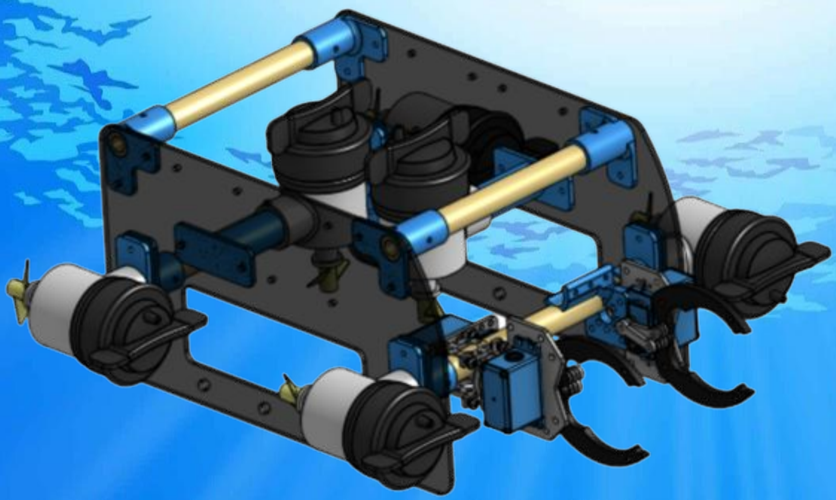
HMS SeaBots



HMS Polaris
CAD created on Onshape
Credit: Mechanical and Software Engineers

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Abstract

We are the HMS SeaBots, a company made of 16 highly skilled engineers committed to designing and building remotely operated vehicles (ROVs). Our ROV, the *HMS Polaris*, was designed in response to the 2022 MATE request for proposals to accomplish tasks related to Marine Renewable Energy, Offshore Aquaculture and Blue Carbon, and Antarctica Then & Now.

HMS Polaris is specially equipped for the real-world tasks that include replacing damaged cables, managing marine environments, creating vertical profiles, and mapping the *Endurance* shipwreck. Our team of electrical, software, and mechanical engineers drew on innovation, collaboration, and sheer determination to develop an ROV to tackle these environmental challenges. *HMS Polaris* has several unique features. One special feature is a dual-action gripper that can rotate to orient vertically and horizontally. This gripper setup allows our pilots to complete missions such as removing ghost nets and replacing inter-array cables. Another special feature is that 1 of our 4 cameras has night vision capability to help pilots see in poor visibility situations under the ice. This camera system utilizes a digital video recorder (DVR), allowing pilots to see all 4 camera views simultaneously on 1 monitor. Our company also designed and built a vertical profiler equipped with a buoyancy engine to complete 2 vertical profiles required to diagnose conditions below ice. These and other advanced features of *HMS Polaris*, as well as the diverse skills of our engineers, are the heart of the HMS SeaBots, a company ready to tackle the 2022 MATE missions.

Figure 1: HMS SeaBots Team Photo
Photo credit: Ms. Barrett

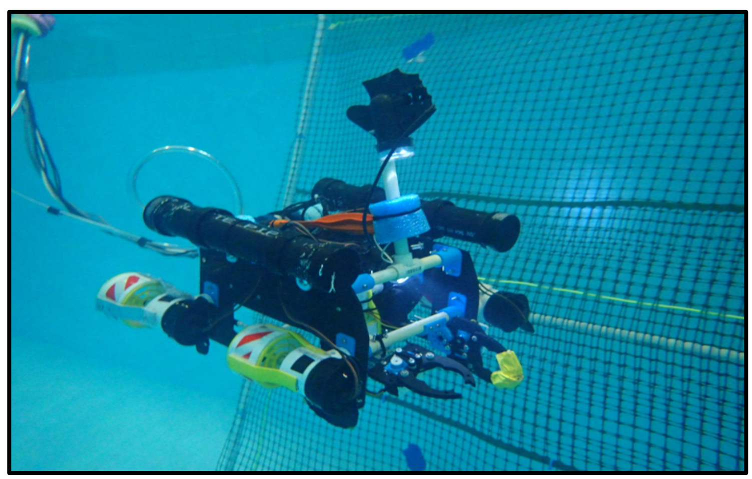


Figure 2: HMS Polaris in Action
Photo credit: Saketh

Company Overview

Instead of having a traditional CEO of the company, **leads were assigned to each engineering department**. The leads were responsible for communicating their progress with the other department leads, similar to a functional organizational structure.

Mechanical Engineers

- Design ROV frame on CAD software
- Construct ROV frame
- Determine proper placement for 6 thrusters
- Design custom shrouds and motor thruster guards

Software Engineers

- Write code for grippers, image recognition, and photomosaic
- Wire cameras and monitor
- Build software control box
- Design and program vertical profiler

Electrical Engineers

- Build main control box
- Secure wires in control box
- Wire motors and attach them to frame
- Use strain relief to secure tethers to ROV
- Waterproof all connections

Time Management/Schedule

We used the following schedule to manage our time. This allowed us to effectively assign tasks, manage our company's productivity, and address all problems as they arose.

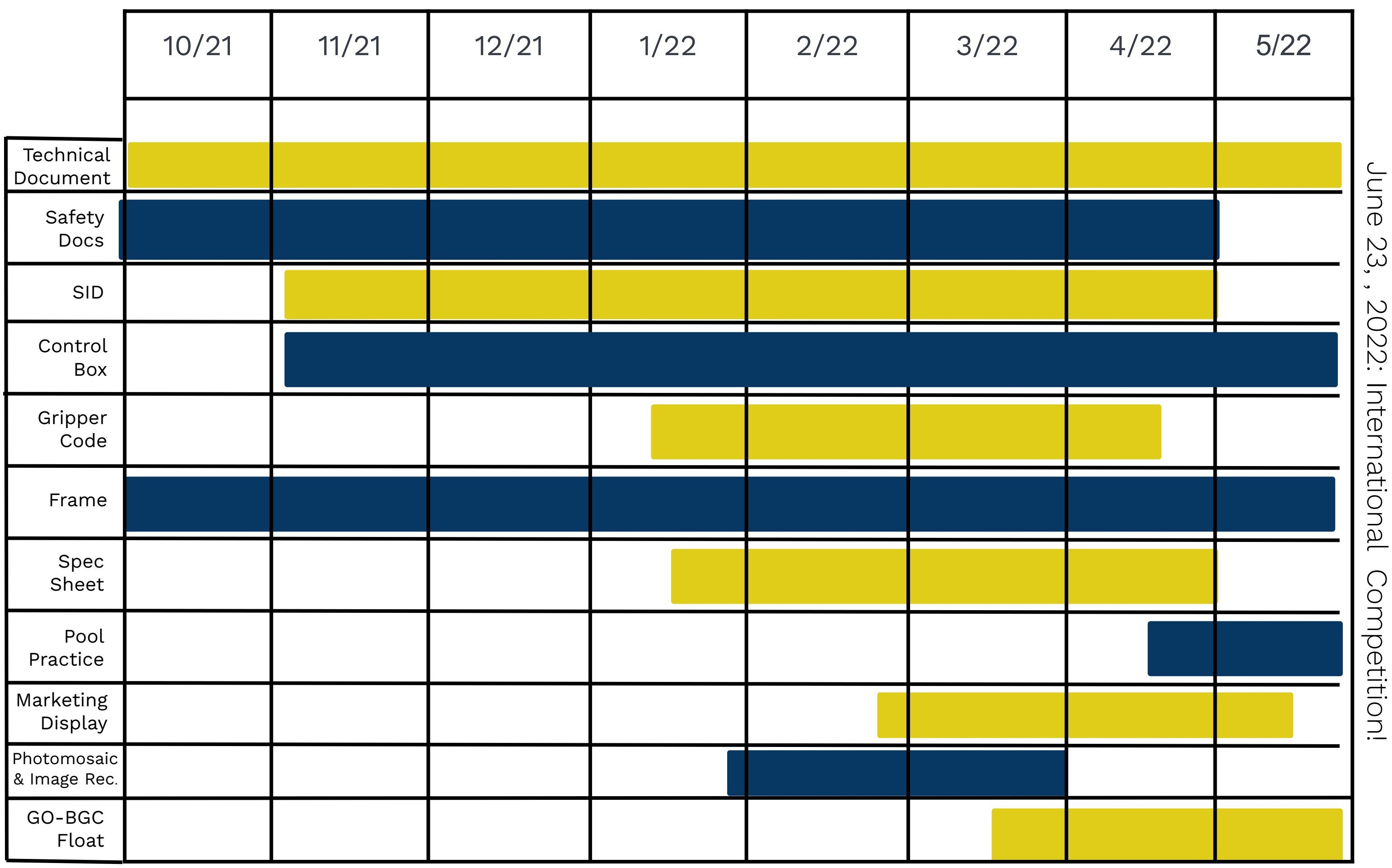


Figure 3: Gantt Chart Time Management Schedule
Credit: Amogh and Harleen

Organization Methods & Daily Operational Procedures

We used various organizational methods and daily operational procedures to help keep everyone well informed of work that needed to be done. One of our main organizational strategies was to **document what we planned to accomplish each meeting**. This way, every company member knew the plan of action and it ensured an efficient use of working hours. This allowed us to manage our time to complete set tasks. We made sure that everyone was working diligently, using our goals for the day as benchmarks so that we could progress as much as possible each day. If a company member struggled to reach the goal, a department member or department lead would step in to help. At the end of each meeting, our company discussed what was accomplished and what needs to be done at the next meeting. We also made sure that everyone had access to the tools and resources they needed. We were expected to put the tools and supplies away neatly at the end of each meeting. This procedure helped us to find and use those supplies in the future. Whether we were offering peer to peer assistance, conducting research, or following up with a mentor, our company made sure that everyone felt confident and contributed.

