Aquatic Robot Recovery Craft
Final Report

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[1]

Abstract

In situations where someone is trapped underwater, rescue personnel must attempt a search for the body in question. This task is extremely dangerous for the rescue personnel that attempt to locate the body. Drowning, hypothermia, and decompression sickness are some possibilities that could happen to a diver, while trying to locate a missing person. This project proposes the Aquatic Robotic Recovery Craft (ARRC), which can take the place of a diver during the search for the missing person. This system is capable of powering its thrusters to propel through the water, using a camera to look at the surrounding area, and using visual tracking to map the bottom of a body of water. The prototype for the robot could be used by any fire department in order to search for a body under the water in a safe and effective way.

Acknowledgements

Over the course of this project, help has been received from various people and various groups. First of all, the team would like to thank Blue Robotics for their quality components for creating an underwater robot. The ten percent discount was extremely generous and allowed us to remain within budget after buying all of the components. Also, the team would like to show their appreciation of the Natick Public Schools who allowed the team to use their patent to get this project started. Furthermore, the Natick Fire Department was outstanding in providing specifications so that the team could have a better understanding as to what needed to be done for a search and discovery robot.

In particular, the team would like to give a big thanks to our advisors, Professor Kenneth Stafford and Professor Michael Ciaraldi for their continued support throughout the process. In addition, Professor Ciaraldi made a generous donation from his budget that allowed for the completion of the ROV and the buoy. Ms. Katherine Crighton deserves recognition for her administrative expertise and help with the budgeting and component tracking from the beginning of the year. Lastly the team would like to show their appreciation to Mr. Ian Anderson for his assistance in the majority of the manufacturing and his noteworthy commitment to the Washburn Shops at Worcester Polytechnic Institute.

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1 Introduction

Robotics engineering is a combination of mechanical engineering, electrical engineering, and computer science. Today robotics engineering covers a vast number of fields including healthcare, fire safety, cooking, children's toys, and more. Some of the most important areas are those where humans are at risk of their life, and a robot could reduce the risk to the human. For example, in a situation where a person has fallen through ice or otherwise drowned in a body of water, those recovering the body are at a serious risk. The rescuers have the risk of drowning or suffering from hypothermia in cold temperatures. Therefore, a robot that could do the search for them eliminates the danger of being underwater for too long and could be used as a guide for the recovery of the body. To create a solution to this problem, we designed and implemented a robot that could perform the aforementioned task. Our robot, the Aquatic Robotic Recovery Craft (ARRC) aims to solve this problem by searching for a missing person in any type of water.

2 Background

2.1 Project Inspiration

Figure 1: "Sea Giraffe" with President Obama and two members of the Natick Lemelson Inventeam [2]

The catalyst for this Major Qualifying Project (MQP) came from witnessing students present at the Lemelson-MIT Programs' annual EurekaFest event. Lemelson-MIT InvenTeams are teams of high school students, educators, and mentors that receive grants up to $10,000 each to invent technological solutions to real world problems. InvenTeams research intellectual property, exchange ideas, design parts, build models, and make modifications as they develop their invention prototypes [2].

In June 2012, Doug Scott, the Natick High School Technology and Robotics teacher, was invited to submit an InvenTeam grant. In October of that year, the Natick High team was awarded the Lemelson-MIT $10,000 InvenTeam grant to create an invention that would positively impact their community. The team had spent the summer researching ideas for a Remotely Operated Vehicle (ROV) to assist ice search and rescue dive teams [2].

The team, in meeting with their local fire department, discovered a problem in need of a technological solution. Ice search and rescue operations are dangerous for divers who race against time to save lives or recover objects in frigid waters. The result was an ROV equipped with a submersible camera. The "Sea Giraffe" was an invention that would allow dive teams to position the ROV onto the ice, lower the submersible camera into the hole in the ice, and quickly pinpoint the location of the object or victim, making the operation safer for divers and potentially increase the survival rate of drowning victims. The team filed for a patent on April 23, 2013, and on December 6, 2016, the Natick High School InvenTeam was issued the utility patent, US 9,511,833 B2 [3].

2.2 Current Rescue Methods

The Natick Fire Department (NFD) was contacted about their current dive and rescue operations. When a call goes out, the NFD will drive their bus full of needed equipment to the location in question. The divers will always wear dry suits for ultimate protection from the temperature of the water. During the search the divers conduct a sweeping pattern to look for the body of an individual. A good search takes between 30 and 45 minutes. Most of the time, the NFD will deploy from a beach, but there are times when deploying from a boat is the only option. During the winter, if there is a hole in the ice then the NFD will cut a 5 foot equilateral triangle away from the hole and then explore towards the original hole to make sure that they don't miss the person during their search.

Scuba divers use various methods that are similar to breadth first search (BFS) to search for their target object. The methods vary based on location and the number of divers. If the diver is alone and in the middle of the body of water, then the diver will swim in circles to cover the search area [4]. If the search is along a wall, the diver will conduct the search in semi circles [4], the search patterns start to vary. Some methods involve the divers holding onto the ends of a rope so they can be spaced out evenly and catch objects with the rope [4].

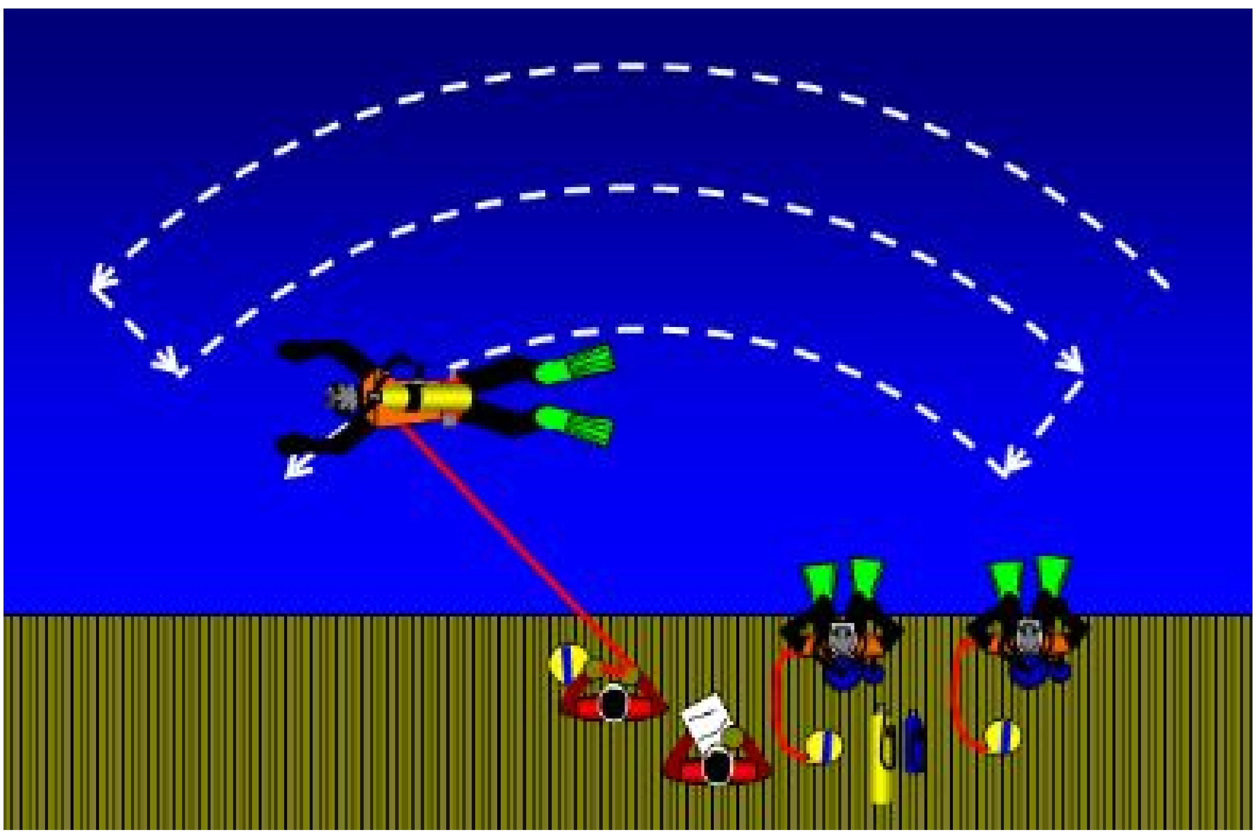


Figure 2: Example of a diver's search pattern [4]

After analyzing these methods, we needed to come up with the proper way for a robot to successfully search and find a person. For our application, there will only be one robot deployed, so that eliminates the method of two divers holding a rope to catch objects. Additionally, scanning back and forth in a breadth first search design allows the robot to cover the most range before it targets a specific area to inspect further. Breadth first search is a common algorithm to use in code, and therefore provides us with a means of making this procedure autonomous. This robot will ultimately imitate a lone diver searching for a body. Now that we understand the conventional ways to conduct a search in order to find a person underwater, we need to research and analyze various submersibles that have successfully survived underwater. That way, we can find out the best methods for hardware, sensing, and control to implement the best robot possible.

2.3 Previous Academic Works

In 2012 to 2013 a group of WPI students designed a submersible robot titled ROBOSUB, a modular underwater robotics platform [5]. The ROV was a rectangular prism with six thrusters and active ballast control. All the electronics are contained in a waterproof electronics housing with external connectors for additional modules. The group wanted the ROV to be easily modified in order to be used in underwater robotic competitions such as the RoboSub competition. Therefore the electrical, mechanical, and software systems were made more complex than would be necessary for a non-modular ROV. The main processor had USB and Ethernet ports connected to external waterproof connectors to enable the attachment of arbitrary electrical systems. The chassis was built using 80-20 aluminum extrusions which are designed to have additional 80-20 connected with minimum difficulty. Further the mechanical design of the pressure vessel needed external connectors. The connectors used by ROBOSUB were IP68 rated which specifies that they are dust proof and resistant to water submersion under pressure for a long duration as seen in Appendix A. Actual specifics for duration and depth depend on the specific connector.

A 2014 to 2015 MQP titled Walrus designed a remotely operated vehicle for search and rescue operations such as in an urban environment after a disaster [6]. While the vehicle was primarily a land rover, it was capable of traversing on top of water and as such had a waterproof hull. Walrus used treads that were capable of propelling it on top of water. However, Walrus was slower than expected on water due to the increased weight causing the rover to submerge more than anticipated, reducing its efficiency of propulsion. Walrus was water resistant and would not suffer significant leaks within twenty to thirty minutes of water travel, but eventually water would leak through the drive shaft seals.

Aside from projects implemented solely at Worcester Polytechnic Institute (WPI), underwater vehicles have been implemented over a vast number of projects ranging from competitions to strict academic applications. One competition in particular is hosted by the Robonation Robotics Community and sponsored by the Association for Unmanned Vehicle Systems International (AUVSI) and the Office of Naval Research. In the 2016 RoboSub Competition, students of high schools and colleges competed to make the best autonomous robot to fit certain tasks and win the most points. The first robot that we analyzed from this competition was the grand prize winning Dory from the California Institute of Technology (CalTech) Robotics team. The tasks are relevant to our robot in that they involve "underwater manipulation, navigation, and visual inspection [7]." Dory being used for this purpose can be seen below in Figure 3.

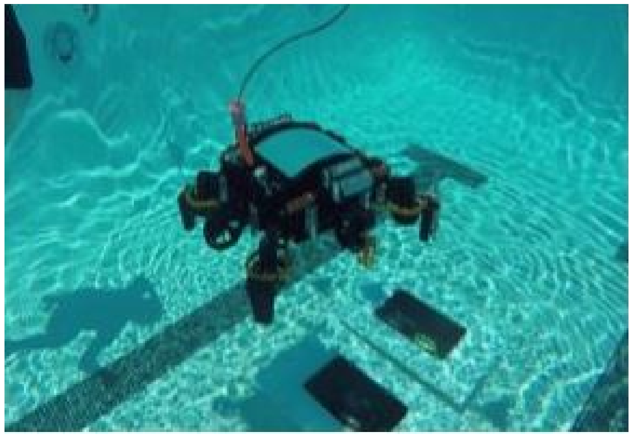


Figure 3: CalTech's entry for RoboSub Competition: Dory [7]

The Dory robot has a square shaped chassis with thrusters on each of its four corners. For our purposes, it allowed for "precise and accurate movement in all six degrees of freedom [7]." On the electrical side, this project applied many sensors that our group may want to consider. The sensors that this robot used were to provide accurate movement in the water, an application that is crucial to our success. The sensors included a camera, an attitude and heading reference system, a Doppler Velocity log, a depth sensor, and a sonar system. All of these sensors used together can provide tools for the robot to track its position, monitor how deep it has gone, and look around for objects, which is exactly what our application needs. Optically, the robot from CalTech used many methods to optimize the images. In order to see in various lighting, the group used high quality optics and charge coupled device imaging, exposure control, white balance control, and an on-demand shutter [7]. This seemed to be sufficient for seeing accurately for this robot.

