One Degree North Crimson

[Singapore American School, Singapore]

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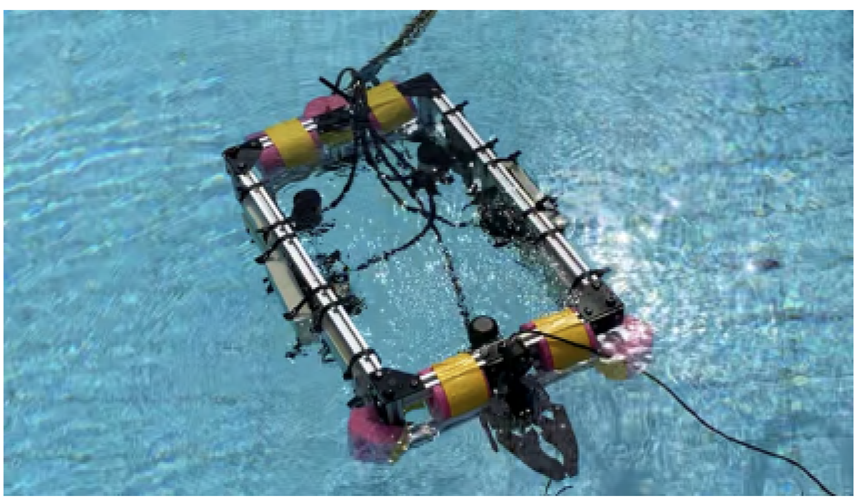
1. - Introduction

1.1. - Abstract

Octopus Prime is the submersible ROV created by team One Degree North in order to compete in the Ranger challenge. The sophisticated design of the ROV exemplifies efficiency in its field as it is able to swiftly complete the various number of tasks that it is required to do.

Octopus Prime is created with a variety of different materials, parts, and electronics that allow it to do each of the tasks seamlessly. With carefully thought out placement of thrusters and buoyancy, the ROV is able to maneuver through the water with ease. The manipulator and camera have been outfitted with specially made mounts to provide clear vision in the water, as well as being able to hold things precisely in the water. Furthermore, with its simple controls and ingenious electronics design, the drivers are able to easily make the most of the ROV. We believe that simplicity is elegance, and that philosophy is exemplified in the Octopus Prime.

Throughout the process, we have constructed a strong, efficient, and affordable machine which is highly capable. Octopus Prime's design, material usage, and construction have been integral in leading to a ROV which boasts stability and efficiency in the water.



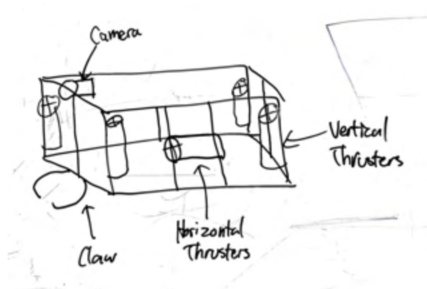
A photo of the Octopus Prime in Action.

1.2. - Table of Contents

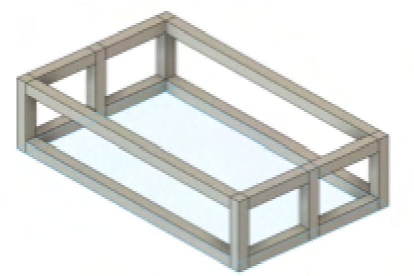
2. - Mechanical Design

2.1. - Chassis

We used aluminum for our chassis because we wanted our robot to look sleek as well as be sturdy. Using aluminum to build our robot required lots of planning because the material is more expensive and harder to source than PVC. Using Fusion 360, we created a rudimentary model of our chassis to figure out optimal dimensions and the number of pieces needed after drafting our initial ROV design.

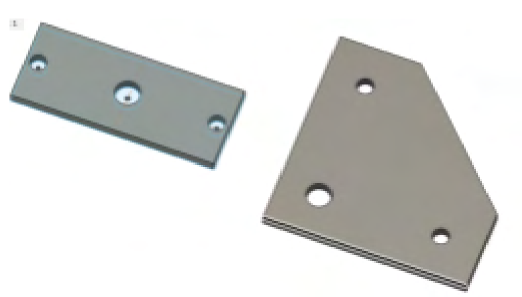


Whiteboard sketch of ROV Design



3D render of ROV chassis.

The chassis we designed was a rectangular shape because it is a stable shape that allows the thrusters to be spaced out. We strategically placed pillars to add structure to the build as well as provide sections for the claws, thrusters and camera to be attached. We used four 2 x 2 x 46 cm pieces and fourteen 2 x 2 x 12 cm pieces to assemble the chassis. The only issues we really had was that we sanded some of the pieces too much and the pieces were loose but we were able to combat this issue by cutting more gussets and securing the pieces.

