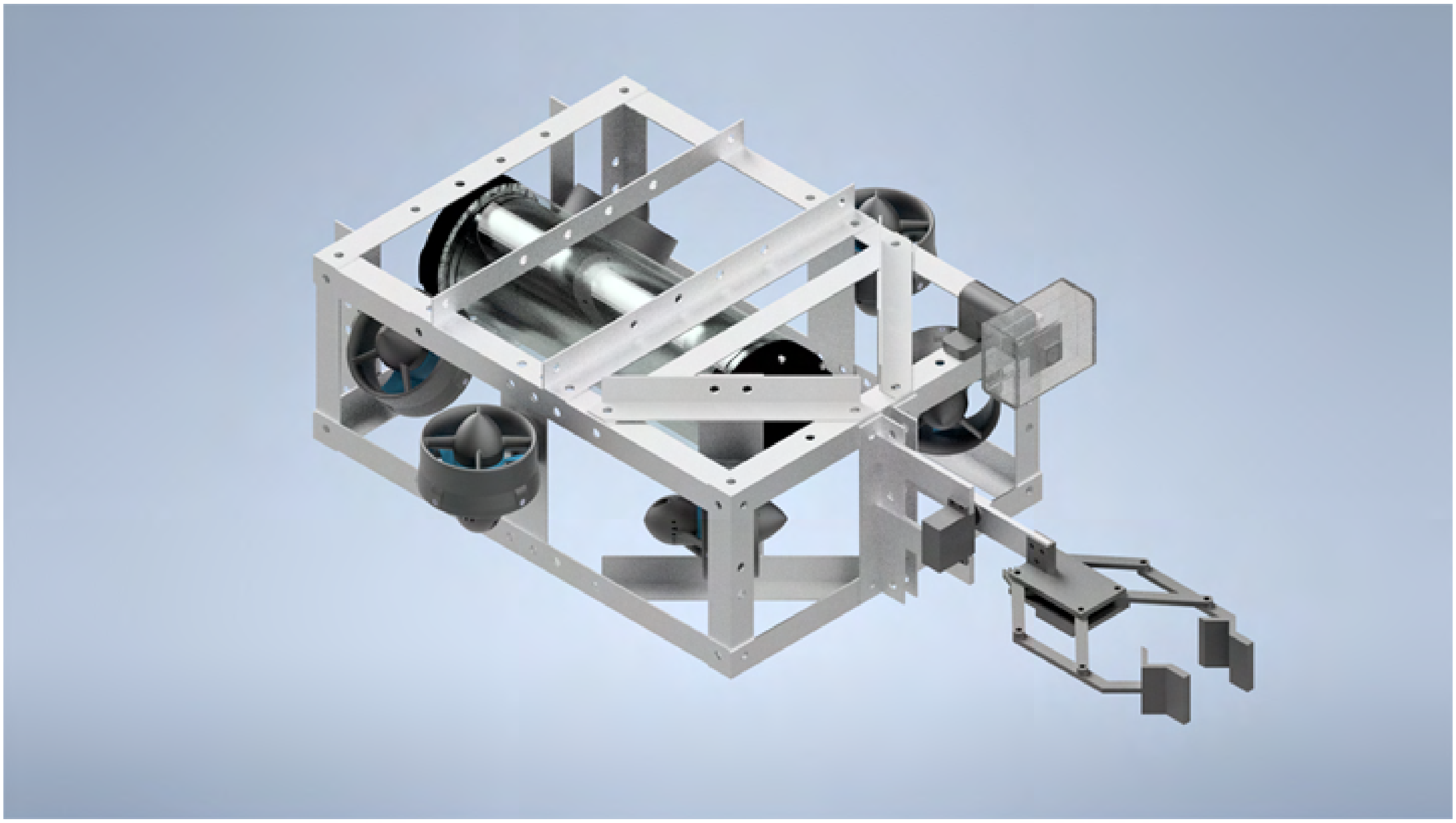

Milligan Robotics

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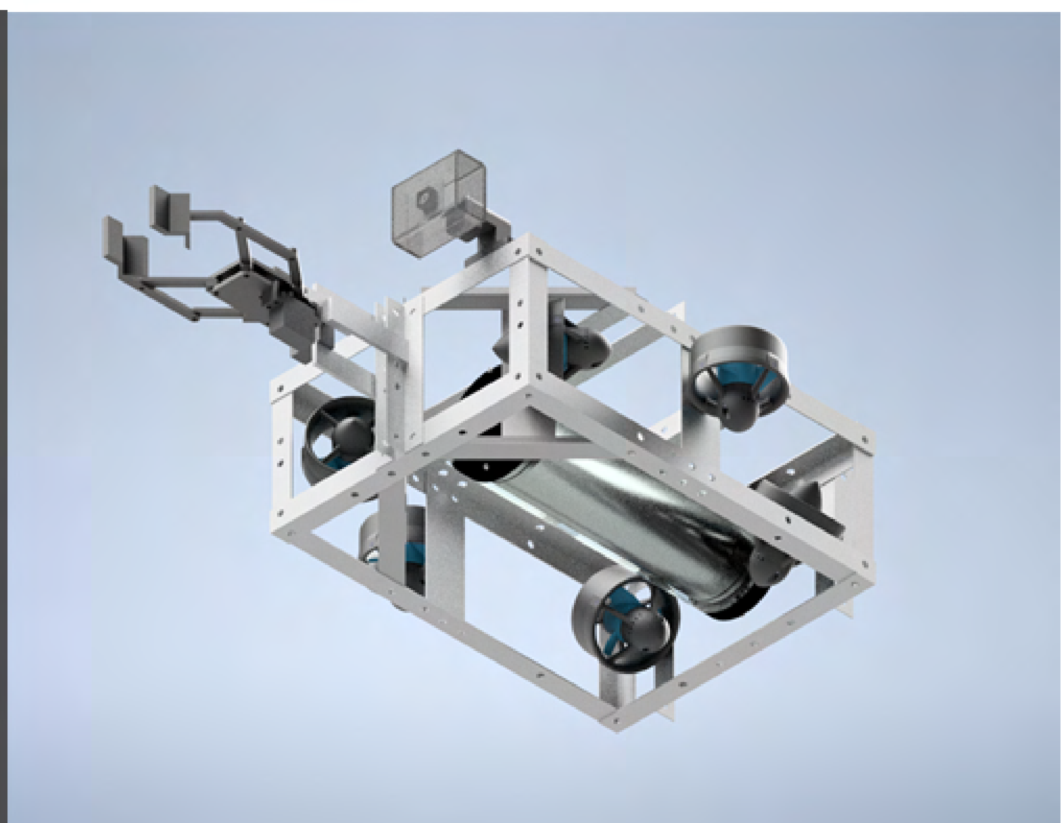


