one degree north red

singapre american school

singapre, singapore

Technical Report

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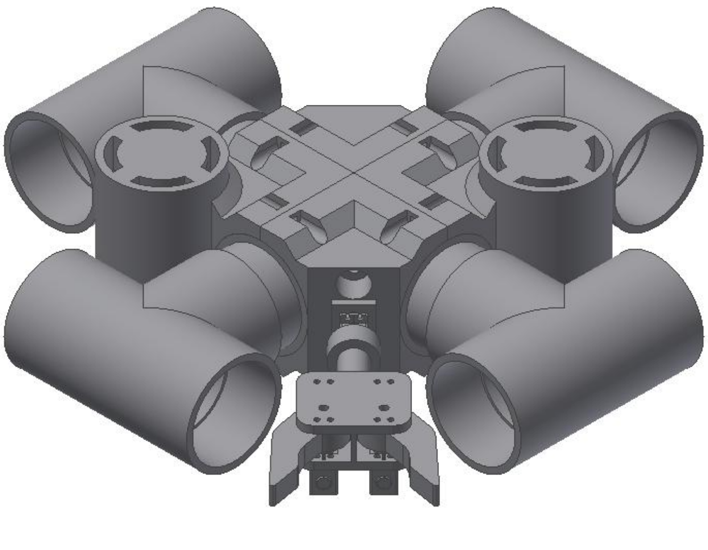
Abstract

Green T is the latest submersible created by the One Degree North Red robotics corporation. Its advanced components and modular frame allow it to perform complex maneuvers underwater, allowing it to investigate shipwrecks nimbly and effortlessly. Apart from deriving accurate details from a sunken vessel, Green T can also perform scientific measurements of the surrounding area and aid in conservation efforts.

With advanced machinery suited to completing the tasks at hand and expertly trained drivers who have been heavily involved with the Green T's construction from start to finish, the Green T can adapt itself to the given situation fluidly. The powerful claws and hooks that were custom-made for the ROV will allow specific actions, while the impressive array of basic operation tools like motors, cameras, and a ballast, have been personally outfitted and adapted to solve the problems at hand. With an extremely innovative cross-shaped design, the ROV blends form and function by being nimble, creative, and eye-catching.

With an eye on the price, One Degree North Red has managed to outdo itself, rising above past years' expectations by creating an affordable yet unbelievably powerful machine. This long-lasting, durable robot can perform mission-critical jobs and responds efficiently to driver commands. Safety has always been a top priority for the company, and with unparalleled new safety requirements it has kept this principle close to heart.



The final CAD model for the Green T Machine

CEO and Founder's Reflections

"When I was asked to help start Singapore American School's MATE team two years ago, I had no experience in robotics. That year, I learned a lot about what you do in robotics; how to identify problems (and find solutions), how to communicate effectively, and how to work well both in a team and independently. The next year, I learned about another important aspect of robotics: the passing on of knowledge. This year, I am excited to see that I, along with many of my peers, continue to learn more about robotics and teach each other what we know.

Through my time with the team, I have watched us grow. At first, we were a slightly disorganized group of novices, and we have since become not only a group of thinkers and fixers, but also teachers and students. For this, I'd like to thank Barton Millar and Meredith White, who, over the course of two years, have reached into seemingly endless reserves of encouragement to bring us where we are today."

-William Whalen-Bridge, Founder

"As my team gently submerged the robot into the pool and began to run preliminary tests, I realized that our weeks of preparation and hard work had finally paid off: the robot that I had helped create from scratch was now fully functional. This first successful run of our underwater robot was the culmination of countless late nights in the lab, last-minute trips to the hardware store, and intense team debates. Looking back, it was also the moment when I crossed the Rubicon and left behind a childhood hobby for what will be a lifetime pursuit of robotics and engineering.

My engineering interests had become the tools with which I could impact the world around me. As a child, I simply built things for fun, but upon leaving the realm of Legos, I discovered that I could build with a purpose. Now, whether it is through what I can build, the problems I can solve, or the people I can teach, I intend to make the most of my passion for inventing, building and creating.

MATE has changed the way I look at robotics. It has guided me towards engineering in college and instilled in me a true love of the revision process inherent in any robotics endeavor. Our goal as One Degree North Red is to provide this same experience to all of the members of our team, whether they are new or returning, young or old, engineers or businessmen."

-John King, CEO

Theme

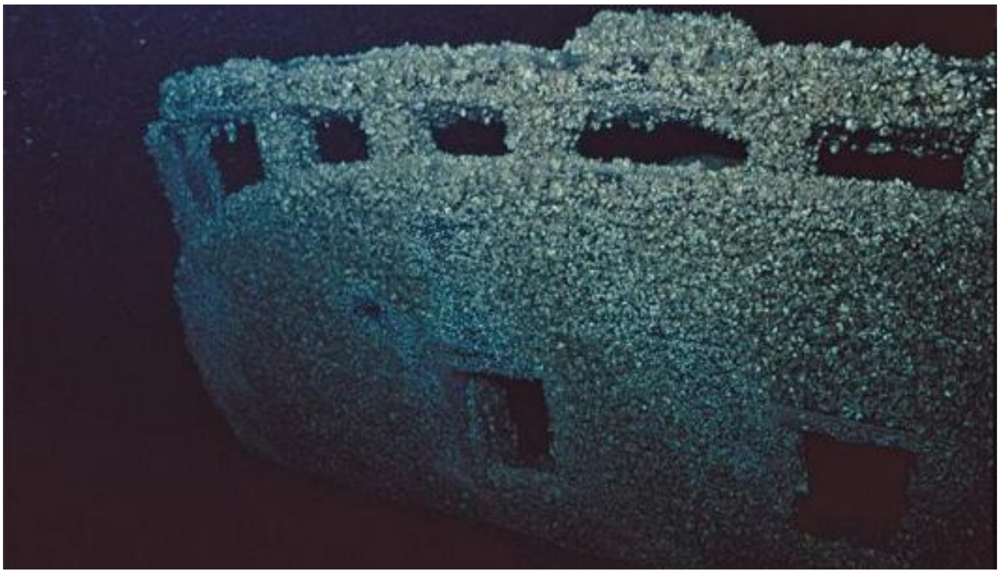
Shipwrecks are a portal to the past. The amount of historical information locked in these sunken treasures is massive. Investigating each object that that remains untouched sheds new light onto the practices of the past.

