NOVA Underwater Technologies

Halifax Robotics

Halifax, Nova Scotia

Technical Report 2017

Team Members:
Saul Hughes - CEO (Grade12)
Liam Acres – CTO and Pilot (Grade12)
Logan Crooks – Chief Electrical Engineer (Grade12)
Will Paul – Senior Electrical Engineer (Grade 11)
Matt Glencross – Chief Mechanical Engineer (Grade12)
Morgan Higginson – Senior Mechanical Engineer (Grade 11)
Daphne Finlay – Mechanical Engineer (Grade12)
Yuhai Li – Software Engineer (Grade 10)
Yuyang Li – Software Engineer (Grade 10)
JinHyuk Mo – Software Engineer (Grade 10)
Francisca Annan – Senior Structural Engineer (Grade12)
Warren Fisher – Structural Engineer (Grade 10)
Ellis Keener-LaCroix – Structural Engineer (Grade 10)
Johnny Ye – CFO (Grade12)
Noah Mason – Safety Officer (Grade12)
Simon Qi – Internet Marketing Manager (Grade 11)
Colin Melia - Mentor

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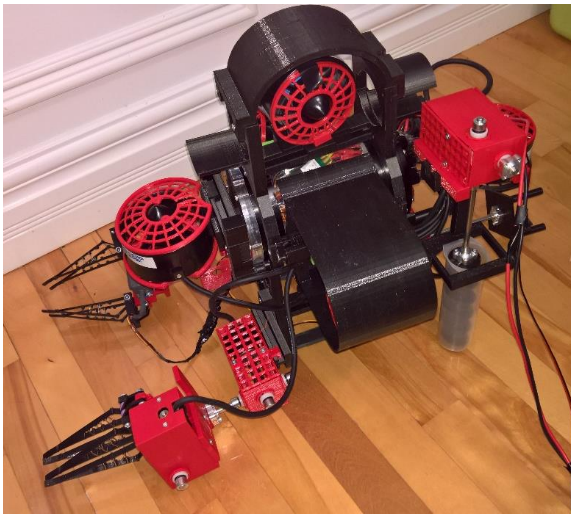
Abstract

Returning for our third year, Nova is proud to present our newest ROV, N6.

N6 has purpose-built articulators that can interact with all the objects in the tasks, primarily a pair of multi-purpose claws (also able to rotate 90 degrees). Our ROV is also equipped with an auger, built for extracting and storing up to 150ml of agar, and a tool designed for turning valves. The claws are driven by waterproofed and insulation-tested servo, while the others use worm gear boxes with a hybrid of commercial insulation and electrical brushless motor magnets.



Our Complete Reginal ROV, "N6"

We have retained our 6-thruster design housed in a completely new 3D-printed frame, operated from an Xbox controller through the surface laptop. We've added a motion sensor and magnetometer to help with specific tasks. Our robot software was brought to Raspberry PI 3 running on Windows 10.

N6's frame is 3D printed entirely of PLA. This compact design gives a 38cm(w) x 38cm(h) x 44cm(l) (with articulators removed) ROV weighing only 8.3kg (without tether), and tested to 4m in a local pool.

N6 also has a laser for measuring the distance between itself and other objects, perfect for mapping out underwater areas, a stabilization system which feeds back gyro data to the software which controls thrusters, as well as buoy for marking off objects of note to be visible from the surface.

Not only do we have a much lighter and stronger frame, but a lighter tether featuring just 4 conductors. We run a full network over the signal wires carrying images from our 6 IP cameras back to the laptop.

Major Product Features

- Light frame
- Easily Replaceable Frame and Components
- Waterproofed Main and Satellite Electronics Enclosures
- Small Electronics Core
- Six-Axis Movement with Six Thrusters
- Thruster Safety
- Auger
- Spinning Articulator
- Flexible Claw Articulator Jaw
- Laser Measurement
- Waterproofed Servos
- Insulated Gear Box Motors
- Universal Windows App on Raspberry Pi 3
- Universal Windows Platform Control App on Windows 10 Laptop
- 6 IP Cameras
- Network over Power
- Buffer Tube
- Light and Safe Tether

Theme Alignment

Entertainment

The robot has interchangeable parts so they can either blend into the environment or be boldly coloured or branded as necessary.

Commerce

The robot has easy to replace frame parts. Reasonable overall replacement cost and software control allows for updates of control.

Safety

The robot has safety features for both users and the robot. It uses incorporated shrouds and finger guards for thrusters and gear boxes. The robot core is surrounded by a frame, shields surround the thrusters and software regulates the motor power.

Environment

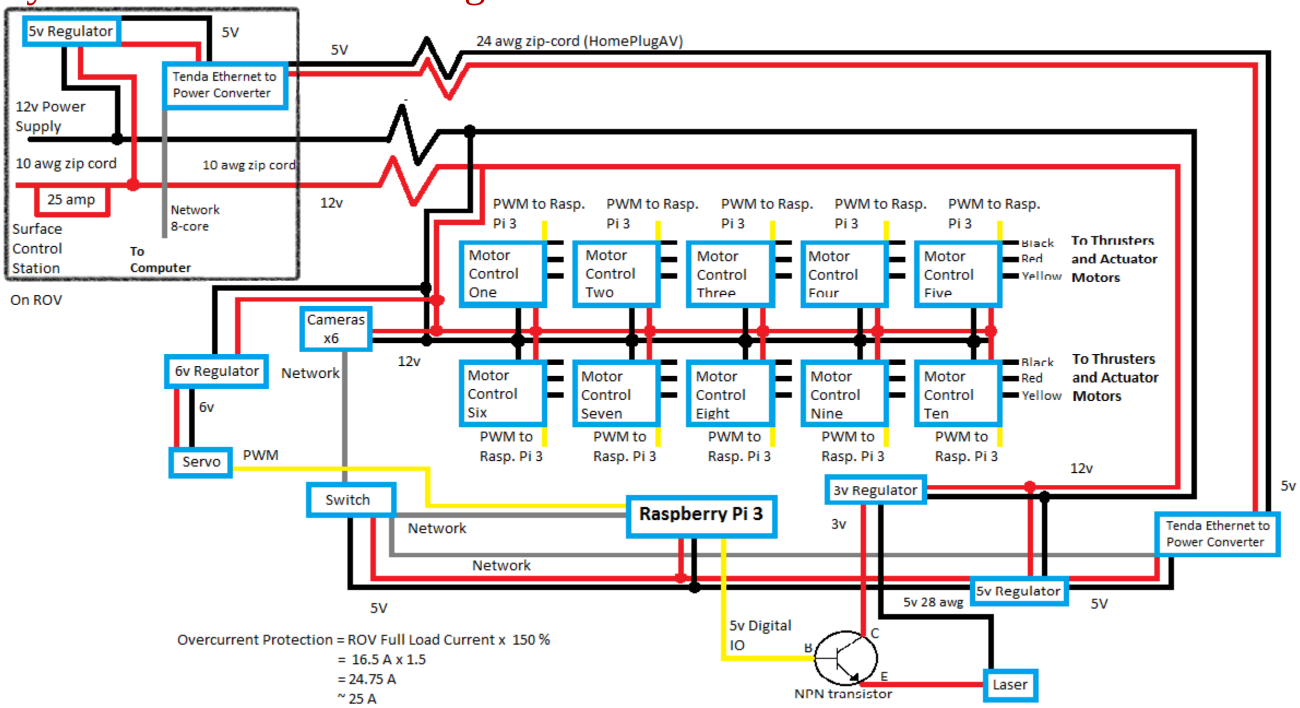
The frame uses biodegradable PLA materials. We can replace components without replacing the whole frame.

