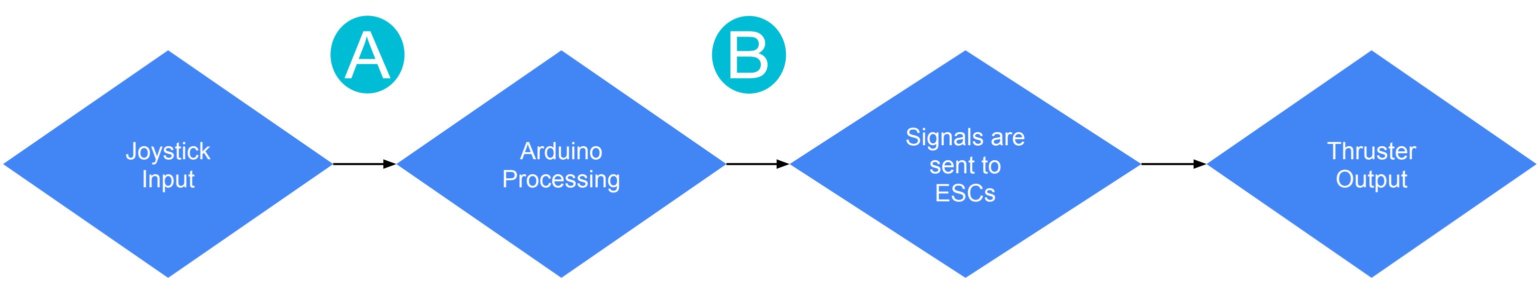


Figure 41. Motor Control Algorithm; Created on Drawings by V. Jagadeesan

8.4 Interpersonal Challenges, Lessons Learned, and Development of Skills

After the regional competition, our company was faced with a decision: whether or not we should overhaul our existing propulsion system (consisting of four bilge pump thrusters) with a new T200-based system. Though we believed that these new thrusters would make *Triton II* more agile and maneuverable, we acknowledged the immense amount of workload that would come with the change. Our company held a vote. The decision to make the change was passed with an 8-4 vote, and *Triton II* was born.

Ever since our journey began, our engineers have developed several skills, both technical and interpersonal. As we were under a time constraint, we learned invaluable time management skills. Through the build process, we also understood the importance of collaboration and diligence. Interpersonal skills aside, our engineers have gained various engineering skills. Mechanical engineers became proficient with 3D design. Servo control engineers learned how to program, wire, and operate servos. Motor control engineers mastered fundamental electrical and software concepts, such as voltage drop and Arduino programming. All our engineers gained extensive troubleshooting experience. Overall, our company overcame challenges, learned lessons, and developed important skills while building *Triton II.*

9. Accounting

9.1 Budget

Below is the company budget for this season's build. This budget was developed as an approximate allocation of our expenses at the start of the project. The company CFOs frequently referenced the budget to ensure that company spending would not exceed available funding:

HMS SeaBots Budget

School Name: Harrington Middle School — Start: 4/29/21
Coaches: Ms. Maureen Barrett and Ms. Marieve Patterson — End: 6/31/21
Mentor: Mr. Adithya Selvakumar

Income

Source	Amount
Harrington Middle School	$2,000
Exxon Mobile Grant	$500
Team family funding	$14,840.00

Expenses

Category	Type	Description/Examples	Projected Cost
Mechanical	Purchased, re-used, donated	PVC, thrusters, grippers	$5.40
Electrical	Purchased, re-used	Rear backup cameras, tethers	$388.00
Software	Re-used	Arduino Uno, VRMs, Hitech servos, sensor	$0.00
Miscellaneous	Purchased, re-used	3D printed parts, waterproofing materials, tape, etc.	$277.00
Competition	Purchased	Travel, hotel, uniforms	$14,840.00
		Total Income:	$17,340.00
		Total Market Value:	$17,100.00
		Total Expenses Purchased:	$15,510.00
		Total Expenses Re-used/Donations:	$1,590.00

Figure 42. Budget Planning
Created by D. Hou and H. Southard

9.2 Cost Accounting

The company CFOs maintained a project costing spreadsheet to track total expenses, and outline how total funding was distributed between the company's departments (mechanical, electrical, and software).

