

AUVSI Robosub

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Midterm Update Report

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1) Introduction

1.1) Overview

The Association for Unmanned Vehicle Systems International (AUVSI) hosts an annual autonomous underwater vehicle competition. The NAU AUVSI Robosub team is a group of senior mechanical and electrical engineers who are tasked with entering and competing in the 2016 AUVSI competition. Participation in this competition is our capstone project. Team 9 has completed a second round of designing while building the “Trident” autonomous submarine, which will compete in the competition.

This report is a midterm update describing the older design briefly, what changes have been made, the newest design, the current progress and future progress needed.

1.2) Competition Constraints

There are several constraints that must be met when considering designs for the RoboSub. Due to the nature of the competition, they are all more-or-less equally important; if the constraints are not met, the team runs the risk of being disqualified and being unable to compete the task. First and foremost, the RoboSub must be autonomous. It may not be controlled by or communicate with an outside source, and must do all of its problem-solving and decision-making independently. It must weigh less than 57 kg, and fit into a box not exceeding 1.83 by 0.91 by 0.91 meters. Another consideration for the competition is that the robosub must complete all tasks within a designated time of fifteen minutes. It must have a clearly marked manual kill switch accessible from the outside designed to terminate power to all propulsion components. This is done to prevent injury or damage to the equipment or other participants in case of malfunction or error. The sub must be electrically/battery powered, and the batteries must be sealed to reduce risk of damage or corrosion; the batteries cannot be charged inside of sealed vessels, and open circuit voltage may not exceed 60 VDC. Except for torpedoes and markers, no part of the sub may detach during the runs. The sub must be able to be slung on a harness or sling for measuring, transportation, and safety purposes. Failure to meet one or more of these constraints, including additional ones not detailed here, can result in the team’s disqualification from the competition.

1.3) Competition Objectives

The competition lists numerous tasks that can be completed to gain points during the competition. The first task that must be completed is that the robosub must pass through a gate. Other tasks involve hitting targets with a torpedo, make contact with targets that are of a certain color while avoiding other colors, and dropping markers into a bin after removing the lid. The task map can be referenced in Appendix A. All of these tasks must be completed autonomously

meaning that there must be a great deal of programming to make the sub recognize different shapes and colors.

2) Design Changes During Development

2.1) Introduction

There have been many changes since the submarine's last semester design. There has been an increase in the size of the tubes for the electronics, as well as splitting the tubes. Mechanical changes have affected: brackets, torpedo tube, claws, the camera box, and some of the internal frame for the sub. Following are the details of the changes.

2.2) Thruster Layout

The main thruster orientations haven't changed dramatically, only in the sense that there isn't a plate of aluminum for mounting the motor brackets towards the back of the hull. Instead, the Trident will use a tiered tube system, in tandem with the normal motor mounting brackets in order to achieve the same thruster layout pattern. With the addition of a second tube, the three plane thrusters are situated below the center of buoyancy. This creates a stable sub platform that will be less prone to unwanted roll on the sub.

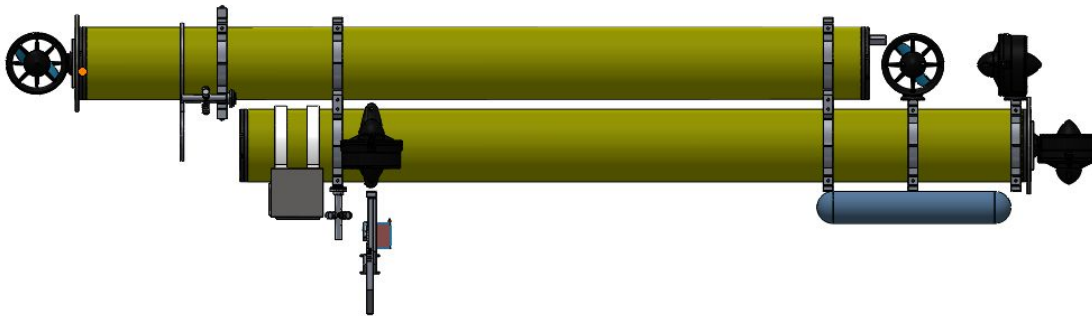


Image 2.2.1 : Side view of sub showing the thruster layout.