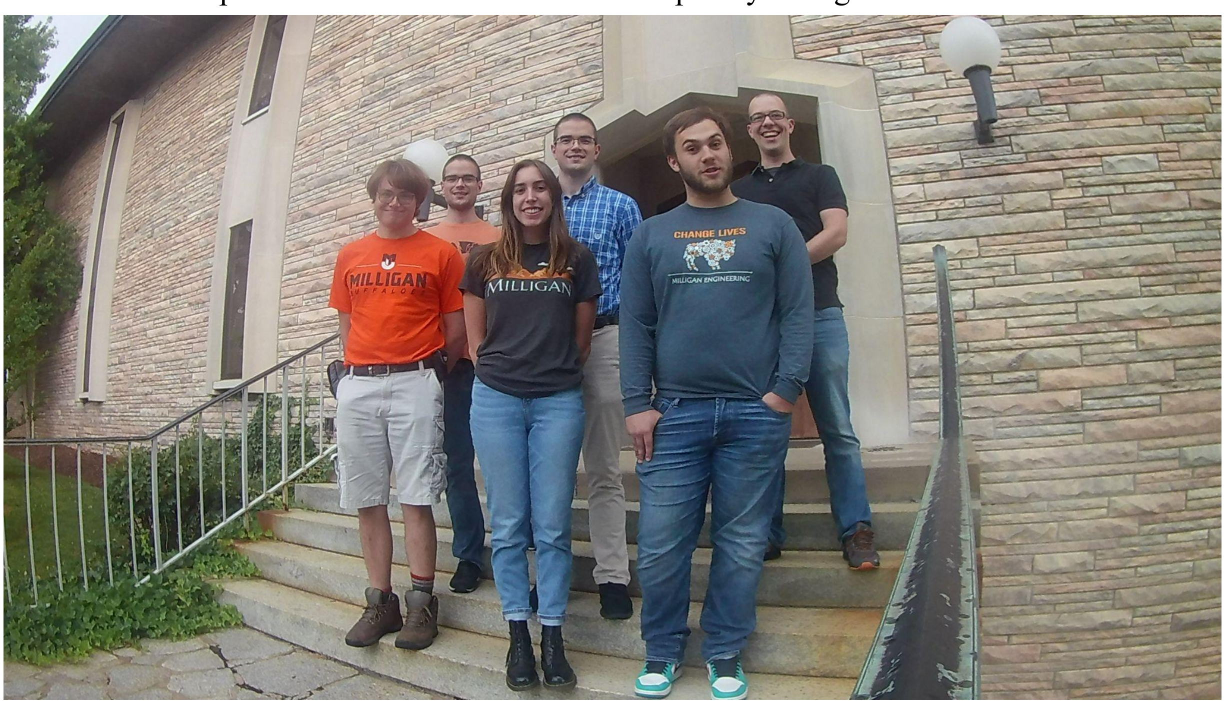
Table of Contents

I. Abstract

Milligan Robotics has developed a Remotely Operated Vehicle (ROV) to meet the request for proposals. This year, Milligan Robotics was tasked with creating our first ROV, the TRILOBYTE. TRILOBYTE has a range of capabilities, such as the ability to pick up and move items like coral and plastic waste in the ocean. TRILOBYTE also has image recognition capabilities, which can be used to monitor coral reef health, and can aid in promoting ecosystem health by culling Crown of Thorns Starfish and relocating eel traps.

Milligan Robotics is broken down into three teams: Mechanical, Electrical, and Software Development. Each team was tasked with formulating the designs for each component of the ROV they were assigned, and communicating with the other teams to ensure that the completed components would interact well with each other. This was achieved by members from each team taking part in design discussions and the actual construction of the TRILOBYTE to ensure that a singular clear vision for the final product was held by each team.

As a first year company, the primary goal of Milligan Robotics was to gain the knowledge and experience necessary to complete our first ROV design. The TRILOBYTE offers many capabilities, but has great room for improvement. Its current design offers many of the key capabilities of a robust ROV, while maintaining affordability and a framework that will be easy for future teams to build upon. The following documentation will describe the design rationale and construction process of the TRILOBYTE developed by Milligan Robotics.