Project Costing

Date	Type	Expense	Description	Amount		Running Balance
MECHANICAL						
6-21-21	Donated	Frame	6 T200 Blue Robotics Thrusters	$1,074.00		-
6-21-21	Purchased	Motors	3D Motor Attachements	$0.90		$0.90
6-21-21	Purchased	Frame	6 3D Thruster Guard Sets	$4.50		$5.40
6-21-21	Re-used	Frame	135 inches o (1/2 inch)	$2.91		-
6-21-21	Re-used	Frame	5 PVC Tee's (1/2 inch)	$3.60		-
6-21-21	Re-used	Frame	8 PVC 3-way Conenctors (1/2 inch)	$16.00		-
6-21-21	Re-used	Frame	3D-printed Tether Thimble	$1.80		-
6-21-21	Re-used	Frame	3D-printed Servo Camera Holder	$0.20		-
SOFTWARE						
6-21-21	Re-used	Gripper Box	2 Arduino Unos	$42.00		-
6-21-21	Re-used	Gripper Box	3 Hitec Servos	$129.00		-
6-21-21	Re-used	Gripper Box	2 Standared Gripper Kit A	$20.00		-
6-21-21	Re-used	Gripper Box	4 Terminal Block Strips	$52.00		-
6-21-21	Re-used	Gripper Box	2 Voltage Regulators	$28.00		-
ELECTRICAL						
6-21-21	Re-used	Frame	3 Rear Backup Cameras	$60.00		-
6-21-21	Purchased	Control Box	6 Tethers	$300.00		$305.40
6-21-21	Purchased	Control Box	Power Cord	$8.00		$313.40
6-21-21	Purchased	Control Box	2 Camera Monitors	$80.00		$393.40
MISCELLANEOUS						
6-21-21	Purchased	Gripper Box	Magnets	$5.00		$398.40
6-21-21	Purchased	Gripper Box	Velcro	$3.00		$401.40
6-21-21	Purchased	Frame	Sealing/Waterproofing	$40.00		$441.40
6-21-21	Re-used	Frame	Caution Tape	$1.00		-
6-21-21	Re-used	Frame	Surface Debris Retreival Mechanism	$11.00		-
6-21-21	Donated	Frame	Watertight Enclosure Tube	$148.00		-
6-21-21	Purchased	Electronics	Watertight Enclosure Electronics	$229.00		$670.40
COMPETITON						
6-22-21	Purchased	Travel Cost	Flights and hotel	$14,000.00		$14,670.40
6-22-21	Purchased	Apparel	26 Team Uniforms	$840.00		$15,510.40
					Total Raised:	**$17,340.00**
					Total Spent:	**$15,510.40**
					Final Balance:	**$1,829.60**

Figure 43. Project Costing Notation
Created by D. Hou and H. Southard

10. Acknowledgements & Sponsors

What we encountered this year was quite different from any other experience ever. Through the pandemic, remote learning, and social distancing, it was extremely challenging to work as a team and build an underwater robot. Regardless of these challenges, our endeavors were made possible because of the support of certain

10. Acknowledgements and Sponsors (cont.)

individuals. We would like to start by thanking our coaches, Ms. Maureen Barrett and Ms. Marieve Patterson, and our mentor, Mr. Adithya Selvakumar. Without their tireless support we would not have been able to make it this far. Thank you to Ms. V. Vanessa Morris and Ms. Jane White for organizing the 2021 MATE PA Regional Competition, and thank you to all the MATE PA sponsors. We would also like to thank the Tornese family, the Jersey Wahoos Swim Club, and the Larchmont Swim Club for letting us test our ROV and practice in their pools. Additionally, we are very thankful to the Mount Laurel School District for their financial support of our MATE program, ExxonMobil for a STEM grant, and Horizon Robotics for their donated materials. Finally, none of this year's endeavors would be possible without the loving support of our families who provided us transportation to school, meals during our meetings, and for financing our trip to the MATE World Championship.

Figure 44. Sponsor Logos

11. References

1. "El Blog Del Plástico." *" PLA VS. ABS PLASTIC – THE PROS AND CONS El Blog Del Plástico*, elblogdelplastico.blogs.upv.es/2015/01/31/pla-vs-abs-plastic-the-pros-and-cons/.
2. MATE Educate, educate.materovcompetition.org/.
3. Posted June 8, 2018. "ABS, PVC, PEX or Copper? Which Is Better for Your Home?" *Diamondback Plumbing*, 2 Dec. 2019, www.diamondbackplumbing.com/residential/plumbing-repair/abs-pvc-pex-or-copper-which-is-better-for-your-home/.
4. "SeaMATE Store." SeaMATE, seamate.org/.
5. "Seabin Project - Cleaner Oceans for a Brighter Future." Seabin, seabinproject.com/.
6. "THE 17 GOALS | Sustainable Development." United Nations, United Nations, sdgs.un.org/goals.
7. "What Are the Differences between CPVC and PVC?" CPVC vs PVC Pipe Comparison and Differences, pvcpipesupplies.com/cpvc-vs-pvc.
8. "Home." Calculator.net: Free Online Calculators - Math, Fitness, Finance, Science, www.calculator.net/voltage-drop-calculator.html.
9. "Underwater ROVs, Thrusters, Sonars, and Cameras." Blue Robotics, 9 June 2021, bluerobotics.com/.
10. ROV, MATE. "Safety Inspection Tutorial." MATE ROV COMPETITION, M. Gardener, 2021, files.materovcompetition.org/2020/scoring/2020_Safety_Inspection_Tutorial_EX-RNG.pdf.
11. "Voltage Drop Calculator." Calculator.net: Free Online Calculators - Math, Fitness, Finance, Science, 2021, www.calculator.net/voltage-drop-calculator.html.
12. "Collaborate & Create Amazing Graphic Design for Free - Canva." Canva, www.canva.com/.
13. "From Mind to Design in Minutes." Tinkercad, www.tinkercad.com/.
14. "Google Workspace." Google Workspace | Business Apps & Collaboration Tools, Google, workspace.google.com/.
15. Moore, Steven W., et al. Underwater Robotics: Science, Design & Fabrication. Marine Advanced Technology Education (MATE) Center, 2010.
16. Mhproductionhouse. "LEARN OPENCV in 3 HOURS with Python | Including 3xProjects | Computer Vision." YouTube, YouTube, 25 Mar. 2020, www.youtube.com/watch?v=WQeoO7MI0Bs.