Another group in this RoboSub competition the same year had a slightly different approach to the competition tasks and a different robot design. Beaver Country Day School was analyzed as they had a different background to CalTech, since they are a college preparatory school, and used different processes. Using an aluminum rectangular frame, Beaver Country Day School's robot, the Prospero Autonomous Underwater Vehicle (AUV), utilized an acrylic hull and a series of modular mounting rails [8]. Prospero's final design can be seen below in Figure 4.

The electrical components they used varied slightly from Dory. This was due to the fact that Prospero used only three main sensors: an Inertial Measurement Unit (IMU) for orientation, a camera for sight, and a sonar system for obstacle detection. Therefore, based on the fact that both Dory and Prospero used similar sensors, it creates a base for what our robot will need.

2.4 Existing Commercial Remotely Operated Vehicles

There are a vast amount of commercial underwater submersibles that are already in use. One example, HarborScan, is an unmanned underwater vehicle (UUV) that is used for underwater inspections of various things, such as ship hulls, and surveying an area [10].

Figure 4: Beaver Country Day School's entry for RoboSub Competition: Prospero [9]

This UUV has a modular form allowing for certain parts to be removed when appropriate. HarborScan used a torpedo shaped chassis to reduce the amount of drag underwater, but its maneuverability wouldn't be easy to control since the body is seven feet long with one propeller at the back [10].

Figure 5: Design of HarborScan [10]

Another submersible that has a modular base is the SeaExplorer. This submersible uses a glider system to propel itself underwater [11]. This is done by changing the buoyancy of the submersible [11]. In order to prevent any entanglements with weeds or any other debris, this submersible does not have wings. Its primary purpose is to monitor the environment and locate mines, thus being another key project to analyze for our similar purposes [11].

Throughout the research of the submersibles from the AUVSI competitions, there seemed to be some similar traits and features, such as the material of the chassis. Most of the submersibles used an aluminum or carbon fiber hull. Both of these materials are well protected from saltwater corrosion. Another feature that was very common was using propellers for movement. The second most used was gliders, which work by shifting the buoyancy of the

Figure 6: SeaExplorer's design and movement [11]

submersible in order to control its motion.

Most basic forms of the submersibles were a mixture of a torpedo shape with wings. Some other options were a teardrop shaped and an open frame design. The torpedo and teardrop shape would have less drag than an open frame. An open frame ROV has more maneuverability and control compared to a torpedo shape because the torpedo shape usually has one propeller at the back and fins around the center of the body, which causes a wider turn radius.

2.5 Remotely Operated Vehicle Process

Robots have three key components that allow them to function. The components are actuators, sensors and control capabilities. Actuators allow the robot to change its environment. Sensors allow the robot to detect its environment and measure the change it has caused using actuators. Control algorithms allow the robot to make decisions on what to do based on sensor data.

2.5.1 Actuation

The three main types of underwater propulsion are drifters, gliders, and thrusters. Drifters move by using the water's currents to propel themselves. Gliders propel themselves by changing their buoyancy, which cause them to travel up and down [12]. Gliders use wings to redirect the vertical motion to propel themselves forward. Thrusters use propellers and motors to move through the water. This method allows for easy maneuverability against the water current, given there is enough thrust.

2.5.2 Sensing

As mentioned previously, sensors are a big component in design for the submersible robot. One of the most prevalent components that we found for sensing throughout our research was sonar. Fish finders have also been researched due to the fact that they have a similar principle for searching as sonar. However, a fish finder is unidirectional while a sonar system is omnidirectional. Since we are looking in all directions for the body, a fish finder is not suited to the application as well as a sonar.

However, after further research and brainstorming in the sensing category, sonar became much less practical than what was originally thought. Sonar systems can be big and difficult to orient on a robot of our size. Therefore, we did not placing a sonar system on the robot and instead used vision tracking to detect objects.

In addition to the vision tracking system, some other sensors that could be useful for our robot are a sensor that detects water leakage and an IMU for orientation purposes. These components seemed to be the base sensors on many submersible robots of the past, so we could start there with our design. We could also implement some of the sensors used by CalTech for their prize-winning robot. This includes a Doppler Velocity Log for position, and a depth sensor which we can use for verifying actual depth.

2.5.3 Control

Aspects of control for robotics include motion control, path planning, and mission specific decisions. Motion control is controlling the actuators of the robot to achieve desired motion. Path planning is a higher level of motion control that focuses on determining a sequence of steps for the motion control algorithm to follow to get from start to end configuration. Mission specific decisions can vary from robot to robot but set the objective for the path planning algorithm based on goals that the robot wants to accomplish.

Most motion control algorithms for mobile robots rely on knowledge of where the goal is relative to the state of the robot. The state is usually defined as a matrix that contains the position and orientation of the robot relative to a fixed origin. In land based situations typically the surrounding fluid (air) can be ignored when calculating the dynamics. However in underwater situations, fluid resistance cannot be ignored. In [13], a model for control of an underwater ROV is described. Later in [13], it mentions that many of the hydrodynamic coefficients used in the model are not well known and as such, model based control methods will not accurately control the ROV. Instead [13] recommends a parameter adaptation algorithm (PAA), which estimates the parameters for the model based on recent samples of input and output. The paper concludes that by using a PAA control scheme, a simplified model can be used to obtain acceptable control of the ROV.

Path planning algorithms take input from high level control algorithms and calculate a path to follow to get to the destination. One common path planning algorithm is A*(A Star) which relies on a preexisting map of the environment and a heuristic to calculate the shortest path between two points [14]. In our case, since the search pattern is predefined, the path planning algorithm should follow the path and deviate only if necessary to avoid obstacles or to check an area of interest.

Mission specific algorithms depend on the purpose of the robot but typically involve using sensor data alongside predetermined objectives to make changes to the path planning algorithm's objective and deploying end effectors. In our case the mission specific algorithm is detection of a body in the water. This would allow the robot to determine areas of interest and direct the path planning algorithm to move towards those areas for closer inspection.

3 Design Requirements

The purpose of this section will be to lay out what our group has decided as the baseline requirements for the ARRC, specifically analyzing the mechanical, electrical, and software components that will be needed. Below is a table used for outlining these features, with detailed descriptions following thereafter.

Requirements	Details/Value
Maximum Size	32 in. x 32 in. x 32 in.
Maximum Weight	100 lbs.
Minimum Speed and Mobility	3 ft/s forward, 1.5 ft/s backward, up and down
Minimum Pressure	10 PSI
Emergency Blow Procedure	Ascend 20 ft in 15 seconds
Minimum Spotlights	200 Lumens main lights, 100 Lumens Omni-directional Lights
Minimum Battery Life	30 minutes of operation
Manual Control	The ability to manually control the robot
User Interface	Simple enough for people with minimum practice to use
Minimum Data Stream	8 Mb/s

Table 1: Design Requirements

3.1 Mechanical

3.1.1 Size

There were a few considerations that went into the size of our robot, primarily considering length, width, and height. In order for our team to be able to modify the robot indoors or display it conveniently in a sheltered location, it would have to fit through a standard doorway. Massachusetts regulatory standards state that an open doorway can be no less than 32 inches [15]. In addition, the Natick Fire Department stated they wanted the size at maximum 32 inches x 32 inches x 32 inches. This will satisfy the NFD's requirements and will fit through a standard doorway.

3.1.2 Weight

For weight, our robot is limited to the standards set by the National Institute for Occupational Health and Safety as well as the NFD. By the ergonomic standards, the maximum amount of weight that can be safely picked up by one person is 51 pounds [16]. During emergency situations, there will always be at least two divers, so the weight of the ROV can safely be doubled (100 pounds)

3.1.3 Speed and Mobility

The minimum speed for our robot will be based on what a human is capable of. The average human swim speed is about 2 miles per hour [17]. In order to quantify the mobility for the robot, we will be using the forward speed as a model. For driving backwards, we will need our thrusters to drive at least half as fast as the forward speed. With the forward speed being 3 feet per second this puts our backward speed at about 1.5 feet per second and accounts for half of our mobility. To handle the speed of moving up and down through the water, we figured it would be a similar to the speed of going backward. The backward, up, and down directions are less important than forward speed, and therefore, the up and down speed should be 1.5 feet per second as well. This correlates to a reasonable number based on the information given by the NFD. They estimate that the average search depth conducted is 20 feet. Traveling down 20 feet at 1.5 feet per second gets our robot to its average search depth in about 14 seconds, which is reasonable for our purposes.

3.1.4 Pressure Requirements

Based on the information provided by the NFD, their average swim depth is 15-20 feet below the surface. This means our robot absolutely needs to withstand the pressures of this depth. Beyond that, we can set a goal of reaching a maximum of 100 feet based on the Natick Fire Department's information. Diving to that depth is not common, so for this project, we have decided to focus mainly on the NFD's average dive depth.

3.1.5 Emergency Blow Procedure

In the event of an emergency that causes the robot to lose power or connection to the command station, the robot should rise to the surface. This must be accomplished without the use of the thrusters. The emergency blow procedure must be able to detect a loss of power and return the robot to the surface from the average search depth of 20 feet within 15 seconds, which is equivalent to the ascent speed of the thrusters. Without propulsion, we would need to adjust the buoyancy of the robot. There are two ways to accomplish this. The first is that we can reduce the mass of the robot. The mass could be decreased by releasing a weight from the robot. The second method is to increase the volume of the robot. The volume could be increased by expanding a bladder from a container of compressed fluid. Through either method, the robot without power to it must have a slightly positive buoyancy which would make it eventually come to the surface. As long as it reaches the surface in the required time, it satisfies the requirement.

3.2 Electrical

3.2.1 Spotlight

The submersible needs to have a spotlight in order for the camera to have a clearer image. The Natick Fire Department currently uses 200 Lumen spotlights. Therefore, our spotlight needs to have a minimum of 200 Lumens. The best way to check this requirement is to look at the specification sheet of the spotlight.

3.2.2 Battery Life

When the NFD searches for something underwater, it takes about 30 minutes on average to complete the search. This is why the battery life of the submersible needs to be at least 30 minutes long. This can be tested by timing the run time of the submersible when it is searching for the target object.

3.2.3 Omni-Directional Visibility

For everyone's safety, the submersible needs to be spotted very easily. This is why the submersible needs enough lights to be seen by the diver. The omnidirectional lights (ODL) should have a minimum of 100 Lumens. This is half as many Lumens as the search lights, since the divers should not be blinded by the ODL. The lights need to have a way to alert the diver about what operation the submersible is doing, such as active, standby, or an error. Some of the ways to alert the diver could be different colors for each operation or creating a pattern with the flashing of the light.

3.3 Software

3.3.1 Manual Control

In order to move the ROV around in the water, the users near the base station will need to use a manual control so that they can search and identify the target. The remote control should be intuitive enough for expected users to be able to control the robot with minimal difficulty. This is to say that an expected user should be able to pilot the robot effectively after being given a tutorial on operation.

3.3.2 User Interface

In a similar manner to the controls needing to be intuitive, the user interface (UI) needs to be easily understandable. The UI will need to display the camera feed, vision tracking, depth, and other important information in an easily accessible manner. This would make it so any reasonably trained user could understand the state of the robot.

3.3.3 Data Stream

The data stream between the robot and control computer will need to have enough bandwidth to transmit status information, control data, and the camera feed. Since the camera feed will require more bandwidth than all other signals combined, an estimate can be made based on required video quality for the necessary bandwidth. Using a standard 1080p video at 30 frames per second will require at least 8 Mb/s (megabits per second) bandwidth [18].

4 Design and Analysis

The entire project consisted of three systems: the ROV, the buoy, and the base station. The ROV was the system that remained underwater to search for the missing person while the base station remained on land to control and to receive feedback from the ROV. The buoy served as the bridge between the base station and the ROV. The first step in creating this robot was designing the physical components and analyzing the mathematics to ensure that everything works underwater properly. The first system assembled was the ROV, which required much more integration than the buoy due to its complex electrical circuits. The ROV required an electrical housing inside the pressure hull to incorporate all of the various electrical communications. After the various electrical and mechanical designs, the drag and torque were calculated in order to understand how the ROV would behave underwater.

With the buoy system, the design and analysis were done more so after the fact. The components were bought based on the design specifications, and then the analysis was simply done based on the drag that was needed to tow the buoy. The primary purpose of this was to ensure that the ROV could drag the buoy regardless of if there was any more tether remaining. Once proved that the buoy could simply float and be dragged through the water easily, the system was verified as complete based on design and analysis. More detail is given to these systems below.