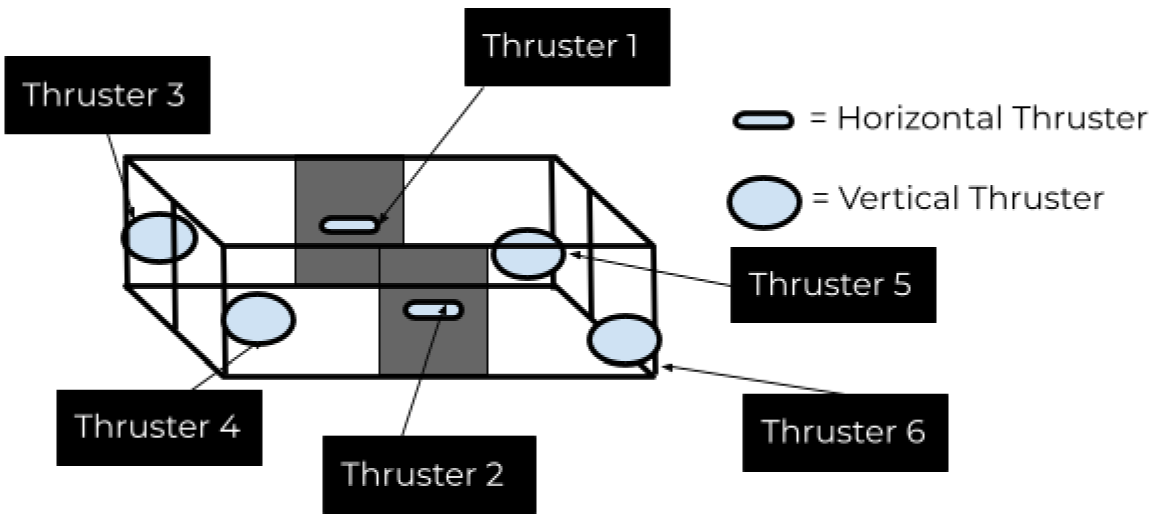


3D render of Delrin gussets.

2.2. - Propulsion

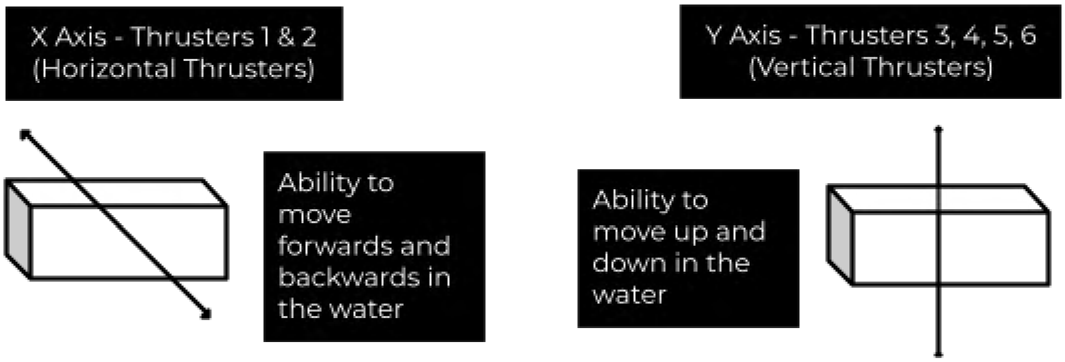
2.2.1. - Propulsion Overview

Our team mounted a total of 6 thrusters onto the Octopus Prime: four for vertical propulsion, and two for lateral propulsion. Each thruster was mounted onto the ROV with delrin plates designed by our team.



Thruster Placement Diagram

The placement of the vertical facing thrusters was specifically designed to help increase and decrease the depth of the robot in the water while also maintaining balance to the best degree, since keeping the robot upright while driving it is crucial to success in completing tasks. As for the horizontal thrusters, we placed two on opposite ends of the ROV, right in the middle of the frame to provide the best control.



ROV Propulsion Diagram

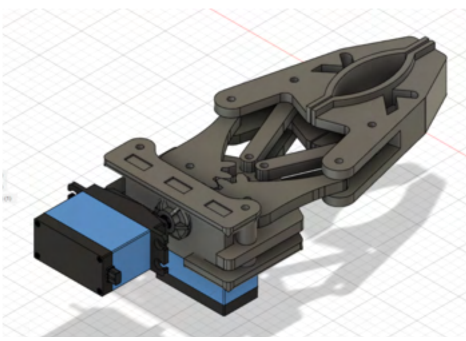
2.2.2. - EMCT4372-1 Thrusters

The thrusters that we selected were based on several factors including its functionality and eco-friendliness. We selected the EMCTs since they were both cheap and made using recycled plastic. The thrusters were some of the few components that we purchased instead of fabricating or recycling materials, so we made an effort to ensure we continued to source sustainable components. The specifications of the thrusters include a KV 300 engine, with a diameter of 82mm with a propeller diameter of 60mm. For these thrusters, we utilize 12 volts to operate the thrusters at optimal capacity.

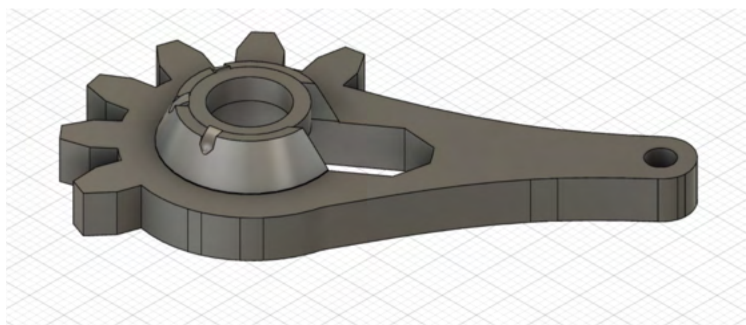
Picture of an EMCT thruster

2.3. - Claw

The claw Octopus Prime is equipped with two servos; one for gripping and one for rotation. We decided to 3D-print the components and attach them in a gear formation on the ROV. The reason we chose to 3D-print the claw is because of its more cost-efficient nature as opposed to purchasing a claw. We browsed several CAD community websites and found two great designs. We combined both designs to form the base pieces, the gears and the fingers, while redesigning portions of the claw, such as the servo gear and support rods to better fit the tasks our ROV needs to execute. Having the claw be 3D-printed as opposed to buying the claw also gives us more options for customization than we would have otherwise. We went through many iterations of our claw, initially utilizing entirely 3D-printed components, then eventually incorporating the use of two servo horns in one of the gears and the back of the claw to make sure both components are more secured. Our claw went through a few iterations with meticulous adjustments made to optimize its efficiency.