Product Pricing

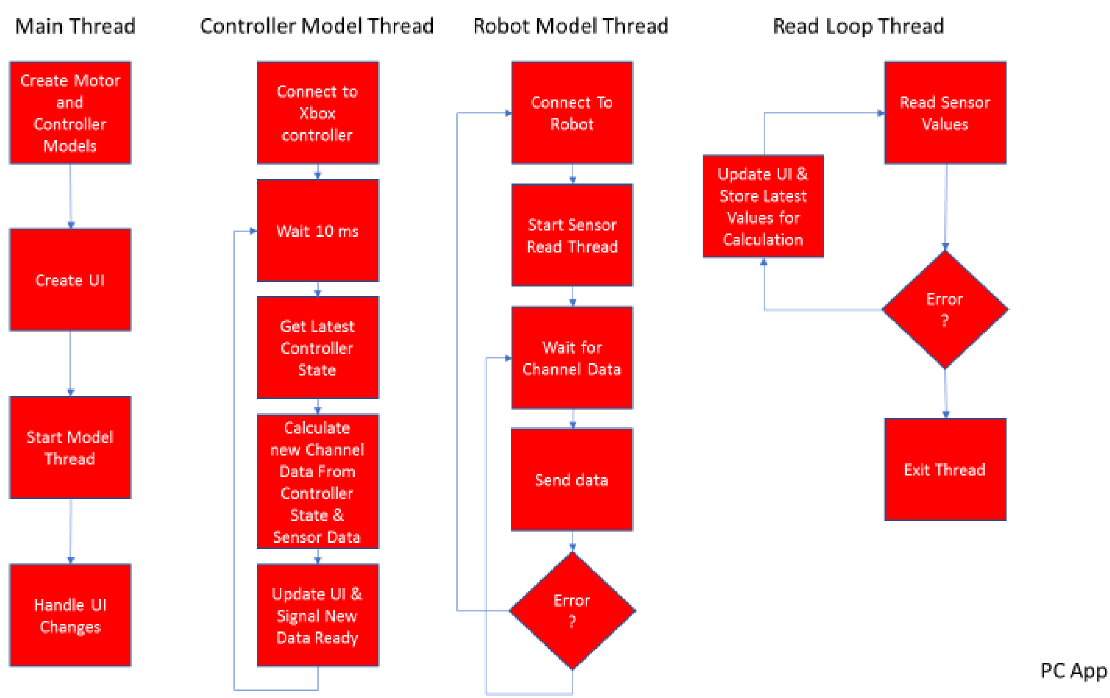
For the purposes of manufacturing our ROV, we have provided a cost estimate of how much it would take to re-produce it from scratch based on what we spent building the final product.

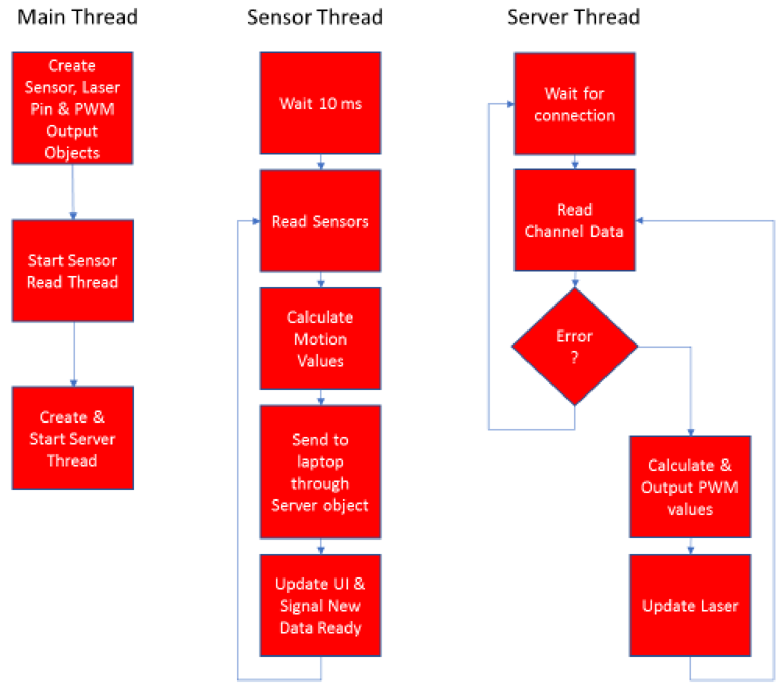
The total price of our ROV is $5,326.43 CAD, or $4,097.25 USD. A full breakdown of our budget can be found in the appendix, including costs we spent on research and on providing spare parts, as well as sponsorships.

System Interconnected Diagram



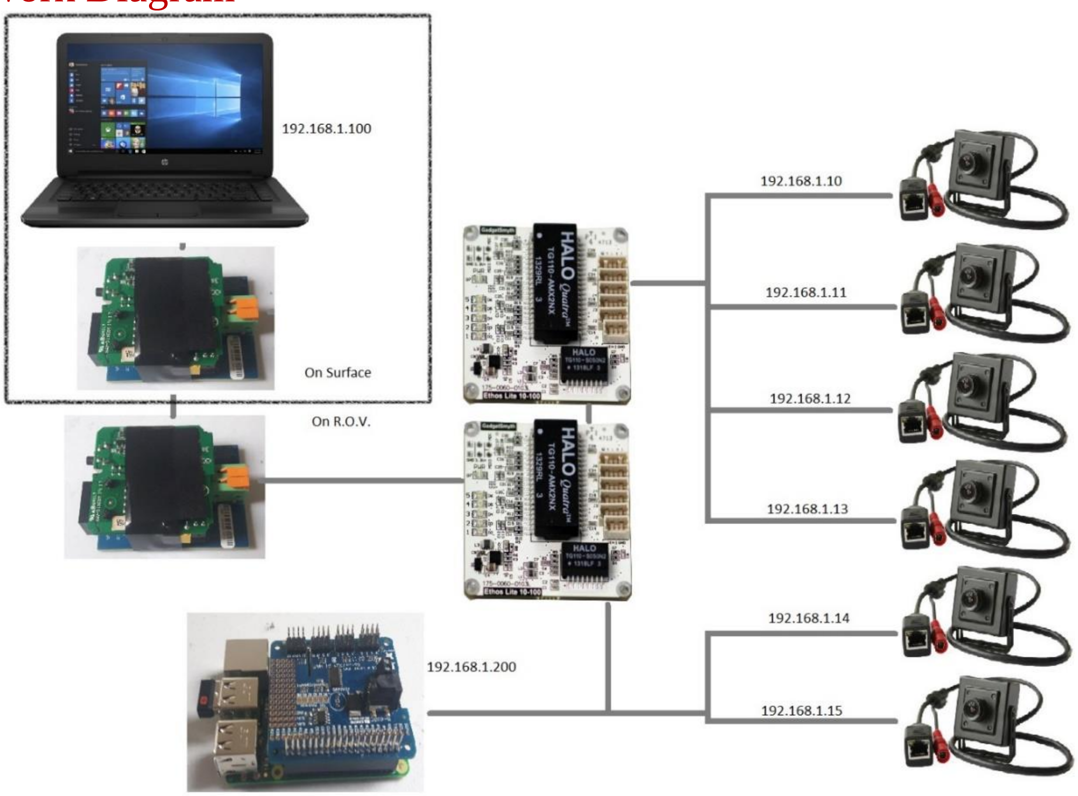
Software Flow Charts





Robot App

Network Diagram



Design Rationale

Light Frame

Our Goal

Our biggest concerns when constructing this year's frame was keeping it light and compact.

Implementation Details

To meet this goal, the frame of our ROV is constructed entirely of 3D printed PLA. The core structural components are printed of high in-fill pieces. The less structurally important components are printed of low in-fill PLA. We went through various iterations, and even tried major parts printed of Carbon-fibre-reinforced material but this made the robot heavier and still easily split under load in some cases.

