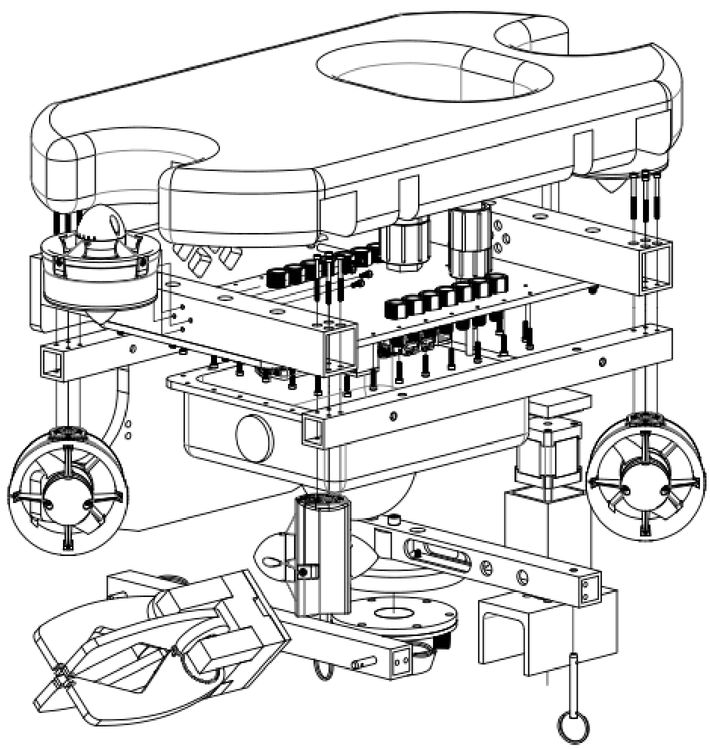
Wentworth Institute of Technology

NUGGET INDUSTRIES

Vehicle Name: N.U.G.G.E.T.

MATE ROV EXPLORER CLASS “JET CITY” 2018



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CFO: Alec Hewitt
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Lead Mechanical Engineer: Nicholas Stratton
Lead Software Engineer: Bobby Martin
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Nugget Industries serves to appeal to underwater applications regarding remotely operated vehicles. This year, Nugget Industries will compete in a bid for a vehicle that can provide valuable assistance to the fields of sunken airplane salvage, tidal energy generation, and earthquake monitoring. The vehicle delivered, to be known as N.U.G.G.E.T., is a maneuverable, sleek machine that can safely operate within the specified depth range given in the *Request for Proposals* from MATE International.

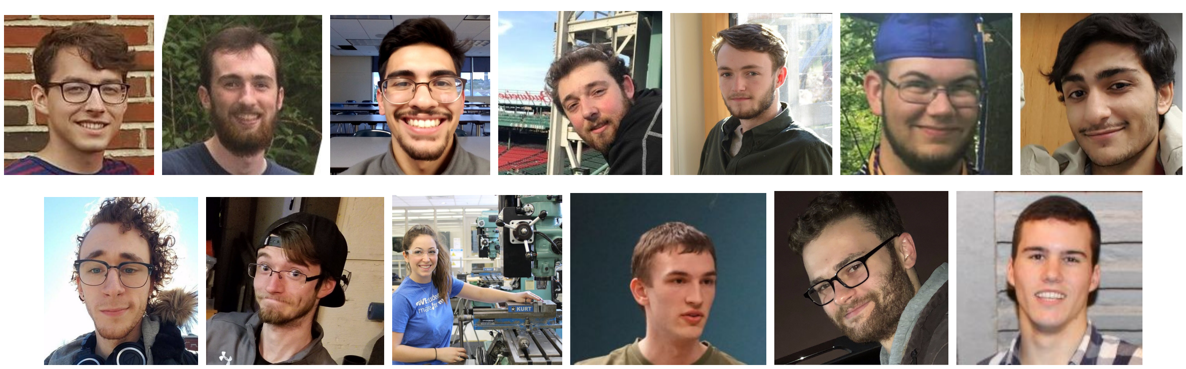
Introduction

Nugget Industries is the culmination of research and development over the course of three years, finally leading to a competition worthy vehicle for the 2018 season. Tens of thousands of hours have been put into the design, manufacturing, testing, and debugging of N.U.G.G.E.T. The sheer amount of passion and attention to detail can be seen in the final product. Nugget Industries is a thirteen person, multidisciplinary team of undergraduate students at Wentworth Institute of Technology. Students on the team come from the following fields of study and expertise: Electromechanical Engineering, Electrical Engineering, Computer Science, Mechanical Engineering, and Applied Math.

Abstract

The Nugget Industries N.U.G.G.E.T. is a 1200W precision machine that can be contained within a 64cm circular perimeter. It is composed of custom machined aluminum, various engineering plastics and polymers, 3D printed parts, and a series of custom designed circuit boards. Novel solutions for multiple mechanisms were employed, including complete geometric constraint on the removable side walls, a magnetic shaft coupling employed within the leveler subsystem, and a worm gear offering four claws a simultaneous, bidirectional grip. Many of the design choices were made with specific design intent that will be discussed in their appropriate subsections.

The Team



From left to right: (TOP) *Andrew Zucker (CEO), Bobby Martin (Lead Software Engineer), Michael Spalluzzi (Lead Electrical Engineer), Nicholas Stratton (Lead Mechanical Engineer), Alec Hewitt (CFO + Design Engineer), Joshua Caron (Electromechanical Design Engineer), Amin Akbarinakhjavani (Mechanical Design Engineer).*

(BOTTOM) *Joseph Prendergast (Electromechanical Design Engineer), Thomas Dorman (Manufacturing Engineer), Alyssa Vallese (Electromechanical Design Engineer), Chris Thierauf (Software Engineer), Ryan Maresca (Vision Processing Architect), Devin Taylor (Electrical Design Engineer).*

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Glossary of Abbreviations

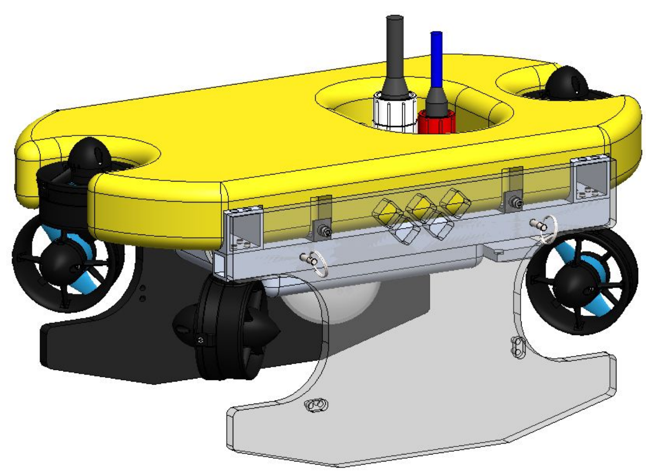
- CNC: Computer numerical control
- DOF: Degree of freedom
- ESC: Electronic speed controller
- ESR: Equivalent series resistance
- FEA: Finite Element Analysis
- HDPE: High density polyethylene
- I2C: Inter-Integrated Circuit
- IC: Integrated circuit
- MOSFET: Metal-oxide-semiconductor field-emitter transistor
- N.U.G.G.E.T.: Natatorial Umbilicalized Grippy Gripper Equipped Thing
- PDB: Power distribution board