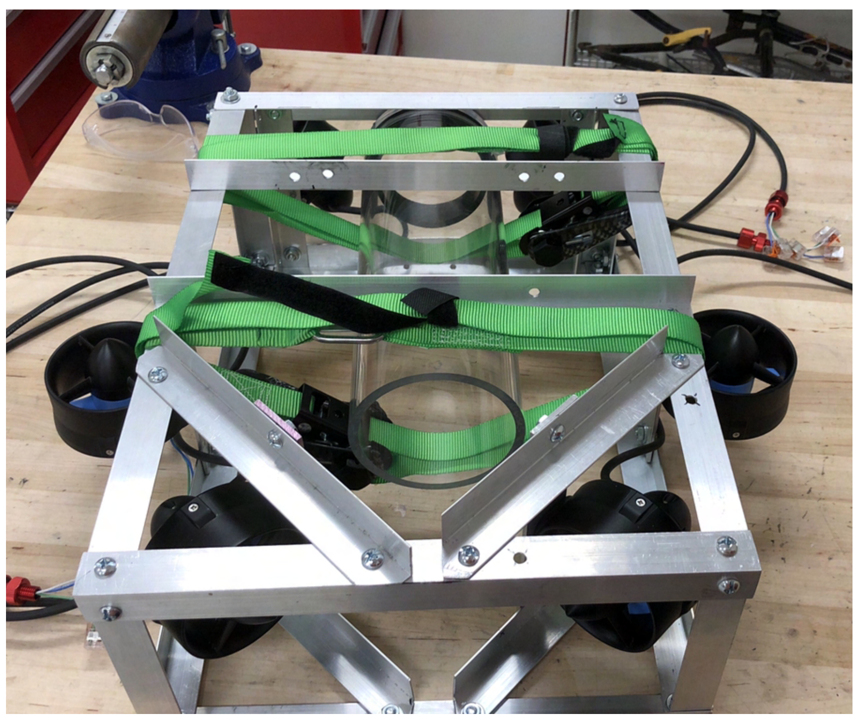


II. Mechanical Design

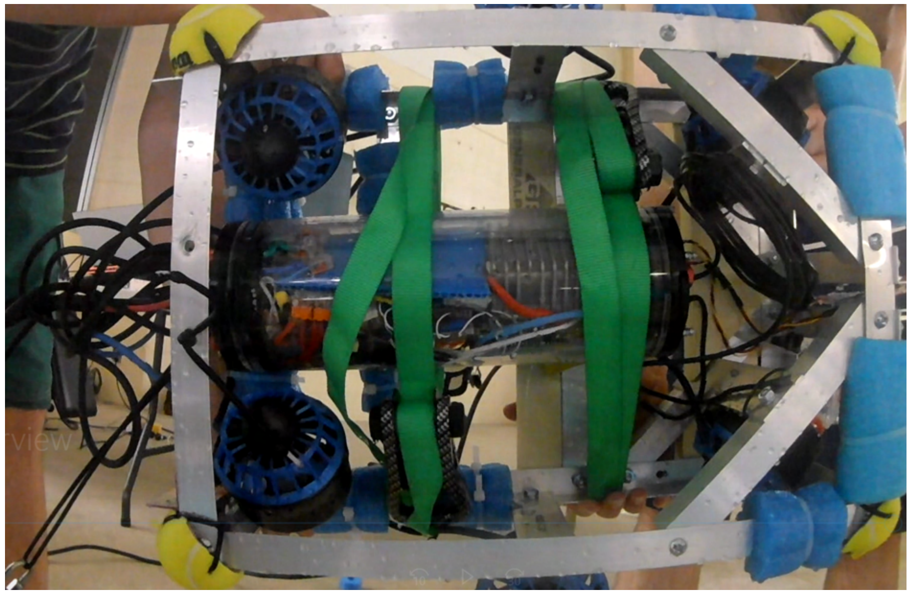
A. Frame

For the TRILOBYTE frame, the overall design goal was to create a frame that could be easily constructed using aluminum and bolts. Aluminum was chosen because it offers high strength and machinability, while also being lightweight and adaptable to any design that we come up with. Each member of the aluminum frame was custom cut and bolted into place by the team using a band saw and drill press. To maintain consistency and allow for easy frame construction and modification, all of the structural members were fastened together using quarter inch, twenty thread per inch, stainless steel bolts. These bolts are sturdy and easily available, and when combined with lock washers, are capable of securely fastening the frame together without concern of the bolts being knocked loose. The sharp edges of the frame were filed down to ensure that no damage would be done to the pool or team members handling the TRILOBYTE. To further increase the safety of the frame, tennis balls were attached to the corners using zip ties to make the frame easier to transport, and to minimize the likelihood of the corners damaging the pool and other surfaces.

B. Canister



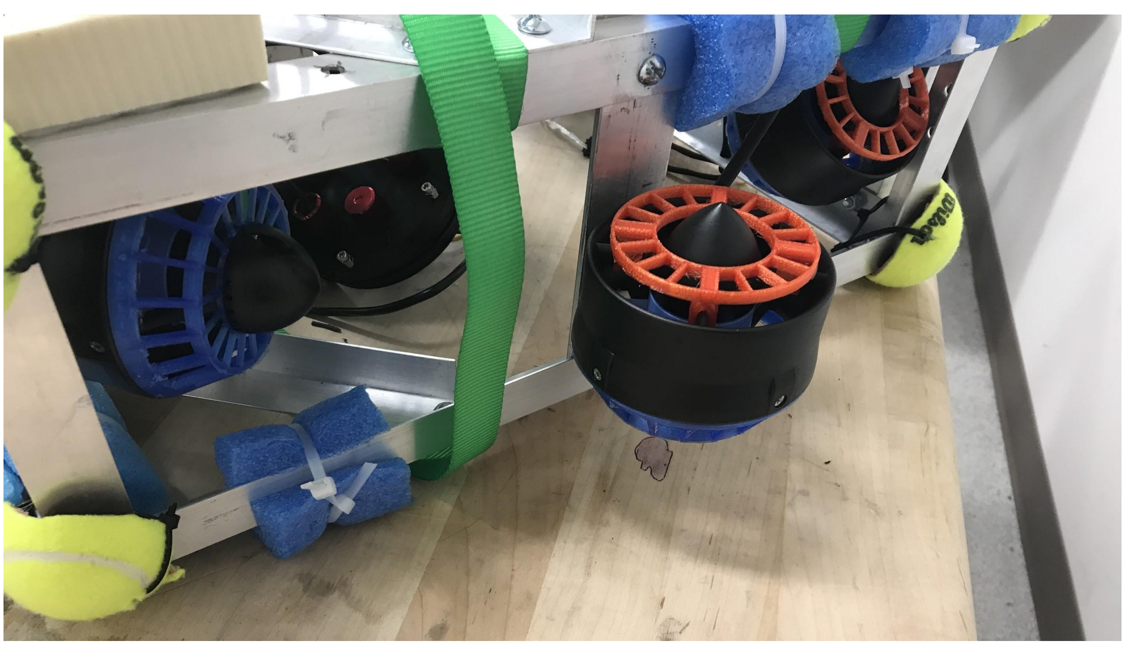
One of the key components of the mechanical design was to have an enclosure that would protect the TRILOBYTE's electronics from exposure to water, while also allowing the team to adjust the electronics and troubleshoot issues as easily as possible. After researching several different ideas, the team reached the conclusion that the best option would be to work with the Blue Robotics 4 inch acrylic pressure canister. The acrylic allows the team to quickly and easily monitor the state of the onboard electronics, while the end caps of the canister offer fast waterproofing and adjustment through the use of the Blue Robotics penetrators. While multiple designs that could have been developed by the team were considered, the Blue Robotics canister was chosen because it offered everything the team needed since it offers high adjustability for future iterations of the TRILOBYTE, and is created out of high strength acrylic, which Milligan Robotics does not have the tools to develop on our own at this time.



Mounting the canister to the TRILOBYTE in a secure manner was also vital to ensuring the proper operation of the vehicle. After multiple design iterations with aluminum brackets to hold the canister in place, the team reached the conclusion that the best method for securing the canister would be to use ratchet straps acquired from a hardware store. The ratchet straps offer a secure mount for the canister, preventing it from sliding during ROV operation, while also allowing for adjustability in the placement of the canister and rapid dismounting of the canister for electronics troubleshooting and repair.