Results

The 3D printed components used in N6 worked very effectively, making it both light and compact. Further the frame is completely biodegradable, and all other components (tubes, thrusters, etc.) are reusable. This make our ROV 100% environmentally efficient, something we were striving for when constructing our frame.

Easily Replaceable Frame and Components

Our Goal

A large lesson we learned from last year in building our frame was to try and design our frame around our components, and not the other way around. We also wanted to create modular parts to easily replace and work on components. Having had parts break in previous years, we wanted to have spare parts on hand that we could replace in minutes.

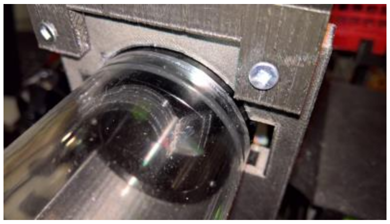
Options Considered

We looked at various materials from which to construct the frame, including wood, metal, plastics and 3D printed materials. We also considered different ways to modularize the frame and put the pieces together, such as glue and screws.

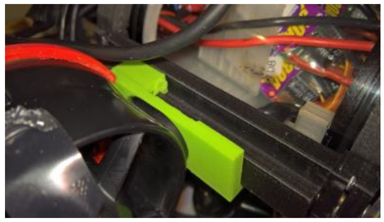
Chosen Implementation

While there are tools for wood and metal working, we decided to build on last year's experience with the 3D printer, and went all out to build the entire frame from 3D-printed parts. We used threaded inserts in the frame so that parts of the frame surrounding the central tube can be taken apart without compromising the integrity. We made it possible to easily separate the frame from wired-in components by creating twist-hold camera mount, twist-snap thruster mounts, and twist-snap articulator mount. This flexibility also means the fully assembled robot can be bigger than 48cm, but fall below this measurement with parts removed and placed on the frame (inside a notional 48cm sphere) using velco.

Threaded Inserts



Camera Twist Hold Mount



Thruster Twist Lock Mount

Articulator Twitch Lock Mount

Challenges Faced and Lessons Learned

One problem we had was having to reprint designs numerous times because of small measurement errors. Next time we are going to try and be much more precise in how we design our components before printing them. We would also aim to include pilot drill holes into the prints to reduce errors in integration – <u>something we've added in placed since the regional finals.</u>

Waterproofed Main and Satellite Electronics Enclosures

Our Goal

We wanted our main electronics, cameras, and laser to be fully waterproofed in order to be safe when in the water.

Solution Chosen

Based off the success we found last year, we used Blue Robotics waterproof tubes in order to do this. 2"-diameter tubes were used for the laser and cameras, with a 4" tube for the primary electronics enclosure. Given our success with these components, we didn't feel it appropriate to consider other options. The components are affordable and reliable.

Small Electronics Core

Our Goal

Last year, the majority of the size of our ROV came from our central tube frame which was 11" long. This year we wanted to make it much more compact to help meet the size requirements for the ROV and also to reduce the weight.

Solutions Considered

We had two main ideas. The first and most popular one originally was to have two much shorter tubes in order to create a squarer design, and thus take up less surface area. However, we were worried about the number of connections needed between the tubes.

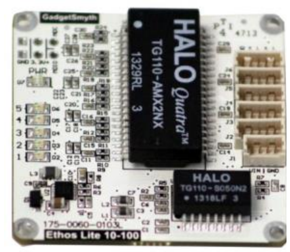
Chosen Solution & Challenges

We decided that we could use one very short tube (4" diameter by 6" long) if we were able to use smaller components. Because we also wanted to reduce the weight of the tether, not use pneumatics, and go with an all-electric system, we also had to have a network switch in the tube to connect to all network devices. We found one by BlackBox which seemed small enough, but was still too large. We found another one called EthosLite which was much smaller. This came with its own challenges because it uses extremely small Pico Blade connectors that are difficult to attach. The other factor in shortening our tube was to mount components neatly inside the tube. We were inspired by the Blue Robotics product used in an 11" tube, and made our own mounting tray and made our own 6" tray of a similar design.

Inspiration - Blue Robotics Tray

Early prototype 6" electronics tray

Considered - Black Box Switch



Used - EthosLite Switch – 1.5" x 1.5"

Six-Axis Movement with Six Thrusters

Our Goal

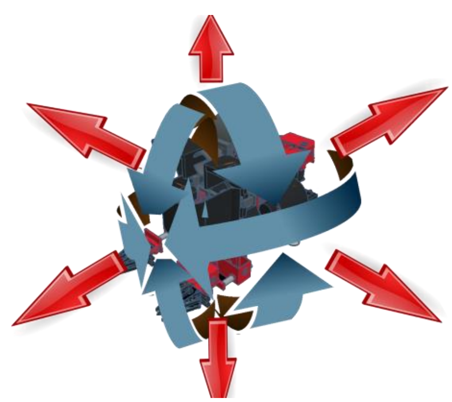
For thrusters, we simply wished to maintain our main feature of last year, being able to move in 6 axes – 3 translation and 3 rotation.

Chosen Solution

N6 has kept our main attraction from the last two years of ROVs, our six Blue Robotics T100 thrusters. Theses have been extremely reliable and so we have continued to use them this year.

Challenges

In order to get this flexibility, we need not only neutral vertical buoyancy but also rotational neutrality. This necessitated some additional buoyancy adjustments. We also need to maintain some stability through pilot skill so have taken steps this year to try and automate stabilization.



3 translation & 3 rotation axes

Implementation Details

They are arranged in a perfectly symmetrical orientation so as to provide the maximum balance for our ROV. With this design, we can move in 3 lateral directions, and rotate along all three axis. This allows for the most maneuverability possible, making no task impossible. We've also attempted to include auto-stabilization using gyro/magnetometer feedback to automatically adjust thruster power while moving.

Thruster Safety

Our Goal

A major concern when designing any part of an ROV is safety. We needed to properly protect our thrusters from any objects that may be caught in them, as well as from impact, while also protecting users from spinning blades.

Solutions Considered

One idea that we eventually threw out was to create a shell that would encompass our entire ROV. We eventually considered this impractical to 3D print.

Thruster Safety Guard & Shield

Solution Chosen

We decided that we would instead 3D print individual covers and guards for each thruster.

Implementation Details

Our covers were a web-like circular design printed with scaffolding that was then removed and screwed to our thrusters. We also did this for our gears boxes. The shields were arch shaped PLA components that wrapped around the thruster to provide maximum protection.

Auger

Our Goal

One of the most interesting requirements for this year's ROV was the ability to pick up agar from underwater. We needed a specialized tool to do this.

Solutions Considered

We went through multiple design iterations trying to come up with a solution to this task. Primarily we considered a scoop and syringe. The scoop idea was quickly thrown out due to impracticality in removing the agar from a cup. The syringe idea was heavily considered to the point at which we ordered a 150ml syringe.

Auger

Chosen Solution

We eventually decided to use an auger. We believed this would be much more effective than the syringe due to not having to rely on air pressure or a small opening. As well, we would be able to fully use the rotational movement of our motors, instead of having to convert it to lateral for the syringe.

Implementation Details

While the task only required us to pick up 100ml, we decided to be safe and allow our ROV to pick up 150ml. We re-used the shell from a syringe in order to house our auger mechanism, and store the agar once it is extracted. The auger itself is the only component on our ROV not completely designed by our team. We acquired an open source design from Thingiverse, and modified it to fit the size we wanted.

Result of Our Solution

We performed extensive testing both in and out of water to make sure that our auger could pick up agar. The design proved to be extremely successful, making it to our final ROV design.

Spinning Articulator

Our Goal

The other major task that we designed a specialised tool for was the turning of a valve in order to control the flow of liquid. The reason we designed this device is due to limitations on our main articulators.

Chosen Solution

The tool we designed is extremely simple. It is a four pronged, 3D printed, device that can rotate. The pilot of our ROV would have to simply place the device onto the valve, and hold a single button to begin rotation.