- PWM: Pulse width modulation
- ROV: Remote Operated Vehicle
- RPi: Raspberry pi
- SB: Sensor board
- VDC: Volts, DC

Design

Mechanical

The mechanical design for N.U.G.G.E.T. began in late November 2017. Given the size restrictions given by MATE International, designing a ROV employing compact and modular design was vital and made to be a priority in early drawing stages. The side walls were designed for easy removal, and the subsystems were put onto a removable rail system to allow ease of disassembly and reassembly, as well as access to the electronics enclosure and thus to the electronics. All of the machined parts were manufactured by team members at Wentworth Institute of Technology. Likewise, 3D printed parts were all printed by team members at Wentworth Institute of Technology.



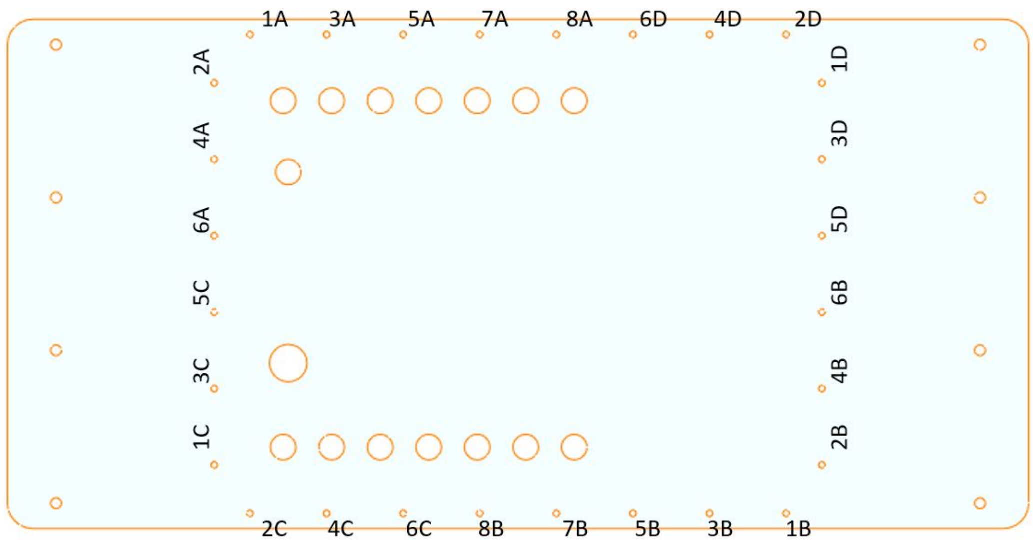
Chassis

Given tight size constraints, the N.U.G.G.E.T. chassis was designed around the electronics. The electronics enclosure is composed of two parts, known as the “plate” and the “pan.” The plate is bolted to the 4 crossbars that hold the thrusters as well as the remaining subsystems.

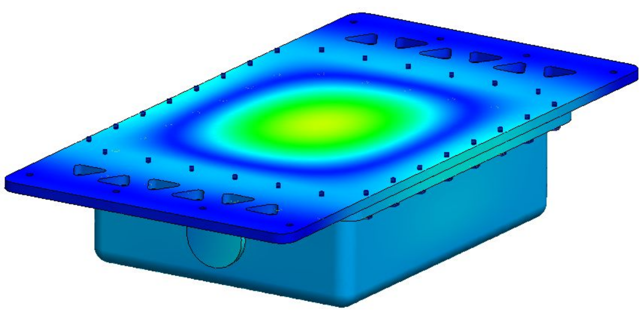
The Seal

Between the flat plate and the pan, an o-ring groove was designed to be the main seal, keeping the electronics dry as N.U.G.G.E.T. is submerged. The groove was designed according to the Parker O-Ring Handbook **[1]**, and utilizes an ⅛” nominal diameter o-ring. It is made of Buna-N rubber, a material that can withstand oils, caustic chemicals including salt water. The o-ring sits in a rounded rectangular groove, called a raceway groove, and a custom sized o-ring is placed within. The rubber is consistently greased with silicone grease before closing the seal. The o-ring receives appropriate compression and stretch within the seal, allowing it to effectively keep water out of the electronics. The pan bolts to the plate using 28 M4 hex head bolts and is bolted together using a very specific bolt pattern. The 28 bolts are placed slightly more than six bolt diameters away from one another, producing an even compression when the bolts are torqued in a proper pattern **[2]**. Ideally, the bolts should be three to six bolt diameters apart. Although the number of bolts seems very high, the design intent was to have an incredibly stable main seal.

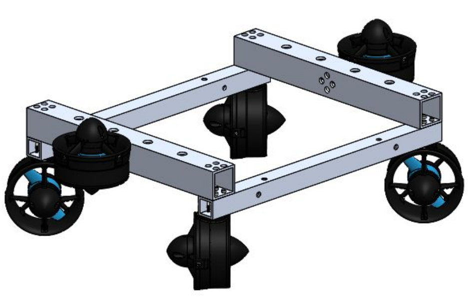
The bolt pattern consists of a 28-point cross-star pattern, and is always run twice with a torque wrench. The first pass is done at a low torque, (2.3 N-m), and is run the second time at full torque (3.5 N-m). These torques were experimentally found to provide reliable results. The torque pattern can be seen below.



Regarding depth capability of the seal, Figure 3-2 in Parker, **[1]**, shows a figure for pressure capability before extrusion failure as a function of diametral clearance. The seal on the ROV is not a piston/cylinder setup as the figure shows, and therefore diametral clearance between piston/cylinder will be instead taken to mean distance between the sealing faces within operating conditions. For the case of the ROV, this distance approaches a flush surface against a flush surface, approximating 0mm/0in clearance. According to such Figure 3-2, this creates a seal capable of withstanding over 1000 psi or about 2000 feet of depth. The housing itself would likely deflect greatly before the seal were to fail. An FEA analysis of the housing is shown to the right, simulating a depth of 30 meters. Max deflection is less than one millimeter.