But these incredible objects are under threat. Not only are there organisms like zebra mussels which invasively cover every square inch of the vessel's surface, eating away at the metals, the natural environment can also be detrimental to the preservation of the wreck. High salinity levels that increase the conductivity of the water can corrode the metal faster and cause the shipwreck to collapse. Furthermore, the effects of humans cannot be overstated - trash and debris that accumulates on the ocean floor can complicate relief efforts and hurt the wreck.

Conservation efforts are, however, by no means simple. Mats of cyanobacteria that thrive in the cold, salty environments of sinkholes can be destroyed by intrusive drivers, while small holes are not conducive to human exploration. Resources could be much better spent by investing in modular technologies that can perform many of these tasks remotely and efficiently, with a lower environmental footprint as a result.

That's why One Degree North Red is extremely excited to be a part of this scientific venture. The Green T submersible is perfectly suited to solving the shipwreck protection and monitoring issues in the Thunder Bay area of Lake Huron. The Lake's particular environment lends itself to sinkhole creation, while the cold temperature of the water has preserved many shipwrecks as historical artifacts. Green T will be able to perform scientific measurements and aid in the conservation efforts as an agile aid to humans.

Zebra mussels have completely covered this shipwreck.

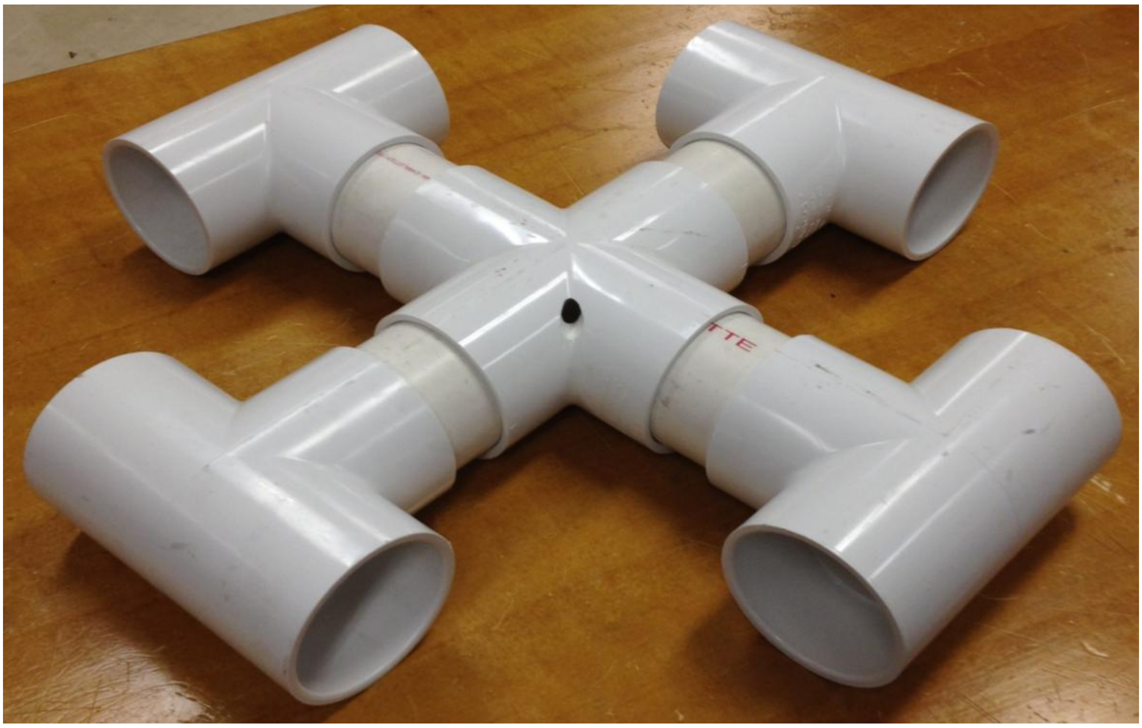


Vehicle Systems and Design Rationale

Frame

When designing the frame, a couple of key considerations came to mind. The first, of course, was the material of choice. One Degree North Red decided to go with a PVC-based frame because of its cost-effectiveness. A lightweight, neutrally-buoyant, yet strong material, we felt that PVC would suit our team's methods best. Unlike metals and carbon fiber rods, PVC tubing is abundant in Singapore; we can thus choose from a wide variety of interfacing types and sizes. PVC also fit in well with our modular design, as it was easy to replace and modify as we saw fit; a metal system would not be as easy to modify.

Another design option was the actual frame shape. The Green T ROV is shaped like a cross rather than the standard rectangle. This unusual cross shape allows the payload of the ROV to be contained within the arms of the ROV itself in order to reduce the overall footprint and increase maneuverability inside small spaces such as the shipwreck. This design decision forced us to source a lot of self-made customized parts, showing One Degree North's ability to seek out opportunities to adapt the ROV to this task.