Implementation Details

Our 3D printed articulator was printed several times in order to properly fit the valve, but we eventually found the right size. The prongs were made to extend well beyond the width of the valve to provide proper grip.

Spinning Articulator

Results of Our Solution

This extremely simple design was very efficient at completing the task in our testing, but we modified it after the regional by removing two prongs and widening the remining two to easy the process of 'docking' to the target.

Flexible Claw Articulator Jaw

Our Goal

Last year a major problem we had was losing grip of objects at some point during transport. We needed a design that had an extremely tight grip.

Inspiration - Servo City Claw

Solutions Considered

We immediately settled on a flexible claw design. This worked effectively due to the fact that the fingers will curl around an object when pressure is applied to the inside. Our main area of debate was material. We tested both PLA and carbon fiber, but the carbon fiber proved too brittle for the fingers. We also tested different closing method in order to get the best grip on things.

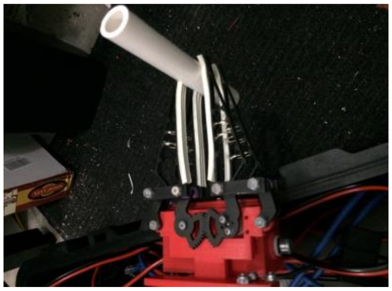
Chosen Solution Implementation

Our flexible claws would be constructed entirely of PLA, in order to provide maximum flexibility. Each claw is constructed from four of these fingers. They are constructed from 3D printed PLA and stainless steel wires. For the motion of the jaw we were inspired by a claw kit from ServoCity.com. We created a hybrid between this and our own design.

The Flexible Articulator Up Close

Results of Our Solution

These fingers proved extremely effective in gripping small objects, perfect for the majority of tasks our ROV must complete.



The Flexible Articulator in Action

Laser Measurement

Our Goal

We needed a way to measure distance from the ROV to object in front of us.

Solutions Considered

We looked at sonar solutions, but these were bulky, using a simple tape measure (which we may still consider as a backup) and light-based solutions, but still a potential backup solution.

Chosen Solution Implementation

We have built a system which fires a single green dot laser beam (<1 M 532nm non-diverging) parallel to our camera's line of sight. Our software then measures the distance from the centre to the green dot and with some calibration, and live calculations, we can determine the distance to the object the dot is on.

Waterproofed Servos

Our Goal

We wanted to have electrical actuators to reduce tether weight and control system complexity.

Solutions Considered

We started experimenting with Servos which we could control using PWM signals just like our existing thrusters.

Challenges

After some attempts and following guidance from videos we were able to create waterproofed servos that worked down to 4m. However, we discovered that a MATE bulletin requires custom-built motors to pass specific insulation tests – 10MOhm+ and our servos were not passing. We modified our technique and were ultimately able to get a specific servo model to be waterproof to 4m, still operate and pass the insulation tests.

Insulation testing with Samyo meter

Chosen Solution Implementation Details

We remove the top and bottom of the servos. We apply liquid electrical tape to all the circuity and let that try. We then apply marine grease liberally to all the machinery. After this, the outside of the servo was covered in liquid electrical tape, followed by epoxy. We then epoxied any place along the wire where there was a connection made.

The wire connections made use heat activated shrink wrap and silicone to be waterproofed. We then coated this already safe connection in liquid electrical tape and epoxy to be sure of its security.

Servo waterproofed to 4m+ and

Results of Our Solution

This method proved to be more than enough to safely waterproof the servos as designated by the MATE March technical bulletin, which required 10Meg ohms of resistance after being immersed in water over night. The following are our results of these successful tests on our three fully waterproofed servos (one on the ROV, two backups):

Servo ID	Date of Test	Initial Resistance	Resistance After Overnight Soak
1	29th March	>100 Mohms	>100 Mohms
2	19th May	>100 Mohms	>100 Mohms
2	19th May	>100 Mohms	>100 Mohms

Gear Boxes

Our Goal

While trying to get servos to be waterproofed and pass the insulation test, we realized that we needed a backup plan. We also need good rotational drives. We also realized that we had no continuous rotation servos working well at all.

Solutions Considered

We started by using Blue Robotics M100 motors since there was a video shown how to establish an insulated connection.

Challenges

Unfortunately, the M100 motors with the insulation applied, did not pass the test. We had lengthy correspondence with Blue Robotics. Also, these motors run quickly and so we'd need a way to reduce the speed down to something manageable for our articulators.

Custom Gearbox with plastic gears/bearings

Chosen Solution Implementation Details

Following further correspondence with Blue Robotics, we created a hybrid solution using a Blue Robotics T100 Thruster core which passed the MATE insulation test (and we tested them ourselves too), combined with a Blue Robotics M100 motor magnet shell.

We also built gear boxes which translate the high RPM of the motors down using worm gear components we bought.

The boxes themselves are 3D printed of PLA. We used a 30 to 1 and 50 to 1 worm gear in order to slow the motors enough to operate our devices. The open side of our gear box has a safety guard of PLA. This properly shields our gears but also allows in water for properly lubricating the motors.

Universal Windows App on Raspberry Pi 3

Our Goal

To build on our existing code base but improve the development lifecycle, while being able to use the latest tools and platforms

Chosen Solution Implementation

Unlike previous years in which we used a Netduino Microcontroller, this year we used a Raspberry Pi 3 microcomputer to host software from within our ROV. It runs Windows 10 IoT Core with a C# app. This provided some improvements to the development and testing phases of our design, most notably the ability to deploy, run and debug the application remotely over the network cable. We could also add a 16-channel PWM 'hat' to be able to control all of our motors, thrusters, servos, etc.

Universal Windows Platform Control App on Windows 10 Laptop

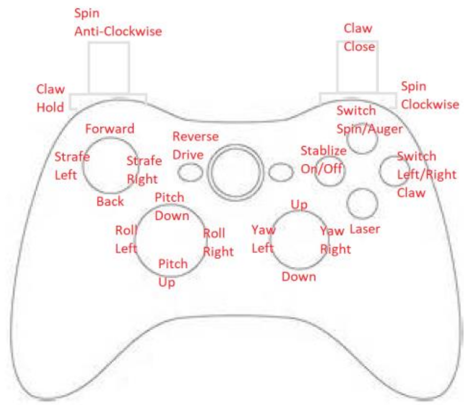
Our Goal

Keep the same control software we had, but add cameras and perhaps additional sensor output.

Chosen Solution Implementation Details

We kept most of the implementation the same, but added an H264 IP camera control, created space in the UI for the camera images, and made the flow of data to and from the robot be asynchronous.

Every 10ms, the software checks the Xbox controller and uses the state (along with the latest sensor data from the robot) to send output values to the robot – 1 byte per channel. The robot converts these to PWM values for electronic speed controllers (ESCs) for motors (used to open/close and turn articulators) and thrusters, and to on/off values for the laser. The robot reads the sensors values every 10ms and sends those back to the laptop app.



Controller control scheme

Challenges

We wanted to get pitch, yaw & roll values, but the calibration for the magnetometer was tricky. We also had to convert some open source code from C to C# - Mahony & Madgwick algorithms – to get those values. In the end, we decided that a combination of results from both algorithms would be best. Going forward we will use these values to provide automated stabilization.

6 IP Cameras

Our Goal

We wanted our cameras to have full view of all our tools and surroundings.

Solutions Considered

We previously used composite video feeds. This required either a conductor per camera (plus 1 common ground) which produced ghosting over such a long connection, or 2 conductors per camera with a balance-unbalance circuit, needing even more wires.

Chosen Solution

We have six H264 streaming IP cameras attached to ROV in order to properly view all four tools, the front and back of the ROV, and line up the laser correctly.

Implementation Details

Our cameras are IP based and send signals over ethernet cables. The signals from all of our cameras are run through a EthosLite switch in order to get them down a single network connection. We had to make adjustments to the IP camera settings to avoid auto-exposure from making unexpected changes to the frame rate and quality.