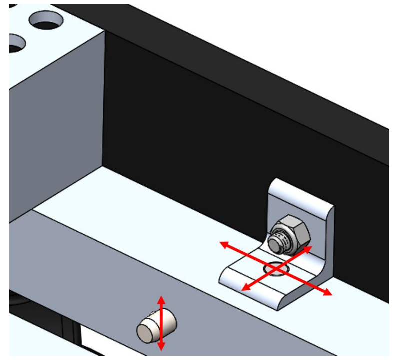
Thruster Frame



The thruster frame consists of four metal bars that have through holes that align with the six Blue Robotics T-100 thrusters. The entire thruster frame is held together through the thruster mounting points, thus eliminating extra assembly hardware on the chassis.

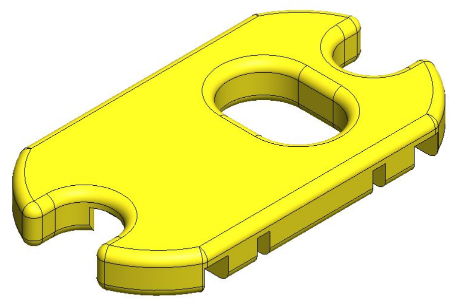
Side-Walls

The marine-grade HDPE side walls are made both easily removable, and rigid by a simple four pin solution. There are two stainless dowel pins attached to angle brackets on the walls that fit into precision bored holes in the thruster frame. These pins prevent X-Y cartesian movement, but allow the wall to be lifted upwards for removal. Once the walls are seated, stainless quick pull pins are inserted in the side of the wall and thruster frame. These pins prevent the wall from moving in the Z direction. Once these pins are installed, the walls are fully constrained and are very rigid.



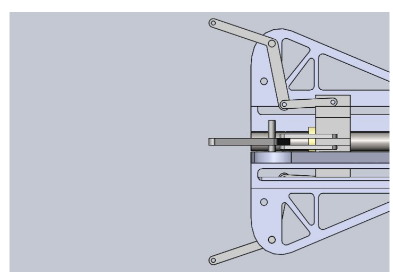
Buoyancy Foam

The buoyancy foam is made from two large pieces of Blue Robotics R-3318 foam that were glued together using epoxy and were CNC machined as two pieces. The volume of foam was oversized to provide buoyancy which allows for the ROV to float back to the surface while unpowered. Lead weight was added to balance the vehicle in the water, and helps to bring the vehicle closer to neutral buoyancy. There are channels milled into the foam to provide wire management and mounting options to the thruster frame. It was painted the team's signature bright yellow in enamel paint.

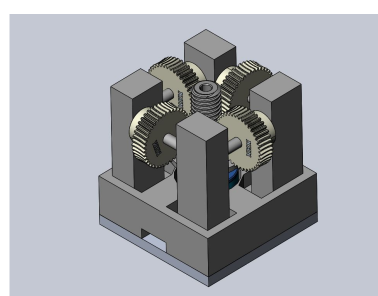


Manipulator

The design of the custom use manipulator was worked and reworked multiple times before settling on the current iteration. It was decided on to be one of the more crucial subsystems, considering the amount it is used.



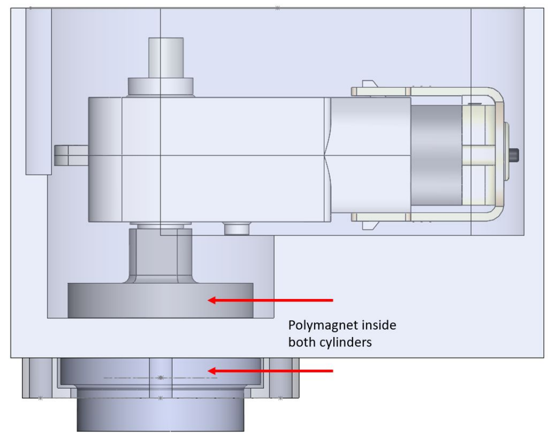
Using four fingers was a clever choice made to avoid having to make a manipulator that was wrist rotation capable. A wrist would give the manipulator the ability to grab pipes oriented both vertically and horizontally using only two fingers capable of pinching in one direction. However, with a wrist oriented design, size and complexity is added. A wrist would require another motor to function, which requires another waterproof seal, adding a point of failure. To combat this, we decided to use four fingers to both satisfy the requirement of grabbing multiple pipes and create a simpler design.

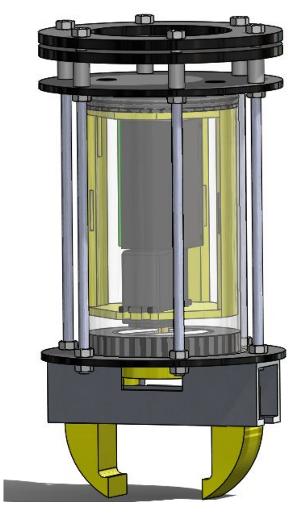


The drive system that was developed for our team used a worm gear and crown gears. This configuration gave the manipulator a 40:1 gear reduction, which gained the manipulator the ability to exert large moment forces through the crown gears. This extrapolates to powerful gripping strength.

Leveler

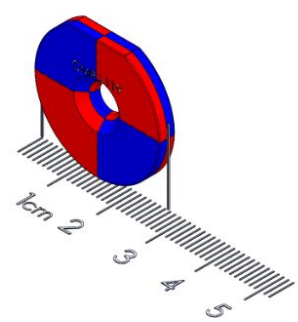
The leveler subsystem consists of a simple DC motor that is waterproofed inside a solid, potted box. It mounts to one of the removable chassis crossbars. The internal motor is coupled to the outer side of the end effector through a magnetic coupler consisting of two polymagnets, a type of magnet with multiple poles on a single face . This magnetic coupling allows torque transfer through the solid HDPE bearing surface. While torque is transferred through the magnetic coupler, the end effector is separately retained using a ring of milled aluminum.





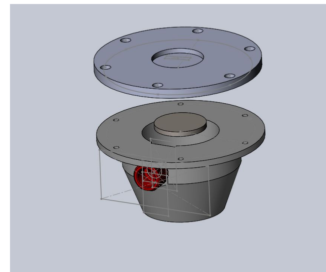
Lift Bag

The "Lift Bag" is a small detachable assembly consisting of an inflatable bladder which is designed to attach to debris and engine on the pool floor and facilitate it's lifting and movement. The capsule was designed to be positively buoyant so that it will return to the water's surface when uninflated and detached from debris. Since the capsule itself is positively buoyant, the inflatable bladder was designed to lift only the max engine mass of 60N (~13.5 lbs) as such, a commercial diving lift bag capable of 25lbs of lift was chosen. A frequency-selective acoustic triggered actuator was used in the initial design with a magnetic coupling serving as the leveler system. During filming technical difficulties developed resulting in implementation of a purely mechanical solution with a static claw. This claw attaches and detaches to the debris via movement of the ROV while the lift bag is held by the main ROV manipulator. Air is supplied via a manual pump located poolside. An air tube incorporated into the tether is inserted into the bladder at the surface while the liftbag is being inserted into the manipulator. The bladder is parachute shaped such that the tube can easily pull away from the bladder when fully inflated. In the case of reinflation, the lift bag must be placed back into the manipulator and tubing re-inserted by hand.