A top view of the ROV frame, showing spaces for the self-contained motors

Propulsion System

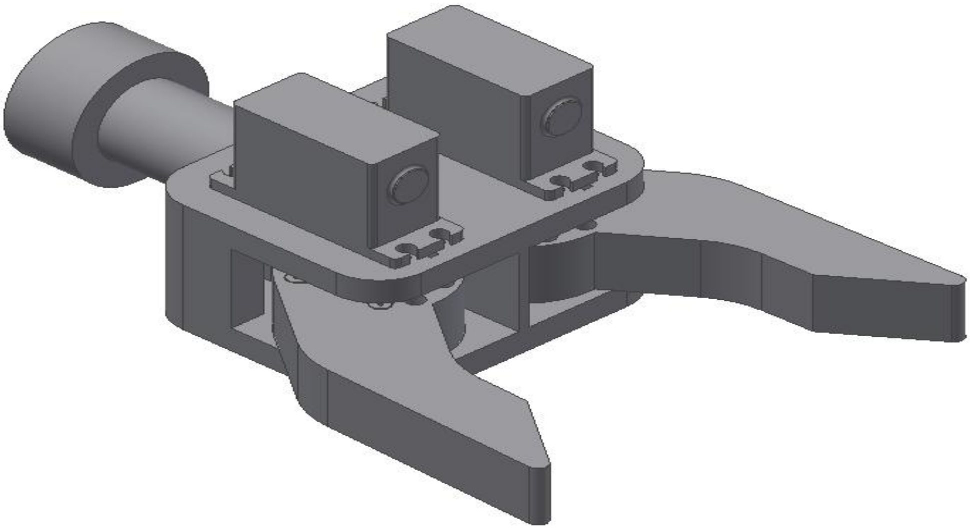
All of the motors and propellers used on the Green T submersible were specifically chosen to create a truly agile, quick underwater robot. One Degree North Red purchased all of the motors this year, and positioned and paired each with propellers best suited to their positions on the robot. For example, all of the forward-facing propellers used this year were boat propellers, regularly used for such applications. Due to the large payload requirement for this ROV, we decided to use larger, aluminum propellers that proved to have an extremely high thrust to power ratio. These larger propellers were found to be too powerful for the lateral motors as their speed would decrease the maneuverability. However, the large 10 N payload for one of the tasks meant that these stronger propellers would work well for the upwards motors. Extensive component and system testing went into this design decision.

A view of one of the motors. Note the specialized propellers in particular.

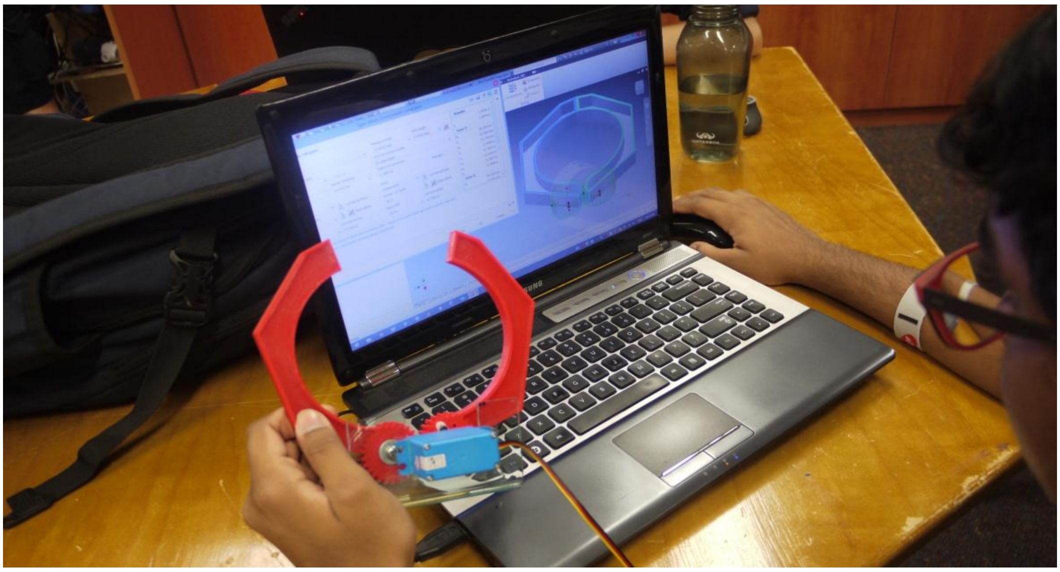
Furthermore, perhaps the most powerful addition to our robot's propulsion systems this year was the creation of a multidrive mechanism. With this slightly more complicated but very rewarding new drive type, the ROV has become much more maneuverable, with a faster pivot speed and a much wider range of movement (including lateral, horizontal, vertical, and diagonal). In the discussions between using a slide propulsion system and a multidrive system, the multidrive won hands down because it used one less motor but could still allow for higher speeds.

Manipulator

The claw was one of the most important parts that our company had to fabricate. It also was a feat of One Degree North Red engineering, designed and built completely from scratch for the Green T ROV. In order to carry the heavy payload of the 10 Newton sensor strings, the ROV needed a manipulator with multiple degrees of freedom that could lock strongly and fit the right way for other tasks like opening the cargo hold. To this end, we designed a 3D model of the ideal claw using AutoCAD, and we then were able to 3D print this model using our Makerbot Replicator 2x 3D printer at school. Thus, our team had constructed the ideal claw, perfectly suited for this year's mission and effective and strong enough to handle large weights.