12V IP Camera before re-wiring

Network over Power

Our Goal

To get a lightweight tether.

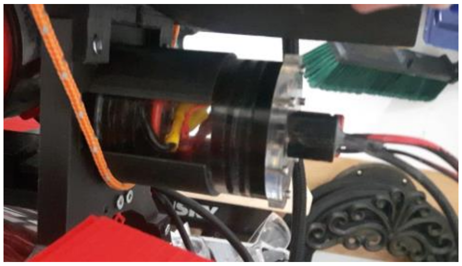
Solutions Considered
We wanted to get rid of the pneumatics cables so we knew we'd have to go all electric. In doing this we'd still need network signal to carry our control system data. We decided to explore network over power using the HomePlug AV protocol in some TENDA hardware listed on OpenROV.org with the hope that we could get down to just two conductors (for +12V and GND) with the signal going over the power wire.

Challenges
We didn't get a definitive answer from MATE on whether this would be allowed for safety reasons. We also couldn't get a stable signal. When we turned on the thrusters, there would be data packet loss. We consulted various forums and tried solutions including ferrite cores and capacity banks but ran out of time to find a solution.

Chosen Solution Implementation Details
We decided to carry the network signal using the TENDA network over a 5V 24 AWG signal pair. This meant we'd have two power conductors and two signal conductors. The devices can take ethernet RJ45 plugs going into them on each end. The surface end goes into the control laptop and the robot end goes into the EthosLite switch. This is still much lighter than having an 8-conductor network cable.

Buffer Tube
One of our most important features for proper testing is our buffer tube. While all of our electronics are contained within our main body tube, this smaller 2 inch tube serves a vital purpose.

While constructing, we wish to continually test parts of our ROV; however, we will do this over much shorter lengths of wire, since our tether is one of the last features we will put together. We do not wish to seal small lengths of wire into our main tube, effectively waterproof and test everything, and then have to break those seals to secure our full-length tether (which then requires re-sealing, waterproofing, and testing all over again). To solve this problem, we have the buffer tube. Short wires are run out of main tube into the buffer tube, where inside a connection is made to our main tether. This allowed us to effectively connect the small length of wire we are using for testing to our final tether. We would rather not make these connections loose in the water (requiring extensive waterproofing, and, even then, still with a risk of issues), and so do it within a 2-inch tube. We used this same technique last year to great effect, and so have continued its use this year.



Buffer tube on robot

Light and Safe Tether
In terms of safety of the tether, it is contained in a tough but flexible nylon cover. This should protect it from any form cutting or tearing our ROV could encounter. The other primary safety feature is in how our tether connects to our frame. We were worried about potential pulling causing the tether to break waterproof sealing on our buffer tube. To solve this issue, we have the tether run though a tight gland on the top of our frame before meeting with the buffer tube. The idea here is that, if pulled, the tether will only apply pressure to the secure PLA frame, and not the more delicate tube connectors. The tether is made slightly buoyant by use of noodle foam every 16 inches.

Tether with buoyancy every 16"

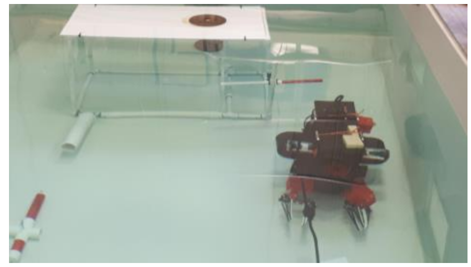
Specification & Task Testing
Out Goal
Based on experience in previous years, we wanted to make sure the robot met the specified requirements as well as possible and that we were prepared for tasks

Chosen Solution Implementation Details

In addition to testing to competition depth (4m at a the Canada Games Centre), insulation testing (100MOhm with Samyo meter), sizing down to 48cm (with a card hoop we cut), weight (using scales) and control system testing, we also decided to build all the props this year.

Results of Our Solution

These testing tools have helped to increase our task completion rate and have helped us to build a safe (passing insulation tests by 10x standard required) and functional robot (nicely controllable) with a minimal size (less than 48cm with items detached) and weight (8.3kg + tether).



Testing robot on Entertainment task

Safety

The following table a record of the steps taken by Halifax Robotics staff to diminish, mitigate, or eliminate safety hazards, and to meet or exceed safety standards and requirements established by MATE. The criteria used to define these safety requirements is the 2016-2017 MATE On-Site Safety Checklist, and the 2016-2017 MATE Laser Safety Checklist.

On-Site Safety Chart

MATE-Defined Safety Requirement	Method of Achievement
2.1: All items attached to ROV secured	By design, any items attached to ROV are bolted/screwed in place, held in place by snaps, or held under tension. No loose components.
2.2: Hazardous items identified, protected	Yellow-and-black hazard tape used to identify hazardous components, moving parts. PPE worn by crew during all assembly and operation procedures.
2.3: All ROV thrusters, propellers shrouded	Blue Robotics T-100 thrusters shrouded by design; additional shrouding screens built into ROV design and secured over each propeller.
2.4: No sharp edges present on ROV	All sharp edges, protrusions, puncture hazards rounded off or removed.
3.1: Single attachment point to power source	ROV tether connected via single Anderson plug within secure surface enclosure.
3.2: Anderson power plugs utilized	Anderson plugs used for all direct electrical connections within surface enclosure.
3.3: 30A fuse within 30cm of power source	25A fuse within 30cm of power supply.
3.4: Surface station constructed in workmanship-like manner, secure	Surface enclosure contained within single waterproofed box. Strain relief included. All wiring, components secured to enclosure container. All electrical components contained within enclosure.
3.5: Tether properly secured	Tether is connected to power source within surface enclosure. Strain relief included.
3.6: No exposed wiring	All wiring is properly sheathed, shielded, and insulated from contact with water or personnel.
3.7: 120v AC wiring separated from DC wiring	AC-DC transformer included in surface assembly.
3.8: Separated 120v AC and DC wiring identified	Markers included in surface assembly to identify DC wiring and AC wiring.

3.9: Surface station strain relief	Abrasion and strain relief is included on all surface wiring.
3.10: Connectors used in proper rated methods	All connectors are used in their prescribed operating procedure, and do not exceed their maximum voltage or amperage.
4.1: Passed pneumatics/hydraulics test	Fluid power quiz completed and passed
4.2-4.14	N/A (pneumatics/hydraulics not used)

Laser Safety Checklist Chart

MATE-Defined Safety Requirement	Method of Achievement
Laser Specification Sheet	Laser spec sheet included on company spec sheet and technical report.
1.2: Electrical schematics	Laser SID and schematic information included on company spec sheet and technical report.
1.3: Pre-approved laser	Personal approval of MATE's Matt Gardner.
2.1: On-off switch at surface station	On-off switch and power disconnect included in surface controls.
2.2: Powered through MATE power supply	Laser power is drawn from the same power supply provided by MATE. No batteries or other generators are included on the ROV.
2.3: No batteries included	ROV does not include batteries or other methods of power generation. All power is drawn through the MATE-provided power supply.
2.4: Laser within visible wavelength range	Laser is visibly green (~532nm).
2.5: Class I, II, or IIIA category	Laser used is of Class IIIa type.
2.6: Laser less than prescribed power use	Laser used draws less power than MATE standard maximum of 1.5mW
2.7: Explorer-class notification sheet	N/A
2.8: Beam stop within 30cm when out of water	Opaque cap included to stop beam when ROV is out of the water.
2.9: Beam stop painted flat black	Beam stop is constructed of opaque black plastic.
2.10: Laser is not focused, or deviates	Laser beam is not focused.
2.11: All team members at inspection have PPE	Anti-UV laser safety glasses are worn by all team members during laser operation.