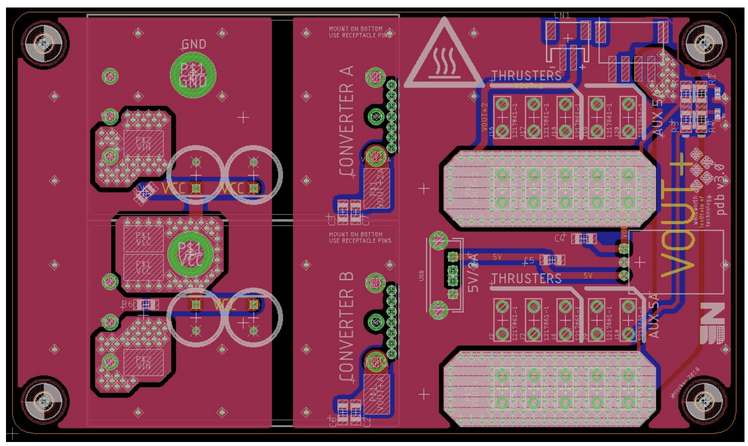
Power Pod

The “Power Pod” is a small capsule designed to facilitate WiFi communication from the OBS component. The design intent of this subsystem is to provide a stable and non-attenuating RF signal between the OBS and the ROV, while the vehicle completes the leveling task. The capsule was manufactured from HDPE plastic and features a flange-sealed 1/8th-inch Buna-N rubber o-ring, accompanied by a circular bolt pattern along the outer circumference of the flange, which provides sufficient radial compression. The subsystem is connected to the ROV via a physical tether which enables remote power transfer and data relay. The tether is secured to the Pod with a 10mm cable penetrator housing which was sealed using marine epoxy. The Pod itself has a ferrous metal disk on it’s top side, which is secured to (and released by) an electromagnet on the ROV. The electromagnet’s power is modulated by internal ROV electronics (see Electrical), allowing rapid and consistent positioning of the system before and after completion of the task.



Electrical

Power Distribution Board



Features:

- (2x) 600W 48VDC isolated high frequency switching buck converters in parallel
- Modular connectors for major components
- LED status lights
- Bleeder resistors in parallel with input bypass capacitors (<5s discharge)
- High current traces are via-stitched through both sides to increase current capacity
- Surface mount components to keep footprints small

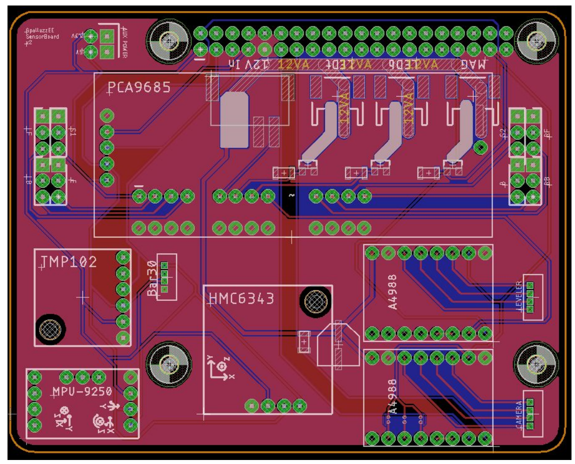
The power distribution board, the most critical and governing ROV side component was designed to be highly modular in terms of part replacement. The switched mode power converters are mounted on appropriately sized pin receptacles such that they may be easily be removed and replaced without soldering if they become damaged. ESC’s were also modified to have specialized spade connectors to facilitate rapid connection and removal. A USB port provides a 5VDC output to power the RPi.

It includes two (2) 600W isolated DC-DC switched mode converters in parallel regulate the MATE specified 48VDC to 12VDC used on the thrusters, electromagnet, power pod, leveler and headlights, and convert to the 5VDC/2A for the dedicated USB for the Raspberry Pi. A detailed breakdown of these components and their operating voltages can be found in the electrical SID.

High voltage tether power is routed to surface mounted wire entry points which lead to current ripple smoothing capacitors (specified at 100uF, low ESR, per the converter datasheet). Bleeder resistors in parallel with the capacitors ensure rapid capacitor discharge at a rate less than five seconds of ROV powering down.

Heat management was a priority throughout the design of our central electronic components. High current traces were designed with no solder mask so that they could be cooled with convection through the use of a small 12VDC, 40mm fan.

Sensor Board

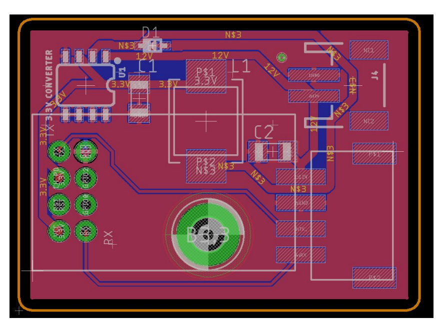


Features:

- Serves as break-out board for Raspberry Pi
- Houses various sensors including Temperature, Accelerometer, Gyroscope, Magnetometer, and Pressure sensor
- I2C and Serial communication
- Power distribution
- Control hub for thrusters, manipulator, and subsystems

The sensor board (SB) acts as the communication and control hub for the ROV. This board routes power and communication between the Raspberry Pi and the various ICs within the vehicle. These ICs include the TMP120 (Temperature), HMC6343 (Magnetometer), MPU-9250 (9DOF), Bar30 (Pressure/Temperature), ESP8266 (WiFi), and the PCA9685 (PWM Driver). The TMP120, HMC6343, MPU-9250, and Bar30 sensors as well as the PCA9685 all communicate with the Raspberry Pi via I2C allowing parallel communication with all devices at the same time over the same channel. Serial communication with the ESP8266 allows communication with the WiFi module to receive data from the OBS.

Thruster and subsystem control comes from the PCA9685 on the SB. By using PWM on the 300Hz output signal from the PCA9685, speed and direction of the seven Blue Robotics T100 thrusters can be controlled. This same principle is used on two servos which control the camera swivel and leveler subsystem as well as to drive two switching MOSFET circuits on the SB to provide variable brightness to the two illumination LEDs on the ROV. A PWM signal drives a third switching MOSFET circuit, however the duty cycle of this signal is varied only from 0% to 100% to only provide on/off control of the electromagnet.



Power Pod Board

Features:

- Switched mode 12V-3.3V DC converter

- Wifi-enabled

The power pod board supplies DC power to the POD, and serves as an interface between ROV and the electronics enclosed within the subsystem. These electronics include a wifi module, and a 3.3V on board, discrete buck converter.

Software

Overview

Core functionality of the ROV is written using Node.js. Node.js was chosen for its native asynchronous capabilities and for its support for easy-to-use network sockets.