Design Rationale

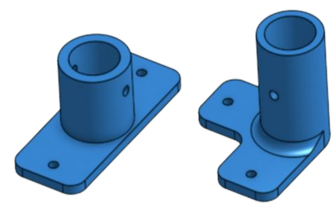


Figure 4:
Custom Design Connectors
Credit: Krithik

Engineering Design Rationale

Our goal was to create an ROV as **lightweight** as possible and best equipped for the 2022 tasks. After careful analysis of our performance at the New England Regional, we realized that our robot had lots of room for improvement. Even though we qualified for the World Championship, we wanted to increase the **speed and maneuverability** of the ROV to better accomplish the tasks. This robot was built out of ½" Schedule 80 PVC, which was weighing the robot down. The first brainstormed option was to change the ½" PVC (schedule 80) to ½" schedule 40 PVC, which was lighter due to thinner walls. Another idea was to completely redesign our frame with an completely different and lighter material. After conducting research on a variety of materials (chart on page 6), we decided to use **UHMWPE (Ultra High Molecular Weight Polyethylene)**. According to the material specifications, UHMWPE is less dense and lighter in weight than PVC. This idea meant that we would have to spend extra time redesigning and rebuilding a new frame, forfeiting 2-3 weeks of pool practice. We were willing to make these trade-offs.

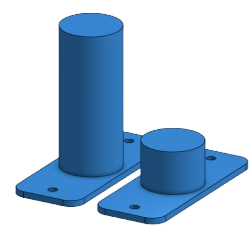


Figure 5:
Custom Design 3D Printed Motor Mounts
Designed in Onshape
Credit: Krithik

Our new frame is made of 2 plates of 3.175 mm (⅛") thick UHMWPE. We designed our frame in the CAD software *Onshape* and cut the frame pieces using a Glowforge laser cutter. The plates are connected in the middle using ½" CPVC pipes with custom designed 3D printed connectors (Figure 4), and the thrusters are attached to the frame with custom designed 3D printed parts (Figure 5).

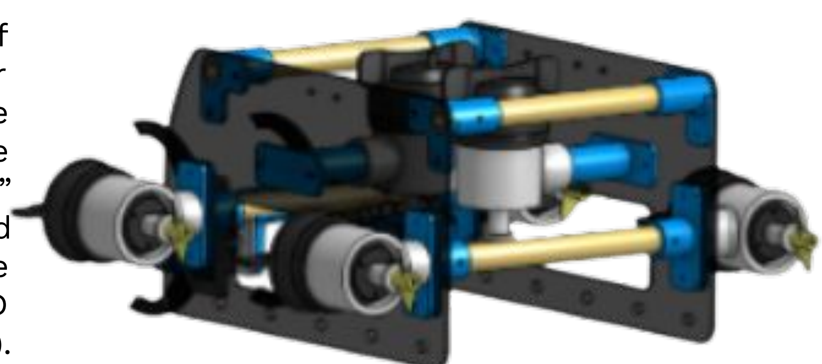


Figure 6: Back-Side of Final ROV
Designed in Onshape
Credit: Krithik

We utilized 6 Johnson bilge pump motors. We positioned 4 thrusters horizontally, and 2 vertically. This decision was made because we wanted more to horizontal thrust and speed rather than vertical thrust. To get more vertical thrust, we incorporated a variable ballast system (page 10).

Innovation

- Custom designed frame made of **UHMWPE plates with custom 3D printed PLA (polylactic acid) connectors and motor mounts**
- **Dual-action gripper** that can rotate 180 degrees to perform a variety of tasks at various angles
- **Four cameras** strategically positioned to give our pilots multiple perspectives. One camera is a **night vision camera** to see in low visibility situations.
- Cameras controlled by a **4-channel video DVR** to manipulate video feeds and record underwater footage
- **Photomosaic program** to take 8 discrete photos at high resolution to be autonomously stitched together to create a photomosaic of the *Endurance* shipwreck in Task 3.2
- Custom **vertical profiler** that autonomously completes 2 vertical profiles required in Task 3.1 MATE Floats!
- **Custom-made program** that allows us to determine the longitude and latitude of the vertical profiling float using the variables provided by MATE
- **Hand-crafted AI code** that distinguishes dead fish (morts) from video footage provided by MATE for task 2.2

Problem Solving

Mechanical

We brainstormed different frame materials and then researched their specifications. Using this information, we found that UHMWPE was the best material for our ROV due to it tensile strength, cost, and the fact that it can be cut using the laser cutter that was available to us.

	Acrylic	Polycarbonate	HDPE	UHMWPE
Cost (12" x 24" x ⅛")	$19.94	$10.67	$14.96	$13.92
Weight (g/cm^3)	1.19 g/cm^3	1.2 g/cm^3	0.96 g/cm^3	0.975 g/cm^3
Tensile Strength (PSI)	11,030 PSI	8,000 PSI	4,600 PSI	5,800 PSI
Glowforge Friendly	No	No	Yes	Yes

Electrical

We started our build season with a partially built control box that our team members began during the 2019-20 season. Our electrical engineers never finished this control box due to the COVID shutdown. However, this box could not be finished due to a fault within the circuit board. We brainstormed different ways to fix the problem. Our first attempt involved avoiding the entire circuit board. This solution worked well when tested with 4 motors, but we faced several issues when it was run with 6 motors. The horizontal motors would run when they weren't supposed to, even after calibrating them, and we frequently smelled burnt electrical components. The root of this issue was the relationship with splitting joystick signals with the Sabretooth motor controller. We finally solved this problem by adding a third joystick which let us pair each joystick with its own Sabertooth motor controller. Although this solved our electrical problem, our pilot would have to adapt to using a third joystick, which he was able to.

Figure 7: Motor Control Box (Top View)
Photo Credit: Coco

Systems Approach

Our team used a systems approach to simplify and organize our thoughts. We applied a **hierarchy technique** in which we identified all the separate systems that work together to make our ROV function. Our ROV is considered our "**supersystem**" which is composed of several "**subsystems**." Our subsystems consist of frame, propulsion, buoyancy, vision, and payload tools. All of these subsystems are designed by their specific division (electrical, mechanical, and software). We strongly believe that using a systems approach is beneficial because: 1) it simplifies and organizes the components and subsystems; 2) it is an easy way to divide the labor based on the specific subsystem; 3) It saves time because work takes place on different subsystems simultaneously.

Vehicle Structure

Our rationale for the ROV structure was to be **cost effective** while optimizing efficiency in reference to size and weight. Our ROV frame was first made of ½" PVC pipe and PVC connectors. When we built our ROV it was too big. We thought a large ROV would be better at completing the tasks. However, we soon realized that a lightweight ROV would be easier to maneuver and more energy efficient. Because of this, we decided to remove several connecters and reduce the amount of PVC pipes on the frame. After our regional competition, we decided to switch to UHMWPE plates for our frame with custom-made 3D connectors, and CPVC pipe. Though the cost for the UHMWPE was a little more expensive than the PVC, the decision to change the frame scaled down the ROV's size to 45 cm x 44 cm x 40 cm and the weight to 4.5 kg. Our smaller, compact frame increased our maneuverability and speed.

Vehicle Systems

Subsystem	Relevant Emergent Property
Frame	Our mechanical team constructed a cost-effective frame consisting of UHMWPE plates, CPVC, and custom 3D printed connectors.
Buoyancy	Two buoyancy tubes mounted on the top of the ROV are supplemented with a variable ballast system. This consists of a balloon, aquarium tubing, and a hand pump. Inflating the balloon allows us to return to the surface faster and in addition to retrieving objects such as the buoyancy module in task 1.2. Many of the components in this system are reused.
Propulsion	We used 6 1250 GPH Johnson bilge pump motors for thrust. 4 of our thrusters are for horizontal movement and 2 are for vertical movement.
Power/ Control	Our ROV is powered by a 12-volt battery. We have 2 separate control systems. The electrical control box controls the motors via the joysticks. Our software control box operates the cameras and grippers. Our power/control subsystem was constructed with reused materials.
Vision	Our camera system consists of 4 cameras positioned in such a way that our pilots have an open field of view. The cameras are connected to a DVR that receives all 4 camera inputs and displays them on the main camera monitor. Our cameras and monitors were reused.
Payload Tools	Our gripper system consists of 1 dual-action gripper and 1 single gripper. The dual action gripper can rotate to open both vertically and horizontally. This allows us to grab objects at various angles, including picking up the hydrophone in task 1.3 and the seagrass in task 2.4.
Tether	Our software team is using 4 tethers (3 tethers for our camera system; 1 tether for the payload gripper system. Our electrical team utilized two 4-pair 18 AWG tethers for the thrusters.