2.3) Hull Design and External Brackets

Since the beginning of the project, the hull design has undergone two radical changes. Initially, before the design requirements were made known, the sub consisted of a single bullet-shaped closed shell. This shell would contain all of the components in a watertight enclosure so that no wiring or mechanisms would be exposed to the water. This design was thought to be sufficient, as it had all the components the competition would require: Camera, thrusters, a prong to pick up objects, and torpedoes. However, as the semester progressed and the requirements were released, it became evident that the design was not acceptable.

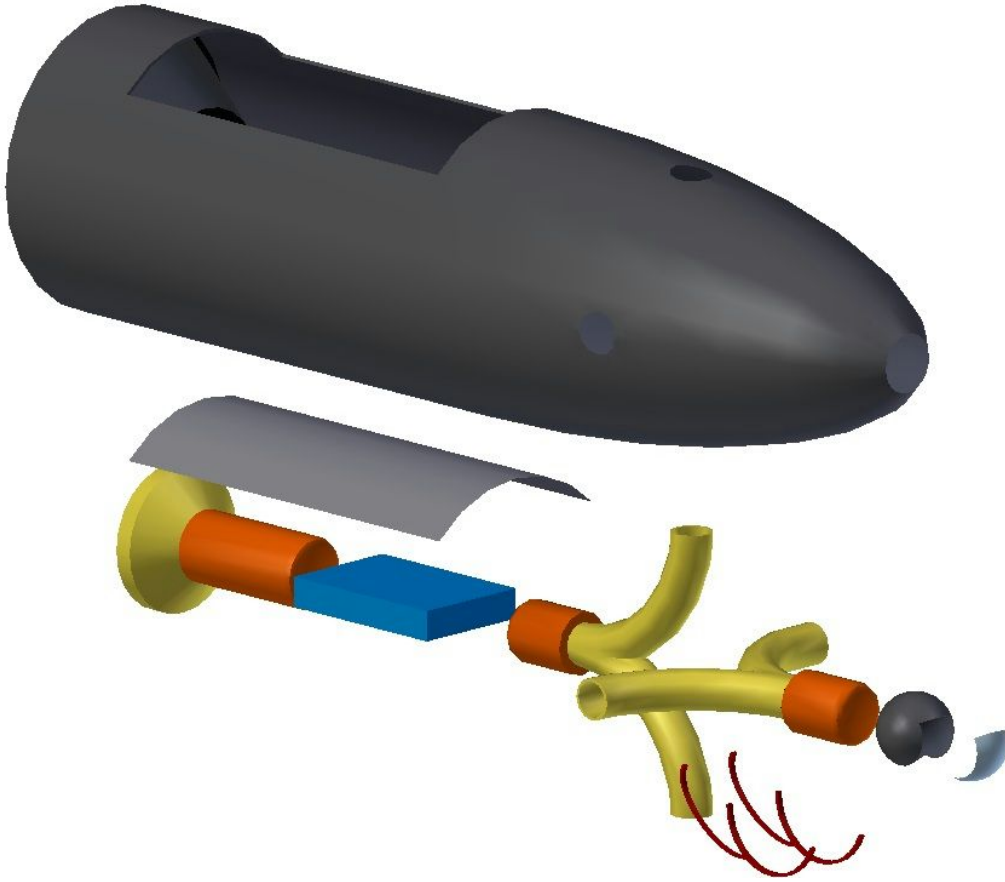


Figure 2.3.1: Initial submarine concept

The second iteration saw a shift from a large shell with an extensive frame to a small tube with holders for various electrical components inside. This was due to the fact that the prongs needed to be able to manipulate objects (pick up, move, etc.) and that the previous design was oversized and would have been disqualified. The camera was still intended to be on the front of the submarine and still in the main part of the tube. This was intended to reduce problems with wires going through the water or necessitating through-ports. The thrusters were also standardized; instead of three thrusters (one larger for propulsion, two smaller for bi-directional movement), there was now a total of six equally-sized ones (two for propulsion, 4 for orientation/movement). This required a new mounting system to be designed since the thrusters could no longer be integrated into the main shell. In addition, these new brackets enabled the standardization of “attachments” onto the submarine. If properly designed, components created by other team members could easily be attached to the brackets due to the equal spacing of all of the mounting points, based on the dimensions of the thruster mount.