All communication between the ROV and the surface station happens over a TCP socket. The surface station sends commands to the ROV and the ROV takes the appropriate action for each command received. Each command is represented by a token with predetermined fields based on the type of command.

The on-ROV node.js process is managed by a daemon called the nugget daemon.

Deployment

The codebase for this project includes a fully automated deployment process for a raspberry pi that has already been setup with the proper nugget daemon. Given the IP or mDNS address of the raspberry pi to deploy to, the deployment script will copy the appropriate files to the pi and restart its nugget daemon. The files that get copied are located in the "remote" package.

Communication

All communication between the surface station and the ROV happens over a TCP socket with a structured protocol.

Protocol

Communication between the surface station and ROV is dictated by a structured protocol.

The communication protocol is made up of a set of tokens. Each token has three fields: type, headers, and body. A token's type describes the task the ROV should perform when it receives the token. A token's headers contain a unique ID associated with the sending of the token and the completion of the task the token is commanding the ROV to perform. This ID is known as the transaction ID. Finally, each token has a body. A token's body contains information the ROV needs to know to perform the task described by the token's type. The most commonly used token types are "controllerData," "magData" (for magnetometer data), and "piTempData."

Socket

All communication between the surface station and the ROV happens over a carefully managed TCP socket.

Nugget Industries has written a Node.js package called “bot-socket” to manage the connection between the surface station and the ROV. When the ROV starts, it will listen for a TCP socket connection on port 8080. The bot socket package is run from the surface station and connects to the TCP socket server that is listening on the ROV.

Surface Station

The surface station software is comprised of two parts. The core of the surface station runs as a Node.js process. This process handles the bot-socket connection with the ROV, communication with the joystick, and it hosts the second part of the surface station. The second part of the surface station is a web page that acts as an interface to the sensors on the ROV and has buttons to control the connection and disconnection to the ROV.

Degrees of Freedom Mapping

There is a package that runs on the surface station to handle the mapping of joystick values to the degrees of freedom upon which the robot can move. Each axis on the joystick controls a different degree of freedom on the robot, a degree of freedom being a linear direction on which or axis about which the ROV can move. Nugget Industries’ ROV has 5 degrees of freedom with its current thruster configuration.

Degrees of freedom are sent to the ROV in a controller data token as an array of values ranging from -1 to 1 inclusive. For each value, -1 tells the ROV to move completely backwards in that degree and 1 tells the ROV to move completely forwards in that degree.

Subsystem Control

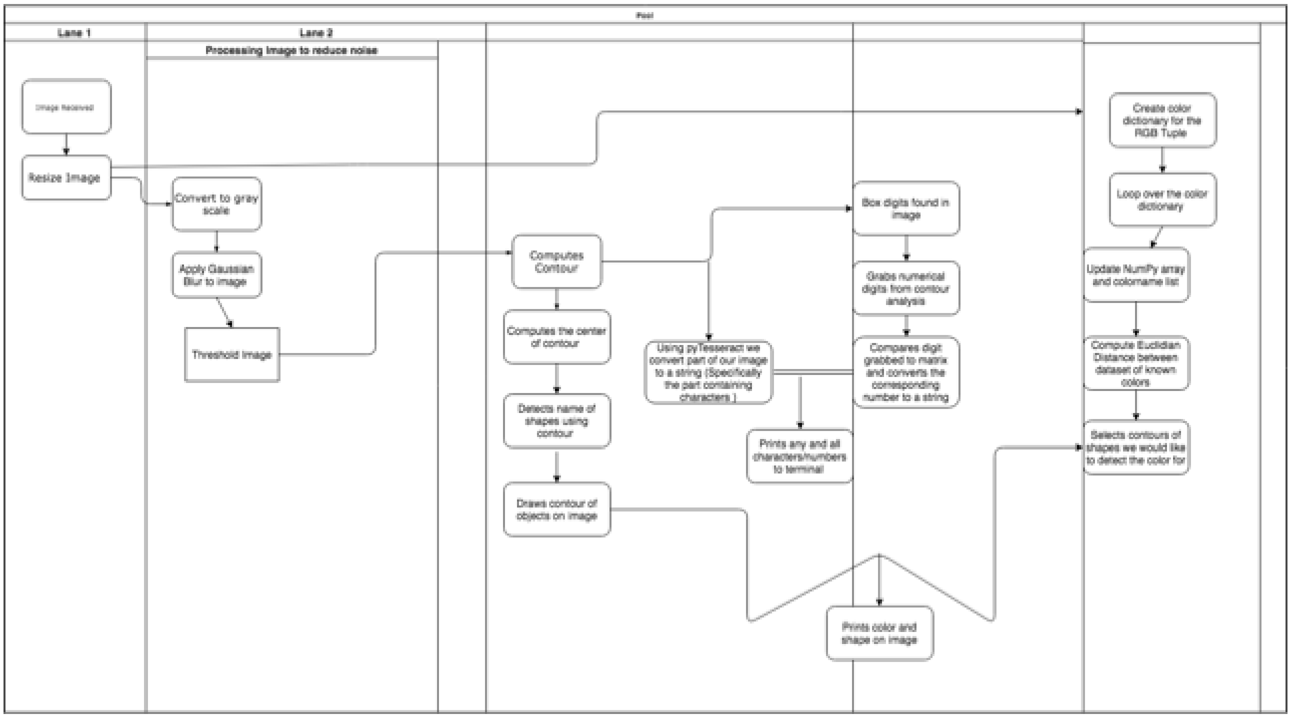
Joystick axes and buttons are also used to control the two subsystems on the ROV. One button is used to spin the leveler and the combination of a certain button and an axis are used to open and close the manipulator. Motor values for these two subsystems are sent with the degrees of freedom data in a controller data token.

Sending Data

Joystick axis and button data is stored in the joystick mapper package and checked every 16 milliseconds. Upon checking, degrees of freedom and subsystem motor values are calculated. If these newly calculated values are different from the values that were sent to the ROV last, the new values are sent to the ROV. If there is no change, nothing is sent.

Image Processing

Image processing is a resource-consuming task, and as a result is handled on the surface station. To keep resource usage low, a still image of the ROV’s camera feed is captured at a regular interval and fed into the image processing program, written in python.



On-ROV

Tokens are consumed on the ROV and an event is emitted with the token's type. Handlers are attached to each token type event to handle the task being commanded by the token. The data sent with the token is also sent to the handler so the task may be performed properly.

Degrees of Freedom Mapping/Thrusters

All motors are controlled using a PCA9685 PWM driver chip. The ROV can interface with this chip in the form of a Node.js library.