Figure 8: Vehicle Systems Chart
Credit: Harleen and Samyak

Control/Electrical Systems

We have 2 control boxes: a propulsion control box (our main box) and a software system control box. The main control box provides power to our thrusters and consists of 3 joysticks, 3 Sabertooth motor controllers, and a power distribution block. The software control box receives power from the main control box. Our software box consists of an Arduino Mega, a 4-video channel DVR, a joystick, a potentiometer, a voltage regulator, and a power distribution block. Both control boxes have a kill switch for the safety of our team and ROV.

Propulsion Control System

To control our propulsion system, we used 3 analog **joysticks**. Each analog joystick has 2 potentiometers (variable resistors) which are wired to the **2 X 5 Sabertooths**. When the joysticks are used, the potentiometers are turned, which then creates analog signals. Those signals are then forwarded to the 2 X 5 Sabertooths. They take input from the joysticks and then output different amounts of power to each of the 6 thrusters. Depending the direction and magnitude of the joysticks, we can reach various speeds and positions to more efficiently maneuver around the pool floor.

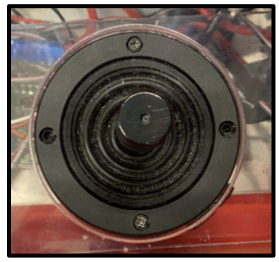


Figure 9: Joystick on the Main Control Box

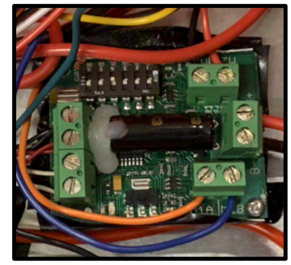


Figure 10: Sabertooth on the Main Control Box

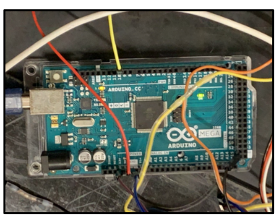


Figure 11: Arduino Mega on the Software Control Box

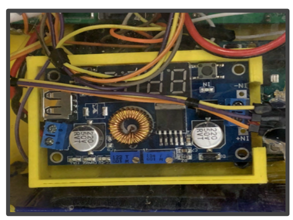


Figure 12: Voltage Regulator on the Software Control Box

Software System

To power the **Arduino Mega**, we have a **voltage regulator** adjusting 12V DC coming from the main control box to 7V DC. From the Arduino, we send 5V of power to the joystick and potentiometer, which controls our rotating gripper and stationary horizontal gripper respectively.

Tether Design, Management, and Protocol

Tether Design:

Our tether bundle consists of 7 tethers.

- 2 18 AWG wires are used for the thrusters.
- 5 wires go from the cameras and the grippers to the software control box.

Since numerous tethers were used, floats were added to reduce drag and prevent them from damaging mission props.

Tether Management:

We designated one person to be our tether manager. Roles of the tether manager include:

- Make sure that there are no tangles/damage in the tether.
- Ensure that the tether flotation is properly attached and evenly spaced.
- Check if self-bonding adhesive tape is applied to keep tether bundle together.
- Respond to pilot's feedback during the product demonstration to ensure tether is not being snagged during the product demonstration.
- Create and follow the tether management protocol.

Tether Management Protocol:

- Check that tether strain relief mechanisms are properly attached to the ROV.
- Properly coil tether after every pool practice using velcro ties to prevent damage and stop tangles and/or kinks in tether.
- Inspect tether for cuts or damage before and after every pool practice.
- Replace self-bonding adhesive tape as necessary.

Propulsion

Our ROV has 6 thrusters: 4 horizontal and 2 vertical. We decided to use Johnson bilge pump motors because we had many used motors in stock, saving us money in our budget. We could also choose between 500 GPH (gallons per hour) or 1250 GPH motors, so we weighed the pros and cons of each motor. As seen below, the 500 GPH draws less current and is slightly lighter in weight. The 500 GPH seemed like the better choice until we ran a Bollard test to calculate the force in Newtons (N) of the 1250 GPH motors vs. the 500 GPH motors. We held 3 test runs for each type of motor. One very important thing that we noticed was that the force in Newtons of the 1250 GPH motor was almost **40% more force than the 500 GPH motor**. This was an extremely desirable feature given the missions and anticipated depth; hence, we decided to use 6 Johnson bilge pump 1250 GPH Motors for our ROV. Our motor placement allows for great mobility of our ROV, providing control in multiple directions. In addition, the force provided by the 1250 GPH motors made it easy to complete tasks that required the ROV to pick up mission props, such as the sea grass, inter-array cable, and mort.

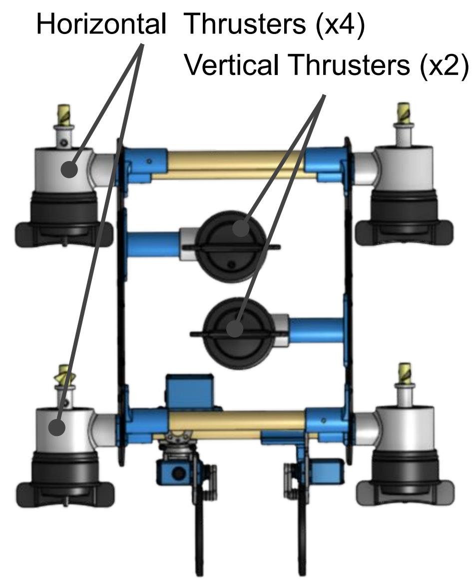


Figure 13: Thruster Placement: Top View of HMS Polaris
Credit: Krithik
Designed in Onshape

Johnson Bilge Pump Motor Comparison

GPH (Gallons Per Hour)	Max Amp Draw	Dry Weight (lbs)
500	2.5	0.60
1250	3.0	0.70

Figure 14: Johnson Bilge Pump Motor Comparison Chart
Credit: Samyak

Bollard Test: Motor Thrust Measured in Newtons (N)

	Trial 1	Trial 2	Trial 3	Average Force
500 GPH	0.25 N	0.24 N	0.22 N	0.24 N
1250 GPH	0.25 N	0.41 N	0.31 N	0.36 N

Figure 15: Ballard Test Chart
Credit: Samyak

Buoyancy and Ballast

We wanted our ROV to be **neutrally buoyant**. Hovering in the middle of the water column would be beneficial for two reasons: to be more energy efficient and for easier piloting.

One of the most prevalent options for floatation devices for ROVs are pool noodles -- they are inexpensive and can fit any size and need. However, we realized that pool noodles would become saturated with water and lose effectiveness over time, especially at deeper depths. A better alternative to pool noodles is buoyancy tubes. We made our tubes out of 1½" ABS pipes with end caps on both ends. We tested various lengths of pipe until we determined the exact length needed for our robot to be neutrally buoyant with no load on the ROV.

However, our testing depicted issues when lifting heavier objects such as the buoyancy module. To solve this new problem, we added a **variable ballast system**. It consists of a balloon, aquarium tubing, and a hand pump. With this system, we can control the ROV's vertical placement in the water by pumping air into the balloon that is mounted on the top of the ROV. Filling the balloon makes the ROV less dense than the water and therefore **positively buoyant**, making it float to the top. Once objects are transferred to the surface side of the pool, air is released from the balloon and our ROV becomes neutral buoyancy again.

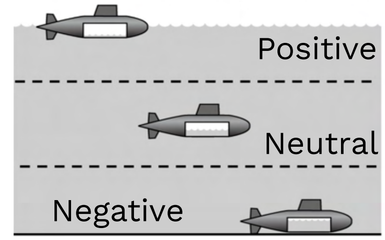


Figure 16: Three Types of Buoyancy Made in Google Drawings Credit: Akanksha

Figure 17: Variable Ballast System in Action Photo Credit: Ms. Barrett

Payload and Tools

Camera Systems

Our ROV features **4 cameras**. Every one of our cameras has been strategically placed to ensure that our pilot and co-pilot have the largest field of view possible. Camera #1 is pointing straight ahead of the ROV so that the pilot can navigate accurately and have the greatest chance at completing all the mission tasks. Camera #2 points at our grippers to assist our copilot in accurately picking up or transporting mission items. Camera #3 points downwards in order to complete Task 3.2. This involves taking photos of the *Endurance* shipwreck and then upload the photos to our stitching software. Camera #4 is facing the rear end of our ROV. This allows the ROV to be safely maneuvered backwards.

Arduino Software

Our software team decided to use the **Arduino Mega** and its software to serve as a means of communication between the servo motors and the pilots. Our decision to use this specific microcontroller was an important one because the communication to the servos (and therefore to our gripper system) is instrumental in completing almost every task required by our clients. Arduino IDE is an open-source platform that communicates through the Arduino boards. The IDE is consumer friendly and provides programmers with great versatility while being a simple and clear programming space. We chose to use the Arduino Mega 2560 because we felt they are very user friendly. The Arduino Mega 2560 has 54 digital PWM capable I/O pins and can take 7 to 12 volts to power. This helps us a great deal because with this, we are to connect our Arduino to the same power supply as our servo motors. As you will see in our comparison chart in Figure 18 on the next page, the Arduino Mega was the right choice for our team.