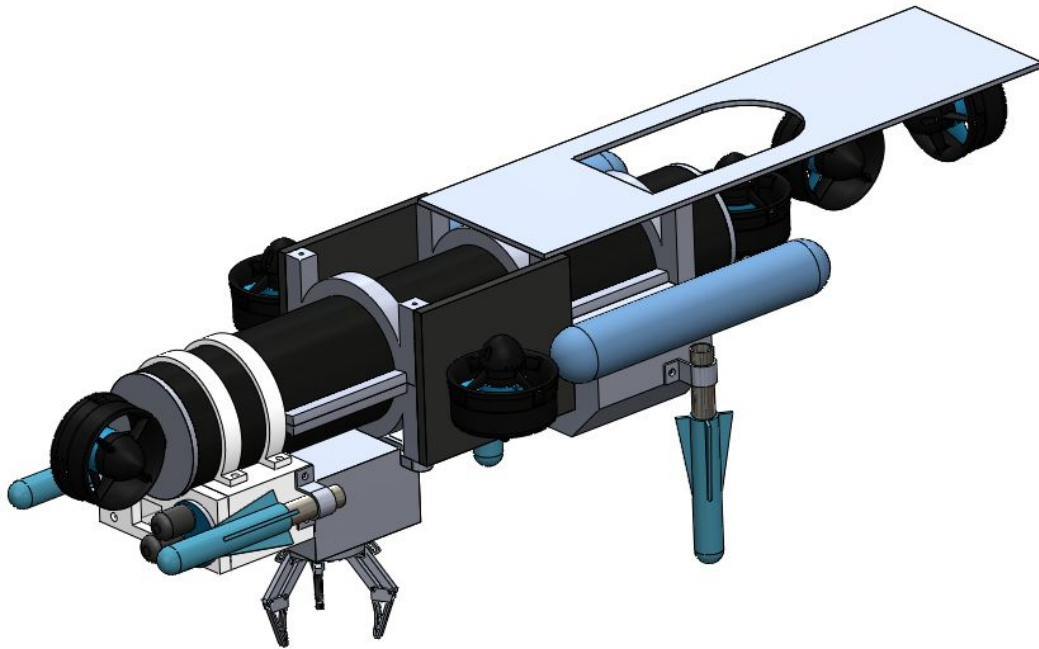


Figure 2.3.2 : Second iteration

The third and latest iteration was not as much of a radical change as the previous one. Due to the addition of more internal electrical components, additional space needed to become available; the choices were to extend the length, enlarge the diameter, or add a second tube. Eventually, it was decided that a second tube would be added - extending the length would make the submarine unwieldy, while enlarging the diameter would require a complete redesign of the internal framework. As such, an additional same-sized tube was the best choice. In doing so, the previously-designed brackets had to be slightly modified to be able to mate the two sections together; this also had the side effect of increasing vertical mounting space for such components as torpedoes and sensor equipment. In this design, the camera box was moved to be slung under the top tube, which is offset by some short length so the lower tube sits flush with the back of the box. The clasp was also reoriented to face downwards. Additional brackets were also needed for proper spacing and reduction of deflection of the tubes.