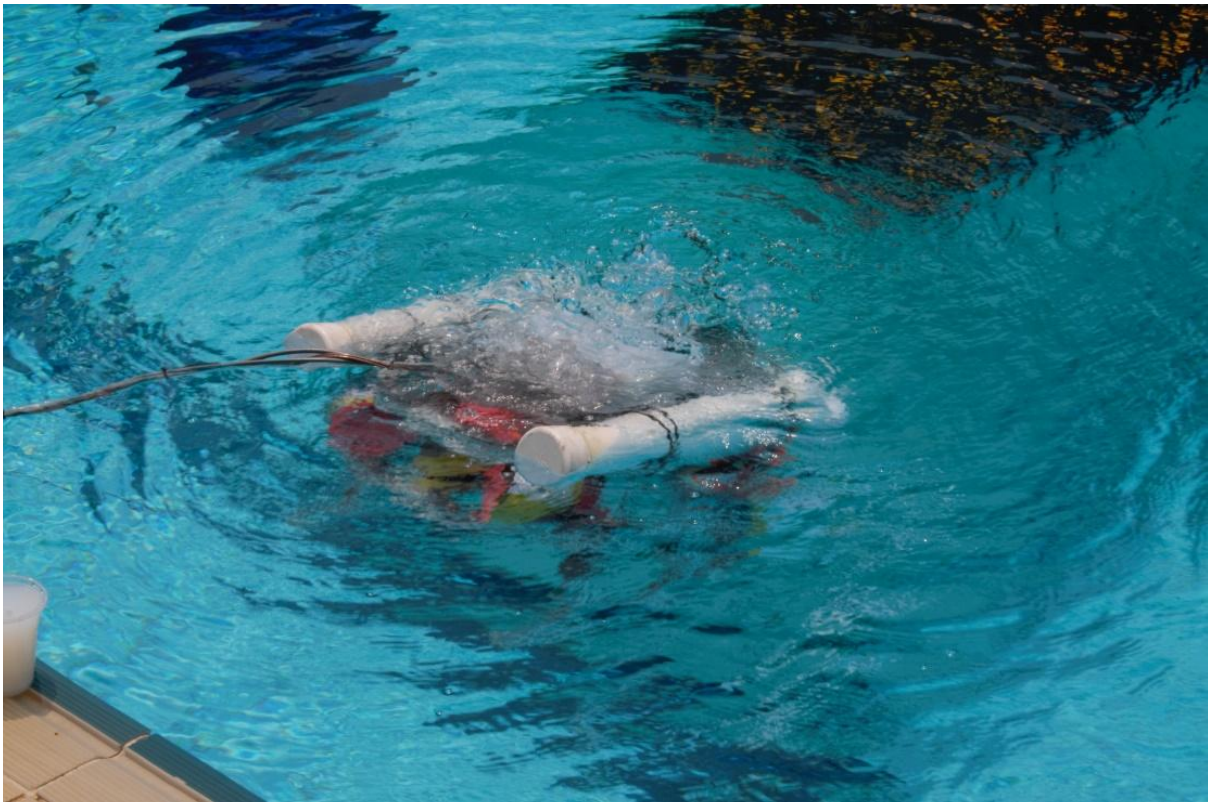
This model shows the design for the claw, which then became a 3D-printed reality



Control System

This year, our control system was not purely mechanical. One Degree North Red decided that in order to best take advantage of the new multidrive system and integrate the readings received from the claw and the sensors. All of the user interfaces (including for the lights, cameras, and motor controls) could also be consolidated by moving to a computer-based system.

After building the code and the programs entirely from scratch, our team procured some new joysticks and managed to effectively control the robot's movements. Mission tasks that required a high level of maneuverability were perfectly served by this new program, and our ROV could then effortlessly replace the sensor strings, enter the shipwreck, open the cargo hatch, and investigate the salinity. All of these actions are benefited by the agility of the multidrive and the simplicity of the control program.



In the Hong Kong regional MATE competition, the Green T machine performed extremely well, completing many of its assigned tasks.

System Integration Diagrams

Diagram 1: ROV (below water) system

This diagram displays the below water systems for the ROV. It consists of two tether components (signal and power) that together control the underwater performance