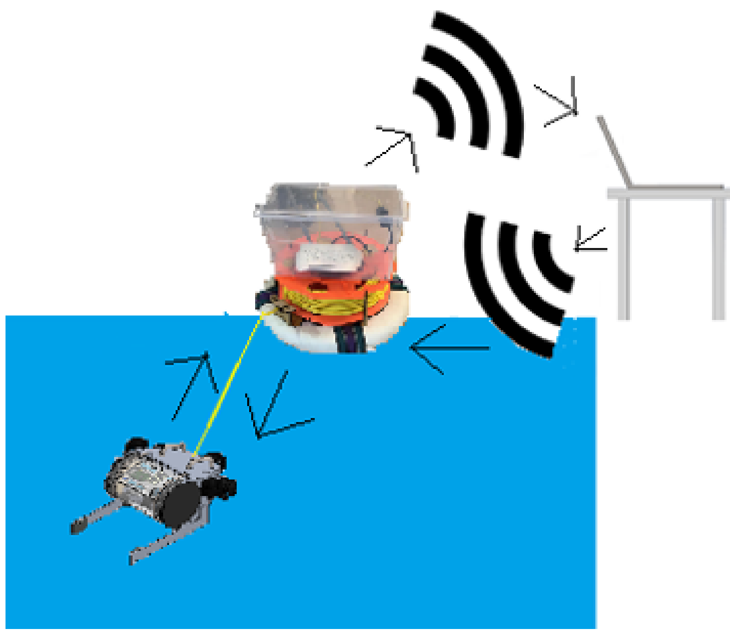


Figure 7: Overview of the project

4.1 ROV

The submersible needs to meet the physical constraints based on the design requirements. The overall dimensions of the robot must be under 32 inches in all directions, and weigh less than 100 pounds. It needs to have four degrees of freedom: Forward, Up, Yaw, and Pitch, to achieve all of the necessary movements. A tether needs to be attached to the electronic housing of the submersible to communicate to the workstation. Two spotlights are added to the bottom of the robot to light up the area so that the camera in the pressure hull has a better view.

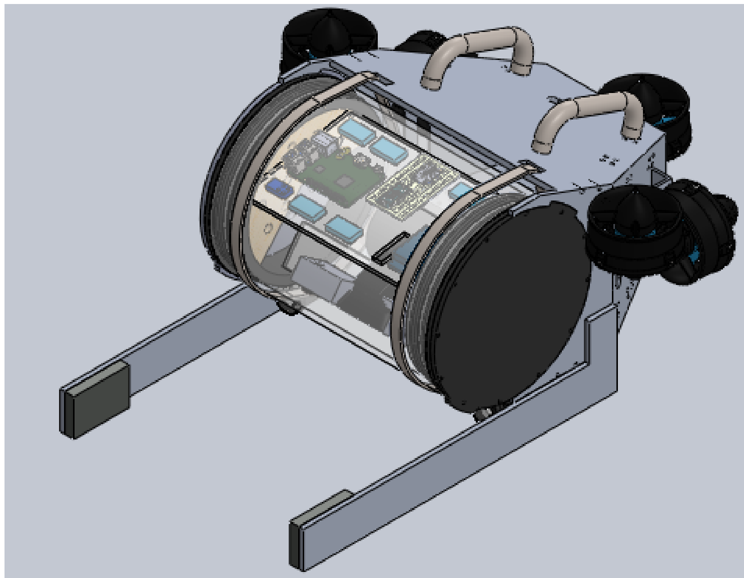


Figure 8: Isometric view of ROV design

This design above is the team's idea for the submersible. This idea has control over five degrees of freedom (all but horizontal translation) and weighs about 34 pounds. The dimensions are 32 by 21 by 13 inches. Most of the material will be comprised of 5052 aluminum, which is treated for underwater purposes. All of the electronics will be housed in an eight inch, water tight, pressure hull. The hull will be mounted to the chassis with two hose clamps. In order to stop the pressure hull from constantly rotating, the side plates had some parts cut to surround the pressure hull's endplates. There are two thrusters in the horizontal direction, while three additional thrusters are placed in the vertical direction. The third thruster would be placed at the back for pitch control. Handles will be attached to the submersible to give the user an easier method of carrying and moving it. For ease of use, the submersible will have positive net buoyancy in order for the submersible to reach to the surface of the water in case of issues or emergencies. The goal is to obtain positive net buoyancy force between 0.1 to 0.5 pounds.

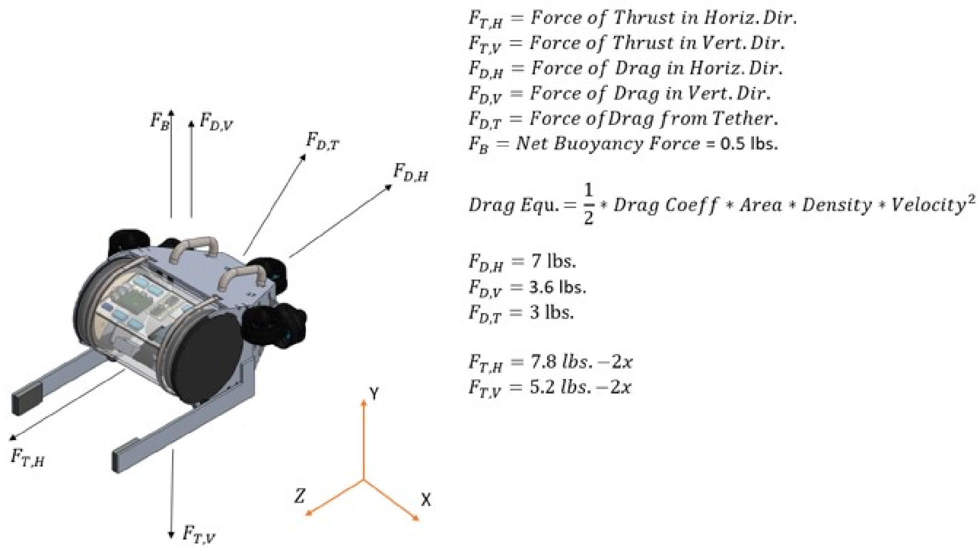


Figure 9: Drag Analysis of the Submersible

One issue that the submersible will face will be drag forces when it tries to move forward or up. A rough estimation of the drag forces will help determine the necessary output forces from the submersible. The velocities used are based on the desired maximum speeds for the submersible. The area displayed is the contact area as water hits the submersible in a particular motion. The density displayed is that of water since it is water pressure that causes the submersible to rise. The coefficient of drag is set to 0.6 since the submersible is a hybrid shape of a box and tear-drop shape. The horizontal drag, which affects the forward movement of the submersible, is calculated to be at seven pounds. The tether adds an additional three pounds, which will be explained later, to make a total drag force of ten pounds. This is why there are two T200 thrusters, which can output at about 7.8 pounds each. When calculating the vertical drag, the assumption is that the submersible wants to move down instead of up. This would make the buoyancy force work against the thrusters and help the drag force. Adding the tether to this calculations, the total force facing the vertical direction is about seven pounds. The submersible has two T100 thrusters that act as the main method of vertical movement. Each thruster has a max output of 5.2 pounds, which will be more than enough to cover the buoyancy, drag, and tether forces.

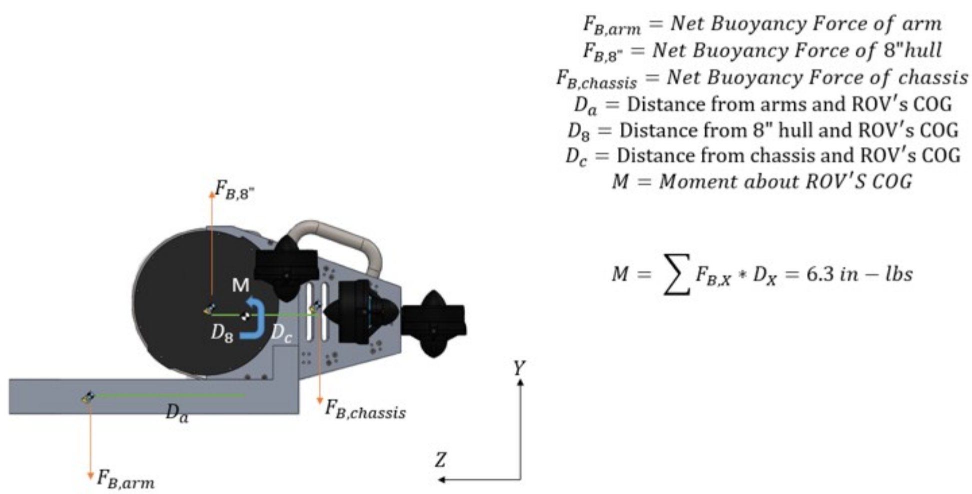


Figure 10: Torque Analysis of the Submersible

Another issue is that the submersible will like to pitch upward due to the placement of buoyancy forces. The eight inch pressure hull is one the main sources of positive buoyancy while the metal chassis is the main source of negative buoyancy. Since the center of mass is in between both of these forces, the torque caused by both of them causes the submersible to rotate until the front is facing the top. To counter this, arms were added to place ballast to negate the torque. Without the arms, the submersible had a moment of 55 in-lbs, but the arms with extra weight has reduced it to about 6.3 in-lbs. The remaining torque will be handled by the three vertical T100 thrusters.

4.2 Buoy

The second system that was designed for the final product was the buoy. Since wireless signals do not work well underneath the water, there needed to be a way for the ROV to communicate via Ethernet connection and the system above the water to communicate wirelessly with the command station. The tether carries an Ethernet signal from the ROV to the buoy which contains a wireless router inside of a water resistant container. The router then transmits a wireless signal to the base station.

The best way that was found to ensure flotation of the buoy was to use a life preserver ring. However, this life preserver ring needed to have a method to store the tether and to prevent the router from being exposed to water. These problems were solved with the two other components that the buoy has. The first is a storage reel that could hold the tether. The tether was 82 feet long to be able to search to the targeted depth of 20 feet. Finally, a plastic storage container was used to provide a waterproof shield for the tether. The minimum size for this plastic container had to be the length of the router's antennas at a 45 degree angle. In order to select components for the buoy we researched potential options and how we could integrate them together. Most standard life preserver rings would satisfy this requirement. The best solution that we found was an 18 inch life preserver ring that could hold about three times the amount of weight of the router for safety. After finding this, we used the dimensions to find a spool that could hold 82 feet of tether and be similar dimensions to the life preserver ring. One benefit of the spool that we purchased was that it had an independently rotating handle located at its center. As we will explain in Section 5, this allowed us to release the tether while the spool spins and unwinds it. Lastly, we were able to acquire a reasonably sized plastic storage container easily. Once all of these components were fit together in a clean way that provided everything needed, analysis was done to ensure that it fit well with the ROV below the water.

Analysis of the buoy was relatively simple. Once the weights of all of the components and how they would be put together was determined, the analysis was simply calculating two important properties. The first property was the center of mass and the second property was the towing drag caused by this system. The center of mass was easily determined using the SolidWorks model.

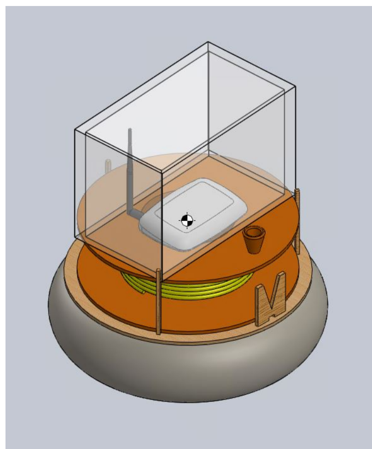


Figure 11: Isometric view of the Buoy

From there, we could use the weight of the buoy to calculate the force required to tow the buoy. From the style of the buoy's face, we determined a good shape to approximate the coefficient of drag was 0.6. Based on the model, the density of water since the buoy is traveling through water, a velocity of three feet per second and the reference area is the area of the cross section of the life preserver ring that is under the water, the drag was calculated as three pounds. A visual of the determinations of this calculation can be seen in the figure below.

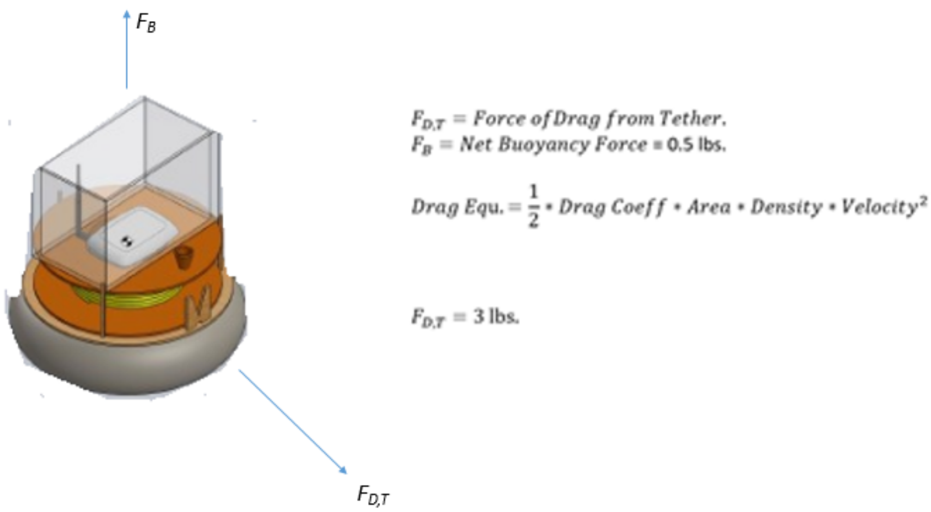


Figure 12: Calculations of tow drag on the buoy

This calculation was later used to see how much the robot needed to pull and if the thrusters were strong enough. It was eventually proved that this was the case. Therefore, this buoy would work great as a way for the ROV to communicate to the surface. All of the components were ordered, and we could finally work on the manufacturing of this essential component to the system.