C. Thrusters

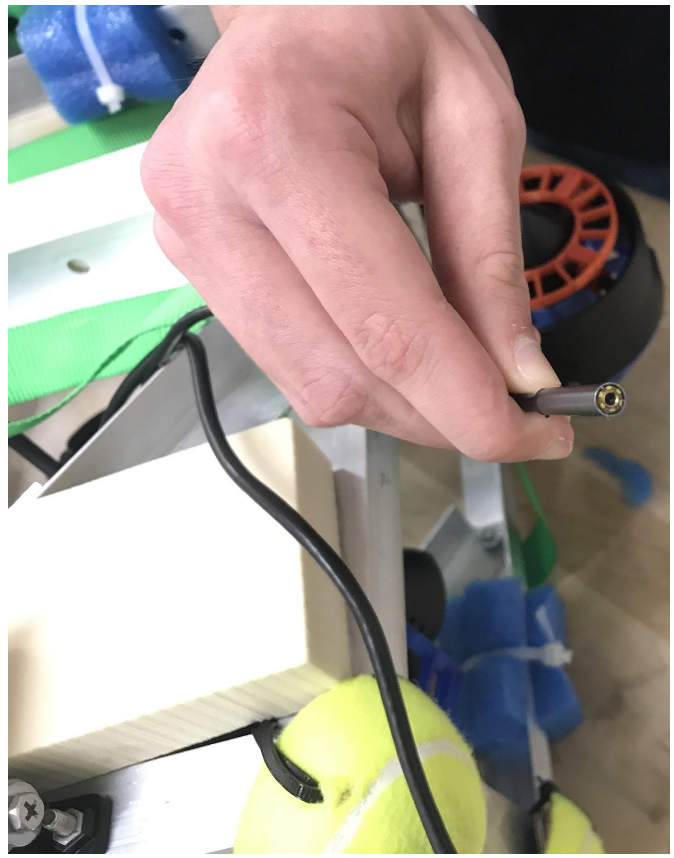
Rather than designing and developing underwater thrusters, the team chose to use the Blue Robotics T200 thrusters as our primary thrust source. The T200 thrusters easily mount to the ROV frame, since they can be secured with M3 bolts to the frame. Six thrusters are used on the TRILOBYTE that are arranged in a vector steering configuration that allows the ROV to move forwards, backwards, vertically, and control the pitch, roll, and yaw of the vehicle. This



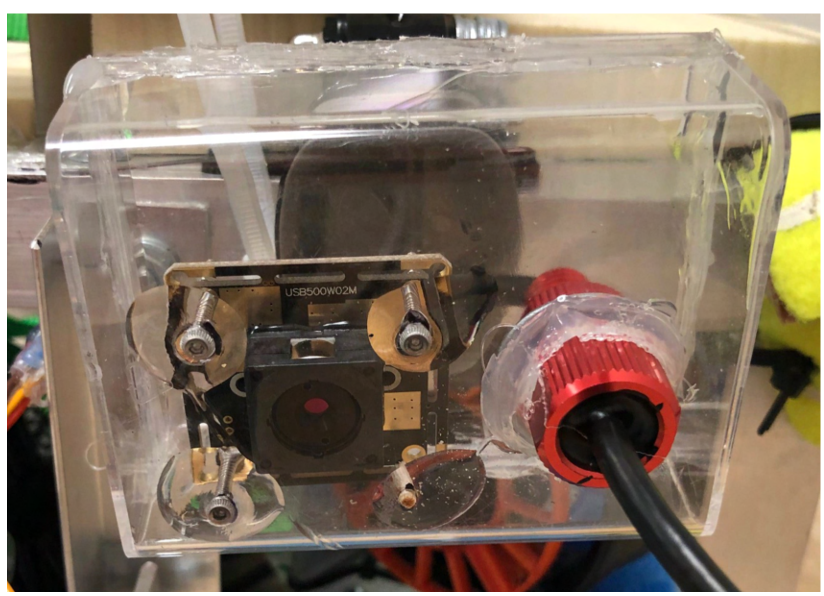
allows the pilot of the vehicle to position the vehicle in any orientation necessary to complete the tasks, and gives the pilot the ability to adjust for any upsets to vehicle balance that could be caused by picking up objects or unexpected currents in the water.

D. Cameras

Mounting and waterproofing cameras for use on the TRILOBYTE proved to be one of the biggest technical challenges for the team. Commercially available waterproof cameras tend to be fairly expensive, but waterproofing our own cameras presented many challenges. The solution to this problem was to use two different types of cameras for mounting at different points on the vehicle. The primary camera is a high resolution USB camera, which the team developed a waterproof enclosure for. The waterproof enclosure is a clear plastic box, which has M3 bolts passing through it to fasten the camera in place. The box was then sealed using clear epoxy resin for a sturdy seal, combined with a hot glue layer on the exterior to hold the box in place while the resin cured. The primary looks off of the front of the vehicle, and is used for image recognition, navigation, and manipulator control.

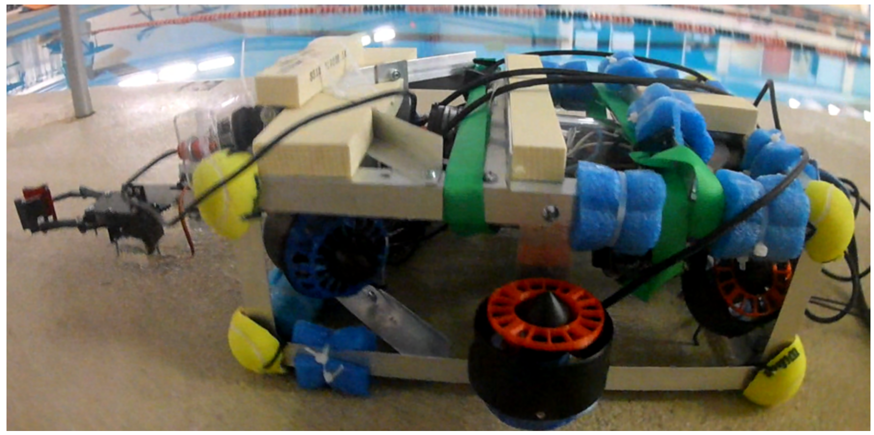


In addition to the primary camera, two auxiliary cameras are mounted to the ROV. The auxiliary cameras are waterproof endoscope cameras, which can be adjusted and easily mounted anywhere on the frame using zip ties. These cameras will be used to look downwards to aid with navigation and for watching the tether to help the pilot ensure tether safety. These cameras can also



be quickly adjusted to meet the task at hand, should the need arise.