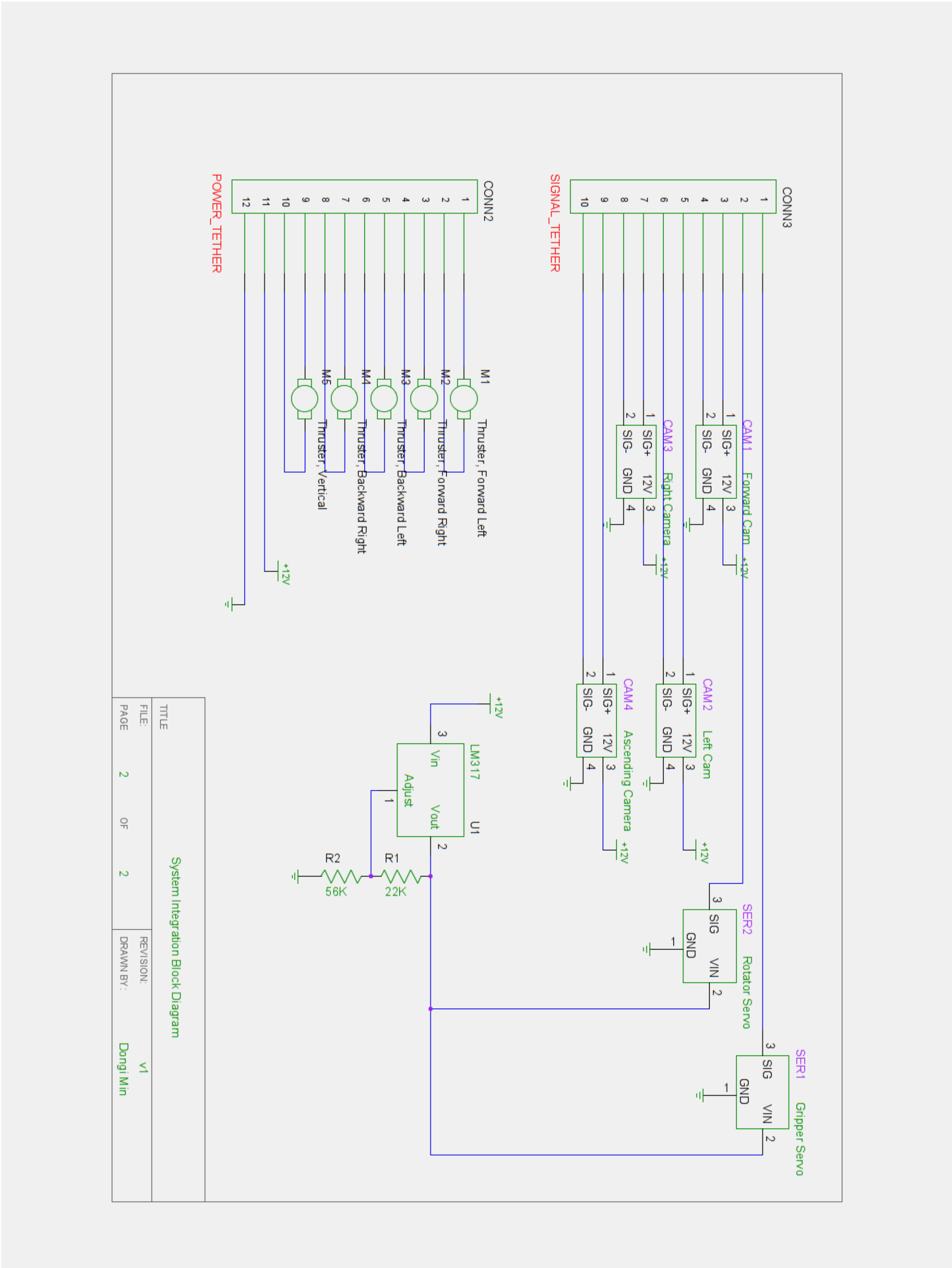
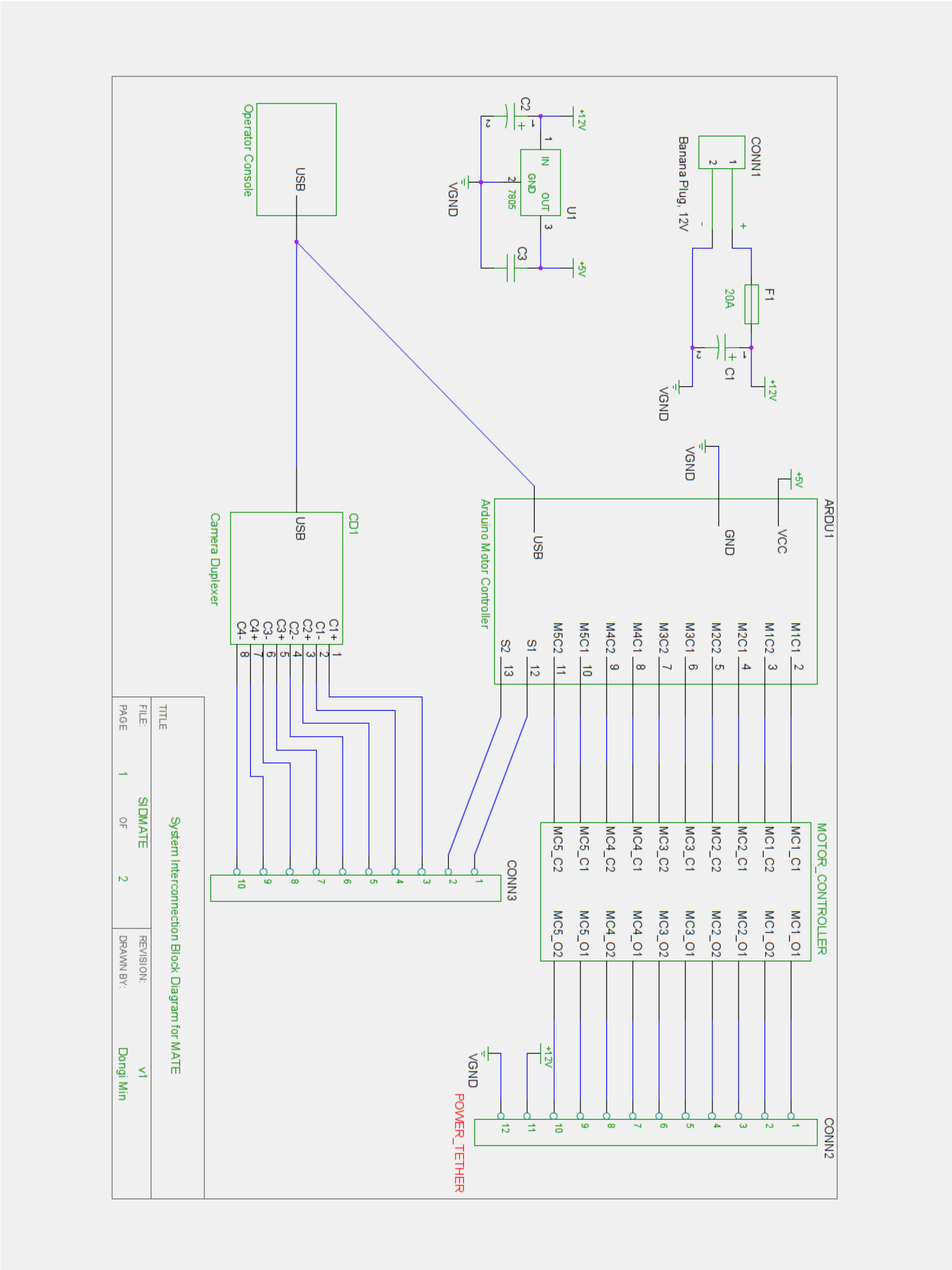


Diagram 2: Above Water Components

This diagram displays the ROV components that remain on the shore. Signals and power are eventually routed to the tether which leads to the ROV. Notice the main 20 Amp fuse F1 located before the first connector (CONN 1).