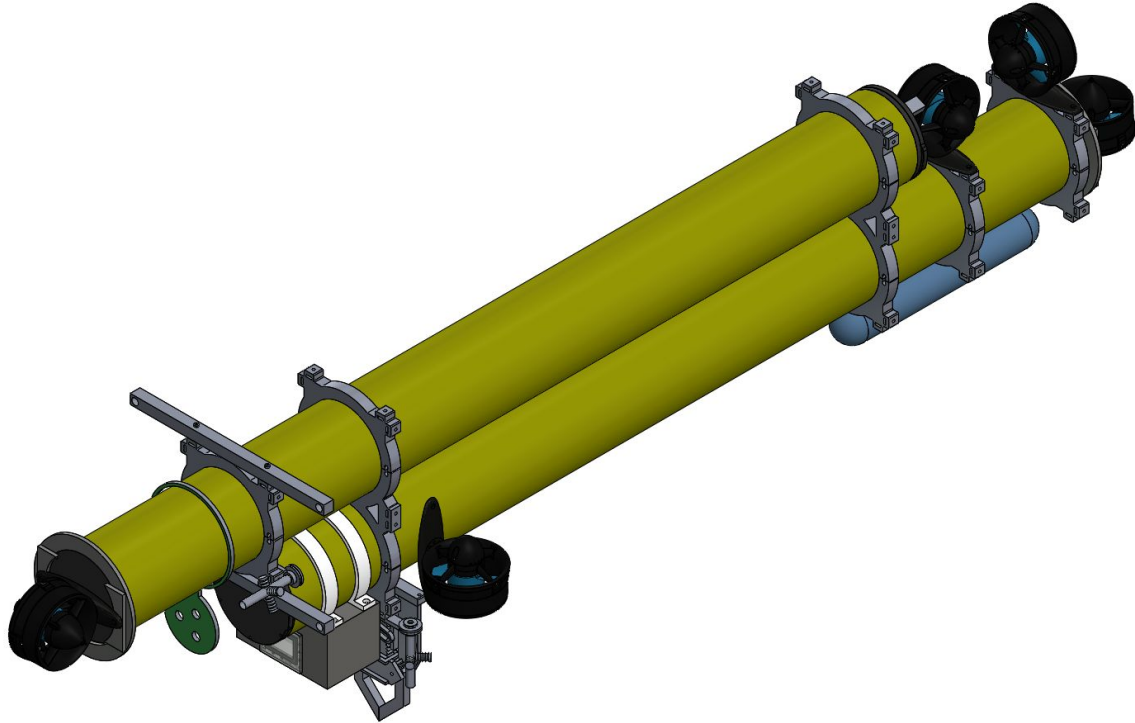


Figure 2.3.3: Current design

2.4) Camera Box

The second iteration for the camera box involved using a rectangular PVC box which had two acrylic windows, one facing downward and one facing forward, and an internal mount to support the cameras facing in each respective direction. It was to be mounted to the hull via two C-clamps.

The third iteration saw few changes to the camera box design. Initially, the acrylic windows were to be mounted to the acrylic with some adhesive. Further design work deemed it necessary to include rubber seals to ensure there would be no water leakage. The acrylic windows were to be secured to the PVC with several screws to ensure a tight seal between the rubber gaskets and the adjoining surfaces. Also, a rubber gasket was added to the seal between the PVC box and the hull to further ensure a water-tight fit.

2.5) Clasp Design

The design of the clasp also underwent drastic changes from what was originally envisioned. Before the guidelines were received, it was thought that a simple prong to lift the object would be sufficient. This idea was quickly dropped after the guidelines were known, since the control systems would be too difficult to program and objects needed to be manipulated more carefully.



Figure 2.5.1: Prong design

An overhaul of the holding system was needed; thus, the idea to use a pneumatic claw was formed. Due to the desire to use pneumatics to actuate and fire the torpedoes, it was thought that such a claw would be relatively easy to design and program. However, after thorough discussion, it was decided that the design was too mechanically complex and the pneumatic actuation would be difficult to design and implement, in addition to the fact that it would add unnecessary weight which could be avoided by using an electric system. In addition, not enough work was done to successfully implement the claw - little effort was made to integrate it with the rest of the system or to make sure it would fit the design requirements.

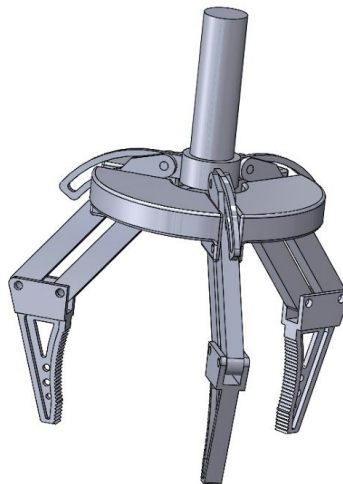


Figure 2.5.2: "Claw" grabber

The final and current design was discussed thoroughly to expose any shortcomings and weigh them against the desired qualities of an ideal clasp system. The pincer, shown below, is robust, easily fabricated, easily actuated, and can be integrated with the rest of the submarine through the use of two bolts. In addition, it can be easily expanded or reworked to fit the final design requirements. While currently 3D printed to reduce cost and weight, all parts can be relatively easily machined due to their 2D shapes and simple profile, requiring no “specialty” tools; this would increase the strength of the design as long as the servo is capable of holding the object under load.