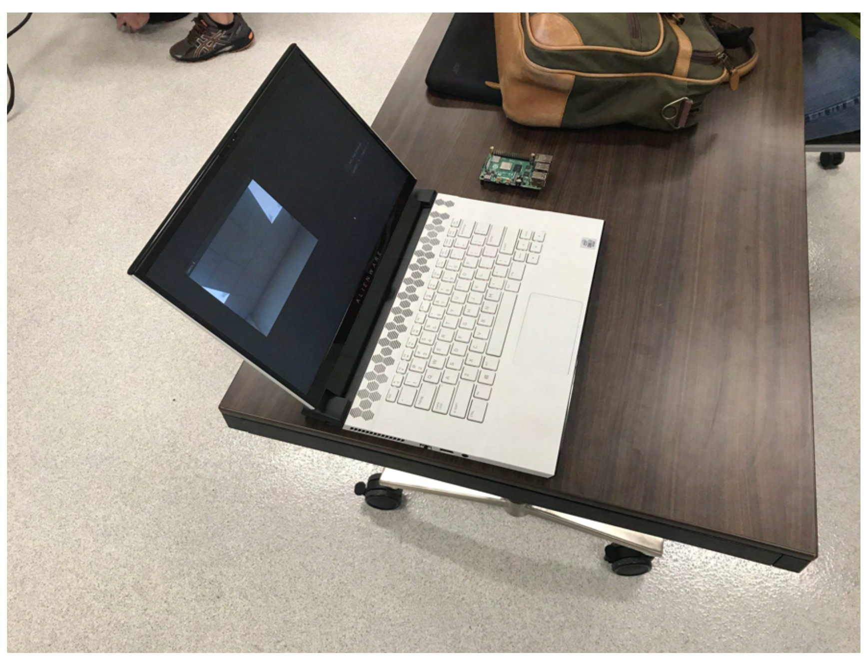
E. Buoyancy and Ballast



Buoyancy and ballast were considered throughout the entire mechanical design process of the ROV, with heavier components such as the T200 thrusters being located at the bottom for ballast, and buoyant components such as the pressure canister being placed near the top for buoyancy. Additionally, the ROV was designed to be symmetrical about the axis going from the front of the vehicle to the rear of the vehicle to ensure that the ROV would not be unbalanced. Once all of the components were attached to the ROV, Buoyancy foam calculations were made assuming the problem could be treated as a straight line, accounting for torque about the center of mass to keep the ROV from tilting unexpectedly. The buoyancy foam was then attached, and further adjustments were made pool side with the addition of pool noodles to ensure the ROV would float and maintain balance.

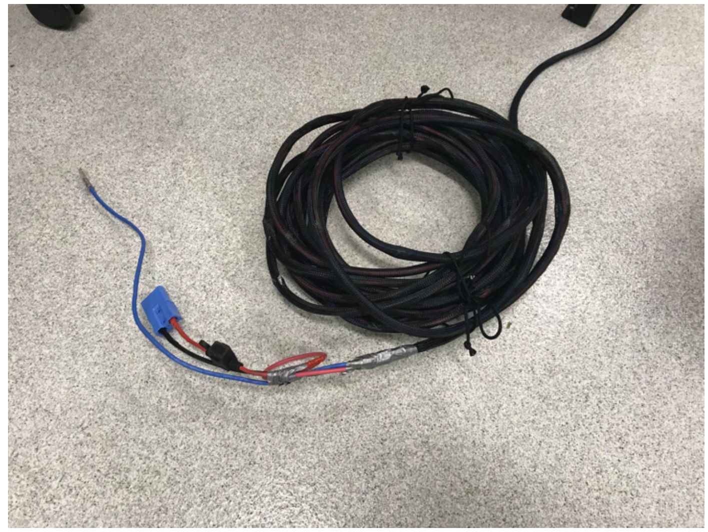
<u>III. Electrical Design</u>

A. Controls



TRILOBYTE is controlled using two primary components: a laptop with the Control Station software installed, and a raspberry pi. The laptop is powered by 120VAC, while the Raspberry Pi is powered through the tether after a voltage reduction. Communication between the two devices is accomplished using a CAT 5E ethernet cable that is part of the tether. The information sent through the ethernet cable is then used by the Raspberry Pi to send control signals and other information to the various ROV components.

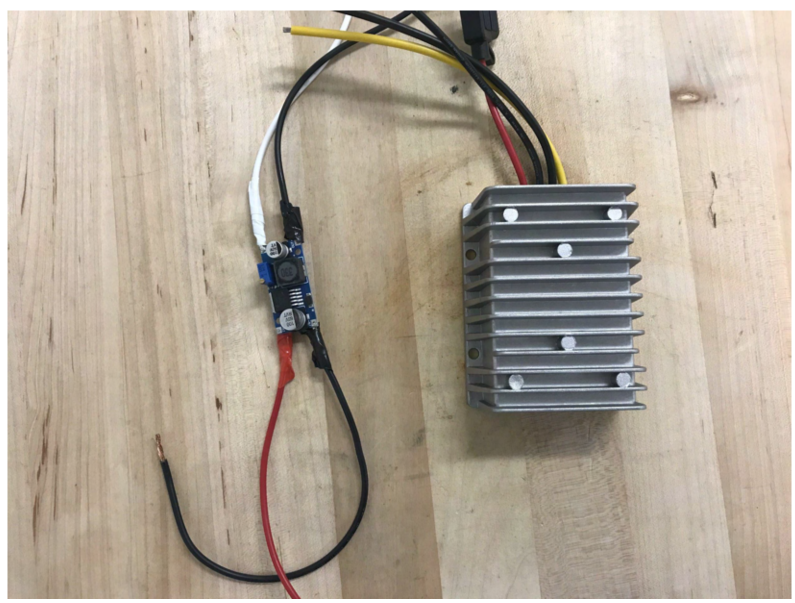
B. Tether



T.R.Y.L.O.B.Y.T.E's tether transmits instructions from the control box, and 48 volts DC into the ROV's pressure canister. is made of two 21.3 meter (70 foot) lengths of 10 gauge wire for power transmission and an Ethernet cable of roughly the same length which connects the control box to the Raspberry Pi. The red "+" wire is soldered to a fuse holder, which contains a 30 amp littlefuse.