First printed claw iteration.



Revised servo gear.

2.4. - Buoyancy

2.4.1. - Buoyancy Overview

Buoyancy was an important thing to consider in designing our ROV, as aluminum is not a naturally buoyant material. Though aluminum provides rigidity and stability, it was very heavy and needed to be offset by some buoyant material. After assessing the effectiveness of pool noodles, polyurethane foam, and air tubes, we settled on using air tubes supplemented by buoyancy foam.

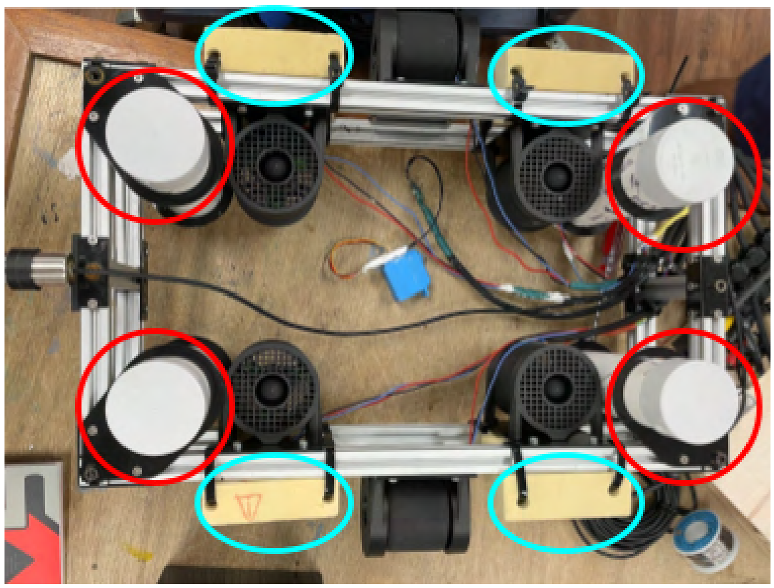


Photo depicting layout of air tubes (circled in red) and polyurethane foam (circled in blue).

2.4.2. - Air Tubes

To counter the heavy aluminum frame, we fabricated four 17-inch tubes out of 56mm-diameter PVC and installed them into the four corners of the frame, securing them in place with eight custom-cut Delrin plates. These plates screwed into the extrusions of the T-slot aluminum the same way our Delrin gussets did. We designed our air tubes to be longer than the mounting plates to allow them to shift and adjust, which made our ROV more stable. The air in the tubes was modified on a trial-and-error basis until the ROV was balanced in the water. However, after installing the tubes, the ROV was still negatively buoyant.

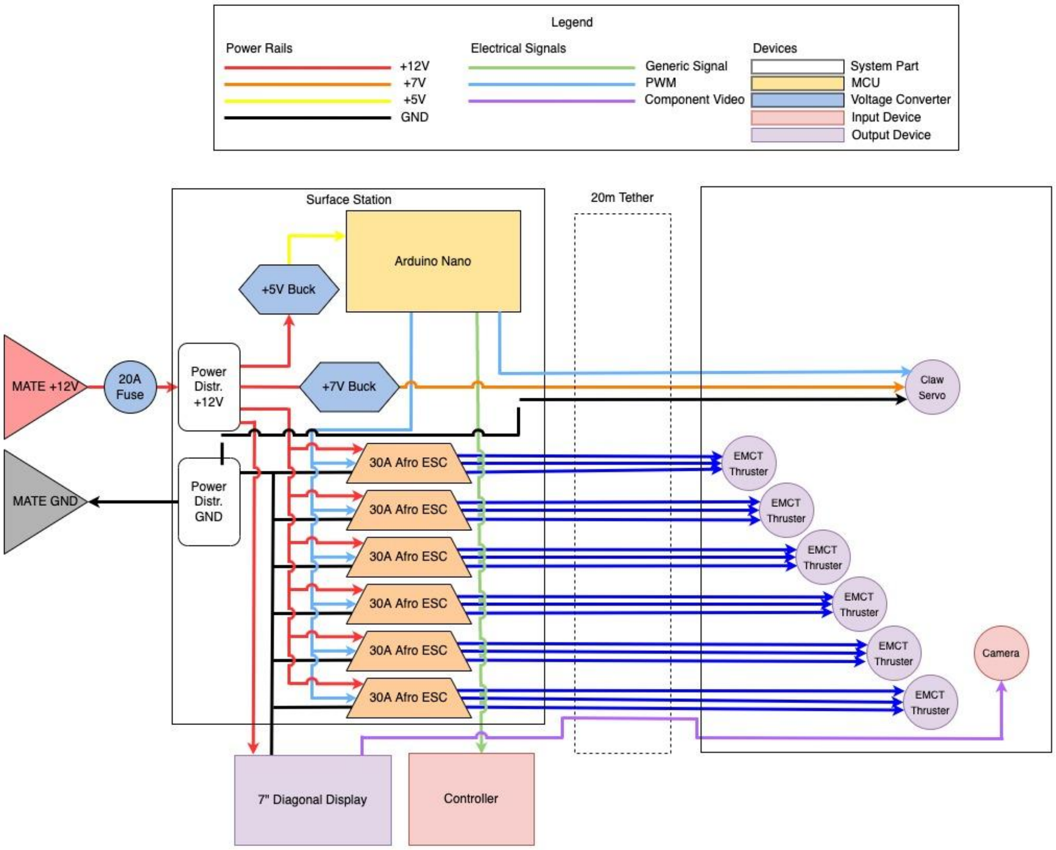
Close up photo of an air tube.