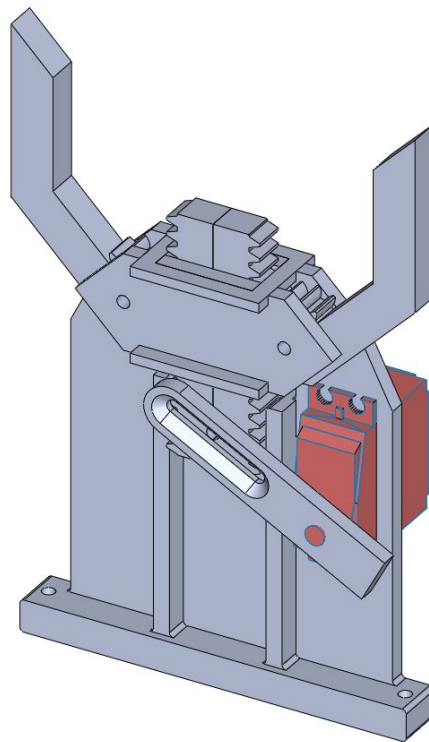


Figure 2.5.3: “Pincer” clasp design

2.6) Torpedo Design

The original torpedo design was to use a compressed air tank to power the torpedo pneumatically. The use of the compressed air is easy control, creates a force strong enough to drive the torpedo and the pneumatics, and can also be used for other systems included in the sub design such as the clamping system and release of the markers. The figure below shows the original design chosen for the torpedo. The metal tube inside of the blue torpedo shell would be permanently attached to the frame and have a ¼ inch standard pipe threading to attach the tube from the pressurized tank to a solenoid. To fire a torpedo, a pneumatic solenoid will engage to

release compressed air. Due to the snug fit of the torpedo on the tube, the design will also use these in the vertical position so that the torpedos will also double as the marker droppers.

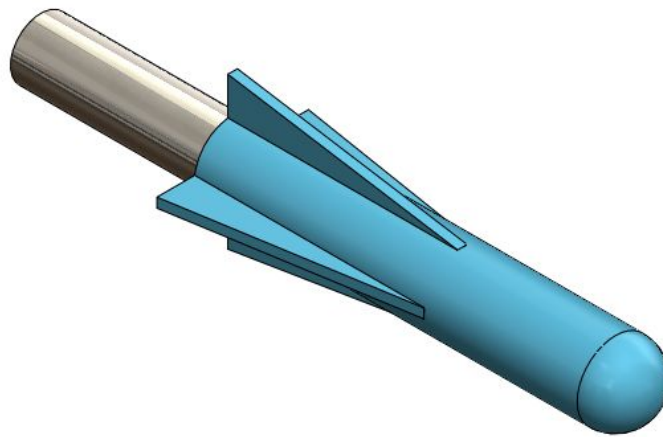


Figure 2.6: torpedo design

2.7) Light Structure

Light is an electromagnetic radiation that is usually within a certain portion of electromagnetic spectrum. The word light basically refers to any form of visible light that may be visible to human eyes as well as being responsible for sense of sight. In addition, visible light is basically defined to have wavelengths ranging from four hundred to seven hundred nanometers, or 4.00×10^{-7} to 7.00×10^{-7} m, which is between the infrared, the longer wavelengths, and ultraviolet, the shorter wavelengths. The wavelengths are usually used in implying the frequency range of approximately 430 to 750 terahertz.

2.8) Internal Frame

Having one tube three feet long made it hard to the team to compact all the electronics together in the sub. the difficulties that were faced concerned contacting the wires, and the heat that was created within the sub.