The tether is cased with a mesh sheath which bundles the wires and cable together and protects their insulation. The red and black power wires are fitted with a blue SB 50 Anderson PowerPole connector. Each power wire and the ethernet cable enter the ROV's pressure canister through a potted Blue Robotics cable penetrator.

C. Voltage Reduction



TRILOBYTE's various components require different power inputs. Two different kinds of converter are used to run these components.

The tether's red and black power wires connect the 48 volt power supply to the input terminals of a "golf cart converter" which outputs 12 volts at 30 amps. This converter is used to power six T200 thrusters. The output terminals of the golf cart converter are wired in parallel to the two input power terminals of each of six blue robotics electronic speed controllers (ESCs).

The blue robotics ESCs receive pulse width modulation (PWM) signals from the raspberry pi via a positive and a ground signal terminal on each ESC. These terminals are connected to the raspberry pi through its general purpose input output (GPIO) header. Each ESC connects to each thruster with three wires.

The input terminals of two LM2596HV buck converters are placed in parallel with the input terminals of the golf cart converter to receive the same 48 volt input.

One of these converters is used to supply power to the Raspberry Pi. It is adjusted to output 5 volts. This converter is connected to a USB C power adapter which is plugged into the power input port of the raspberry pi.

The second LM2596HV buck converter is used to supply 7 volts to the two servo motors in the ROVs arm.

IV. Software Design

A. Overview

The TRILOBYTE's software is split into two components Control Station and ROV Software. Control Station is the user interface for controlling the TRILOBYTE and is run on a PC connected to the ROV. ROV Software controls the thrusters, arms, and camera on the ROV and is run on the TRILOBYTE's Raspberry Pi 4b. Both components are written in python and are designed to be as cross-platform as possible. The two components communicate with each other via JSON messages transmitted over ethernet.

B. Control Station

Control Station consists of the user interface and image recognition software. Control Station uses Pygame along with Pygame GUI to allow the pilot to interact with the ROV using a desktop application and an Xbox One controller. The desktop application displays camera feeds from the ROV and allows the pilot to initiate image recognition systems. The XboxOne controller allows the pilot to send movement data to the ROV via a six component vector consisting of x, y, z, pitch, roll, and yaw. The XboxOne controller is also used to control the TRILOBYTE's manipulator.

Internally, Control Station is based on the publish subscribe pattern. This allows Control Station to be highly modular. Each of Control Station's subsystems (GUI, Camera, Controller, ROVConnection, and Image Recognition) operate independently of each other. If any of the subsystems determines that it has useful information to share, it will pass that information to a publisher. Subsystems can subscribe to receive information from the publisher. This allows for the subsystems to communicate with each other while remaining modular.

C. ROV Software

ROV Software controls the hardware on board the TRILOBYTE. It receives control information from Control Station and converts it into PWM signals for the thrusters and motors ROV Software is also responsible for reading video data from camera's attached to the Raspberry Pi and transmitting this video data back to Control Station.

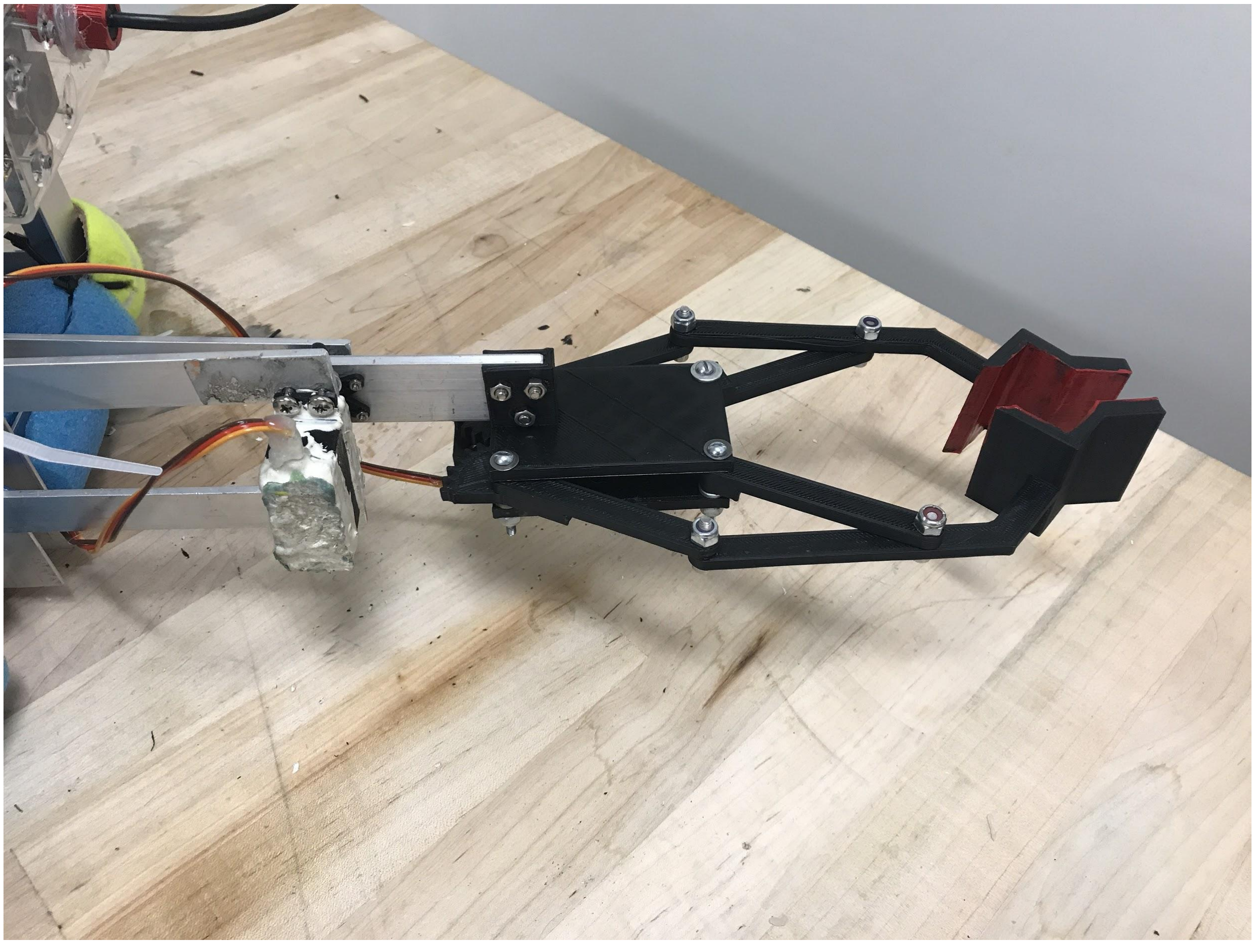
ROV Software is designed to be easily configured. It achieves this goal by loading a JSON configuration file on startup. This configuration file contains information on thrusters, motors, network interfaces, etc. and it can be easily modified if hardware changes to TRILOBYTE necessitate changes to ROV Software.