2.4.3. - Polyurethane Blocks

To supplement the tubes, we added four 10 x 12 x 8 cm polyurethane foam blocks onto the ROV. Polyurethane foam is highly buoyant and tough, and would not need to be used in large amounts to make our ROV more buoyant. By using zip ties, the blocks were attached in between the bars of the frame where space was available. Similarly to the air tubes, the foam was added on a trial-and-error basis until we found an amount that established neutral buoyancy for the ROV.

3. - Electrical and Software Design

3.1. - Architecture

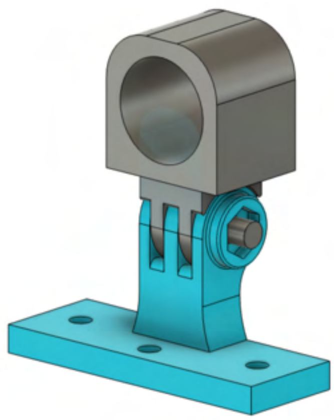


Electronics SID

The system architecture consists of the ROV and the control station, connected via multiple 20-meter tethers. Offboard electronics were used, as it nullifies the need for waterproofing. An arduino nano on the surface was used to translate commands imputed from a controller and output commands into ESCs and to thrusters. The camera feed was directly connected to a display.

3.2. - Camera

The camera on Octopus Prime is a small camera with a 12mm lens, which has a wide field of view and gives our team the ability to see clearly in the water. In order to fit the camera onto the ROV, our team 3D-printed a custom-made mount. The mount is tight enough to be stable in the water, but it is still able to be moved with some manual force to adjust its angle.



3D render of camera mount.

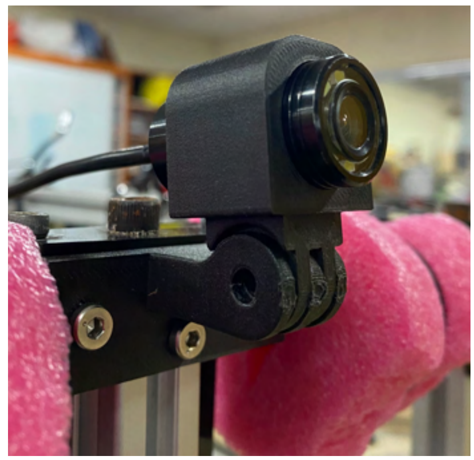


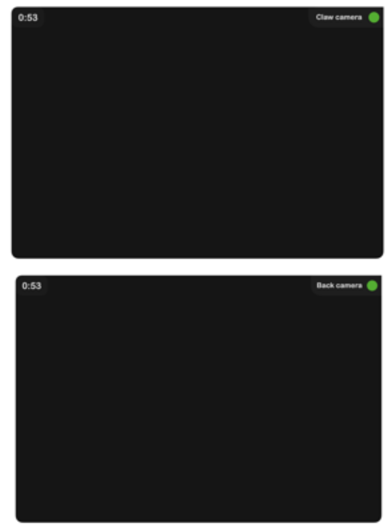
Photo of camera mount.

The camera is connected through tether directly to a monitor. Through the feed, the team is able to perform the tasks remotely on land.

3.3. - UI/UX

The user interface is an important aspect of the robot as a whole. It should consist of a variety of things including a GUI which should be able to display a live feed of all three cameras at the least. However, another key component is the user experience. To achieve this, we included a wide variety of additional features such as a stopwatch, console, connection statuses, and more.

Driver Control GUI

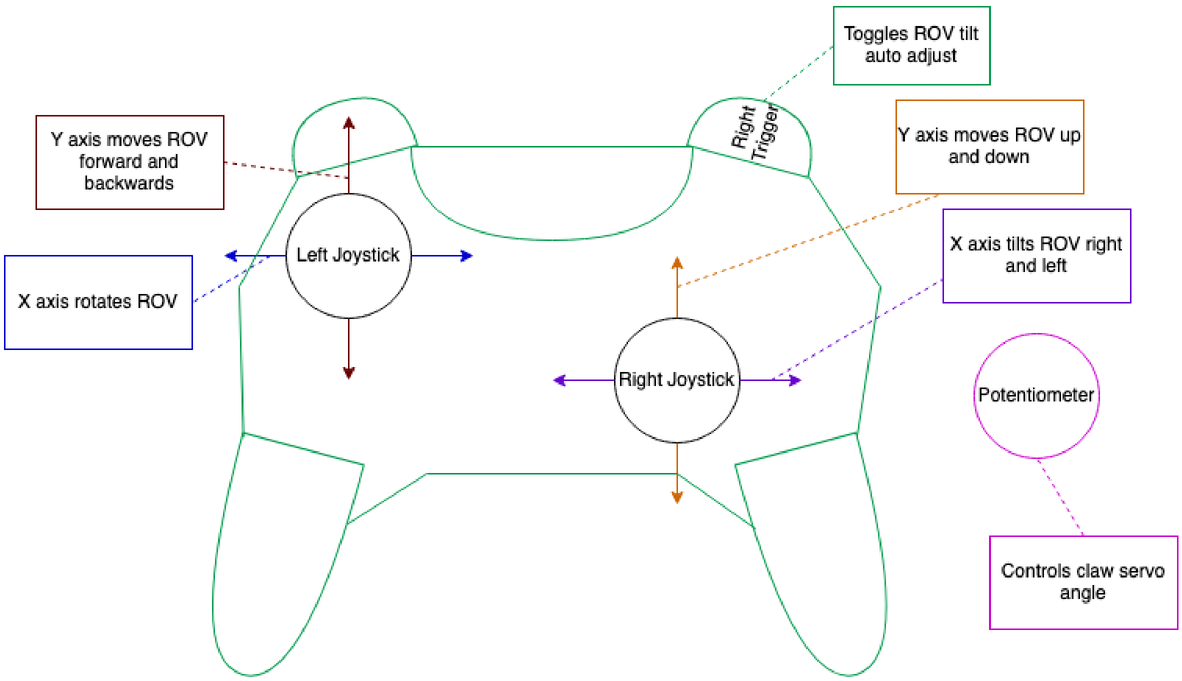


Claw and back camera views

However, as the GUI got progressively complex, it was important to make the interface as intuitive as possible. We did this by implementing images/graphics that users would be familiar with into the buttons.