Budget/Expense Sheet

Part Name/Subsystem	Purpose	Amount	Cost per Unit (SGD)	Total Cost (SGD)	Purchased/ Reused/ Donated	Expected
ROV Frame						
3/4-Inch PVC Pipe	Structure	5 meters	2	10	Purchased	--
3/4-Inch PVC Elbow	Connector	8 pieces	0.5	4	Purchased	--
3/4-Inch PVC Tee	Connector	29 pieces	0.5	14.5	Purchased	--
				28.5		
Payload						
Screw Hook	Carrying Payload	1 piece	0.5	0.5	Purchased	--
Tape Measure	Measuring Shipwreck	1 piece	9.5	9.5	Purchased	--
Underwater Servo	Actuating Claw	2 pieces	25	50	Reused	--
Servo Horn	Interfacing Claw with Servo	2 pieces	0.5	1	Reused	--
13 Gauge Wire	Carrying Data Signal	60 meters	1	60	Reused	--
				121		
Optical System						
Waterproof Camera	Vision	4 pieces	50	200	Reused	--
Camera Cable	Carrying Data Signal	30 meters	1	30	Reused	--
USB 4-Channel RCA	Adapting signal for USB	1 piece	40	40	Purchased	--
				270		
Propulsion System						
Bilge Pumps	Movement	5 pieces	70	350	Purchased	--
Propeller Adapter	Interfacing Propellers with Pumps	5 pieces	4.99	24.95	Purchased	--
Propeller	Providing Thrust	5 pieces	2.89	14.45	Purchased	--
10 Gauge Wire	Carrying 12v power	150 meters	0.5	75	Donated	--
				464.4		
Control System						
Pelican Waterproof Case	Containing Control System	1 piece	136	136	Donated	--
Acrylic Board	Sealing Control Box	1 sq meter	1	1	Reused	--
9v Relay	Controlling Motors	10 pieces	2	40	Purchased	--
2N2222A	Controlling Motors	10 pieces	0.25	2.5	Purchased	--
Diode	Controlling Motors	10 pieces	0.1	1	Purchased	--
12-Pin connector	Interfacing Tether with Box	1 piece	29.96	29.96	Purchased	--
10-Pin connector	Interfacing Tether with Box	1 piece	29.96	29.96	Purchased	--
Banana Plugs	Interfacing with MATE Power	2 pieces	0.5	1	Reused	--
12v Fan	Provides Cooling for Control Box	1 piece	6.95	6.95	Purchased	--
				248.37		
Miscellaneous						
Snakeskin	Improving Tether	15 meters	0.5	7.5	--	Expected
				7.5		
			Grand Total:	**$1139.77**		

Funding provided by Discover Technology ($500) and the SAS Foundation ($639.77)

Safety Report

Company Safety Philosophy

In order to provide an enjoyable experience for all of our members, One Degree North has instituted a comprehensive safety philosophy. Our company prides itself on the advanced machinery that we use and engage with, but we place safety above all else in the use of these tools.

Our robotics lab itself is purposefully designed to allow students to take full advantage of tools while being as safe as possible. The partitioning of the room into a sound-proof heavy tools room, a linoleum workstation and a carpeted classroom allows all members to work together in close proximity while still allowing safety protocols to be tailored to the situation at hand. In the heavy machinery room, separated from the other sections by a soundproof glass, not only are closed toed shoes, gloves, safety goggles, and other basic safety precautions required, ear protection and veteran mentors are also necessary. In the linoleum section, students can work on parts with hand tools like drills and saws. Most of the ROV assembly occurs in this section. Finally, the classroom area is the only place where students can eat, allowing for casual collaboration, design meetings, and business events. The basic safety precautions in this area (such as close-toed shoes) ensure that students are able to take full advantage of this area for its intended purpose. Finally, the location of a teacher sponsor/parent mentor desk in the middle of this room means that an adult is present at all times.

Our mentorship program also promotes good safety practices. In our lab, all new members must be trained by a teacher before being authorized to use any power tools. Also, we hold veterans responsible for themselves and new members, ensuring that all members of the team are looking out for each other. These kinds of policies make sure that our company can be safe and efficient during construction

Jonathan Ong safely uses this saw within the power tools section of the robotics lab

Vehicle Safety Features

Green T, like past One Degree North Red ROVs, is designed modularly. The modular design means replacement of tools that have become safety hazards is easy, while also allowing us to efficiently pick out potential threats because of the simplicity of component testing. Furthermore, all motors are self-contained within the robot. All of the thruster units have mounts that incorporate casing and fan guards to completely contain the unit, thereby eliminating any possibility of injury by spinning propellers. With the vertical thruster in particular, rather than positioning the motor at the bottom of the frame as other companies have done, One Degree North Red has decided to position it facing downwards at the top of the ROV body. This reduces the stress placed on the vertical motor and propeller, and reduces the chance of parts breaking.

For the ROV's electronics, One Degree North Red has left no stones unturned in its pursuit of safety. Especially given the fact that this submersible needs to be used in a civilian pool, the company has used individual component and full machine tests to ensure a human-safe ROV. Furthermore, stress loops for all terminal wires on the tether will prevent solder joints from being accidentally yanked out while the ROV is in motion. Also, One Degree North Red prioritizes protecting all exposed wires (both inside the water and on the pool deck). Thus, all terminal wiring is contained in splash proof control boxes and is interfaced using safe 10-pin connectors. Finally, screw-in connectors also serve the same purpose of protecting the wiring from being exposed to the elements.

All of the motors are completely encased and covered by fan guards.

Most of the main electronics are placed in this splash-proof box

Safety Precautions

Our safety practices while using the robot consist mainly of methods to ensure strong cooperation and collaboration between engineers on deck and our pilot. This is done because of the remote operation requirements of the mission. For example, before any member is allowed to pick up or touch the robot they must yell "clear" to the driver, who will then shut the motors down. Furthermore, any testing or modification done to the robot is always done with the power off and the tether unplugged.

Safety Incidences

The only injury that has occurred on the team was to a member who accidentally reached for the robot without shouting "clear" to the driver. After seeing a motor shift from the mount, the tether operator reflexively attempted to grab the motor and was slightly nicked as a result. Our other tether operator yelled clear, and the member's finger was only slightly grazed (we used our on-site first aid kit to give him a band-aid). After this incident, we were even stricter on safety protocols, forcing tether managers to stay at least two steps away from the water to prevent future recurrences. Our regular washing of the robot with freshwater had ensured that no corrosion or rust had built up, and so the member was not at a very large risk. Finally, we have since created comprehensive propeller guards to fully prevent any human contact with these moving parts.