Like Control Station, ROV Software is based on the publish subscribe pattern. Its subsystems are Camera, Configuration Loader, ControlConnection, and Hardware Control. Since both ROV Software and Control Station are based on the publish subscribe pattern, local and remote subsystems communicate with each other in an identical manner, making it easy to add new features to any part of the software.

V. Mission Tools

A. Manipulator (Arm)

The TRILOBYTE arm was designed and developed by the team to meet the following criteria: the arm could reach upwards and downwards using an "elbow" and have the ability to grasp objects using the "claw". The elbow assembly for the arm was created out of aluminum, which was readily available due to also being used for the frame while also being strong enough to meet the task requirements. The claw was 3D printed out of PLA, which allowed for rapid prototyping and development of claw designs, while also allowing for easy adjustability for future designs.



Actuating the arm has proven to be one of the most technically challenging aspects of the ROV. The actuation of the arm is done using two servo motors rated for 10 kgcm of torque. One servo actuates the elbow while the other actuates the claw. Waterproofing the servos is accomplished by filling the servos with oil, or marine grease to repel water, then sealing the seams, and finally putting an O-ring with marine grease on the servo tooth to seal out the water. This design is effective, but leaves much room for improvement in future iterations. The cost of these servos is vastly reduced in comparison to commercially available waterproof servo motors, further increasing the overall affordability of the ROV design.

VI. Project Management

A. Organization

Milligan Robotics is organized into two teams: the Engineering team and the Software team. The engineering team is responsible for all hardware on TRILOBYTE. The Software team is responsible for developing both Control Station and ROV Software. Each team has a designated leader who meets with the company CEO to plan development on the ROV. Milligan Robotics has a full company meeting once a week to ensure development is progressing as expected. Individual teams meet throughout the week to focus on more specific technical details of their assigned components.

B. Schedule

Task	Start Date	End Date
Mechanical Design	1/11/21	3/15/21
Software Design	1/11/21	5/4/21
TRILOBYTE Assembly	3/15/21	5/4/21
TRILOBYTE Testing	5/4/21	6/4/21
Software and Mechanical Modifications	6/4/21	6/11/21
Video Submission	6/11/21	6/18/21
Finalize Documentation	6/11/21	7/1/21

C. Budget

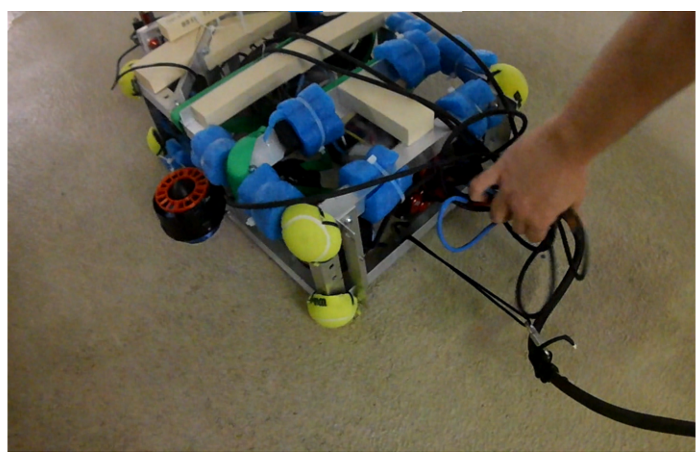
Expenses	Cost	Budgeted Funds	Donated Funds
Thrusters and ESCs	$1,200.00	$1,200.00	$0.00
Pressure Canister	$216.00	$216.00	$0.00
Aluminum Frame	$116.94	$0.00	$116.94
Raspberry Pi	$75.00	$0.00	$75.00
Golf Cart Converter	$29.99	$0.00	$29.99
Endoscope Camera	$39.16	$0.00	$39.16
Buck Converters	$29.90	$0.00	$29.90
Ratchet Straps	$30.00	$0.00	$30.00
Tennis Balls	$9.00	$9.00	$0.00
Travel Expenses	$0.00	$0.00	$0.00
Primary Camera	$50.00	$50.00	$0.00
Wiring	$75.00	$75.00	$0.00
Buoyancy Foam	$14.00	$14.00	$0.00
Donated Funds		$1,564.00	
Budgeted Funds		$320.99	
Total Funds		$1,884.99	

VII. Safety

A. Standards

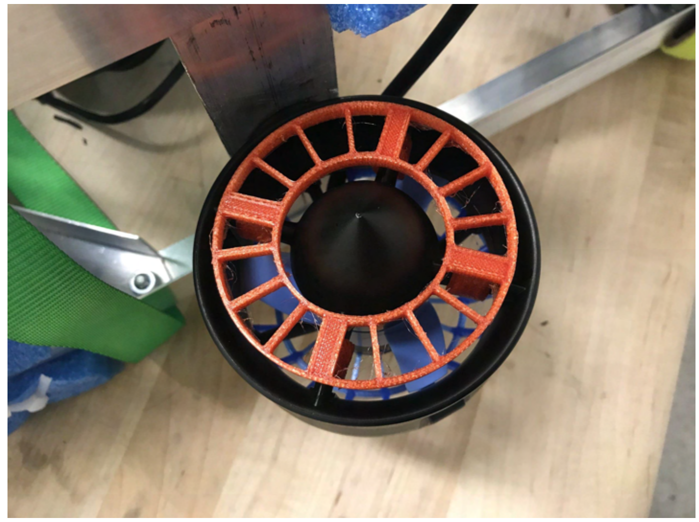
Milligan Robotics has two safety principles that govern its operations: *protect people* and *protect surroundings*. Milligan Robotics uses a multitude of procedures to ensure these principles are followed. Safety equipment is provided to all members of the team while working on TRILOBYTE. Team members must be certified before using potentially hazardous equipment. All electrical components are powered off before any modification is made on TRILOBYTE. In addition to these procedures, all team members are encouraged to immediately raise any safety concern they may have with the construction or operation of TRILOBYTE. Safety concerns are given priority over any ongoing work and addressed immediately.