Intuitive GUI Button

3.4. - Driver Controls



Overview of driver controls

We used a controller for our controls due to its ergonomics and easy manipulation. The use of left and right joysticks along with a potentiometer provide incremental values that make movements such as moving forward, backward, and rotating easy to adjust.

```
typedef struct Joystick {
    uint8_t pin_x;
    uint8_t pin_y;
    int16_t x;
    int16_t y;
    int16_t default_x;
    int16_t default_y;
} joystick_t;

typedef struct Trigger {
    uint8_t pin;
    int16_t default_value;
    int16_t value;
} trigger_t;

typedef struct Output {
    Servo servo;
    uint8_t pin;
    int16_t min;
    int16_t max;
} output_t;

void printJoystick (joystick_t* joy) {
```

Arduino Code

Software on the Arduino was designed to map the designated controls to their corresponding outputs and to print the current status. We made our code easily expandable and modifiable by abstracting input and output devices into structs and mapping input and output values to between -100 and 100. This allowed our code to be more modular and easy to trace, map new controls, and change on the fly.

4. - Safety and Team Management

4.1. - Safety Report

4.1.1. - Safety Philosophy

Safety is our top priority when working with our robot. By ensuring that nothing harms our teammates on MATE Octopus Prime, we facilitate a collaborative and free workspace where members feel comfortable. As these values should never be compromised in our lab, we as a team followed a set of standard safety procedures established by teams before us.

4.1.2. - Safety Procedures

We have many rules in place to ensure nobody gets hurt or injured in the process of making our ROV. One precaution is using the right equipment and workspace. Our team has been given the privilege of using Singapore American School's robotics lab. This lab offers a wide variety of tools and equipment to enable us to build and innovate our robot efficiently and safely, as using the proper equipment for different processes is the first step in being safe. In order to maximize this opportunity, we have to go through a safety briefing on our first day in class, and we consistently remind each other to uphold the rules specified to us. We also obtain training and supervision from our senior members to ensure that everyone is comfortable with and observes proper protocol when dealing with the heavy and potentially dangerous equipment.

Lab Safety Checklist

- [ ] Students must wear safety goggles when in the lab
- [ ] Hearing protection must be worn when powering loud equipment
- [ ] No one must come within 1m of students using a soldering iron
- [ ] No food and drinks in the lab

ROV Pre-Run Safety Checklist

1. Team is alerted for the run
2. Control station is stationed over 1m away from the pool

3. Check electronic connections
    a. Check breadboards for disconnections
    b. Ensure tethers are properly waterproofed
    c. Uncoil tethers
4. Check structural integrity
    a. Check for any loosened components in the frame
    b. Check that all aluminum structures are secure
5. Ensure that thrusters are not tangled by tether
6. Check claw for operational readiness
    a. Ensure claw is firmly mounted
    b. Check claw servo
7. Ensure that all onshore electronics are at a safe distance from water
8. Plug in 12V power
9. Gently put ROV in water
10. Turn on 12V power
11. Check systems functionality
    a. ROV motion in all directions
    b. Claw functionality
    c. Camera functionality

ROV is ready for mission deployment

In conclusion, our safety philosophy has many parts that help ensure our safety in the workplace. As a result, no major harm has come to any of our team in the lab. With rules like mandatory ear protection and glasses to protect vision and hearing, it is no surprise that our safety philosophy has been a great guideline for a safe and comfortable class setting for many years.

4.1.3. - ROV Safety Features

Our ROV is equipped with many safety features in order to ensure optimal safety for all of our team members. One of the most important safety features that we included was sanded-down edges on the metal pieces in addition to the delrin corner plates. We did this so the robot did not scratch any of our members and was safe to carry and move.