Project Management

Roles in the Company

With such a large team, we needed clearly defined roles in order to organise everybody efficiently. We went with a simple solution of splitting into five specialised teams.

Designers specialised in 3D printing the frame and organising how everything was going to fit together. Our mechanical engineers were responsible for creating our tools, and gear boxes, while our electrical engineers would handle cameras, servos, and the internal components. The software engineers programmed and updated the control mechanism for our ROV. And finally, our administrative team organised and planned tasks, managed the budget, and created technical documentation.

A few people had roles that spanned across two teams; however, most were extremely specialised. This philosophy allowed us to organise the team much more effectively than previous years.

Phases of Design

We developed out ROV in two distinct phases, the first being a research phase over about 2 months from December in which we tested out ideas in a prototype like setting, the second was completing a set of specific tasks to build our ROV in a more refined fashion.

Our research phase involved making 3D printed designs of various components and testing them on objects. For example, our multipurpose claw designs were printed and operated by hand to find the best design.

The task phase used an Agile Scrum to list out a set of tasks. This began once we had decided on designs and set about creating more refined versions. For our frame, this was creating a carbon fiber version of each component.

The blue parts of the frame had yet to be replaced with the green iteration parts.

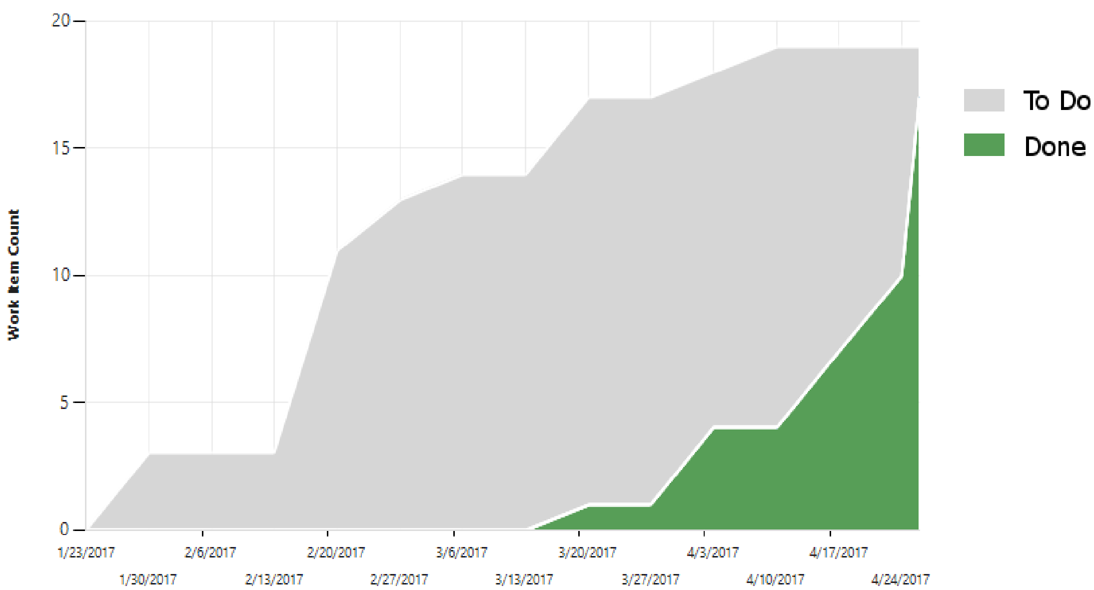
Organising Components

Organising our components was important to organising the team as a whole. We used labels and colour coding primarily for this purpose. For examples, our thrusters were each labeled one through six, in correspondence to where they connected. This allowed for easier management of cables when deconstructing the ROV for maintenance. Our frame used colour coding to show what version a certain component was one. Each iteration was printed in a different colour PLA to keep a clear visual record of what still needed to be replaced.

Agile Methodology

This year, to manage the large amounts of tasks and people, we used an Agile Scrum system methodology on Visual Studio Team Service. Over the course of months, we organised sprints of roughly two weeks long to decide what needed to be done and by who. This greatly increased the efficiency of getting work done, as people were rarely sitting around with nothing to do.

We tracked all of features using a Kanban board with the simple categories of “To-Do” and “Done”. Here you can see a breakdown of at what pace we completely various features:



Challenges Faced and Lessons Learned

Technical Challenge

Our biggest challenge in a technical sense were the issues we faced with waterproofing our servos to 4 meters. MATE regulations, as stated in the March technical bulletin, required us to perform a resistance test on our waterproofed servos. To use in the competition, we needed to have 10Meg ohms of resistance after soaking over night. This proved to be extremely difficult, but we eventually prevailed though a series of modifications and attempts.

Team Challenge

Our largest team challenge this year involved a job action by the provincial teacher's union in our province of Nova Scotia. In November, the teachers voted to go on a work to rule protest in order to bargain with the government. This had a massive effect on all extracurricular activities, specifically, there were none.

While the majority of teams simply decided not to run a team in the competition (or to begin one once the job action was over), we chose a different option. The action was indefinite so we certainly did not want to wait, and so we decided to set up our own, independent team, essentially out of the garage of one of our team members.

With a great deal of help from one our mentor, we were able to create our own independent group to host the team from. Due to this, we not only actually had a team (unlike most others in the province) but we were far more independent than in previous years.

While it was a great challenge to get started, this has been a net positive for the team. Not having to rely on teacher's schedules and school facilities has given us a lot more time to work on the ROV. Overall is has been a much more positive experience, and despite the work to rule job action being over, we decided as a team to stay independent for at least next year also.

Future Improvements

- One feature we wanted to include this year but couldn't due to time limitations was an auto-pilot. Next year we want to be able to fully implement this vision.
- We could increase the main tube by 1" to allow for easier access to bullet connectors.
- We could experiment with other motion sensors for improved accuracy.
- We could add software monitoring of power distribution and internal temperature.
- LED lighting would allow the robot to be themed and align better with the Entertainment theme

Team Reflections

Matt Glencross

Three years ago, I joined Nova Underwater Technologies not knowing where it would lead to. The first two years provided endless learning opportunities outside the traditional classroom, but this past year in particular helped me identify my post-secondary goals. This year I focused on designing and constructing many of the mechanical components including the multi-purpose claws. Through this process I learned how to use 3D printing to bring my ideas to life, use CAD software for designing prototypes, develop mechanical gear boxes, effectively communicate ideas, and work efficiently with fellow teammates, all of which will be valuable in the future. The MATE Underwater ROV competition has provided me with once in a lifetime experiences that will never be forgotten, including the opportunity to visit NASA's Neutral Buoyancy Lab. I am looking forward to pursuing a career in mechanical engineering and will continue to be a part of any available robotics team.

Logan Crooks

This is my third year as a participant in the Mate R.O.V competition and my final year in the ranger class. Last year we made it to the international competition which made me want to work doubly hard to make it to the international competition this year. After three years working to on designing and building the robot I feel as though I have learned many valuable skills, such as teamwork, budgeting time, and working with electronics. This competition has deadlines which has helped me learn to budget time in order to make sure all of my responsibilities were finished in the correct order and at the proper time. I work with the electrical and network systems on the robot and thus learned a lot about how many different electrical systems work. All in all I am glad I joined the team and will have great memories for years to come.

Daphne Finlay

During my time with Halifax underwater technology I learned many things, including how to properly apply liquid electrical tape and epoxy. These things must be applied while wearing rubber gloves and respiratory masks. This is done to prevent toxins from spreading on the skin and in your lungs. I also learned how gears work and how if one is jammed they all stop working resulting in the servo needing to be reopened and re waterproofed. But perhaps the most important thing I learned was that it takes extremely good communication as well as very good patience to productively work well as a team.

Yuhai Li

The programming code was easier for me to understand than my brother, because I already did some programming before then. There were many skills I learned. I now can understand C# and can solder things together, along with doing some wire work. The laser code was implemented in the two or three week lull waiting for the PID controller. The cameras were going to start working soon. I feel somewhat accomplished because I was able to do many of the programming challenges that I was working on.