Comparison of Microcontrollers

Name	Arduino UNO	Arduino Mega	Raspberry Pi
Real Time Processing	✔	✔	✔
Reading Analog Input	✔	✔	
Compatibility			✔
C/C++	✔	✔	✔
# of Pins	21	54	40
Cost	✔		
User Friendly	✔	✔	
SRAM		✔	
Cost	$24	$31	$42

Figure 18: Comparison of Market Leading Microcontrollers
Credit: Amogh

Software Architecture

To create the code for the servo motors, we first imported the servo library. This allowed us to access different functions that correlate to the servos, such as *Servo* and *.attach*. After importing the servo libraries, we named the 3 servos by using the *Servo* function. We then attached the servos to their corresponding pins using the *.attach* function. This allowed us to send value to the pins, resulting in the movement of the servos. We then included script to name the potentiometers and joystick as inputs, and then proportionally map their “input value” to the optimal 180 degrees of rotation. The script then maps the value of the potentiometers and joysticks and “writes” it to the servo, resulting in rotation to the desired angle.

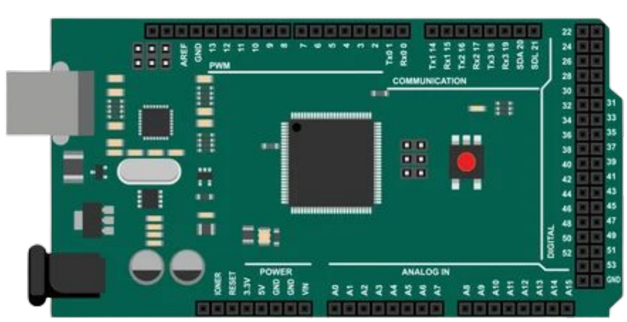


Figure 19: Arduino Mega Clipart
Credit: Shutterstock

Figure 20: HiTEC D646WP Servo Motor
Credit: Shutterstock

Image Recognition

Our company implemented **AI Image recognition** so that we can identify morts (dead fish) on the bottom of the sea floor, which is a part of task 2.2. To create our image recognition model, we first trained a custom weight, which is a file containing images created from the given training videos. Next, we used 3 of the testing videos linked in the MATE Ranger manual and pinpointed every mort in the video. We then applied the model with an accuracy threshold of 50% to the other 9 testing videos. Our training program was based on the newest form of image recognition called YOLOv5 which is the fastest and most optimal form of image recognition for our company because it produces accurate results without an abundant amount of training models and without using a lot of resources and time. YOLOv5 works by splitting the video frame-by-frame and then checks for any distinctive features in the photos that we provided from our model. Using these defining features, the model checks the frame for similarities from the training images. If it is more than 50% confident that a particular section of the frame matches a training image, it draws a red bounding box around it with the percent confidence next to the word “Morts.”

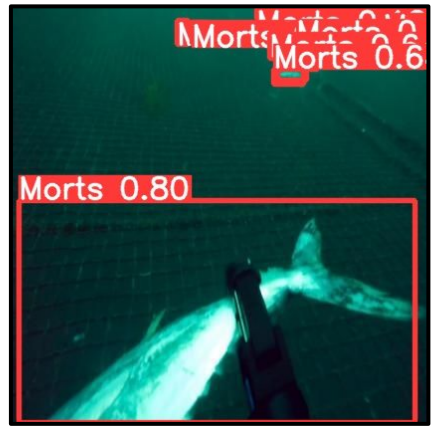


Figure 21: Test photo of AI Mort Detection
Credit: Krithik

Image Recognition Flowchart

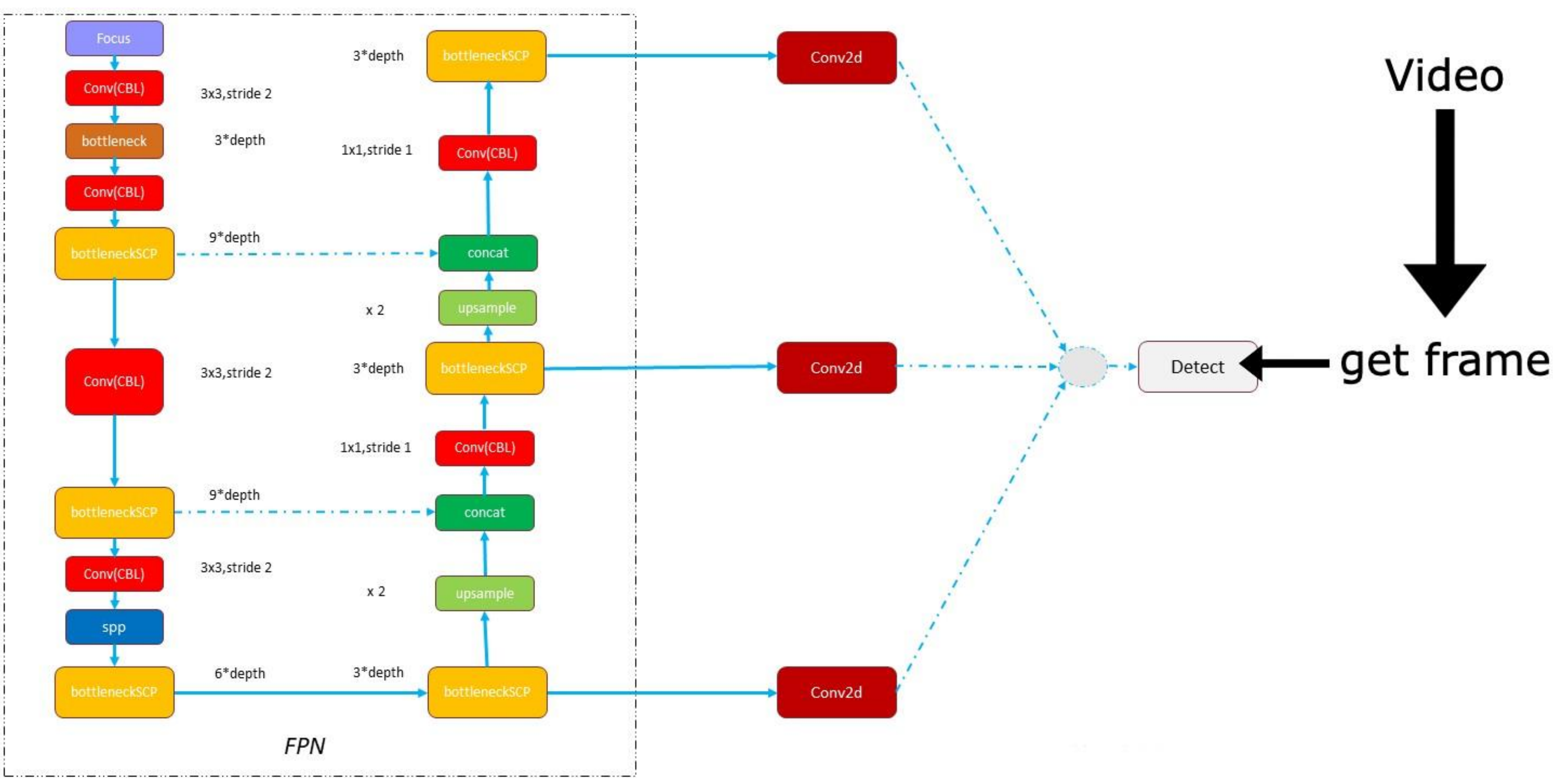


Figure 22: AI Image Recognition Flowchart
Designed in Google Drawings
Credit: Krithik

Photomosaic

In Task 3.2 “Endurance22”, companies must take photos of the *Endurance* shipwreck while flying over it. These **photos must then be stitched together** to show the entire ship. We could opt to do this manually, but our team decided to put the photos together autonomously. This sounded great on paper, but the real challenge was making the program itself. We decided to use Python 3.9, due to it being the latest version to which we had access. We started off with the 2 main packages: 1) OpenCV, to take the images 2) Pil, to put the images together. The program starts off by initiating a loop that displays the video input in a window, and whenever we pass over a rectangle that we need an image of, we tap the keyboard spacebar to take the photo. After taking 8 photos, we save the photos using Opencv, and we put those photos together using the PIL package.