4.3 Base Station

In order to control the ROV, a computer and control interface was required. For compatibility with the RaspberryPi, which is running Ubuntu 16.04, the base station computer should also be running Ubuntu 16.04. Since the ROV will be deployed in remote locations, where an electrical outlet is not available, the chosen computer needs to have a built in battery. To further narrow down potential computer options, the chosen computer needed to have built in wireless networking and at least one USB port to connect a controller with. Since no heavy computations are being done on the computer, nearly any modern laptop would be capable of serving as the base station computer. For the controller, we chose to use a Logitech Extreme 3D Pro joystick since it has multiple axes including a twist axis on the handle.

5 Manufacturing and Implementation

The next step to complete the project was to manufacture and assemble components to create both systems.The ROV's components consisted of two primary parts: the chassis and the eight inch pressure hull. Unlike the chassis, the hull was prefabricated since it was manufactured by Blue Robotics. Manufacturing of the buoy was simpler due to the fact that there were three primary components that needed to be combined. The implementation, as described in this section, was to ensure that the signal was transferred to the ROV properly. In addition, the buoy had to ensure that it kept the router above water so that the signal could be consistently transferred. More will be explained in relevance to these developments below.

5.1 ROV

5.1.1 Mechanical

The 5052 aluminum came in a 24x48x1/4 in. sheet, which was cut, sanded, and ground into multiple shapes to assemble the chassis. Additional gaps were cut or drilled out for cable management. The idea was to keep all of the wires traveling through the inside of the chassis to prevent any outside object from pulling them. These shapes were based on the part drawings of the CAD model. Due to lack of experience and available parts for TIG welding, some 1/8 in. 5052 aluminum was bought in order to create the bridges that would attach the separate parts together. All of these parts were drilled through in order to attach size 8 stainless steel screws for the assembly. Two side plates were cut by the CNC machine in order to achieve a perfect semicircular shape to hold the pressure hull still.

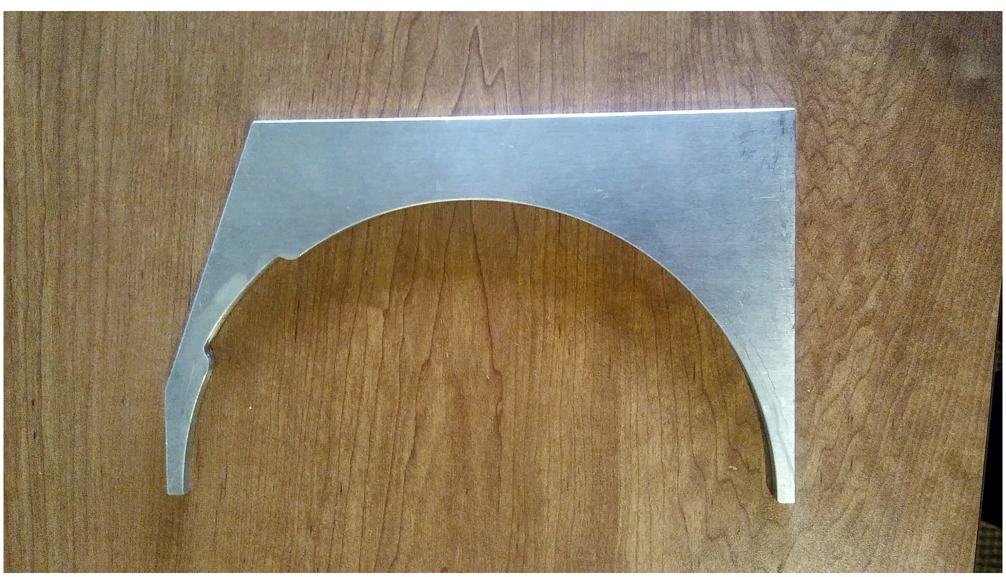


Figure 13: Image of Side Plate

(a) Cables being epoxied

(b) Image of Spotlights

Figure 14: Images of Cables and Spotlights

Once the main chassis was built, some plates, such as the bottom plate were detached to add additional holes for other items, such as the hose clamps and spotlights. Once everything was assembled, the screw holes for the handles were determined and drilled through. The five thrusters were attached onto the chassis with M3 screws. While the thrusters' cables would be placed inside the chassis, the cable ends would need to go through the pressure hull to reach the electronic housing. One endplate of the pressure hull has 15 holes so that multiple cables can pass through. In order to make this sealed properly, the seven unused holes were closed by cable penetrator blanks. The holes that had cables or other sensors attached were equipped with cable penetrators. These cable penetrators and blanks had o-rings equipped for a tight seal. For the cables going through the penetrators, epoxy needs to be added through the gap to ensure that no water would leak into the hull and damage the electronics. One of the blanks was a valve to let air escape when attempting to open or close the pressure hull.

Figure 15: Image of 5 lb. Counterweight

Since the spotlights were placed at the bottom, a stand was created out of some wood. Multiple 2x4's were cut into a rectangular shape so that the submersible could rest on it. The arms were fabricated from the remaining 5052 aluminum and drilled through to attach to the side plates of the chassis. The team obtained a pair of five pound lead ingots to use as the counterweight on the arms. Since we needed about one pound on each side, the lead ingot was cut apart to make the one pound weights. Once cut, the scale indicated that the lead weighs about 1.4 pounds, so the team attempted another cut with the other five pound ingot to achieve another set of counterweights. These counterweights were about 1.2 pounds, which was acceptable since the lead displaced some water and cause the buoyancy to be higher. These weights were attached to the arm by zip ties since the actual placement needed on the arm was unknown until water testing.

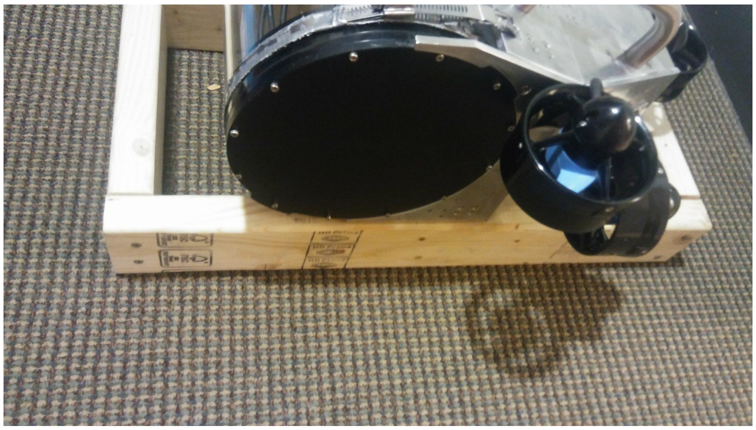


Figure 16: Submersible with the stand

5.1.2 Electrical

A multitude of electrical components were used for electrical integration. The primary components were the RaspberryPi 3, Sparkfun Pro Micro 16Mhz, Adafruit 9DOF Absolute IMU, Logitech C310, Adafruit Laser Diode, Seeed 313080006 (Voltage Regulator), Voltage divider - 5 pack, electrical connectors, and external power pack for the RaspberryPi.

A majority of the ROV's critical systems came from Blue Robotics. From this company, five thrusters and controllers were purchased. In addition to the thrusters, one leak and pressure sensor was also purchased along with one Fathom Tether measuring 82 feet long and two spotlights. The main power source was a 14.6 Volt 18 Amp hour battery which was purchased from Blue Robotics.

The electrical housing was designed to fit within the inner ring of the 8" pressure hull. Below is an image of the housing that was used.

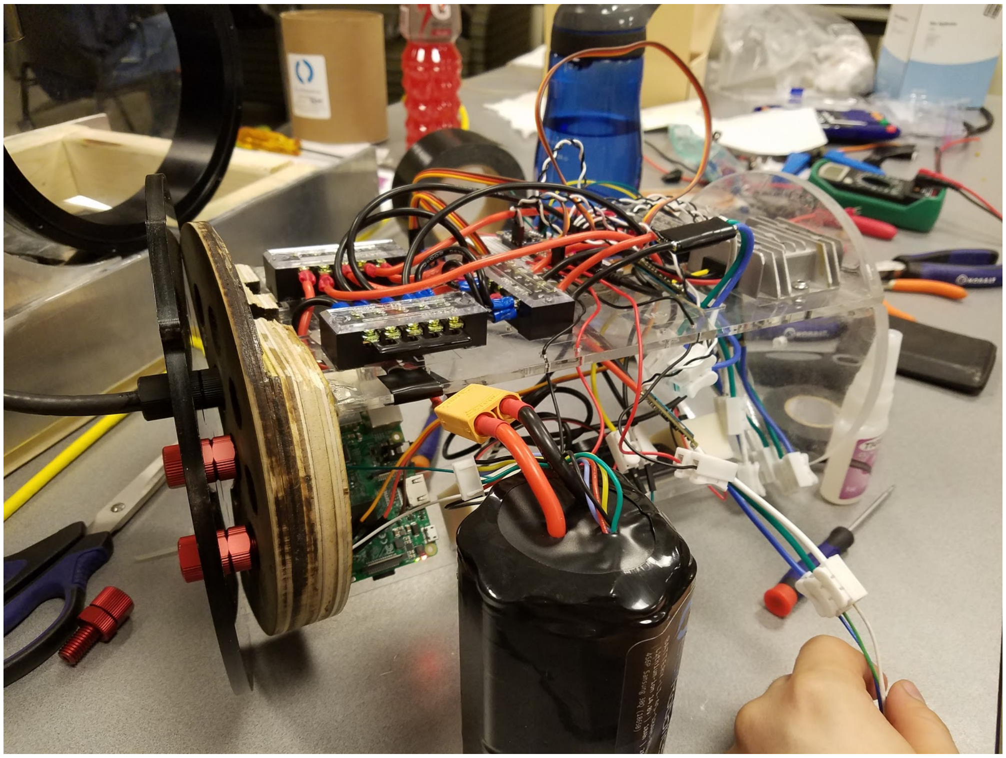


Figure 17: Image of Electrical Housing

The initial electrical layout had to change since the screw terminal, which was used for power distribution, would not fit properly in the pressure hull. In order to power the submersible without constantly removing the battery, a power switch was attached to the power terminals.

The Blue Robotics Battery was originally designed to go to in a separate three inch pressure hull that would allow for an easy way to swap out the battery. Unfortunately, the cable penetrators acquired from Blue Robotics were too small for the battery cable they provided, and with the end of the year approaching, there was not enough time to order a larger sized penetrator. Thus the team decided to remove the usage of the three inch pressure hull and place the battery inside of the main eight inch pressure hull.

A devastating discovery for the team was when we discovered that the connectors we chose to use to allow for easy removal kept melting. The primary theory for this failure is that the high frequency polarity transitions on the three wires of the motor controller caused the connectors to fail at a lower current than they were rated for. The connectors in question were rated for 25 amps. The connectors did not fail due to more current being pulled through them than the rated amount because one pair of connectors was connected to the power supply for one of the motors and continued functioning while the three connectors between the motor controller and the thruster for the same motor controller melted.

5.1.3 Software

The software is written primarily in Python and uses the Robot Operating System for communication onboard the RaspberryPi. The interactions with hardware peripherals is handled between two separate nodes. One node handles communication with the coprocessor, a Sparkfun Pro Micro that controls the motor controllers, leak sensors and voltage monitor. Since the inertial measurement unit (IMU) is intended to be used for stabilization, the lower the latency on updates the better the stabilization would be. The IMU and the RaspberryPi communicate using Inter-integrated Circuit (I2C) protocol. I2C is capable of supporting multiple devices, and the depth sensor is only able to communicate via I2C so that is also connected directly to the RaspberryPi. Aside from hardware peripheral integration nodes, there are two additional nodes. One is responsible for reading joystick values sent from the base station and converting it to motion directions for the ROV to travel. A final node was responsible for stabilization and converting motion directions to thruster speeds.