Degrees of freedom are sent to the ROV using a controller data token. The ROV has a matrix used for decoding degrees of freedom values into the magnitude and direction that each thruster should spin. Upon successful setting of each thruster value, the ROV responds to the surface station with the value of each thruster. Thruster values range from 1100 to 1900 inclusive. These numbers represent the pulse length in milliseconds sent to each thruster speed controller with 1100 being full reverse and 1900 being full forwards.

Manipulator and Leveler

The motors driving the manipulator and the leveler are controlled by separate channels on the PWM controller chip. These channels are dictated by two of the values sent by the surface station in a controller data token.

Streaming Video

The ROV creates a network between the ROV and surface station over which information can be passed. One of those bits of information are two video streams over the network. There's one for each camera, and accessing them allows you to look in front or to look around in the dome. mjpg_streamer is used to make this happen.

mjpg_streamer is a tool that streams mjpg's, and it also has the ability to run network streams. Each device has a systemd command as outlined in 'On-Robot Processes'. mjpg_streamer is used to access the data stream produced by the OS, do some conversion magic, and then spit it out over the network on a port that can be accessed by other devices on the network. This allows video streams to be quickly and easily accessible.

systemd Processes

systemd, a tool built into the GNU/Linux system, allows us to start processes when the Raspberry Pi powers on. Several services have been created to automate the startup of ROV. First, a service that allows the surface station to connect and send data starts. Next, a service starts the picam and the Mobius, allowing their video streams to be viewed using a web browser on the network. Finally, a service to log the ROV's temperatures starts, which is used in the event of a temperature related issue.

Trials and Errors

Mechanical

When designing the manipulator, originally the team planned to use a motor that drove a lead screw to convert rotational motion to linear motion.

However, after designing a lead screw driven system which uses a 4 bar linkage, the amount of force it would be able to apply was in question. In order to find out, we applied our knowledge regarding statics to calculate the amount of force that would be applied in the direction perpendicular to the lead screw. With a goal of a minimum of 10 lbs, we were disappointed to find it had 1.5 lbs of crushing force, with idealized friction values that may not have been realistic to achieve. Other linkage lengths and angles were tested with similar results. This would not provide a large enough factor of reliability to pick up many of the props. The worm gear design was created to solve this issue.

Electrical

Many issues had to be resolved in order to complete the electronics of the ROV. The PDB and SB both went through three iterations, finding problems and places for improvement with each successive iteration. Some issues included crossed signals, shorted connections, incorrect footprints, missed connections, etc.

Wire management and IC shorting was a major issue to overcome. The heatshrink was removed from the ESCs and conformal coating was applied in an attempt to provide electrical insulation while making the overall size of the ESC's smaller. However, when the ROV was closed the wires and components we packed very tightly and the conformal coating failed to provide the insulation desired, causing shorts within the vehicle. This effect also caused the failure of the first RPi. The team initially thought this was a thermal issue, so a fan was added and software to monitor the RPi's core temperatures was implemented. This turned into a positive feature, as the dashboard now shows the temperature of the RPi at all times. The fan only provides positive effects as well, keeping the air moving inside of the enclosure.

Project Management

Team Structure

The team is divided into multiple research and development groups. There are subgroups providing design work on mechanical systems, electrical systems, and software. Many of the mechanical design team members also provided the manufacturing necessary to create the vehicle. Each subgroup has a team lead. Each of the team leads provide a point person for each branch of the ROV. The CEO oversaw all of the branches and provided input and design work as well.

Communication Tools

The team communicated through Slack, Dropbox, and Google Drive. These services allowed collaborative work to happen when the team could not always be together. All of the ROV files were stored in dropbox so that SolidWorks work could be stored on a shared network and would remain up to date.

SID and Fuse Calculations

Fuse calculations

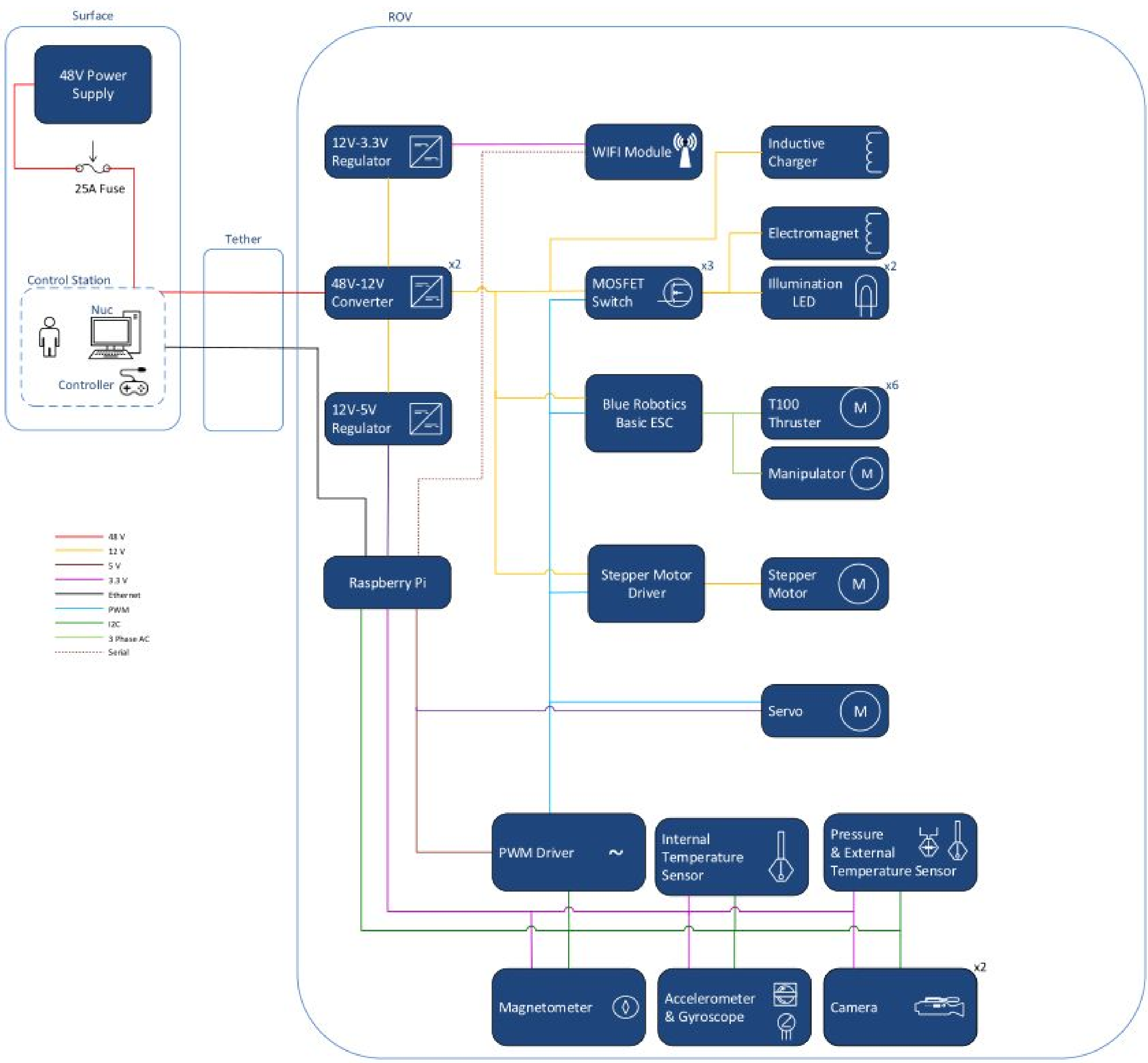
Fuse calculations are begun at the device's native voltage. Each device is then converted to equivalent power draw at 48V. This sum is used to size the fuse. A 25A fuse or 30A fuse can be used to protect the ROV. The ROV can only draw 20A, and thus a 25A fuse should have no ill-effect. Considering overcurrent factors, a 30A fuse is closer to the calculated overcurrent draw.