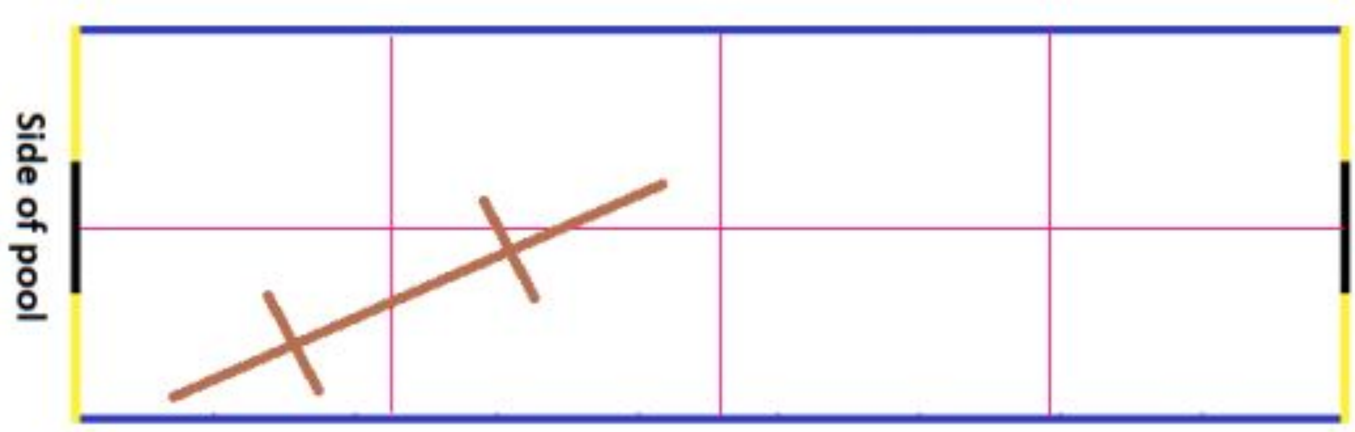


Figure 23: Endurance Shipwreck
Credit: MATE Ranger Manual

MATE Floats!

In task 3.1 “MATE Floats”, We were tasked with calculating the distance from start to finish that a MATE float travels over a certain period of time. We brainstormed multiple options to complete this task. We could have a person on the pool floor that calculates the distance and location of the MATE float, or we could create a software program to do the calculations. We chose the one that would probably be more accurate: the software approach. We used Python 3.9 using PyCharm as our Python interpreter. We approached this problem with trigonometry. We calculated the distance from the starting to ending point using the distance and time formula: $d=t(3.6s)$. We used that distance as the hypotenuse for the right triangle that would be equal to the longitude and latitude from the start to end of the MATE float’s journey. We calculated all of that in 2 equations using d as our hypotenuse, a and b as the 2 legs and D as the degrees (provided by MATE on the pool floor). Because we need a right triangle, we cannot have an obtuse angle in the triangle as D, so we subtract D by 90 until we have a number that is less than 90 degrees. Our equations were finalized as $a=\sin(D)\cdot d$ for the longitude and $b=\cos(D)\cdot d$ for the latitude. This gave us our desired result as seen below.

```
Enter the meters per second the float is traveling at: 0.098
Enter the amount of hours the float has been traveling: 116
Enter the degrees the float is traveling at assuming that 0 degrees is north: 144
The float moved 40.92 km at 144 degrees.
 Calculations show that translates into movement of 33.10497540982285 km South, and 24.052172523808 km East.
```