5.2 Buoy

The manufactured portions of the buoy were made of $\frac{1}{4}$ plywood due to it being relatively inexpensive, easy to work with, and light. A support plate made of the $\frac{1}{4}$ inch plywood connected to the center of the spool to allow the outer portion of the spool to rotate independently of the rest of the buoy. On the bottom of the buoy, a ring was created out of wood that could sandwich the life preserver ring in place. The holes that were drilled into the life preserver ring for the other side were carried through into the bottom wood plate. This also provided a level surface for the buoy to sit on. In order to mount the plastic container without creating additional paths for water to enter the container, we sealed the mounting holes with epoxy. Of note, there are two significant components made of wood that also have to do with the storage reel. The first are three wooden pegs surrounding the reel that ensure that the tether does not simply fall out when unwinding or being wound. They can be seen in the figure below around the reel. In addition, there is a fairlead in the front of the buoy that allows for the tether to have a smooth exiting from the buoy so that the robot or buoy does not have entanglement issues. To further secure this fairlead, a top piece was placed on it to ensure that the tether stayed within the two vertical wood slabs. In order to prevent any wear related to water exposure, before testing could begin, all of the wood was coated with epoxy.

(a) Image of wood being epoxied (b) Image of standoffs in the spool

Figure 18: Images of buoy components

Another aspect of note in the manufacture of this buoy was that the original inner diameter needed to be adjusted to account for the working radius of the tether. From the specifications of Blue Robotics when the Fathom Tether was purchased, it was stated that the tether has a minimum working diameter of eight inches. The spool's inner diameter was measured to be five inches. To fix this issue, standoffs were placed in five locations surrounding the central hole so that the tether could be at its working diameter.

Figure 19: Image of buoy

6 Testing and Results

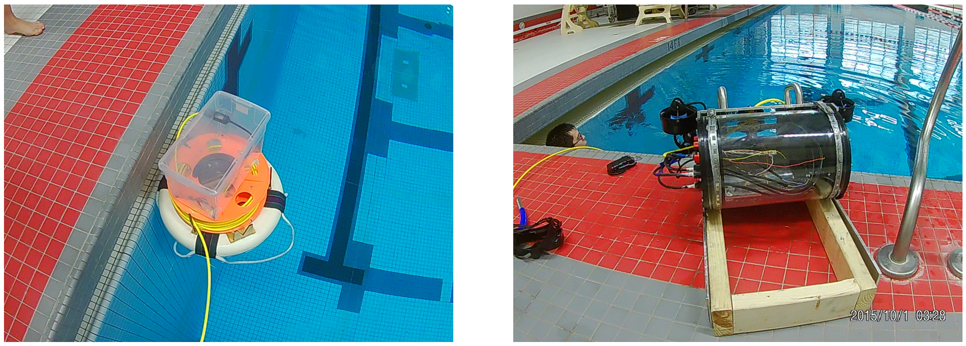
The next step in completing this MQP was the testing portion to ensure that the design requirements and projections worked. The team was able to schedule a few days in WPI's pool that would be sufficient for us to see if the ROV worked underwater and the buoy could transmit the signal. Fortunately, the signal transmission worked great and we had minimal issues with the testing, as described below.

6.1 Testing

Once the epoxy on the cable penetrators had finished drying and solidified, the next step was to submerge the submersible in water to ensure that it does not leak into the pressure hull. The first water test did start to leak, but the issue was found instantly and corrected. One of the cable penetrator blanks was missing an o-ring. Once the o-ring was placed, the testing continued, and the pressure hull no longer leaked. Later on, parts of the epoxy began to crack where the wires would move, but no leakage had occurred. To prevent these cracks from affecting the epoxy, some caulk was added around the cracks as another, more flexible, sealant.

Figure 20: First water test

On April 11th, the first water test in WPI's Sports and Recreation Center was conducted. During this time, the electronics housing was finished, but unfortunately many of the crimps used for the electronics came out, thus most of the testing that occurred was focused on the mechanical portions of the submersible and buoy. The first few tests were focused on the buoyancy of both systems. When placed into the water, the buoy was floating and did not leak as the team predicted. The water line never went higher than the middle of the life preserver ring. Since the tether was not connected to the buoy at the time, additional weight was added to the buoy as a substitute for the tether. Even with the additional weight, the buoy did not budge. Since some had speculated that the router's containment unit size would cause issues with wind and possibly tip over, there were multiple attempts of pushing the buoy to force it to tip over. However, because of the life preserver ring, the buoy refused to tip over. Another part of the buoy that was tested was the storage reel. One person from the team was pulling on the tether to cause the reel to rotate or make the buoy move. The storage reel did rotate smoothly as the tether passed through the fairlead.



(a) Buoy floating on water

(b) Image of ROV

Figure 21: Images of during the first WPI pool test

The submersible was tested next. Before the submersible was placed in the water, the pressure hull had a five pound weight to substitute for the electrical housing. When it was placed in the water, the submersible was double-checked to see if there was a leak in the hull. Once there was confirmation that there was not a leak, the team attempted to measure the buoyancy force of the submersible with a spring scale. There was about two pounds of net positive buoyancy for the submersible, which did not have the counterweights at the time. The final test was an attempt at the emergency blow procedure. One of the team members placed the robot underwater and made a motion to indicate him releasing the submersible. Another member was recording video at the time at the surface of the water. The pool is 14 feet deep, and the submersible reached the surface from the bottom of the pool in ten seconds.

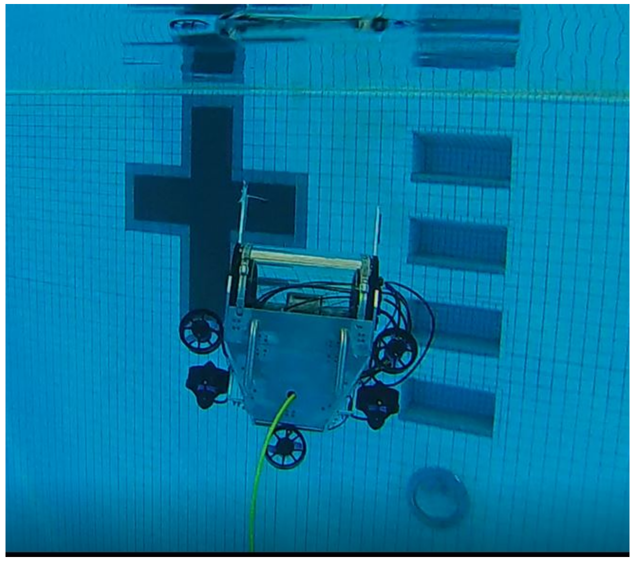


Figure 22: First emergency blow procedure test

On April 13th, the second water test at the gym occurred. The electronic housing was connected into the pressure hull and was ready to be tested. There were two problems on that day, the first problem that occurred was that the RaspberryPi was not getting enough power. This led to the base station not connecting to the RaspberryPi, in addition to that, the co-processor could not control the thrusters and IMU since the co-processor receives its power from the RaspberryPi . Due to this issue, the pressure hull was opened up to find the problem. This then caused the second problem of the day. When placing the electronics housing back and closing up the pressure hull, the hull was not properly sealed, which eventually caused a leak. The battery was the only thing that was barely touched by the water.

Before attempting the third gym test, the submersible was tested in a small container filled with water to determine the source of the leak. After multiple testing, the source of the leak was found. When placing the housing back on, the pressure valve penetrator was not loosened to let air flow through. Since this valve was closed, plate would not properly seal due to air pressure. To prevent this problem from happening again, the pressure valve would remain open when moving the electrical housing from the pressure hull.

The final test was on April 18th, where many things occurred. The RaspberryPi was able to connect to the co-processor and router, so the base station had control of the submersible. This was due to a last minute inclusion of a portable battery pack that would serve as the power supply to the RaspberryPi instead of the voltage regulator. One team member was testing code at the workstation to confirm the ROV's movements. The submersible had the counterweights attached to the arms to fix the leveling of the robot. The counterweights were heavier than expected since the submersible started to sink. When placed into the water, the submersible was able to move around on its own for about thirty minutes before the motors stopped working for the first time. When taking a look at the electrical housing, the thruster cables were disconnected from their motor controllers. As the hull was opened up to reconnect the thruster cables, one more issue was found. The quick connect terminal blocks that attached the thruster cables and motor controllers had melted through the plastic housing and thus were no longer connecting the thrusters to the controllers. Since the team had multiple of these terminal blocks, the melted ones were replaced to continue further testing. Unfortunately, some of the blocks had the same issue as before and melted again. This affected the two main vertical thrusters to the point where they stopped working. The blocks were replaced once again to attempt the last few motion tests and recordings on land.

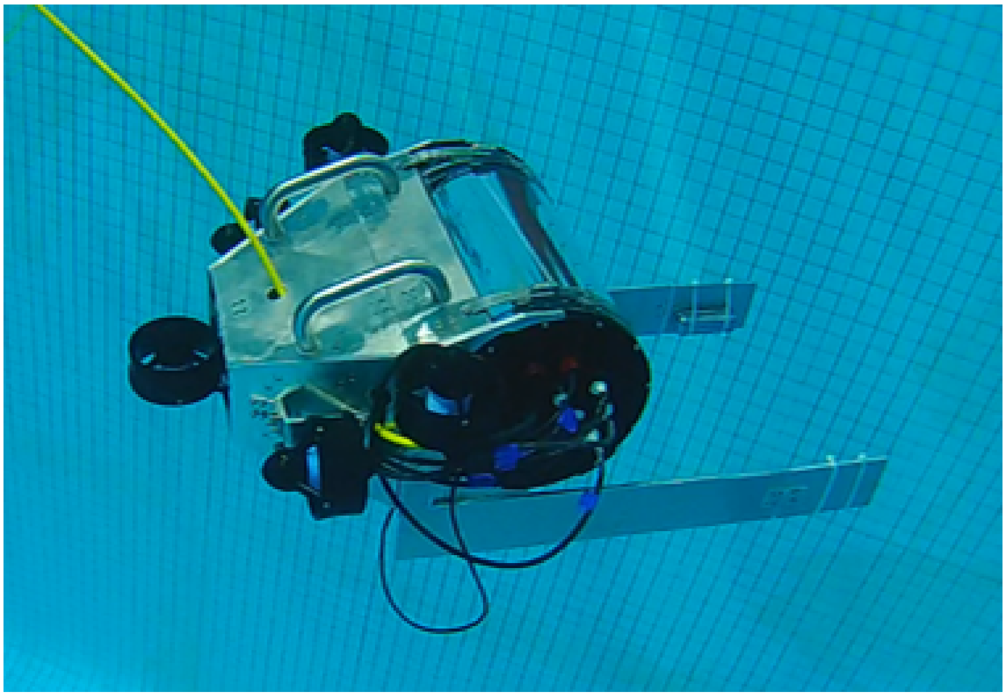


Figure 23: Image of ROV underwater

6.2 Results

In order to measure the success of the project, a comparison between the statement of work and the end product can be made. For each of the goals on the statement of work, a measurable comparison can be determined as seen in Table 2. For the goals that either were not met or were not tested to the extent at which they had been specified, further details can be found below Table 2.

6.2.1 Speed and Mobility

As mentioned previously, electrical issues caused loss of control of thrusters multiple times during testing. For much of the testing, we required a person stabilizing the ROV as it moved through the water and thus could not get an accurate representation of the speed of the ROV. During one of the earlier tests when the thrusters were only being run at half of maximum power the ROV was moving forwards at approximately 1.25 feet per second.

Description	Required Value	Actual Value
Maximum Size	32 in. x 32 in. x 32 in.	32 in. x 13 in. x 21 in.
Maximum Weight	100 lbs.	34 lbs.
Minimum Speed and Mobility	3 ft/s forward, 1.5 ft/s backward, up and down	1.25 ft/s forward, unmeasured, unmeasured
Minimum Pressure	10 PSI	6 PSI Maximum exposed rated for 56 PSI
Emergency Blow Procedure	Ascend 20 ft in 15 seconds	Ascended 14 ft in 10 seconds
Minimum Spotlights	200 Lumens main lights, 100 Lumens Omni-directional Lights	1500 Lumen main, no omni-directional
Minimum Battery Life	30 minutes of operation	2 hours of operation
Manual Control	The ability to manually control the robot	The ability to manually control the robot
User Interface	Simple enough for people with minimum practice to use	No
Minimum Data Stream	8 Mb/s	Not measured - but acceptable

Table 2: Design Results

6.2.2 Minimum Pressure

Due to the depth limit within the pool used for testing, the maximum pressure that could be tested at was six pounds per square inch (PSI). The pressure hull was rated for up to 56 PSI and all other components were rated for at least as much pressure as the pressure hull. It can be reasonably estimated that the ROV would withstand at least the ten PSI specified in the statement of work.

6.2.3 Emergency Blow Procedure

For similar reasons as the minimum pressure the emergency blow did not ascend the full 20 feet as the pool was only 14 feet. However since the ROV was moving approximately 2.8 feet per second and assuming constant velocity for the remaining 6 feet, the ROV would be able to ascend the full 20 feet in approximately 12 seconds.

6.2.4 User Interface

The user interface was not particularly easy to use. The camera feed was decent for seeing the bottom of the pool and theoretically searching for a body. However a lack of visual cue for orientation made piloting the ROV from camera feed very disorienting. Further the automatic stabilization was non-optimal even before several thrusters stopped functioning. This made manual control of the ROV far more difficult than intended.