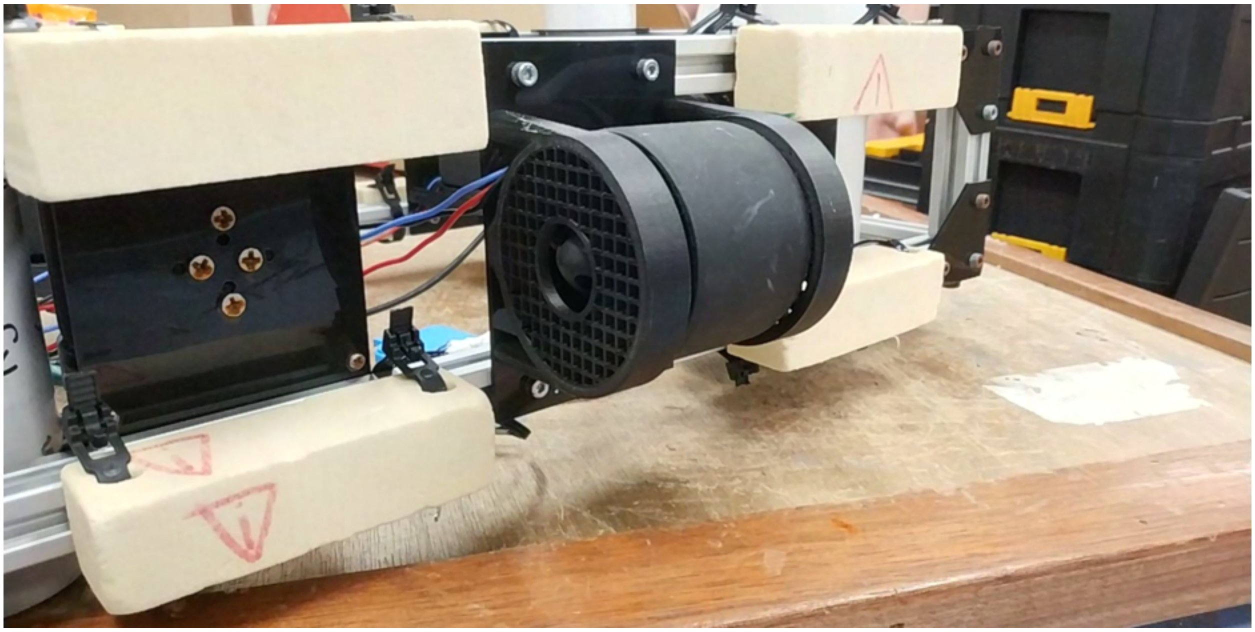


Photo of an installed thruster guard.

The original thruster guards that came with the thruster did not properly cover the blades. As such, we designed custom and 3D-printed IP-20 rated thruster guards for all 6 of our thrusters. The guards supplemented the original thruster guards by encasing the thrusters on both sides, ensuring that stray objects do not get stuck and caught up inside of the thrusters.

Another safety feature is our properly mounted claw, camera, and more, since with proper mounts, we do not need to worry about any pieces falling off of our ROV either breaking or falling and injuring a team member.

Lastly, our most important safety feature is making sure our waterproofing is solid as we do not want anyone in the water to get electrocuted or even when working on the bot in the lab. Overall the Octopus Prime was built professionally with the group adding safety features along the way as we tested.

4.2. - Troubleshooting

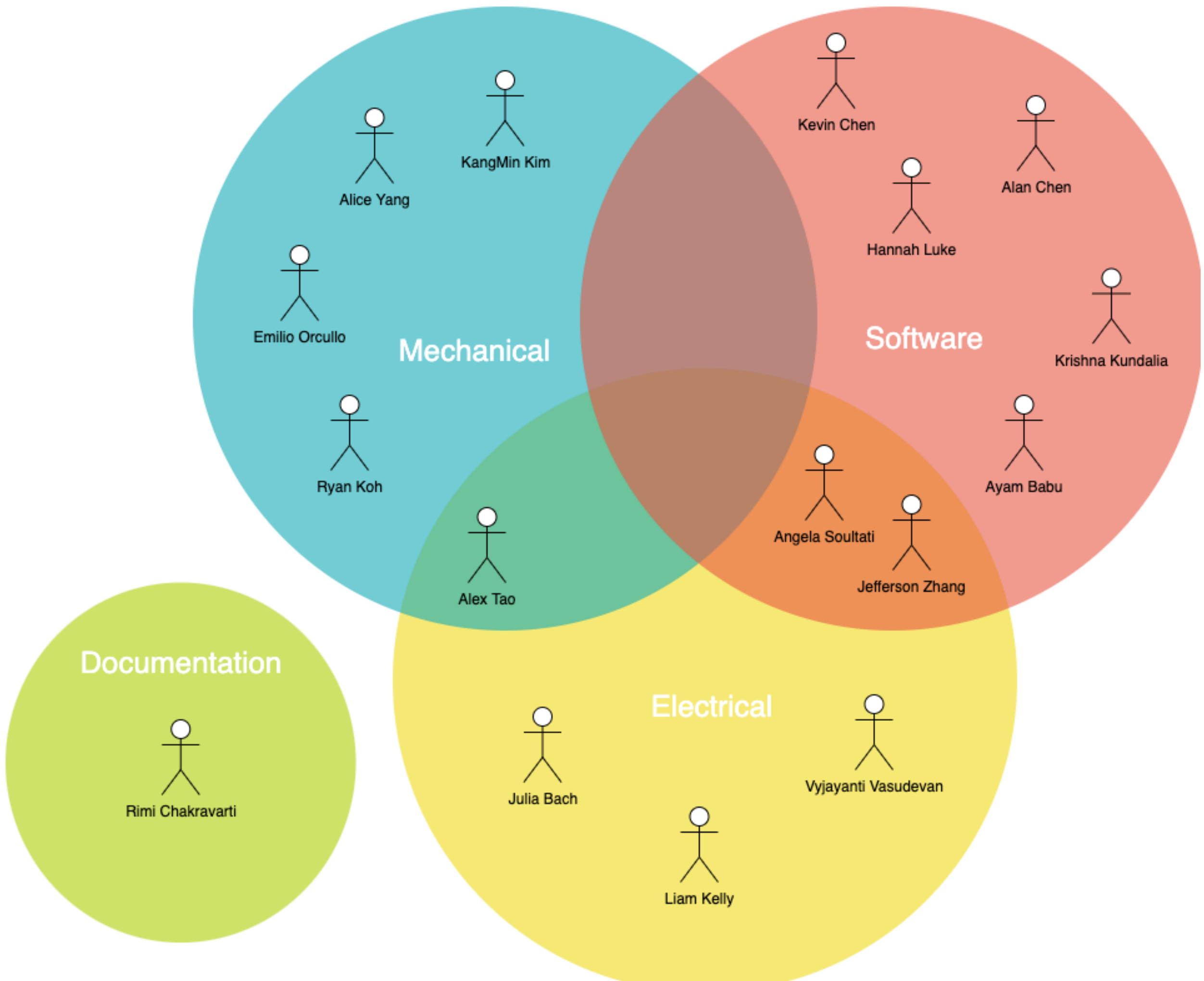
Octopus Prime ran into a variety of problems during its development. To solve these “problems”, we had to work as efficiently as possible. When one of our team members runs into a problem, they first have to identify the issue, then they would inform the rest of our team members. The reason for informing the members and not trying to solve it alone, is because our company prioritizes collaboration, especially in the face of an issue. We found when more members work on an issue, we resolve it faster.