Troubleshooting and Testing

Green T's systems rarely run into glitches, but when they do, One Degree North Red's comprehensive troubleshooting system mitigates the effects of these problems. Apart from a focus on 'all eyes on every project,' a philosophy in which everyone is responsible for monitoring the progress of each component, the company also uses Github to troubleshoot programs. Github is an online, open-source repository of code that others all across the world can access. When we run into code issues, the vast network on github can help us effectively find solutions to our problems.

Furthermore, another troubleshooting method we use is individual component testing. Our modular design allows for components to be taken off and individually replaced or examined, especially as wear and tear takes its toll on the machine. In this way, we can examine the seaworthiness of individual parts in a process of elimination to determine where the true problems lie. Components are regularly tested for days under high-pressure scenarios (claws are placed in buckets with repeated programs that run for hours, control systems are left on to try random processes for days without catching exceptions) to ensure a complete confidence in each piece before it is added to the machine. Once on the machine, it is once again rigorously tested and modified in conjunction with the other parts.

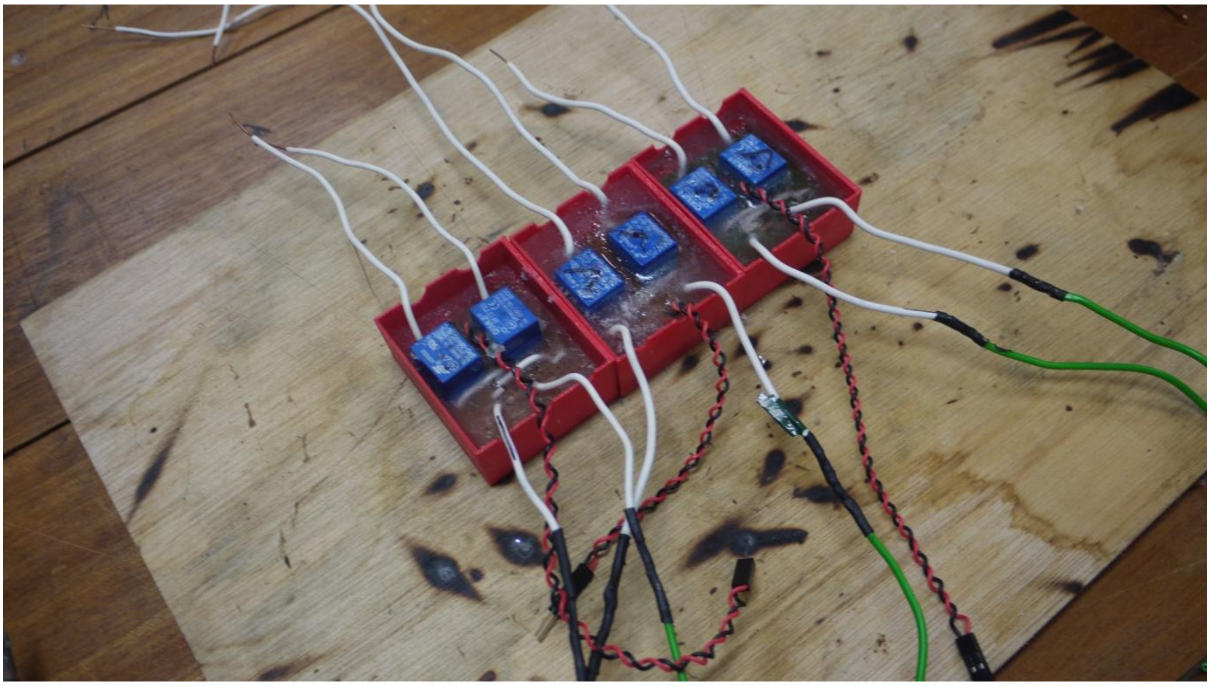
Examples of component testing are numerous, since One Degree North Red tests each component separately before integrating it into Green T. The bilge pumps were each run separately in a water bucket to test their effectiveness, and our propeller tests were also conducted apart from the ROV main frame. Our motor controllers, handmade for the occasion, were extensively tested, as were our servo motors that power our claw.

Challenges

Part Procurement

Living in Singapore, one of the biggest challenges for One Degree North Red is finding parts that are available and affordable. Oftentimes, the inability to interface metric parts with imperial parts shipped from the US, or the sheer costliness of most consumer goods in the country, or the time it takes to transfer items to our lab from overseas, can be prohibitive to our dreams and designs. Creating a sustainable, long-term robotics program in Singapore must be done with part procurement in mind, because this issue is unlikely to resolve itself in the near future.

In response to this challenge, One Degree North Red has adapted by building our own components. We bought basic parts like wires and epoxy, and using 3D printed boxes we created our own motor controllers for a fraction of the price of store-bought specimen. We also saved money and time by bypassing the typical overpriced underwater cameras; we sealed a regular camera in epoxy instead, thereby waterproofing it and giving us a cheap, strong, durable device. These are but two ways we used our knowledge of engineering and our resolve to build the best ROV possible to circumvent the seemingly insurmountable supply chain issues in front of the Green T machine. On our final ROV, most components are self-built.