7 Timeline and Budget

The logistics of the MQP were tracked throughout the span of this project. Primarily, the team kept record of the timeline that was projected and the budget that was predicted. In different ways, these two documents varied as the project progressed. For example, the predicted time table varied as the time it took to complete certain tasks was more than originally anticipated. Furthermore, as more research and feasibility tests were done as the robot was being designed, the budget had to adjust according to the different prices of components over the course of the year.

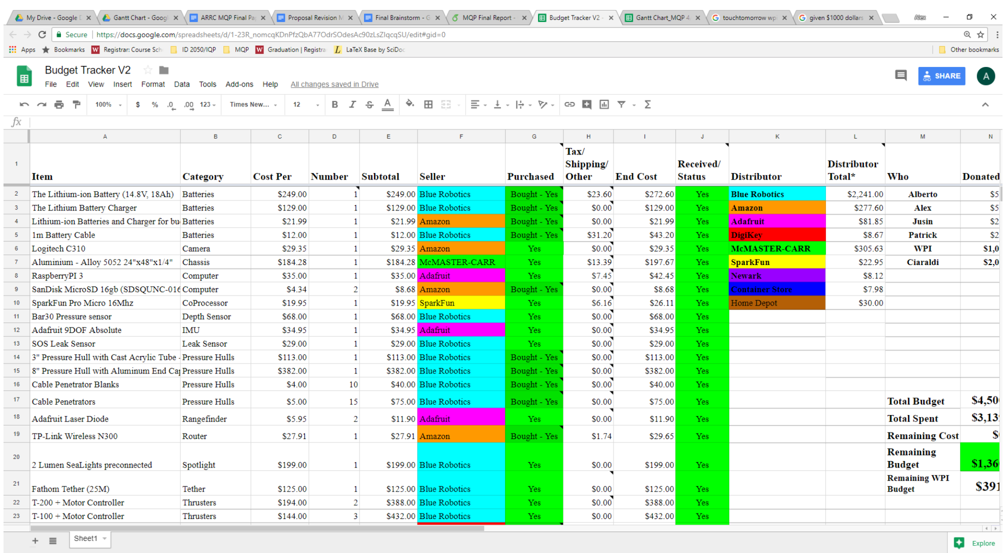
7.1 Timeline

The timeline for the project began in mid-August with design and prototype discussions and continued up until Project Presentation Day on April 20th. The original hope was to split the timeline of this project into four sections: research, building, testing, and summary. However, the actual outcome, due to budget availability and other factors, proved that the initial design would last until late B term, when the projected building should have been complete, and the testing was not done until the beginning of D term, based on the availability of components. Ideally, the hope was to test the ROV around C term. However, we experienced setbacks due to delays in material procurement, coding difficulties, availability of pool and facilities for testing as well as financial constraints. As a summary, the most accurate progression of this project can be seen in the located in Appendix B.

7.2 Budget

The initial budget for the project given to WPI students in the RBE department is $250 dollars per student, giving the team a total of $1000. In addition, the team decided to match the amount of money WPI would give to at least $250 per person, with Alberto and Alex offering to give more if necessary. This brought the total up to $2500. This was still a very restrictive initial outlay for the size and scope of this project as some necessary components could cost anywhere from $144 to $406 for a single part/item. This put a serious strain on the team's ability to construct the prototype as we did not have the financial resources to physically build the robot out of the desired materials. Even after receiving a generous discount of 10% off from Blue Robotics, a vendor that sold a majority of the required parts, the team was struggling to find a way to procure the vital components.

In the beginning of the spring semester one of the team's advisors, Professor Ciaraldi, offered us a very generous donation of $2000 from his budget, which allowed us to finally have the funds required to construct the ROV. Fortunately, we realized that this addition to the budget would allow for the team to purchase all of the necessary components that were needed for reasonable implementation of this robot. Despite the fact that the pressure hull, various thrusters, and ROV battery required money well outside the initial projected budget, this late donation made sure that this robot would become a tangible entity that could be tested thoroughly in the pool. The image below shows a view of how we not only organized the budget, but also tracked how much money was spent on each part, by whom and when. Complete details for the budget of the project is located in Appendix A.


Budget Tracker V2

Item	Category	Cost Per	Number	Subtotal	Seller	Purchased	Tax/ Shipping/ Other	End Cost	Received/ Status	Distributor	Distributor Total*	Who	Donated
The Lithium-ion Battery (14.8V, 18Ah)	Batteries	$249.00	1	$249.00	Blue Robotics	Bought - Yes	$23.60	$272.60	Yes	Blue Robotics	$2,241.00	Alberto	$5
The Lithium Battery Charger	Batteries	$129.00	1	$129.00	Blue Robotics	Bought - Yes	$0.00	$129.00	Yes	Amazon	$277.60	Alex	$5
Lithium-ion Batteries and Charger for bu	Batteries	$21.99	1	$21.99	Amazon	Bought - Yes	$0.00	$21.99	Yes	Adafruit	$81.85	Jusin	$2
1m Battery Cable	Batteries	$12.00	1	$12.00	Blue Robotics	Bought - Yes	$31.20	$43.20	Yes	DigiKey	$8.67	Patrick	$2
Logitech C310	Camera	$29.35	1	$29.35	Amazon	Yes	$0.00	$29.35	Yes	McMASTER-CARR	$305.63	WPI	$1,0
Aluminium - Alloy 5052 24"x48"x1/4"	Chassis	$184.28	1	$184.28	McMASTER-CARR	Yes	$13.39	$197.67	Yes	SparkFun	$22.95	Ciaraldi	$2,0
RaspberryPI 3	Computer	$35.00	1	$35.00	Adafruit	Yes	$7.45	$42.45	Yes	Newark	$8.12		
SanDisk MicroSD 16gb (SDSQUNC-016	Computer	$4.34	2	$8.68	Amazon	Bought - Yes	$0.00	$8.68	Yes	Container Store	$7.98		
SparkFun Pro Micro 16Mhz	CoProcessor	$19.95	1	$19.95	SparkFun	Yes	$6.16	$26.11	Yes	Home Depot	$30.00		
Bar30 Pressure sensor	Depth Sensor	$68.00	1	$68.00	Blue Robotics	Yes	$0.00	$68.00	Yes				
Adafruit 9DOF Absolute	IMU	$34.95	1	$34.95	Adafruit	Yes	$0.00	$34.95	Yes				
SOS Leak Sensor	Leak Sensor	$29.00	1	$29.00	Blue Robotics	Yes	$0.00	$29.00	Yes				
3" Pressure Hull with Cast Acrylic Tube -	Pressure Hulls	$113.00	1	$113.00	Blue Robotics	Bought - Yes	$0.00	$113.00	Yes				
8" Pressure Hull with Aluminum End Ca	Pressure Hulls	$382.00	1	$382.00	Blue Robotics	Bought - Yes	$0.00	$382.00	Yes				
Cable Penetrator Blanks	Pressure Hulls	$4.00	10	$40.00	Blue Robotics	Bought - Yes	$0.00	$40.00	Yes				
Cable Penetrators	Pressure Hulls	$5.00	15	$75.00	Blue Robotics	Bought - Yes	$0.00	$75.00	Yes			Total Budget	$4,50
Adafruit Laser Diode	Rangefinder	$5.95	2	$11.90	Adafruit	Yes	$0.00	$11.90	Yes			Total Spent	$3,13
TP-Link Wireless N300	Router	$27.91	1	$27.91	Amazon	Bought - Yes	$1.74	$29.65	Yes			Remaining Cost	$
2 Lumen SeaLights preconnected	Spotlight	$199.00	1	$199.00	Blue Robotics	Yes	$0.00	$199.00	Yes			Remaining Budget	$1,36
Fathom Tether (25M)	Tether	$125.00	1	$125.00	Blue Robotics	Yes	$0.00	$125.00	Yes			Remaining WPI Budget	$391
T-200 + Motor Controller	Thrusters	$194.00	2	$388.00	Blue Robotics	Yes	$0.00	$388.00	Yes				
T-100 + Motor Controller	Thrusters	$144.00	3	$432.00	Blue Robotics	Yes	$0.00	$432.00	Yes				

Figure 24: A glance at the budget tracker that was used/created

8 Future Revisions

One important issue that we encountered was that the quick connect terminal block melted as the thrusters were powered. This was believed to be due to high frequency changes of current flow between the motor controller and thruster. The thruster is a three stage brushless motor meaning that powering the thruster involves changing polarity of the three stages at a high frequency. One way to improve to this project is to replace these blocks with a more durable connector. Another way to improve this project is to add another switch to power the submersible from the outside, where the diver can easily access. Other options include making the counterweight lighter and the arms longer. This would make the submersible go beyond the size requirement, so another addition would be to make the arms adjustable or removable. One possible improvement could be making the submersible neutrally buoyant which would require less effort for the three T100 thrusters and improve battery life. Since the tether has a working strength of about 80 pounds, the tether can be used to pull the submersible back up.

For future projects that could be inspired by this project, there are some ideas that could improve the current design. Another idea is to implement sonar for mapping and locating objects. Currently, sonar was bulkier than would be allowed on the current ROV. All of the other submersibles were found to implement sonar and were much bigger than the team's submersible. Another idea is to attach an arm onto the submersible so that it will be capable of latching onto the target object. This would prevent any current from moving the target object away from the ROV's location. This would make the submersible heavier but this could be fixed by replacing the quarter inch thick aluminum with eighth inch thick aluminum. In order to ease the burden on the stabilization algorithm a more mechanically stable physical form for the ROV could be constructed. One idea that had been discussed during the proposal stage of the project was a computer vision algorithm to automatically detect potential bodies as the ROV was moving.

9 Social Implications

For this project, there were a few things that needed to be accounted for in regards to social implications. The first thing was the ergonomic issues that may be caused by carrying and moving the robot. Therefore, the first design requirement that was made was that the robot needed to be under 100 pounds. Based on the ergonomic standards [16], a person should not lift more than 51 pounds on their own. With that being the case, two firefighters lifting the robot would be able to do so safely if the robot weighed a maximum of 102 pounds. Fortunately, this was met easily with the actual weight of the ROV, buoy and command station together being less than 50 pounds. Additionally, there were things that needed to be considered with the robot being underwater. First of all, with it being a machine, a human must be able to see it at all times. Therefore, spotlights were incorporated so that it would emit a light strong enough to be seen easily underwater. Another fix to this issue would be to paint the robot a fluorescent color. Since painting can be done at any point after manufacturing, it was not done on the prototype but would be done if the prototype was to be used as a finished product.

The last and certainly most important social implication that this project considers has to do with its original goal. The purpose of this project is to reduce the amount of time that rescue divers spend under the water. With a mechanical system running under the water, one does not have to be concerned about possible injuries or decompression sickness. The robot will last as long as the average search time of a rescue diver, which is about 30 minutes. The fact that this project will reduce risks taken every day by rescue divers proves that it is socially acceptable. All of the materials used to make the robot are friendly to the environment. In addition, it will be able to withstand salt and fresh water at the various depths. The ROV will certainly be a benefit to any fire department, or underwater search team, who use it to search for missing people underwater.

10 Conclusion

The path to complete this yearlong project was certainly an arduous one, and many different design decisions had to be made. However, there was much to learn and the team, in general, has grown as engineers, ready for the professional engineering environment. There has been experience in research, design, construction, implementation, and testing, and all of these areas required analysis and comprehensive thought to alleviate any problems that occurred. The original goal of this project was to create a robot that could search and identify bodies under the water to minimize the time that rescue divers would have to be under the water. With the help of the team's familiar background in robotics, mechanical engineering, computer science, and electrical engineering, the robot was built to satisfy many of the design requirements. The Washburn Labs were used exhaustively so that many of the components could be made, since a significant portion of the hardware was built from scratch. In addition, the faculty in all of the labs proved to be very helpful when determining the best way to approach the problem. The underwater nature of the ARRC robot was difficult to test, but fortunately, through the use of WPI's 14 feet deep pool, testing was able to be successfully completed.

Due to time constraints, some of the more difficult aspects such as full autonomy had to be reconsidered, but this was decided early on. Once the tests were complete, it was clear that the robot was able to complete its dimension requirement, weight requirement, and buoyancy requirement, along with the specifications that the Natick Fire Department had outlined. These specifications and requirements were definitely the most important because it proves that the robot can be used in a practical setting. Ultimately, the team is very proud to accomplish a robotics project that integrates three separate systems. The ROV, the buoy, and the base station communicate together nicely and solve the issue of being able to successfully navigate through water. Moving forward, this project can be improved in the coming years and could eventually become a prototype that is adopted by fire departments throughout the country. The team is optimistic of the future of this project and is very happy with the outcome of their MQP from WPI.