B. Safety Features



Milligan Robotics' safety principles guided the design of TRILOBYTE and there are many safety features built into both its hardware and software. All sharp edges on TRILOBYTE are removed or covered in order to prevent damage to the pool during its operation. Thruster guards prevent damage to the thrusters and their surroundings. Strain relief is used on both ends of the tether to protect TRILOBYTE and the equipment used to operate it from being damaged by the tether. A fuse is attached to prevent TRILOBYTE from drawing excessive current from the power supply.

In addition to the hardware, TRILOBYTE has safety features built into its software. Power distribution to the thrusters is carefully limited to ensure that all components are properly powered during TRILOBYTE's operation. The servo motors used to control TRILOBYTE's manipulator are calibrated to prevent the motors from attempting to turn beyond the limits of the manipulator's hardware. This prevents damage to the motors from overuse and it prevents the manipulator from crushing objects that it interacts with.



C. Safety Checklist

Before Powering On

- ☐ Canister vacuum test
- ☐ Visual inspection of ROV
- ☐ Test strain relief on both ends
- ☐ Vacuum penetrator sealed (after successful vacuum test)

Power On

- ☐ Check laptop-ROV connection
- ☐ Check ROV thruster/arm controls
- ☐ Deploy ROV in water
- ☐ Check for signs of leaks

Begin Mission

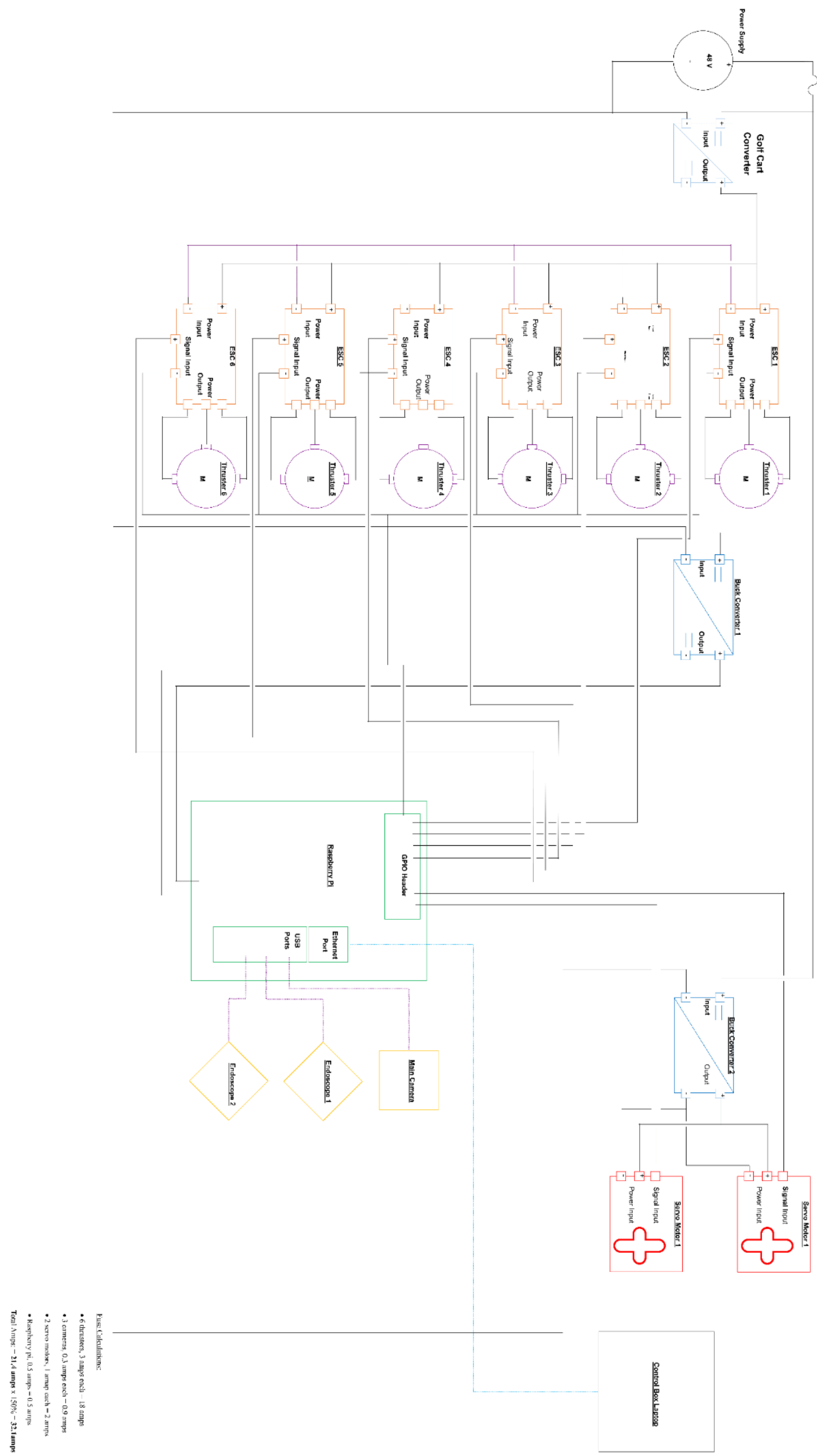
- ☐ All Members away from ROV
- ☐ Tether managers in position

Connection Lost

- ☐ Attempt reconnection
- ☐ Check for surface connection issues
- ☐ Announce power cycle and cycle ROV power
- ☐ Attempt connection again

Leak Risk (e.g. failed vacuum test)

- ☐ Check canister end caps are sealed
- ☐ Check for loose penetrators
- ☐ Check canister for damage


Power Supply
48 V
Golf Cart Converter
Input
Output
ESC 1
ESC 2
ESC 3
ESC 4
ESC 5
ESC 6
Power Input
Signal Input
Power Output
Thruster 1
Thruster 2
Thruster 3
Thruster 4
Thruster 5
Thruster 6
M
Buck Converter 1
Buck Converter 2
Raspberry Pi
GPIO Header
Ethernet Port
USB Ports
Endoscope 2
Endoscope 1
Main Camera
Servo Motor 1
Servo Motor 1
Control Box Laptop
Fuse Calculations:
• 6 thrusters, 3 amps each – 18 amps
• 3 cameras, 0.3 amps each – 0.9 amps
• 2 servo motors, 1 amap each – 2 amps
• Raspberry pi, 0.5 amps – 0.5 amps
Total Amps: – 21.4 amps x 150% – 32.1amps

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