Figure 24: Test of MATE Float Program
Credit: Krithik

Photomosaic Flowchart

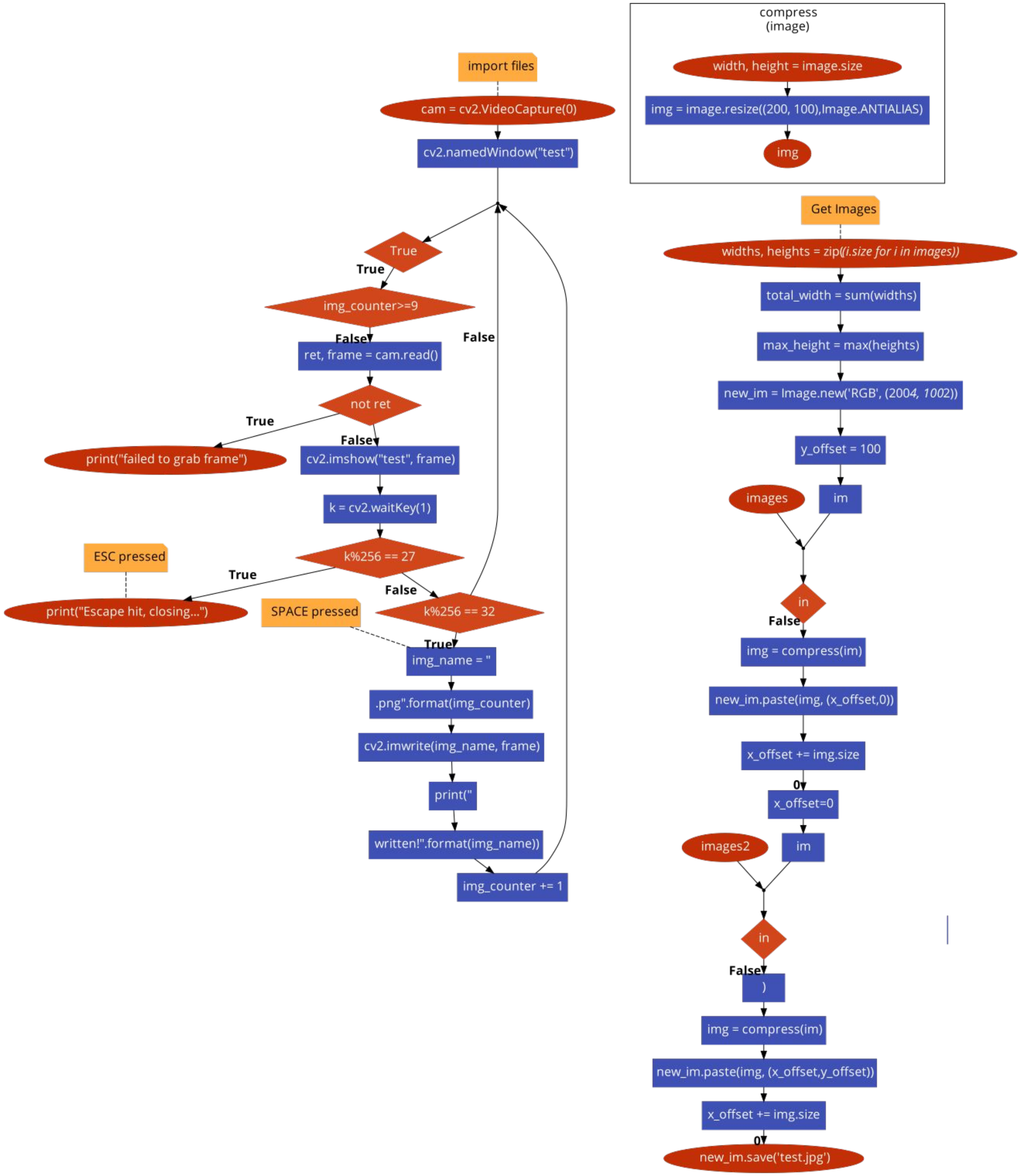


Figure 25: Photomosaic Flowchart
Credit: Krithik in Google Drawings

MATE Floats! Flowchart

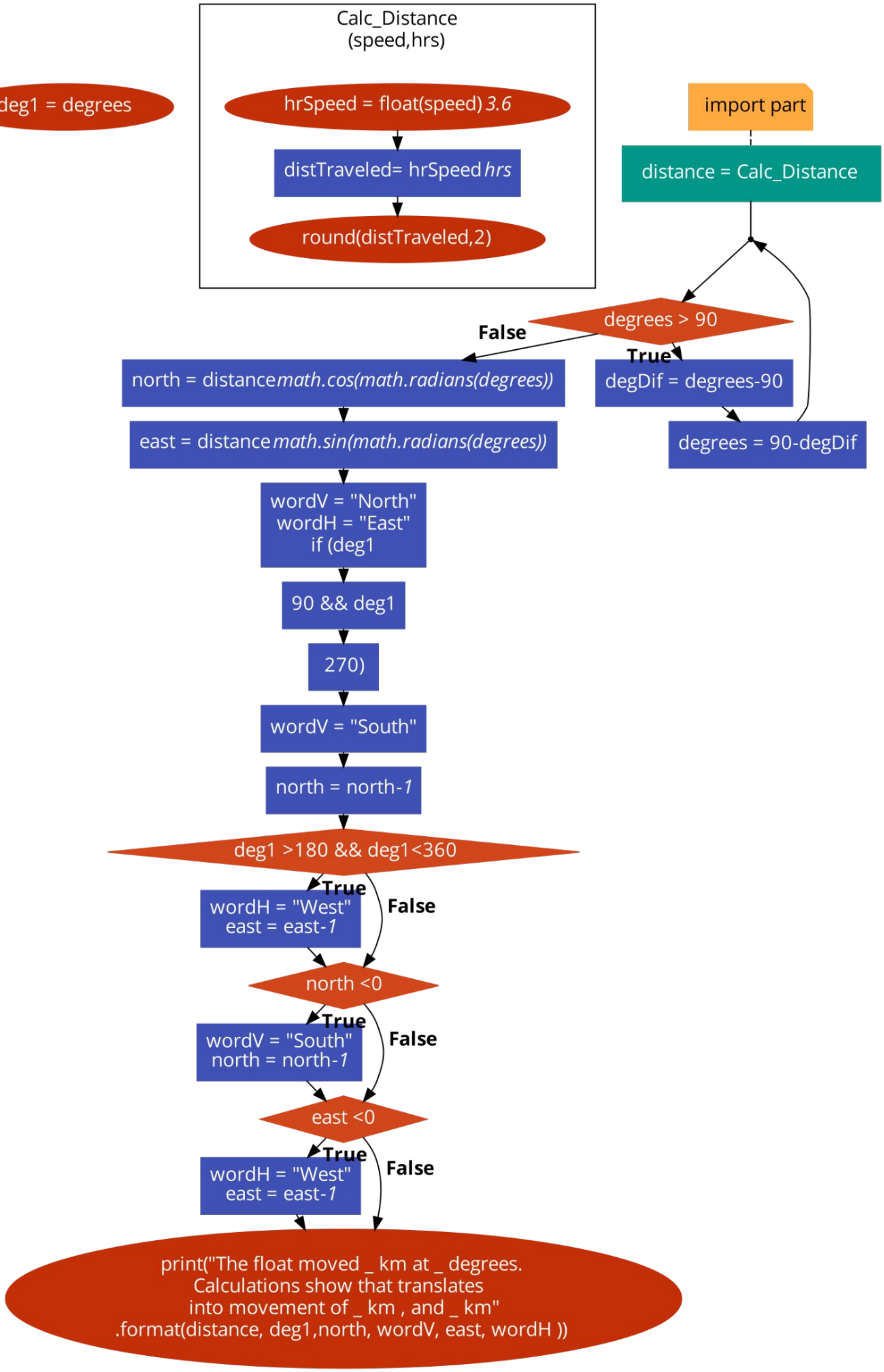


Figure 26: MATE Float Flowchart
Credit: Krithik

Vertical Profiling Float

During Task 3.1, we were asked to design and create a **vertical profiling float** that completes 2 vertical profiles from the surface of the ocean to the sea floor. Our software engineers used the *SeaGlide AUV* for inspiration, an AUV sold by RoboNation. We liked their idea of using a syringe to take in water to change the buoyancy and, in turn, complete a vertical profile. Our AUV float, *Lil' Vert*, consists of an Arduino UNO to control a continuous rotation servo motor enclosed in a water bottle. The servo motor is attached to the plunger with a piece of all-thread so that we can draw water in and expel water out of the bottle making *Lil' Vert* sink and float, acting as a buoyancy engine.

One major complication we faced was leakage and condensation in the water bottle, leading to damaged electrical components. This happened to us multiple times. Our solution was to use silicone earplugs to seal every hole in the AUV, especially around the lid. This fixed our issue with water leakage, but we then had to address the condensation issue. Condensation caused corrosion and rendered our components useless. We fixed this issue by developing a protocol to open the water bottle after use, venting the AUV and preventing condensation. After 24 hours, the silicone is reapplied.

Figure 27: Vertical Profiling Float Lil' Vert
Photo Credit: Gabe

Servo Control

Before starting to build the physical portion of our software control box, we decided to look back at previous HMS SeaBots' gripper systems. The 2019 HMS Ranger Team piqued our interests. They utilized a dual servo gripper that opens, closes, and rotates 180 degrees. Originally, we decided to have 2 single-servo grippers. We then thought that instead of being limited to horizontal grippers, it would be beneficial to have an extra degree of movement. To accomplish this, we added another servo to one of the grippers which allowed us to twist the gripper while opening and closing it at the same time. All of our servo motors are **HiTEC D646WP**. We chose these servos because we had several of them in stock.

We also had many options to control our grippers. Our first idea was to have 2 potentiometers to control the dual action gripper and a button to open and close the single servo gripper. However, the button's signal was questionable, as it incurred a plethora of errors while testing. That's when we decided to use 3 separate potentiometers to control all 3 servos. After connecting these to our **Arduino Mega 2560**, we found out that this would be extremely inefficient and complicated for our gripper pilot. While we were wiring the 3 potentiometers, we were learning how to implement a joystick in such a way that it would control the movement of a stepper motor. We later realized that controlling our dual action gripper with the joystick avoided the need of 3 potentiometers, and made it so that 1 potentiometer controls a gripper while the joystick controls the rotation and opening/closing of the gripper. This makes it easier to control the grippers from the gripper pilot's perspective while also using less power.

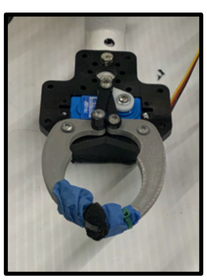


Figure 28: Stationary Gripper
Photo Credit: Akanksha

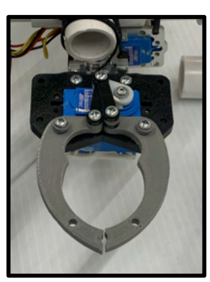


Figure 29: Dual-Action Gripper (horizontal)
Photo Credit: Akanksha

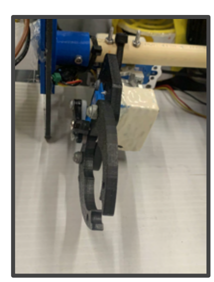


Figure 30: Dual-Action Gripper (vertical)
Photo Credit: Akanksha

Servo Motor Flowchart

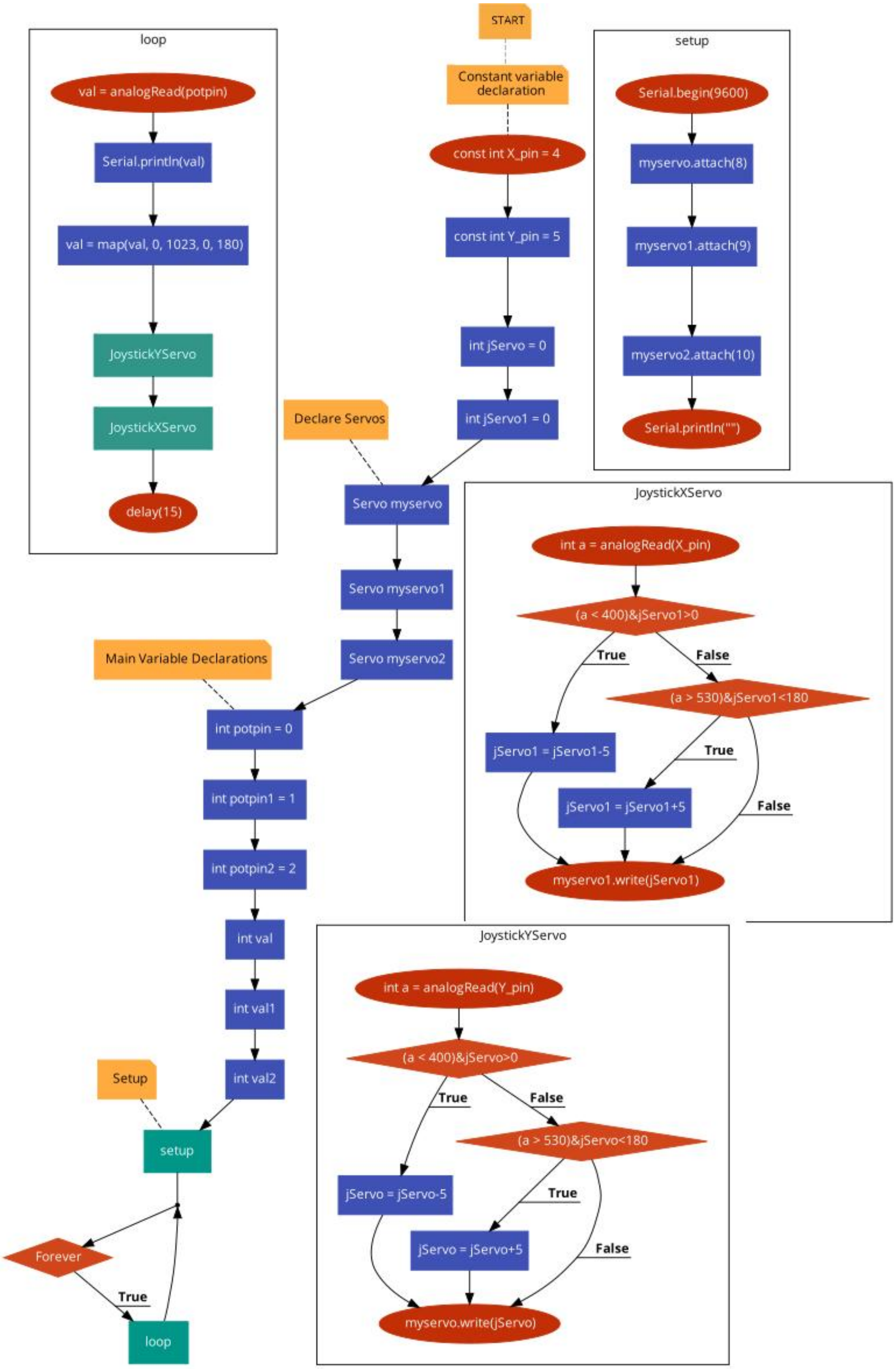
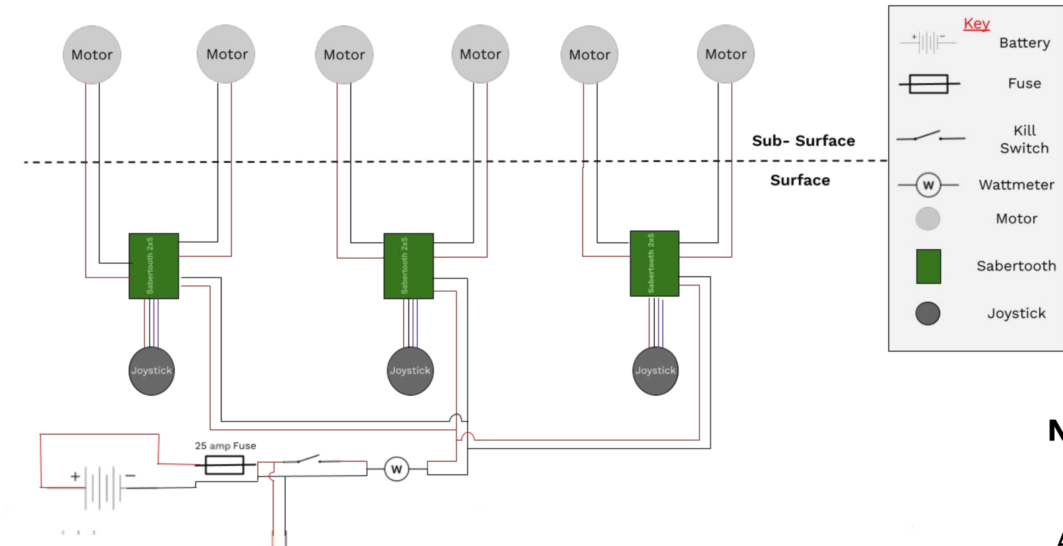
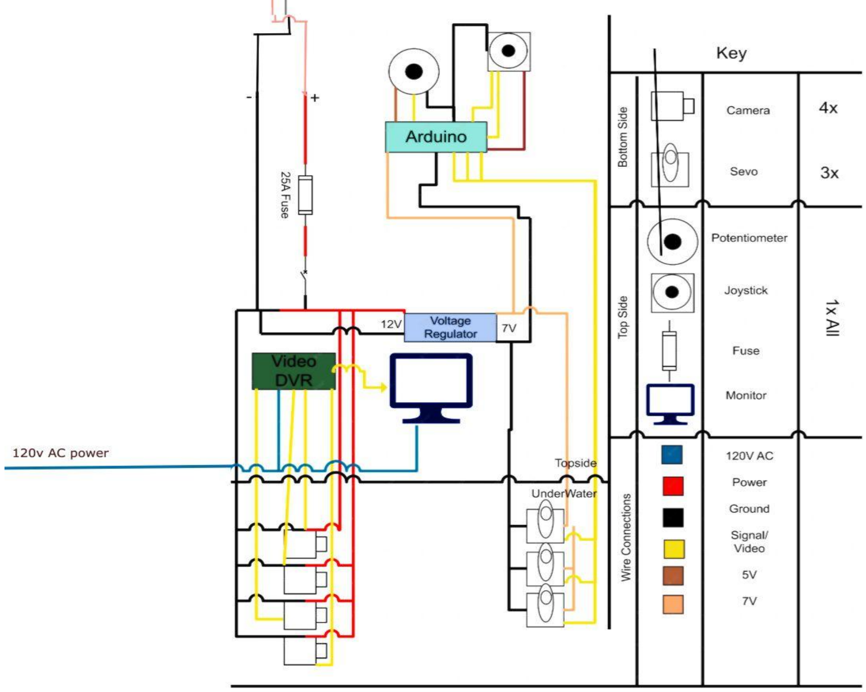