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A

Complete Budget Tracker

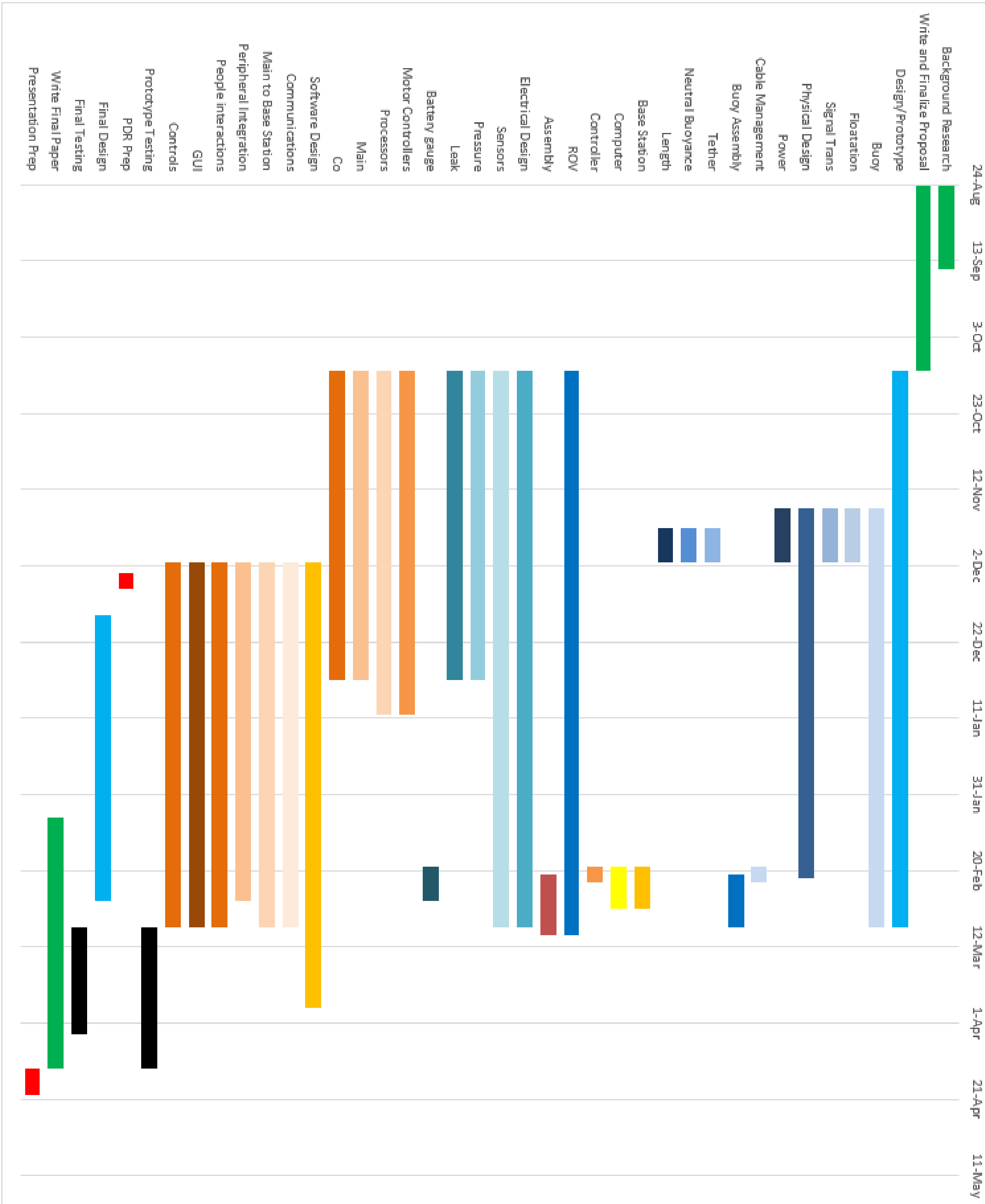
Item	Category	Cost Per	Number	Subtotal	Seller	Purchased [1]	Tax/ Shipping/ Other	End Cost	Received/ Status [2]	Distributor	Distributor Total* [3]	Who	Donated	Spent	Remaining	Orders	Actual Cost	Date
The Lithium-ion Battery (14.8V, 18Ah)	Batteries	$249.00	1 [4]	$249.00	Blue Robotics	Bought - Yes [5	$23.60 [6]	$272.60	Yes	Blue Robotics	$2,241.00	Alberto	$500.00	$299.68	$200.32	WPI #1	$238.92 [7]	1/15/2018
The Lithium Battery Charger	Batteries	$129.00	1	$129.00	Blue Robotics	Bought - Yes [8	$0.00 [9]	$129.00	Yes	Amazon	$277.60	Alex	$500.00	$98.30	$401.70	WPI #2	$106.51 [10]	1/21/2018
Lithium-ion Batteries and Charger for bu	Batteries	$21.99	1	$21.99	Amazon	ought - Yes [11	$0.00	$21.99	Yes	Adafruit	$81.85	Jusin	$250.00	$0.00	$250.00	WPI #3	$30.84 [12]	1/29/2018
1m Battery Cable	Batteries	$12.00	1	$12.00	Blue Robotics	ought - Yes [13	$31.20 [14]	$43.20	Yes	DigiKey	$8.67	Patrick	$250.00	$103.80	$146.20	WPI #4	$570.10 [15]	2/5/2018
Logitech C310	Camera	$29.35	1	$29.35	Amazon	Yes	$0.00 [16]	$29.35	Yes	McMASTER-CARR	$305.63	WPI	$1,000.00	$2,640.07	$359.93	WPI #5	$25.08 [17]	2/8/2018
Aluminium - Alloy 5052 24"x48"x1/4"	Chassis	$184.28	1	$184.28	McMASTER-CARR	Yes	$13.39 [18]	$197.67	Yes	SparkFun	$22.95	Ciaraldi	$2,000.00			WPI #6	$599.20 [19]	2/16/18
RaspberryPI 3	Computer	$35.00	1	$35.00	Adafruit	Yes	$7.45 [20]	$42.45	Yes	Newark	$8.12					WPI #7	$31.76 [21]	2/19/2018
SanDisk MicroSD 16gb (SDSQUNC-016	Computer	$4.34	2	$8.68	Amazon	ought - Yes [22	$0.00 [23]	$8.68	Yes	Container Store	$7.98					WPI #8	$53.81 [24]	2/22/2018
SparkFun Pro Micro 16Mhz	CoProcessor	$19.95	1	$19.95	SparkFun	Yes	$6.16 [25]	$26.11	Yes	Home Depot	$31.41					WPI #9	$25.59 [26]	3/12/2018
Bar30 Pressure sensor	Depth Sensor	$68.00	1	$68.00	Blue Robotics	Yes	$0.00 [27]	$68.00	Yes									
Adafruit 9DOF Absolute	IMU	$34.95	1	$34.95	Adafruit	Yes	$0.00 [28]	$34.95	Yes							#1 (Alex)	$60.32 [29]	1/20/2018
SOS Leak Sensor	Leak Sensor	$29.00	1	$29.00	Blue Robotics	Yes	$0.00 [30]	$29.00	Yes							#2 WPI - Reimbursed	$462.25 [31]	2/6/2018
3" Pressure Hull with Cast Acrylic Tube -	Pressure Hulls	$113.00	1	$113.00	Blue Robotics	ought - Yes [32	$0.00 [33]	$113.00	Yes							#3 WPI - Reimbursed	$464.60 [34]	2/15/2018
8" Pressure Hull with Aluminum End Ca	Pressure Hulls	$382.00	1	$382.00	Blue Robotics	ought - Yes [35	$0.00 [36]	$382.00	Yes							#4 (Alberto)	$18.20 [37]	2/15/2018
Cable Penetrator Blanks	Pressure Hulls	$4.00	10	$40.00	Blue Robotics	ought - Yes [38	$0.00 [39]	$40.00	Yes							#5 (Patrick)	$34.82 [40]	2/26/2018
Cable Penetrators	Pressure Hulls	$5.00	15	$75.00	Blue Robotics	ought - Yes [41	$0.00 [42]	$75.00	Yes			Total Budget	$4,500.00			#6 (Alex)	$7.98 [43]	3/3/2018
Adafruit Laser Diode	Rangefinder	$5.95	2	$11.90	Adafruit	Yes	$0.00 [44]	$11.90	Yes			Total Spent	$3,141.85	(W/ Discount)		#7 (Alberto)	$31.41 [45]	3/10/2018
TP-Link Wireless N300	Router	$27.91	1	$27.91	Amazon	ought - Yes [46	$1.74	$29.65	Yes			Remaining Cost	$0.00			#8 (Alberto)	$110.07 [47]	4/2/2018
2 Lumen SeaLights preconnected	Spotlight	$199.00	1	$199.00	Blue Robotics	Yes	$0.00	$199.00	Yes			Remaining Budget	$1,358.15			#9 (Alex)	$30.00 [48]	4/2/2018
Fathom Tether (25M)	Tether	$125.00	1	$125.00	Blue Robotics	Yes	$0.00 [49]	$125.00	Yes			Remaining WPI Budget	$359.93			#10 WPI - Reimbursed	$31.41 [50]	4/18/2018
T-200 + Motor Controller	Thrusters	$194.00	2	$388.00	Blue Robotics	Yes	$0.00 [51]	$388.00	Yes							#11 (Patrick)	$51.48	4/8/2018
T-100 + Motor Controller	Thrusters	$144.00	3	$432.00	Blue Robotics	Yes	$0.00	$432.00	Yes							#12 (Patrick)	$17.50	4/17/2018
Seeed 313080006	Voltage Regulator	$8.67	1	$8.67	DigiKey	ought - Yes [52	$9.53	$18.20	Yes							#13 (Alberto) [53]	$140.00	4/11/2018-4/18/2018
Break Away Headers - Straight 40 count	Headers	$1.50	2	$3.00	SparkFun	Yes	$0.00 [54]	$3.00	Yes									
Aluminium - Alloy 5052 3"x2'x1/8"	Chassis	$30.84	1	$30.84	McMASTER-CARR	Yes	$0.00 [55]	$30.84	Yes									
Newark S760 [56]	Buoy [57]	$4.06	2	$8.12	Newark	Yes	$23.18	$31.30	Yes									
Aluminium - Alloy 5052 4"x24"x1/8"	Chassis	$12.41	1	$12.41	McMASTER-CARR	Yes	$0.00 [58]	$12.41	Yes									
Screws x100 [59]	Chassis	$7.00	1	$7.00	McMASTER-CARR	Yes	$0.00 [60]	$7.00	Unknown									
Nuts x100	Chassis	$3.03	1	$3.03	McMASTER-CARR	Yes	$0.00 [61]	$3.03	Yes									
Washers x100	Chassis	$2.64	1	$2.64	McMASTER-CARR	Yes	$0.00 [62]	$2.64	Yes									
Life Preserver	Bouy	$24.99	1	$24.99	Amazon	Yes	$0.00	$24.99	Yes									
Wood	Buoy	$31.41	1	$31.41	Home Depot	ought - Yes [63	$0.00	$31.41	Yes									
Lgitech Extreme 3D Pro Joystick [64]	Controller	$27.83	1	$27.83	Amazon [65]	ought - Yes [66	$0.00	$27.83	Yes									
Voltage divider 5 pack [67]	Sensor	$6.99	1	$6.99	Amazon [68]	ought - Yes [69	$0.00	$6.99	Yes									
UbiGear Cable Tester	Connectors	$13.97	1	$13.97	Amazon	Yes	$0.00	$13.97	Yes									
Thruster Screws	Chassis	$4.56	1	$4.56	McMASTER-CARR	Yes	$0.00	$4.56	Yes									
Worm-Drive Clamp	Chassis	$14.16	2	$28.32	McMASTER-CARR	Yes	$0.00	$28.32	Yes									
Screws x100 - corrected	Chassis	$7.42	2	$14.84	McMASTER-CARR	Yes	$0.00	$14.84	Yes									
Nuts x100 - corrected	Chassis	$4.01	2	$8.02	McMASTER-CARR	Yes	$0.00	$8.02	Yes									
Washers x100 - corrected	Chassis	$9.69	1	$9.69	McMASTER-CARR	Yes	$0.00	$9.69	Yes									
Container	Buoy	$3.99	2	$7.98	Container Store	ought - Yes [70	$0.00	$7.98	Yes									
Spool	Buoy/ Tether	$6.77	1	$6.77	Amazon	Yes	$0.00	$6.77	Yes									
Handles	Chassis	$14.59	1	$14.59	Amazon	ought - Yes [71	$0.00	$14.59	Yes									
Tether Cable Penetrator	Buoy	$25.72	1	$25.72	Amazon	ought - Yes [72	$0.00	$25.72	Yes									
1" thick acrylic	Chassis	$30.00	1	$30.00		Bought - Yes [73	$0.00	$30.00	Yes									
Epoxy	Chassis & Buoy	$48.81	1	$48.81	Amazon	ought - Yes [74	$0.00	$48.81	Yes									
CounterWeights	Chassis	$10.00	2	$20.00	Amazon	ought - Yes [75	$0.95	$20.95	Yes									
Electrical Connectors and such	Connectors	$51.48	1	$51.48	Amazon	Yes	$0.00	$51.48	Yes									
RasberryPi Battery Thingy	Batteries	$17.50	1	$17.50		Yes	$0.00	$17.50	Yes									
LifeGuard Hours	Testing	$20.00	7	$140.00		Yes	$0.00	$140.00	Yes									
							$0.00	$0.00										
							Total Cost w/out Discount	$3,341.39	End List									