2.9) Electricals and control system

2.9.1) Sensitive Circuit

There was an overall idea for the system which had its details sorted out as the design progressed. There was no concrete circuit diagrams for the sensitive circuitry. Over winter break, the electrical engineers made progress on the details and did some testing on the configuration of the Raspberry Pis with I2C protocol. This lead to further changes, such as use of Bucks for the 5V power going to the electric speed controllers (ESC) and splitting the 5V batteries, with one going directly to the ethernet hub and the other supplying the rest of the sensitive circuit.

2.9.2) Power Circuit

Not too many changes have happened with this circuit, except for the addition of a relay to shut down all power from the batteries. It would be dangerous and expensive to have all 80 amps of the batteries go through a switch. Instead there will be a relay system in which the batteries would be supplying the coils to the relay with the waterproof switch just activating the main power relay.

2.9.3) Main Splitboard

The details of this board were not clear on the last revision, however, a single design was created after learning from the mistakes of creating the first motor board. This allowed errors to be seen and avoided before they happened. Such as the layout, including the ribbon cable connect and the 8 pin I2C connector. The electrical engineers also made the circuit before the intended attached boards had arrived, which lead to designing the 2.54mm socket layout for the boards to interface with. This proved slightly tricky, however it was accomplished.

2.9.4) Auxiliary Board

The details of this board were not detailed in the previous design. The overall functionality had to be locked down, which did not happen. So this board is dynamic in it's function. It was known that it had to activate solenoids, and detect pressure in the water. Later design parameters required the implementation of multiple water detecting circuits. This was not tested until the development of the circuit.

There were 2 options for water detecting within the sub's hull. Option 1 uses a humidity sensor, with a known safe measurement of ambient atmospheric humidity. In the event of a seal failure, the humidity sensor would detect the subtle change and alarm the sub to surface as soon as possible. Option 2 is using salt soaked rags or cloth of some sort, with conductive thread interwoven into the cloth, the sensor would detect the smallest mist. This detector was devised as a rudimentary and simpler way of detecting water in the sub. The sensors are very local, however the sub is only prone to leaks at the ends of the tubes and in the cutout for the camera box. With 5 sensors, the sub could detect a leak and alarm the main control system.

Solenoid activation would more than likely be at a different voltage than what the control circuitry would be running at. To design with this, the electrical engineers implemented an H-bridge system, with each half H-bridge driving a solenoid. The board will also (and does currently) allow for the introduction of an opto-isolator. This is to combat any current spikes from the inductive loads of the solenoids from affecting other parts of the sensitive circuit.

2.9.5) Motor Control

The electrical engineers had tested the setup for the 3 phase motors with the Arduinos implementing an I2C interface. This ironed out the details of controlling the motors and allowed for the design, and manufacturing of the motor control board. Once the initial design was proto-boarded, there had been some trouble shooting. During this stage, the electrical engineers determined that the ESCs used relatively high amounts of 5V power. This accounted for the use of buck converters to supply the ESCs with enough 5V power to operate.

Testing of the motors was a priority for the sub. The electrical engineers have tested individual DC pumps for the prototype. These DC pumps do not supply enough power, nor reversible thrust for the sub to utilize. The introduction of 3 phase motors was a risky endeavour. Previous electrical engineer capstone teams had difficulty with some of the computer to Arduino interfaces that are purely programmatic in nature. However, advice from graduate electrical engineers suggested the use of I2C communication protocol in order to control the system. The team had luck with testing and decided to further the design.

Tests began over break which lead to the use of a Arduino Micro which was receiving I2C communication commands and translating those commands into PWM signals that would then be sent to the ESCs. The ESCs take a 1100 to 1900 microsecond delay signal in order to work. Better documentation of the control of the ESCs can be found at the Blue Robotics (BR) website. The BR ESCs are an on-market ESC from Afro. However, the BR team managed to update the Afro ESCs firmware in order to run both forwards and backwards, an essential ability for our sub. Engineering time for remaking the firmware would not have been time added value to the submarine.

Protoboarding, testing, and designing lead to the motor circuit that the Trident will use for the time being.

2.10) Software

2.10.1) Overview

An autonomous submarine demands the use of large and intricate programs. The electrical engineers on the team have an emphasis in Computer Science (CS) so there was some known ways of going about the submarine programming. A large intricate program would be easier to make and would make more sense if done with Object Oriented (OO) programming. Higher level languages use this type of programming in order to make all the complexities and difficulties of complex and large algorithms and control structures tangible for a person to program.