Figure 31: Servo Motor Flowchart
Credit: Krithik

System Integrated Diagrams





No Fluid Power Used

Fuse Calculations

Arduino Mega - 0.2A
3 Standard Servo Motors - 3A
4 Cameras - 0.7A
Potentiometer - 0.02A
Joystick - 0.1A
6 Johnson Bilge Pump Motors - 15A
0.2+3+0.7+0.02+0.1+15
=
19.02 * 150%
=
28.53 total amps
The ROV uses a 25 amp fuse

Figure 32 (Left): Electrical and Software SID
Credit: Electrical and Software Engineers

Please Note for Vertical Profiler:

- Fuse is located 5 cm from the battery's positive terminal.
- Relief Valve (not pictured) has a diameter greater than 2.5 cm.

Vertical Profiler Fuse Calculations

Arduino Pro Mini - 0.016A
Stepper Motor - 1.68A
Pushbutton - 0mA
1.68+0.016+0
=
1.696 total amps
The Vertical Profiler uses a 7.5 amp fuse.

Vertical Profiler SID

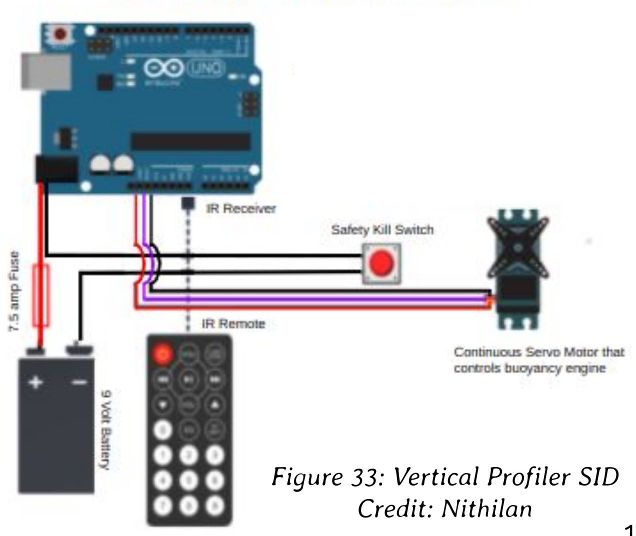


Figure 33: Vertical Profiler SID
Credit: Nithilan

Build vs. Buy

"One man's trash is another man's treasure." This has become our company's motto. Our ROV is basically made from old, reused, and/or trash-picked parts.

Figure 34: TV Monitor (Trash Picked)
Photo Credit: Amogh

After creating the gripper system, our software engineers started on the camera system. We decided to utilize a previous **refurbished monitor.** However, due to an unfortunate occurrence, the monitor was unable to be used. Then, one of our software engineers found an old TV discarded on the side of the road, waiting to be picked up by the trashmen. This piece of trash became our new monitor, providing a large surface area for our pilots. However, we did make the decision to invest in a new DVR so that our pilots could see all 4 camera views to complete the tasks more efficiently for our client's need.

For our regional competition, our mechanical engineers constructed a PVC frame almost entirely out of **used parts**. Of these parts, we reused 2" PVC for our shrouds, ½" PVC for our frame, and ½" connectors. The only new thing on our frame was the 3D printed custom-made thruster guards and custom-made braces to attach the shrouds to the motors. As mentioned on page 5, we made the decision to change the frame from PVC to UHMWPE plates for the World Championship which was also a cost-effective decision, at less than $10. This new frame is not only expensive, it is smaller, lighter and weight and more stream allowing us to complete the assigned tasks.

Our electrical and software engineers built our 2 control boxes with parts collected from the *"ROV Graveyard."* This is a place in on the second floor of our classroom that has all of the of old, discarded, and disassembled ROVs from previous years (see Figure 35). When we needed parts, we visited the graveyard. When we burned out electrical components, we ran up to the graveyard to replace them. We were able to make the best from reused items and still manage to build 2 control boxes that met all of our needs and therefore the needs of our clients.

Figure 35: HMS SeaBots ROV Graveyard
Photo Credit: Coco

Safety

Safety Philosophy

Our company values safety. We are committed to keeping all of our employees safe. Whether our team members are working in the classroom or on the pool deck, we make sure to prioritize the health and wellbeing of our employees, especially when working with potentially harmful tools and/or equipment. While testing the ROV, there are several safety precautions that must be met to prevent any damage to personal or electrical components. Our team has also followed school district COVID protocols including washing hands frequently when working and wearing masks. Our company uses the **construction and operation safety checklist** when working.

Construction Checklist

- ❏ Handle tools properly and safely.
- ❏ The JSO must supervise when someone is using power tools.
- ❏ Safety goggles must be worn while soldering, drilling, cutting PVC, and sawing.
- ❏ Wear gloves and goggles while handling chemicals and/or epoxy.
- ❏ Unplug power tools when not in use.
- ❏ Return tools to their proper place.
- ❏ Workstations must be cleaned and organized after any task is completed.

Operation Checklist

- ❏ Wear rubber, closed-toe shoes.
- ❏ Always walk on pool deck to avoid tripping or falling.
- ❏ Be cautious of ROV, tether, and pool props when walking around the pool.
- ❏ Organize props on the pool deck prior to putting them in the pool.
- ❏ Make sure all control boxes are kept a safe distance from the water.
- ❏ Keep the 12 volt battery away from the edge of the pool.
- ❏ Keep the tether neat and organized.
- ❏ Check control boxes for loose wires that may have become disconnected during transportation.
- ❏ Make sure the crew is aware of their surroundings.
- ❏ Check thrusters and all payload tools before placing ROV in the water.
- ❏ In case of emergency or malfunction, immediately hit the kill switch and retrieve ROV from the water.
- ❏ Properly store the ROV, wrap the tether, and retrieve the props after testing.