A.1 Material and Cost

Item	Category	Cost Per	Number	Subtotal	Seller	Purchased	Tax/ Shipping/ Other	End Cost	Received/ Status
The Lithium-ion Battery (14.8V, 18Ah)	Batteries	$249.00	1	$249.00	Blue Robotics	Bought - Yes	$23.60	$272.60	Yes
The Lithium Battery Charger	Batteries	$129.00	1	$129.00	Blue Robotics	Bought - Yes	$0.00	$129.00	Yes
Lithium-ion Batteries and Charger for bu	Batteries	$21.99	1	$21.99	Amazon	Bought - Yes	$0.00	$21.99	Yes
1m Battery Cable	Batteries	$12.00	1	$12.00	Blue Robotics	Bought - Yes	$31.20	$43.20	Yes
Logitech C310	Camera	$29.35	1	$29.35	Amazon	Yes	$0.00	$29.35	Yes
Aluminium - Alloy 5052 24"x48"x1/4"	Chassis	$184.28	1	$184.28	McMASTER-CARR	Yes	$13.39	$197.67	Yes
RaspberryPI 3	Computer	$35.00	1	$35.00	Adafruit	Yes	$7.45	$42.45	Yes
SanDisk MicroSD 16gb (SDSQUNC-016	Computer	$4.34	2	$8.68	Amazon	Bought - Yes	$0.00	$8.68	Yes
SparkFun Pro Micro 16Mhz	CoProcessor	$19.95	1	$19.95	SparkFun	Yes	$6.16	$26.11	Yes
Bar30 Pressure sensor	Depth Sensor	$68.00	1	$68.00	Blue Robotics	Yes	$0.00	$68.00	Yes
Adafruit 9DOF Absolute	IMU	$34.95	1	$34.95	Adafruit	Yes	$0.00	$34.95	Yes
SOS Leak Sensor	Leak Sensor	$29.00	1	$29.00	Blue Robotics	Yes	$0.00	$29.00	Yes
3" Pressure Hull with Cast Acrylic Tube -	Pressure Hulls	$113.00	1	$113.00	Blue Robotics	Bought - Yes	$0.00	$113.00	Yes
8" Pressure Hull with Aluminum End Ca	Pressure Hulls	$382.00	1	$382.00	Blue Robotics	Bought - Yes	$0.00	$382.00	Yes
Cable Penetrator Blanks	Pressure Hulls	$4.00	10	$40.00	Blue Robotics	Bought - Yes	$0.00	$40.00	Yes
Cable Penetrators	Pressure Hulls	$5.00	15	$75.00	Blue Robotics	Bought - Yes	$0.00	$75.00	Yes
Adafruit Laser Diode	Rangefinder	$5.95	2	$11.90	Adafruit	Yes	$0.00	$11.90	Yes
TP-Link Wireless N300	Router	$27.91	1	$27.91	Amazon	Bought - Yes	$1.74	$29.65	Yes
2 Lumen SeaLights preconnected	Spotlight	$199.00	1	$199.00	Blue Robotics	Yes	$0.00	$199.00	Yes
Fathom Tether (25M)	Tether	$125.00	1	$125.00	Blue Robotics	Yes	$0.00	$125.00	Yes
T-200 + Motor Controller	Thrusters	$194.00	2	$388.00	Blue Robotics	Yes	$0.00	$388.00	Yes
T-100 + Motor Controller	Thrusters	$144.00	3	$432.00	Blue Robotics	Yes	$0.00	$432.00	Yes
Seeed 313080006	Voltage Regulator	$8.67	1	$8.67	DigiKey	Bought - Yes	$9.53	$18.20	Yes
Break Away Headers - Straight 40 count	Headers	$1.50	2	$3.00	SparkFun	Yes	$0.00	$3.00	Yes
Aluminium - Alloy 5052 3"x2'x1/8"	Chassis	$30.84	1	$30.84	McMASTER-CARR	Yes	$0.00	$30.84	Yes
Screws x100	Chassis	$7.00	1	$7.00	McMASTER-CARR	Yes	$0.00	$7.00	Unknown
Nuts x100	Chassis	$3.03	1	$3.03	McMASTER-CARR	Yes	$0.00	$3.03	Yes
Washers x100	Chassis	$2.64	1	$2.64	McMASTER-CARR	Yes	$0.00	$2.64	Yes
Life Preserver	Bouy	$24.99	1	$24.99	Amazon	Yes	$0.00	$24.99	Yes
Wood	Buoy	$30.00	1	$30.00	Home Depot	Bought - Yes	$0.00	$30.00	Yes
Lgitech Extreme 3D Pro Joystick	Controller	$27.83	1	$27.83	Amazon	Bought - Yes	$0.00	$27.83	Yes
Voltage divider 5 pack	Sensor	$6.99	1	$6.99	Amazon	Bought - Yes	$0.00	$6.99	Yes
UbiGear Cable Tester	Connectors	$13.97	1	$13.97	Amazon	Yes	$0.00	$13.97	Yes
Thruster Screws	Chassis	$4.56	1	$4.56	McMASTER-CARR	Yes	$0.00	$4.56	Yes
Worm-Drive Clamp	Chassis	$14.16	2	$28.32	McMASTER-CARR	Yes	$0.00	$28.32	Yes
Screws x100 - corrected	Chassis	$7.42	2	$14.84	McMASTER-CARR	Yes	$0.00	$14.84	Yes
Nuts x100 - corrected	Chassis	$4.01	2	$8.02	McMASTER-CARR	Yes	$0.00	$8.02	Yes
Washers x100 - corrected	Chassis	$9.69	1	$9.69	McMASTER-CARR	Yes	$0.00	$9.69	Yes
Container	Buoy	$3.99	2	$7.98	Container Store	Bought - Yes	$0.00	$7.98	Yes
Spool	Buoy/ Tether	$6.77	1	$6.77	Amazon	Yes	$0.00	$6.77	Yes
Handles	Chassis	$14.59	1	$14.59	Amazon	Bought - Yes	$0.00	$14.59	Yes
Tether Cable Penetrator	Buoy	$25.72	1	$25.72	Amazon	Bought - Yes	$0.00	$25.72	Yes
1" thick acrylic	Chassis	$30.00	1	$30.00		Bought - Yes	$0.00	$30.00	Yes
Epoxy	Chassis & Buoy	$48.81	1	$48.81	Amazon	Bought - Yes	$0.00	$48.81	Yes
CounterWeights	Chassis	$10.00	2	$20.00	Amazon	Bought - Yes	$0.95	$20.95	Yes
Electrical Connectors and such	Connectors	$51.48	1	$51.48	Amazon	Yes	$0.00	$51.48	Yes
RasberryPi Battery Thingy	Batteries	$17.50	1	$17.50		Yes	$0.00	$17.50	Yes
LifeGuard Hours	Testing	$20.00	7	$140.00		Yes	$0.00	$140.00	Yes
							$0.00	$0.00	
							Total Cost w/out Discount	**$3,339.98**	End List

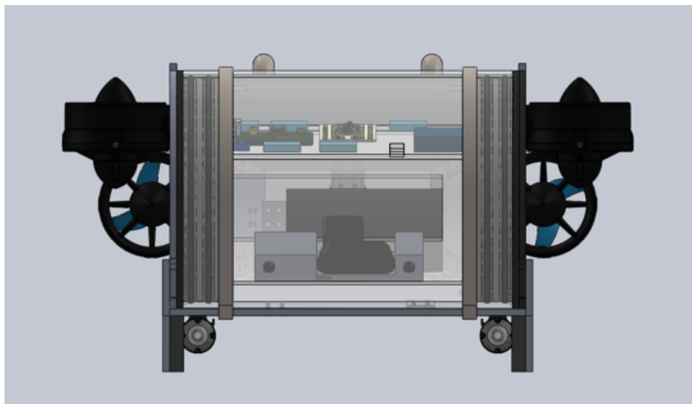
B

Timeline

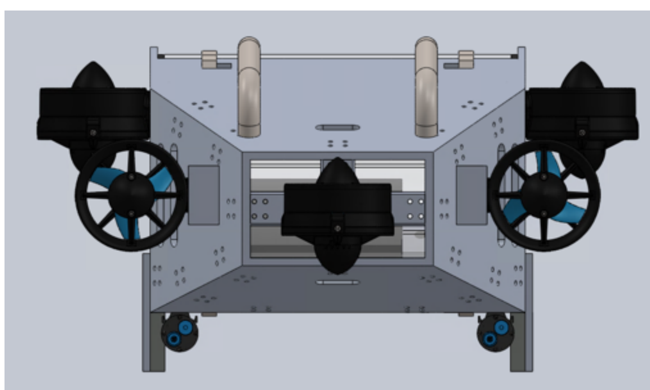

24-Aug
13-Sep
3-Oct
23-Oct
12-Nov
2-Dec
22-Dec
11-Jan
31-Jan
20-Feb
12-Mar
1-Apr
21-Apr
11-May
Background Research
Write and Finalize Proposal
Design/Prototype
Buoy
Floatation
Signal Trans
Physical Design
Power
Cable Management
Buoy Assembly
Tether
Neutral Buoyance
Length
Base Station
Computer
Controller
ROV
Assembly
Electrical Design
Sensors
Pressure
Leak
Battery gauge
Motor Controllers
Processors
Main
Co
Software Design
Communications
Main to Base Station
Peripheral Integration
People interactions
GUI
Controls
Prototype Testing
PDR Prep
Final Design
Final Testing
Write Final Paper
Presentation Prep

C ROV CAD Views

C.1 Front

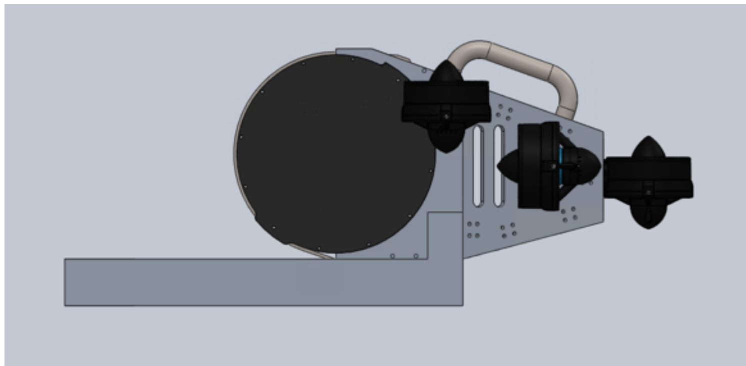


C.2 Back



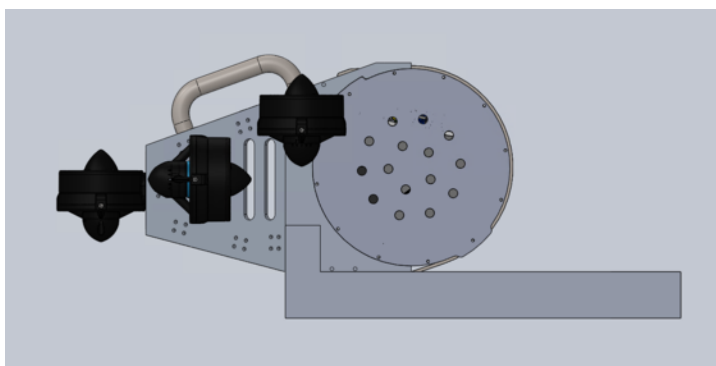
C.3

Left



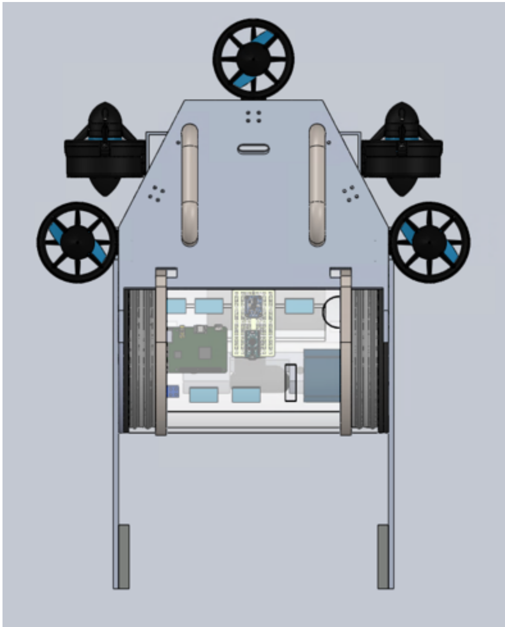
C.4

Right



C.5

Top



C.6

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