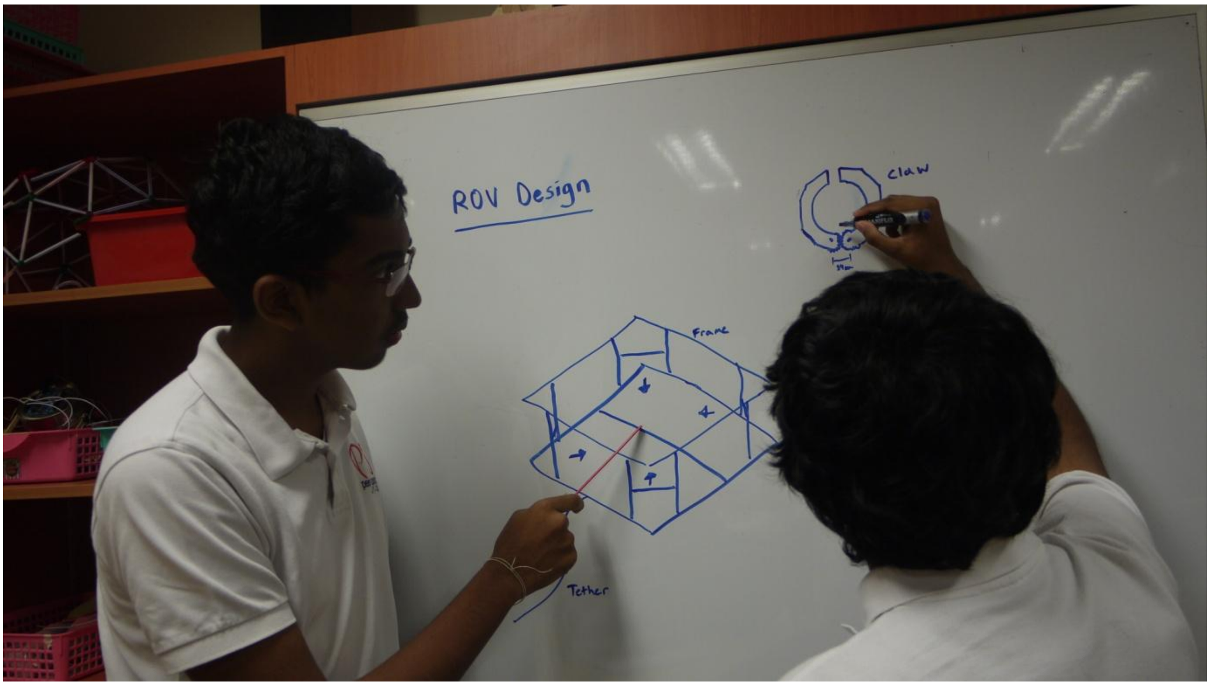
Some of the motor controllers created by One Degree North Red's Dongi Min

Also, One Degree North Red worked on creating a comprehensive guide to find materials and parts in Singapore. By working as team to build this document, we not only pooled our knowledge of the best machine shops/part places in Singapore, we also created a long term solution that will allow future generations to find parts efficiently and effectively.

Teamwork

Another problem we had was with coordinating the schedules of the 13 members of our team. Given the wide variety of activities, extracurriculars, and organizations that each of our members is part of, finding times to work together efficiently and move forward as a group was very difficult.

We overcame this problem by splitting up the roles by our areas of expertise, thereby lowering the quorum necessary within each group to make decisions. In these smaller groups (like the mechanical engineers), it was easier to find common times to meet up and discuss solutions to new problems. Finally, we developed a long-term schedule in our first meetings that illustrated a general plan for our ROV's construction. This schedule let everyone know that the team's progress would not be contingent on any one individual.



Part of the mechanical engineering team meeting to decide claw modifications

Lessons Learned

This year, we were able to implement a wide variety of new programs that have helped us make leaps and bounds forwards as a team. For one, we've learned how to attract not just immensely passionate upperclassmen engineers, but we've diversified into members of other genders, grades, and interests. We did this by allowing others to experience robotics through leveraging many community events, and by showing people with non-engineering interests how a team like MATE could still offer places for them to investigate their passions.

Furthermore, we also learned a lot during the implementation of our first ever digital control system for the ROV. The back to back issues that arose when we attempted to construct this program (including when the joysticks weren't read on the system, and when the motors turned the wrong ways causing the robot to spin in circles) taught us a lot about problem-solving on the go and perseverance. The lessons we've learned have all been passed down to our newest programmers and electrical engineers to ensure that this knowledge is sustainable for the company.

During our Hong Kong regional event, we learned valuable lessons on how to cope under pressure and delegate responsibilities as a team on the go. Because of a few technical malfunctions during the first round in the pool, we were under extreme stress to make modifications in time. Our ability to split the work and share time on the robot allowed us to rectify the problems and ultimately perform admirably.

Future Improvements

One system that we have yet to implement is pneumatics. We hope to soon be able to bring pneumatics to bear on a future mission as practical. While we have had a little bit of practice during the MATE off-season with pneumatics, we haven't had nearly the amount of proficiency we'd need to use such a complicated system on our underwater ROV. Pneumatics in this mission could have been useful for lifting the heavy weights as an adjustable ballast or for puncturing the jars on the ocean floor. We hope that in future iterations, the One Degree North Red team will be able to integrate this extremely useful technology.

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Acknowledgements:

One Degree North Red would like to thank the MATE center and the Hong Kong regional organizers, sponsors, mentors, and volunteers. They have given us the chance to participate in a world class robotics competition that has improved our skills tremendously.

We would also like to thank Discover Technology and the Singapore American School for the funding we needed to carry out this robotics project.

Finally, we'd like to thank our mentors, Mr. Millar and Mrs. White, who have helped us with the design and construction of our robot. Without their support, our robotics team would not have grown to near the size that it is today.

Appendix 1: Safety Procedure

One Degree North A

The Green T Safety Procedure

1. Securely fasten connections to the control box
    a. Plug in data connector (red connector), and screw in
    b. Plug in power connector (green connector), and screw in
2. Check male and female connectors for defects or debris
    a. Control box power cable terminals
    b. Soldered connections within control box
3. Plug RCA connectors into video splitter and video splitter into monitors
4. Ensure propellers are free from entanglement
5. Check claw for operational readiness
    a. Monitor rotational and gripping servos
    b. Check wire connections and claw gears
    c. Utilize 'gentle pull interface test' on claw mount
6. Check fuses
7. Gently deploy ROV in water
8. Open laptop
9. Plug in joystick
10. Plug in 12v power
11. Turn on the master power switch
12. Check systems functionality
    a. ROV motion in all directions
    b. Claw functionality
    c. Camera functionality

ROV is ready for mission deployment