Ellis Keener-LaCroix

During my first year, I learned a lot at Nova Underwater Technologies. I mostly worked with the 3D printers, and 3D modeling. When I started, I didn't know how to 3D model, and didn't know much about 3D printers. Since then, I now know 3D printers inside and out, and I know how to use the 3D modeling software TinkerCAD. Besides 3D modeling and printing, I have learned how different parts of the robot work, like: servos, claws, cameras, the controller, how it connects to the computer on the surface, and more. Next year I hope to learn how to hook up the cameras, and some programming.

Acknowledgements

We would like to give amazing thanks to the following regional sponsors:

Ace of Clouds, Lockheed Martin & Engineers Nova Scotia

We would like to also thank the Nova Scotia Community College for hosting our regional competition, and MATE for providing us with the opportunity. Finally, we would like to give large thanks to our sole mentor Colin Melia for providing us with a work space, equipment, and guidance throughout the year.

Citations

Inspiration for Laser System - https://forum.openrov.com/t/laser-realtime-distance- measurement-plugin/2479

Auger design from Thingyverse - https://www.thingiverse.com/thing:993287

Servo Waterproofing Video - https://www.youtube.com/watch?v=iM3qaMtBrY4

Open Source Code - https://github.com/kriswiner/MPU-9250/blob/master/MPU9250_MS5637_AHRS_t3.ino

TENDA hardware listed on OpenROV - https://forum.openrov.com/t/teardown-of-a-homeplug-adapter/305/18

Appendix: Budget

Costs

We originally estimate that the robot would cost CAD$4000. The final price to build one of these robots is CAD$5,326.43 including CAD$2,350.28 of re-used components or on-hand small parts (indicated in red). The incremental cost for this year is therefore $2,976.15, plus the research parts and spare parts.

The detailed costs are shown below, followed by the additional costs of experimental parts (CAD$2,640.55) used in the design of the robot and spare parts (CAD$2,445.91) we also have on hand for repairs.

Regional Sponsorship Income

We received CAD$1000 from Lockheed Martin, CAD$500 Engineers Nova Scotia, CAD$500 IORE.

Funds for the balance of CAD$2,976.15 (for the new parts) and CAD$5086.46 (research and spares) were provided by Ace of Clouds.

International Travel Cost Estimates

Booked flights for 15 team members and 3 chaperones from YHZ to LAX	CAD $15,730.74
Booked Hotel (estimating exchange rate)	CAD $7,088.90
Booked 3 rental mini-vans (estimating exchange rate)	CAD $1,350.00
Gas (estimate)	CAD $150.00
Robot shipping (estimate)	CAD $200.00
Marketing poster print (estimate)	CAD $120.00
Total	**CAD $24,639.64**

These costs are being paid for by a combination of sponsors (currently at CAD$15,770) and team members.

Robot Build Cost (including re-used parts)

Part	Pack Amount	Pack Size	Each	# Used	Item Total
Red PLA	$ 22.75	1	$ 22.75	0.2	$ 4.55
Black PLA	$ 22.75	1	$ 22.75	0.2	$ 4.55
Clear PLA	$ 22.75	1	$ 22.75	0.3	$ 6.83
Carbon Fiber PLA	$ 65.00	1	$ 65.00	1	$ 65.00
0.25" x 3" D-Shaft	$ 1.81	1	$ 1.81	1	$ 1.81
0.25" x 4" D-Shaft	$ 1.99	1	$ 1.99	1	$ 1.99
0.25" x 6" D-Shaft	$ 2.63	1	$ 2.63	2	$ 5.25
0.25" x 7" D-Shaft	$ 2.90	1	$ 2.90	2	$ 5.80
0.25" Shaft Collar	$ 1.72	1	$ 1.72	13	$ 22.31
0.25 Shaft 0.770 Hub	$ 1.72	1	$ 1.72	4	$ 6.86
0.25 Shaft Spacer	$ 6.49	1	$ 6.49	4	$ 25.95
Metal paperclips	$ 2.20	12	$ 0.18	13	$ 2.38
HS-5646WP Servo	$ 54.33	1	$ 54.33	1	$ 54.33
M100 Motor	$ 86.45	1	$ 86.45	4	$ 345.80
T100 Thruster Core	$ 98.80	1	$ 98.80	4	$ 395.20
T100 Thruster	$ 146.97	1	$ 146.97	6	$ 881.79
4" Tube x 6"	$ 37.05	1	$ 37.05	1	$ 37.05
4" 14-hole tube end cap	$ 34.58	1	$ 34.58	1	$ 34.58
4" clear tube end cap	$ 19.76	1	$ 19.76	1	$ 19.76
4" tube flange with O-rings	$ 35.82	1	$ 35.82	2	$ 71.63
2" Tube	$ 12.84	1	$ 12.84	8	$ 102.75
2" 2-hole tube end cap	$ 9.88	1	$ 9.88	10	$ 98.80
2" clear tube end cap	$ 8.65	1	$ 8.65	6	$ 51.87
2" tube flange with O-rings	$ 23.47	1	$ 23.47	16	$ 375.44
8mm Penetrator	$ 4.94	1	$ 4.94	17	$ 83.98
4mm Penetrator	$ 6.18	1	$ 6.18	7	$ 43.23
Blank Penetrator	$ 4.94	1	$ 4.94	7	$ 34.58

Enclosure vent and plug	$ 9.88	1	$ 9.88	9	$ 88.92
Buoyancy Foam	$ 14.82	1	$ 14.82	1	$ 14.82
Basic ESC - Motor Controller	$ 30.88	1	$ 30.88	10	$ 308.75
Laser	$ 66.92	1	$ 66.92	2	$ 133.85
Raspberry Pi 3	$ 64.99	1	$ 64.99	1	$ 64.99
32GB SD Card	$ 45.98	1	$ 45.98	1	$ 45.98
Tenda HomePlug AV adapter pair	$ 74.10	1	$ 74.10	1	$ 74.10
OpenROV Tenda interface board	$ 39.00	1	$ 39.00	2	$ 78.00
Power Regulator	$ 12.94	5	$ 2.59	4	$ 10.35
Ethos Lite Switch	$ 325.00	1	$ 325.00	2	$ 650.00
8-circuit terminal block	$ 10.30	1	$ 10.30	4	$ 41.18
4-circuit terminal block	$ 8.03	1	$ 8.03	1	$ 8.03
Terminal Block Jumper	$ 5.67	5	$ 1.13	16	$ 18.14
Screw Terminal	$ 1.00	3.5	$ 0.29	4	$ 1.14
Gland	$ 2.50	1	$ 2.50	1	$ 2.50
Bullet Connectors	$ 12.00	20	$ 0.60	70	$ 42.00
Network Cable	$ 20.00	1	$ 20.00	1	$ 20.00
Pico Blade Connectors	$ 50.00	12	$ 4.17	4	$ 16.67
Tether Power Zip Cord	$ 96.68	100	$ 0.97	65	$ 62.84
Tether Signal Zip Cord	$ 14.43	100	$ 0.14	65	$ 9.38
Anderson Connectors	$ 18.19	10	$ 1.82	7	$ 12.73
Fuse Holder	$ 3.37	1	$ 3.37	1	$ 3.37
25A Fuse	$ 0.47	1	$ 96.68	1	$ 96.68
Laptop	$ 699.00	1	$ 699.00	1	$ 699.00
USB to USB/Ethernet	$ 38.95	1	$ 38.95	1	$ 38.95