An example of a troubleshooting issue we had is one of the vertical thrusters not working properly. This was a major issue because if this thruster didn’t work, then our robot would become unbalanced in the water. At first, we tried testing the thruster to try to find what the problem was. Then, we realized that the thruster was jammed: it would not turn even if we used our hands to try to turn it. To solve this problem, we decided to completely remove the thruster, and to rearrange the remaining ones in a way such that the ROV would be balanced. With collaboration, critical thinking, and hard work we overcame this issue. All of us thought that the robot wasn’t going to work when we found this problem, but with a little optimism we fixed it.

4.3. - Project Management

4.3.1. - Company Profile

Our team consists of a total of 16 members who were split up into subdivisions of mechanical, electrical, and software engineers based on both skill and interest. Each subdivision had a lead manager that facilitated progress.



Venn diagram of our team

4.3.2. - Project Management

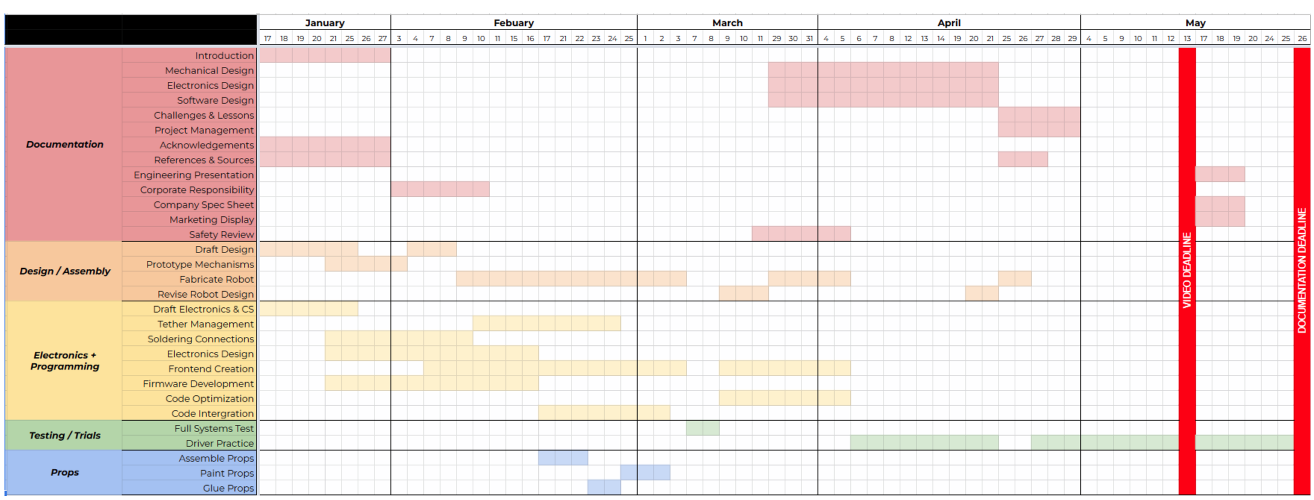
All in-person meetings were held three times a week in the robotics lab at Singapore American School. Outside of these in-person meetings, the team communicated using Mattermost, an open source communication platform. We used this application to update one another on problems, progress, and next steps by using Mattermosts's kanban-style boards.

Meetings, including both in-person and online, typically took place up to five times a week in order to discuss next steps and further communication before moving forward with building the ROV. All members at these meetings were able to discuss ideas and update the other members from other divisions whom they were not working with on a daily basis. For example, our mechanical and electrical teams often worked on different days, so to ensure their work on the ROV would fit together, they communicated during these meetings.

Because of COVID-19 government restrictions that persisted until mid-April, we were unable to meet as an entire group simultaneously due to our company exceeding the group size limit. Therefore, we increased communication and coordination within the sub-teams so that mechanical and electrical team members, who due to the physical nature of their work required in-person collaboration, could meet more frequently than the entire team was meeting in order to ensure progress did not falter. We also logged our progress in a digital engineering notebook on Google Docs so that we were able to update each other without communicating directly.

4.3.3. - Work Timeline

Throughout this experience we consistently documented our progress on a Gantt chart.



4.4. - Budgeting and Expenses

(All prices in SGD)		Projected	Actual
Mechanical			
Frame Materials	Re-used	$790.00	N/A
Polyurethane Foam	Re-used	$2.00	N/A
Epoxy	Purchased	$7.00	$7.00
Zip ties	Purchased	$40.00	$40.00
Teather	Re-used	$250.00	N/A
Electronics			
Arduino Nano	Re-used	$170.00	N/A
Wago Connectors	Re-used	$7.08	N/A
Afro 30A Muti-Rotor ESCs	Re-used	$124.68	N/A
Assorted Cables	Re-used	$25.00	N/A
Power regulating components	Re-used	$52.27	N/A
Waterproof Servo	Re-used	$20.00	N/A
Camera	Re-used	$132.58	N/A
T60 thrusters	Purchased	$90.00	$90.00
Total Expenses		-$1,620.61	-$137.00
Income			
Singapore American School		$4500.0	$137
Personal funding		$0	$0
Total		**-$2789.39**	**0**

5. - Acknowledgements

The One Degree North MATE Team would like to thank the Marine Advanced Technology Education Center for providing us with this opportunity to further our robotics skills. Although circumstances have been difficult and global troubles have hindered certain aspects of the competition, we remain grateful for the opportunity to participate.