48V	
Device	*Current Consumption(A) I=P/48*
Raspberry Pi	
Mobius Camera	

Pi Cam	
Sensors	
PWM Driver + servo (+ sum of all items above)	0.15
Thrusters x6	17.25
LED (10Weach)	0.00
Leveler motor	0.25
Electromagnet	0.25
Power Pod	0.03
M-100	2.88

Total Current=	**20.80**	**Total Overcurrent=Total*150% =**	**31.19**
		Nearest Fuse (less than OC):	**25 or 30**

Electrical SID



Safety

The team considers safety to be incredibly important given the high power nature of the device. The subsections below will detail the safety precautions and procedures that the team follows.

PPE

The team employs simple methods of personal protective equipment. The most commonly used is Z-87+ certified safety glasses while machining or performing other dangerous tasks.

The team avoids wearing gloves while manufacturing to prevent any potential degloving accidents.

Safety procedures

In order to work on the ROV, inside or out, the following procedure must be followed.

1. Power down DC
2. Perform repair or maintenance needed
    a. Any unnecessary hands must step back to allow space to work
    b. Team member(s) working must provide communication to the rest of the repair team
        i. This includes asking for tools, advice, extra hands or a hands off powered test
3. Power up DC

Safety within design

Safety was of paramount concern to the team. The following list of features outlines the main safety features of the ROV.

- Thruster guards
- DC kill switch on surface station
- Capacitor discharge resistors to ensure fast power down
- Magnetic coupling of leveler system to prevent over-torque and motor strain
- Sharp edges removed
- Isolated DC-DC converters to ensure no high voltage can reach low power electronics
- Conformal coating on electronics to protect sensitive electronics
- Thruster soft kill button

Pre dive checklist

- ❏ All penetrators tightened
- ❏ Surface station is running
- ❏ ROV connected to surface station
- ❏ All thrusters functional
- ❏ Both video streams accessible on network
- ❏ All subsystems functional

- ❏ Tether properly connected
    - ❏ Connectors tight
    - ❏ Strain relief connected
- ❏ Torque pattern on enclosure is properly secured
    - ❏ No loose bolts
- ❏ Foam properly secured

Testing and Troubleshooting

As an advanced electromechanical system, the ROV comes with the expectation of things not working properly the first time. Some of these challenges are outlined in the section below.

Testing happened piecewise. As the custom circuit boards were assembled, they were individually tested for proper continuity, and then for powered signal transfer. In terms of the PDB, once assembled and double-checked, it was powered up and the output voltage was measured. From there, a load test with thrusters was done. The sensor board was populated with sensors, and through a command line in the computer terminal, the i^2c bus was polled to see if all of the sensors showed up and were being read correctly.

Technical Challenges

The downfall of many past ROV attempts had been the seal interface that protects the main electronics housing. This year, the team designed a custom o-ring that is guaranteed to work so long as the sealing surfaces are clean and the clamping pressure is even. All of these things were improved over years of past ROV design. Previously a gasket made of a rubber sheet was attempted and was ultimately that past ROV's downfall. Immense care was taken this season to create a reliable seal that works every time.

The leveling subsystem posed electrical challenges of its own. It initially consisted of a stepper motor and a stepper driver that was driven from the sensor board, but the team was having trouble keeping the stepper drivers functional. The drivers seemed to frequently burn out and thus the idea was posed to switch to something more reliable. This led to a brushed DC motor replacement, causing a redesign in the subsystem before the qualification video was filmed.

Non-reliability of the lift bag frequency trigger was heavily in part due to DIY speaker and receiver using piezoelectric discs, and op-amp preamp circuits. Shifting in received tones was also an unforeseen difficulty due to a change in medium the sound waves must have traveled through. Originally a transform function was going to be used to detect frequency peaks but due to the non sinusoidal response of the piezoelectrics, so an eventual peak counter over time method was used to determine the recorded frequency. Some of these issues were solved with a market Sparkfun microphone/preamp board but ultimately the frequency selective speaker/receiver system was not reliable enough for filming purposes and required the aforementioned mechanical system .

Personal Challenges

An advanced machine like the N.U.G.G.E.T. takes thousands of hours to conceive and create. It is incredibly difficult to be a self-sustaining robotics team and a team of full time students with homework, tests and finals. The team managed this by creating a strict Gantt Chart and following it to the best of their abilities. This ultimately led to strong design work initially, and paved the way for intense pushes for work after a short lull in productivity. Likewise, student members strengthened their time management abilities, realizing the increasing pressure of a deadline which for so long seems far away.

Moving Forward

Electrically, the team designed powerful and robust custom circuit boards while using a large amount of off the shelf components like Blue Robotics ESC's. Moving forward, the team has discussed an "all-in-one" circuit board that takes power distribution, sensor breakout, and signal processing, and combines all of those into a single circuit board that a RPi can directly interface with. If this were to be done, the team could create a streamlined electronic system that minimizes the need for a large enclosure.

Mechanically, the torque pattern on the electrical enclosure is very reliable. The largest downside is that this pattern takes a long time to implement. In order to make sealing of the electronics much faster and easier, the team is considering switching to a fast clamping system to replace the bolts for the next season. This would allow the closing and subsequent opening of the enclosure to be much faster.