Experimental Parts Used

Part	Pack Amount	Pack Size	Each	# Used	ItemTotal
PLA	$ 22.75	1	$ 22.75	9.5	$ 216.13
Carbon Fiber PLA	$ 65.00	1	$ 65.00	1	$ 65.00
0.25" x Various" D-Shaft	$ 1.81	1	$ 1.81	18	$ 32.53
0.25" Shaft Collar	$ 1.72	1	$ 1.72	8	$ 13.73
0.25 Shaft 0.770 Hub	$ 1.72	1	$ 1.72	4	$ 6.86
0.25 Shaft Spacer	$ 6.49	1	$ 6.49	4	$ 25.95
Metal paperclips	$ 2.20	12	$ 0.18	30	$ 5.49
Servo connectors & wiring	$ 208.00	1	$ 208.00	1	$ 208.00
HS-311	$ 20.77	1	$ 20.77	2	$ 41.55
HSR-1425CR Servo	$ 22.10	1	$ 22.10	2	$ 44.20
HSR-2645CRH Servo	$ 42.90	1	$ 42.90	2	$ 85.80
HS-7955TG Servo	$ 129.99	1	$ 129.99	2	$ 259.97
HSB-9360TH Servo	$ 232.70	1	$ 232.70	1	$ 232.70
HS-5646WP Servo	$ 54.33	1	$ 54.33	2	$ 108.66
M100 Motor	$ 86.45	1	$ 86.45	1	$ 86.45
T100 Thruster Core	$ 98.80	1	$ 98.80	1	$ 98.80
T100 Thruster	$ 146.97	1	$ 146.97	1	$ 146.97

8mm Penetrator	$ 4.94	1	$ 4.94	6	$ 29.64
4mm Penetrator	$ 6.18	1	$ 6.18	6	$ 37.05
Blank Penetrator	$ 4.94	1	$ 4.94	6	$ 29.64
Enclosure vent and plug	$ 9.88	1	$ 9.88	4	$ 39.52
Buoyancy Foam	$ 14.82	1	$ 14.82	1	$ 14.82
Basic ESC - Motor Controller	$ 30.88	1	$ 30.88	2	$ 61.75
Laser	$ 66.92	1	$ 66.92	1	$ 66.92
Raspberry Pi 3	$ 64.99	1	$ 64.99	1	$ 64.99
32GB SD Card	$ 45.98	1	$ 45.98	1	$ 45.98
Tenda HomePlug AV adapter pair	$ 74.10	1	$ 74.10	1	$ 74.10
OpenROV Tenda interface board	$ 39.00	1	$ 39.00	2	$ 78.00
Power Regulator	$ 12.94	5	$ 2.59	2	$ 5.17
8-circuit terminal block	$ 10.30	1	$ 10.30	4	$ 41.18
4-circuit terminal block	$ 8.03	1	$ 8.03	2	$ 16.07
Terminal Block Jumper	$ 5.67	5	$ 1.13	16	$ 18.14
Screw Terminal	$ 1.00	3.5	$ 0.29	2	$ 0.57
Gland	$ 2.50	1	$ 2.50	10	$ 25.00
Bullet Connectors	$ 12.00	20	$ 0.60	120	$ 72.00
Network Cable	$ 20.00	1	$ 20.00	2	$ 40.00
Pico Blade Connectors	$ 50.00	12	$ 4.17	20	$ 83.33
Tether Power Zip Cord	$ 96.68	100	$ 0.97	65	$ 62.84
Anderson Connectors	$ 18.19	10	$ 1.82	7	$ 12.73
Fuse Holder	$ 3.37	1	$ 3.37	1	$ 3.37
USB to USB/Ethernet	$ 38.95	1	$ 38.95	1	$ 38.95

$ 2,640.55

Spare Parts

Part	Pack Amount	Pack Size	Each	# Used	Item Total
Red PLA	$ 22.75	1	$ 22.75	1	$ 22.75
Black PLA	$ 22.75	1	$ 22.75	1	$ 22.75
Clear PLA	$ 22.75	1	$ 22.75	1	$ 22.75
Carbon Fiber PLA	$ 65.00	1	$ 65.00	1	$ 65.00
0.25" x 3" D-Shaft	$ 1.81	1	$ 1.81	1	$ 1.81
0.25" x 4" D-Shaft	$ 1.99	1	$ 1.99	1	$ 1.99
0.25" x 6" D-Shaft	$ 2.63	1	$ 2.63	2	$ 5.25
0.25" x 7" D-Shaft	$ 2.90	1	$ 2.90	2	$ 5.80
0.25" Shaft Collar	$ 1.72	1	$ 1.72	13	$ 22.31
0.25 Shaft 0.770 Hub	$ 1.72	1	$ 1.72	4	$ 6.86
0.25 Shaft Spacer	$ 6.49	1	$ 6.49	4	$ 25.95
Metal paperclips	$ 2.20	12	$ 0.18	13	$ 2.38
HS-5646WP Servo	$ 54.33	1	$ 54.33	1	$ 54.33
M100 Motor	$ 86.45	1	$ 86.45	2	$ 172.90
T100 Thruster Core	$ 98.80	1	$ 98.80	2	$ 197.60
T100 Thruster	$ 146.97	1	$ 146.97	2	$ 293.93

4" Tube x 6"	$ 37.05	1	$ 37.05	1	$ 37.05
4" 14-hole tube end cap	$ 34.58	1	$ 34.58	1	$ 34.58
4" clear tube end cap	$ 19.76	1	$ 19.76	1	$ 19.76
4" tube flange with o-rings	$ 35.82	1	$ 35.82	2	$ 71.63
2" Tube	$ 12.84	1	$ 12.84	2	$ 25.69
2" 2-hole tube end cap	$ 9.88	1	$ 9.88	4	$ 39.52
2" clear tube end cap	$ 8.65	1	$ 8.65	2	$ 17.29
2" tube flange with o-rings	$ 23.47	1	$ 23.47	4	$ 93.86
8mm Penetrator	$ 4.94	1	$ 4.94	10	$ 49.40
4mm Penetrator	$ 6.18	1	$ 6.18	10	$ 61.75
Blank Penetrator	$ 4.94	1	$ 4.94	4	$ 19.76
Enclosure vent and plug	$ 9.88	1	$ 9.88	4	$ 39.52
Buoyancy Foam	$ 14.82	1	$ 14.82	1	$ 14.82
Basic ESC - Motor Controller	$ 30.88	1	$ 30.88	2	$ 61.75
Laser	$ 66.92	1	$ 66.92	1	$ 66.92
Raspberry Pi 3	$ 64.99	1	$ 64.99	1	$ 64.99
32GB SD Card	$ 45.98	1	$ 45.98	1	$ 45.98
Tenda HomePlug AV adapter pair	$ 74.10	1	$ 74.10	1	$ 74.10
OpenROV Tenda interface board	$ 39.00	1	$ 39.00	2	$ 78.00
Power Regulator	$ 12.94	5	$ 2.59	4	$ 10.35
Ethos Lite Switch	$ 325.00	1	$ 325.00	1	$ 325.00
8-circuit terminal block	$ 10.30	1	$ 10.30	4	$ 41.18
4-circuit terminal block	$ 8.03	1	$ 8.03	1	$ 8.03
Terminal Block Jumper	$ 5.67	5	$ 1.13	12	$ 13.60
Screw Terminal	$ 1.00	3.5	$ 0.29	2	$ 0.57
Gland	$ 2.50	1	$ 2.50	1	$ 2.50
Bullet Connectors	$ 12.00	20	$ 0.60	60	$ 36.00
Network Cable	$ 20.00	1	$ 20.00	1	$ 20.00
Pico Blade Connectors	$ 50.00	12	$ 4.17	20	$ 83.33
Anderson Connectors	$ 18.19	10	$ 1.82	12	$ 21.82
Fuse Holder	$ 3.37	1	$ 3.37	1	$ 3.37
25A Fuse	$ 0.47	1	$ 0.47	1	$ 0.47
USB to USB/Ethernet	$ 38.95	1	$ 38.95	1	$ 38.95

$ 2,445.91