We would also like to thank Singapore American School for providing us with the funding, resources and space to participate in this competition.

Lastly, we thank our teacher mentors, Mr. Millar, Mr. Harvey, and Ms. White, for providing their mentorship and advice to us throughout this experience. Their guidance has been instrumental to our success.

6. - References and Appendix

6.1. - References

RC Hobby'S Store “12-24V Brushless Motor Propeller Underwater Thruster 3-Blades Propeller Ship Model Accessories”. AliExpress.ru, 2022, https://aliexpress.ru/item/1005002565910272.html?item_id=1005002565910272&sku_id=12000021174412885

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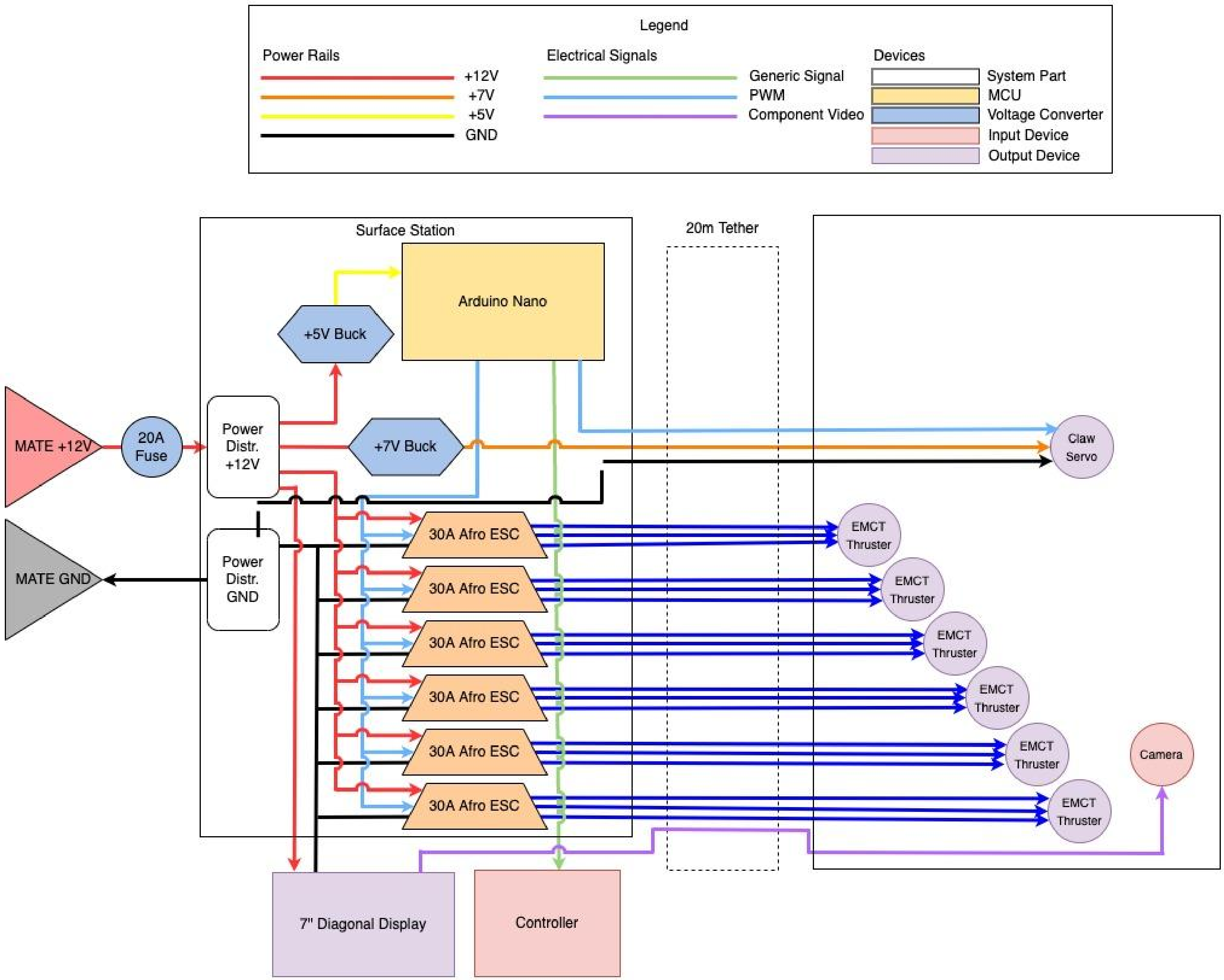
6.2. - Appendix

Appendix I - SID


Legend
Power Rails
+12V
+7V
+5V
GND
Electrical Signals
Generic Signal
PWM
Component Video
Devices
System Part
MCU
Voltage Converter
Input Device
Output Device
Surface Station
20m Tether
Arduino Nano
+5V Buck
+7V Buck
MATE +12V
20A Fuse
Power Distr. +12V
Power Distr. GND
MATE GND
30A Afro ESC
30A Afro ESC
30A Afro ESC
30A Afro ESC
30A Afro ESC
30A Afro ESC
Claw Servo
EMCT Thruster
EMCT Thruster
EMCT Thruster
EMCT Thruster
EMCT Thruster
EMCT Thruster
Camera
7" Diagonal Display
Controller