Budget

The company budget was managed carefully and strategically. An initial funding of $4,000 was provided by the WIT chapter of IEEE in September of 2017. In these early stages, the spending of these funds was carefully scrutinized, while a strategy to gain more financial backing was developed and put into effect. A small sub-committee of company members consisting of Alyssa Vallese, Alec Hewitt, Andrew Zucker, and Nicholas Stratton was formed to execute upon this strategy. This committee applied for several educational grants within WIT. Through hard work, constant outreach to various department heads, academic advisors, and other administrators, and tremendous confidence in a successful product, the company was granted the John P. Heinstadt Professional Development grant and the Mini EPIC Grant, totaling $9,200. At this point, funds were allocated to several accounts within the company, and the team

Schedule

		Name	Duration	Start	Finish	Predecessors
1		**Design Phase**	29 days?	**1/11/18 8:00 AM**	**2/9/18 8:00 AM**	
2		Break Down Tasks	1 day?	1/11/18 8:00 AM	1/11/18 5:00 PM	
3		Stop Light Charts for Each Task	0 days?	1/18/18 8:00 AM	1/18/18 8:00 AM	2
4		Prioritize and Finalize Tasks	0 days?	1/18/18 8:00 AM	1/18/18 8:00 AM	2;3
5		Begin Brainstorming System Designs	1 day?	1/18/18 8:00 AM	1/18/18 5:00 PM	2;3;4
6		Design Review: Finalize Brainstorms	1 day?	1/18/18 8:00 AM	1/18/18 5:00 PM	2;3;4;5
7		Refine Designs	4 days	1/19/18 8:00 AM	1/22/18 5:00 PM	6
8		Design Review: Geometry Review	1 day?	1/25/18 8:00 AM	1/25/18 5:00 PM	7
9		Refine Designs II	4 days	1/26/18 8:00 AM	1/29/18 5:00 PM	8
10		Design Review: Tolerancing Review	1 day?	1/30/18 8:00 AM	1/30/18 5:00 PM	9
11		Finalize Designs	6 days	1/31/18 8:00 AM	2/5/18 5:00 PM	10
12		Final Design in Solidworks	0 days	2/9/18 8:00 AM	2/9/18 8:00 AM	11
13		**Manufacturing Phase**	45 days?	**2/11/18 8:00 AM**	**3/28/18 8:00 AM**	**1**
14		Begin Manufacturing	6 days	2/12/18 8:00 AM	2/17/18 5:00 PM	12
15		Manufacturing Check-Up	0 days	2/17/18 5:00 PM	2/17/18 5:00 PM	14
16		Finalize BOM	0 days	2/11/18 8:00 AM	2/11/18 8:00 AM	12
17		Order all Parts	1 day?	2/12/18 8:00 AM	2/12/18 5:00 PM	16
18		Begin Assembly	5 days	2/19/18 8:00 AM	2/23/18 5:00 PM	14;17
19		Manufacturing Check-Up	0 days	3/8/18 8:00 AM	3/8/18 8:00 AM	14;15
20		Complete Manufacturing	0 days	3/12/18 7:00 AM	3/12/18 8:00 AM	14;15
21		Complete Assembly	0 days	3/12/18 8:00 AM	3/12/18 8:00 AM	18;20
22		Complete Code and Final Touches	0 days	3/28/18 7:00 AM	3/28/18 8:00 AM	20;21
23		FLEX	5 days?	3/21/18 7:00 AM	3/25/18 5:00 PM	
24		**Testing Phase**	10 days	**3/28/18 7:00 AM**	**4/6/18 5:00 PM**	
25		Testing, Troubleshooting & Drive Practice	10 days	3/28/18 7:00 AM	4/6/18 5:00 PM	21
26		Finals	5 days?	4/12/18 7:00 AM	4/16/18 5:00 PM	
27		**Documentation Submission Deadlines**	69 days	**3/16/18 7:00 AM**	**5/24/18 8:00 AM**	
28		Documentation	0 days	5/24/18 7:00 AM	5/24/18 8:00 AM	21;22
29		Video Demonstration	0 days	5/11/18 7:00 AM	5/11/18 8:00 AM	21;22
30		Image Recognition Diagram	0 days	3/28/18 8:00 AM	3/28/18 8:00 AM	22
31		Laser Specs	0 days	3/16/18 7:00 AM	3/16/18 8:00 AM	
32		Software Flow Chart	0 days	3/28/18 8:00 AM	3/28/18 8:00 AM	22
33		Ship Components	14 days	6/4/18 7:00 AM	6/17/18 5:00 PM	21
34		Competition Dates	3 days	6/21/18 7:00 AM	6/23/18 5:00 PM	21

Accounting

All company purchases and expenditures were tracked by the CFO. An itemized bill of materials was kept and updated for records. In conjunction with this, an error-proof method of placing and tracking orders was developed and utilized by the company; formatted materials requests from team members submitted to the CFO were required for purchase, at which point the CFO worked with team leads to determine value and budgetary viability of the order before it's transaction. All spending was categorized into four categories - electrical hardware, mechanical hardware, travel costs, and miscellaneous expenditures. Below is an outline of the company's predicted and actual spending to date.*

Mechanical and Electrical Hardware		$300.00
Thrusters		$200.00
Motors & Controllers		$750.00
Raw Materials (Stock)		$200.00
Hardware		$450.00
Buoyancy Foam		$300.00
Tether Materials		$100.00
Waterproof connectors		$100.00
Vacuum Accessories for Seal Testing		$200.00
Pneumatic Materials		$400.00
Tooling		$500.00
Pelican Case		$450.00
Power Converters		$200.00
Custom PCBs		$350.00
Electrical Components for PCBs		$200.00
High Power Connectors		$200.00
Panel Mount Bezels		$250.00
Mounting Panels		$75.00
Components for custom controller		$75.00
Switching components		$5,300.00
	Total All Equipment	
Travel		$4,117.00
Flights (12)		$1,800.00

Hotel Rooms (3)		$700.00
Misc. Transportation Fees (Ubers, Taxis, Shuttles, etc.)		$6,617.00
	Total All Travel	
Miscallaneous Costs		$325.00
Competition Registration		$575.00
T-shirts		$1,000.00
Emergency account		$1,900.00
	Total All Other Direct Costs	$13,817.00
	Total Costs	
Revenue		**Amount**
Source		$5,000.00
Mini-Grant Request		$5,300.00
IEEE Budget Allocation		$500.00
Fundraising		$4,125.00
Anticipated Donations		
	Total Revenue	$14,925.00

* An itemized bill of materials is available upon request.

Outreach

The team has continuously been reaching back to Wentworth to gain traction with the entire WIT community. Team members have made extraordinary strides with the Electromechanical Engineering department, and were asked on numerous occasions to represent the Interdisciplinary and Electromechanical Engineering programs for school promotional functions.

References

[1] "Static O-Ring Sealing." Parker O-Ring Handbook, Parker Hannifin, 2007, pp. 4–18.
[2] Nisbett, J. Keith. "Gasketed Joints." Shigley's Mechanical Engineering Design, by Richard G. Budynas, 10th ed., McGraw Hill, 2015, p. 436.
[3] Jones, Dave. *EEVblog*, youtube.com/user/eevblog
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[6] "2018 EXPLORER MANUAL." *MATE International*.

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On behalf of the entire ROV team, we would like to extend thanks to all of the people who have helped us through this project. The resources, experiences, and advice received have helped us immensely both personally and as a team. This project would not have been possible without them.

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