Safety Features

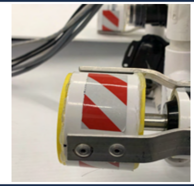
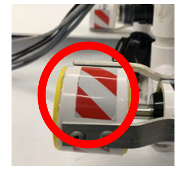
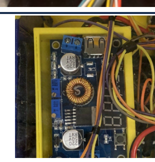
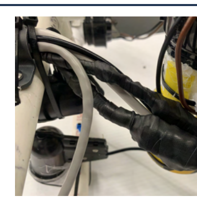
Feature	Purpose	Images
Motor Shrouds	Our motor shrouds are made from 2” couplings and protect people from from being injured by spinning propellers.	
Warning Tape on the Shrouds	The warning tape on the shrouds warns our employees that there are dangerous objects in the vicinity.	
Thruster Guards	Our custom 3D printed thruster guards are attached to the front and in the back of our shrouds. These guards have gaps that are less than 12.5 mm in length, which prevent things from being cut by the propellers.	
Kill Switch	We installed kill switches in our main control box and software box. These switches control the power. In an emergency situation, our team is able to immediately shut down the power.	
In-Line fuses	We installed in-line fuses to our main control box (25 amp), our software box (15 amp), and our vertical profiler (7.5 amp). The control box fuses are attached to the positive wires and is within 30cm of the Anderson power poles.	
Strain Relief	Strain reliefs are used on all wires going into the control boxes, and a strain relief is also used to secure the tether wires to the ROV.	
Voltage Regulator	The voltage regulator prevents excess amounts of voltage from powering our components, which may lead to components being damaged or destroyed.	
Waterproofing	We used a variety of waterproofing methods: marine epoxy, liquid electrical tape, waterproof butt splicers, hot glue, and silicone tape. Waterproofing is a crucial step for ROVs. If not done properly, components may be damaged and/or destroyed.	
Wattmeter	We installed a wattmeter on our control box that allows us to see how much amperage is flowing through the circuit and how much voltage is coming in from the battery.	

Figure 36: Safety Feature Chart
Photo Credits: Akshaj and Amogh

Critical Analysis: Testing and Troubleshooting

Testing Methodology

We used this checklist to ensure our ROV was ready for the water.

Mechanical	❏ Frame and payload tools are secure ❏ No sharp edges ❏ Shrouds and thruster guards are secure
Electrical	❏ No loose wire connections or exposed wires ❏ Fully charged power supply is available ❏ Check waterproofing of electronic components
Software	❏ Ensure a copy of code has been made prior to modifying ❏ Test code in increments – not all at once

Troubleshooting Strategies and Techniques Used

Our initial troubleshooting methods were a bit unorganized, so we developed a protocol to be more effective at fixing the ROV.

1. Identify the issue and report the issue to the department lead.
2. Analyze the situation with members of the engineering department.
3. Identify the root causes of the issue.
4. Formulate a plan to fix the issue.
5. Execute the plan.
6. Evaluate the plan's success and create prevention measures.

Prototyping

When the decision was made to change our frame to UHMWPE, our engineers created a prototype. First, we created our preliminary design in CAD (Figure 37). We used this to create a model (Figure 38). We then used this model to determine if we had the space available for our payload tools. This successful prototyping allowed us to finalize dimensions and component layouts for our final frame design.

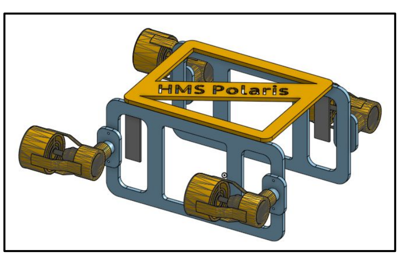


Figure 37: Prototype of HMS Polaris

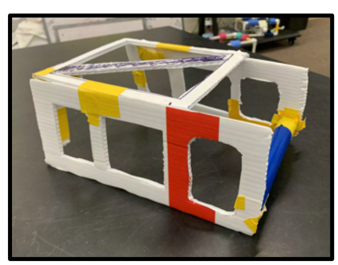


Figure 38: Plastic Prototype of HMS Polaris

Accounting

Our company's Chief Financial Officers created spreadsheets for the team's budget and cost accounting. Our budget shows the projected expenses for the ROV's subsystems and travel to the World Championship. The travel expenses were approximated based off of the number of members in our team and how much it would cost per person. We made an estimate of about $2000, including flight and hotel plans for each individual member.

Budget

School	Harrington Middle School			
Coaches	Maureen Barrett and Marieve Patterson			
Reporting Period	October 2021 to June 2022			
Team Name	HMS SeaBots: Ranger Team			
Income:	Mt. Laurel School District			$135.75
Expenses:	New/Reused/Donated	Projected Cost	Budgeted Value	Market Value
:Power and Control: Main Control Box	New/Reused	$10.00	$10.00	$672.94
Power and Control: Software Box	New/Reused	$74.00	$74.00	$260.73
ROV Frame	New/Reused	$4.60	$4.60	$8.01
Mission Tools	Reused	$--	N/A	$424.90
Thrusters	New/Reused	$1.35	$1.35	$404.43
Miscellaneous	New	$45.80	$45.80	$45.80
Travel Expenses to Long Beach, CA	N/A	$26,000	$26,000	$26,000
Total:				
Total Income:				$135.75
Total Expenses:				$27,816.81
Total Spent:				$27,816.81

Figure 39: Budget Conclusions
Credit: Kristin and Karolina

Cost Accounting

Item Category	Amount	New/Reused/Donated	Amount Spent ($)	Market Value ($)
Power and Control: Main Control Box			**$10.00**	**$672.94**
Sabertooth 2 x 5 motor controllers and joysticks	3	Reused	$--	$390.00
Terminal strip	1	Reused	$--	$1.30
Watt meter	1	Reused	$--	$14.69
Tether	2	Reused	$--	$184.95
Seahorse box	1	Reused	$--	$62.00
Strain relief	2	Reused	$--	$5.00
Power cord with Anderson power pole	2	New	$10.00	$10.00
Kill Switch	1	Reused	$--	$5.00
Power and Control: Software Box			**$74.00**	**$260.73**
Arduino Mega 2560	1	Reused	$--	$55.00
4-channel DVR	1	New	$69.00	$69.00
Voltage regulator	1	Reused	$--	$14.00
Potentiometer and joystick	1	Reused	$--	$4.43
Tether	4	1 new / 3 reused	$5.00	$55.00
Seahorse box	1	Reused	$--	$62.00
Terminal strip	1	Reused	$--	$1.30
Strain relief	4	Reused	$--	$10.00
Power cord with Anderson power pole	2	Reused	$--	$10.00
Kill Switch	1	Reused	$--	$5.00
ROV Frame			**$4.60**	**$8.01**
UHMWPE (plastic sheet)	5ft	New	$4.60	$4.60
1/2 inch CPVC	1ft	Reused	$ --	$2.46
1/2 inch CPVC tees	1	Reused	$--	$0.95
Mission Tools			**$0.00**	**$424.90**
Camera	4	Reused	$--	$300.00
HiTec HS-646WP servo	3	Reused	$--	$105.00
Standard Gripper Kit A	2	Reused	$--	$19.90
Thrusters			**$1.35**	**$404.43**
Johnson bilge pump motors 1250 GPH	6	Reused	$ --	$305.94
Propeller assembly	6	Reused	$ --	$52.50
1 1/4 x 1 1/4 x 1/2 inch PVC tees	6	Reused	$ --	$25.02
Custom shrouds with thruster guards	6	Reused	$ --	$19.62
Custom 3D braces	9	New	$1.35	$1.35
Miscellaneous			**$45.80**	**$45.80**
Butt splicers	16	New	$0.80	$0.80
Wire ties	50	New	$5.00	$5.00
Water-proofing and adhesive products	-	New	$20.00	$20.00
Misc. hardware	-	New	$20.00	$20.00
Total Spent:			**$135.75**	
Total Value:			**$1,816.81**	

Acknowledgements and References

Our company worked very hard throughout the past year to prepare for the 2022 MATE competitions. We could not have achieved our goals without the funds, contributions, equipment and support from many people and organizations. First, we would like to thank the New England MATE Regional coordinators for giving us the opportunity to demonstrate our knowledge and passion for underwater robotics at the *Massachusetts Maritime Academy.* Without an invitation to the NE regional competition, we wouldn't be competing at the 2022 World Championship in Long Beach, CA. We would also like to thank our coaches, Ms. Maureen Barrett and Ms. Marieve Patterson, as well as our mentors: Rohan Gawande, Kalash Kapadia, Saketh Rudraraju, and Aayush Talreja. Thanks, also, to our parents for providing pizza for our late work sessions and for driving us to meetings and practices. Significant gratitude must go to *Jersey Wahoos* and *Giant Fitness* who generously allowed us to test the ROV and practice piloting in their pools. We would also like to thank the Mount Laurel School District for supporting our ROV program and allowing us to travel out of state to competitions. Lastly, and most fundamentally, we thank *MATE II* for organizing this inspirational opportunity for us.

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