Python was the programming language of choice for its ease of use and the possibility of other team members who are not as skilled in programming to possibly help. Python also has a large user community of programmer enthusiasts which proves itself to be very useful.

2.10.2) Visual Module

Previous work on this module for prototyping showed that the submarine will need much programming. The open Computer Vision (openCV) module does reduce our programming time and is open source. However, the module is difficult to install as it was found to require a virtual environment which is hard to access from the computer start up code. A reinstall is most likely in the near future to fix the issue of the need for a virtual environment.

The electrical engineers will also need to utilize the line segment function which will allow the Trident to detect certain Line patterns instead of just lines. This will take some extra work as the software the openCV does most the work but the abstract concepts still need to be developed.

As many mentioned previously the use of openCV libraries greatly reduces programming and mathematical calculation, that can be spent elsewhere. There are built-in functions that make the flow of line detection somewhat straightforward. There are functions to capture an image, storing it in memory is optional. There is a function to convert to a more workable color scheme, HSV, rather than BGR or RGB. There is a function to create a mask to look for certain colors, and then a function to look for edges, and one that looks for lines. All of these functions are very helpful but need to be arranged properly with correct parameters, or the results will still be undesired.

2.10.3) Motor Module

Software to use with the motor board had to be developed with the boards. Lots of the obstacles are detailed in the previous motor board section. The course of development went through trying to create an I2C interface that would send data reliably to the Arduino. This then led to parsing the data into usable commands to send to the ESC's as a ServoWrite function. This then led to the development of the Python end code which was OO and allowed the team to easily create a code that would just would easily control the motors.

2.10.4) Auxiliary Module

I2C protocols are used to communicate between the Raspberry Pi and Arduino. This is a master / slave setup. The Raspberry Pi uses various read / write I2C statements to access the Arduino. Various changes have been made to this program, mostly additions, which are

miscellaneous functions in the class to account for new hardware functionality being added to the Arduino. For more details see section 3.11.4.

2.10.5) Main Abstract Drive

Ultimately there will be one main program on one of the Raspberry Pis that has control of the entire submarine. Everything will communicate to this main program either directly or indirectly through some other program. Data from all sensors including the camera will be read and instructions can then be sent to the motors. This is a major simplification of what is really going on. Many parameters have to be accounted for along the way. This final main program has not yet been created. A scaled down version of a main program was implemented with a rudimentary line detection algorithm, a motor module that controlled two liquid pumps and a first physical prototype. The result was a dampened response from the motors to the line detection algorithm. They would slowly over correct less and less. The thrusters will make this process quicker, but along with quicker thrusters the code has to be more responsive.

2.10.6) Multi-Platform Manager

To make the submarine process data, images, sensor data and compute faster. The use of many cores should be implemented. There are computers today which have 2 or 4 cores built in; utilizing these cores efficiently in terms of actual computation time, and in development time is a tricky task.

The Trident is a narrow hull sub, which means that the biggest computer dimensions the sub may hold is 4 inches at the bulkiest point. This is small dimension, however the use of the small yet powerful RPis allow us to really compute for the sub. Each RPi has 4 individual cores on them, so even with a modern fully fledged computer, the same multi-core platform would apply. The multiplatform is great for true separate processing, as much as there are truly split cores on a computer, there is still the low level Binary Input Output System (BIOS) that will limit the processing power; think of it as the head of a juggler - the juggler can have as many hands as you have truly separated cores, however the thought to manage all those hands comes from one spot, the jugglers mind. If one were to have 2 jugglers, I.E. two computers, all they must do is agree upon who will juggle what. That is where the benefit of the a multi-platform computer comes from.

There are really 8 cores the sub can utilize in computing, 2 RPis with 4 cores each. Technically the cores aren't hyper threaded like some fully fledged computers, but the sub will still be a computing powerhouse. The same way to manage different threads on a computer with python can be done to manage the different cores. Some cores need to be threaded but that will be talked about in the next section.

2.10.7) Thread Manager

A thread essential would be a juggler who is juggling objects. While the objects are in the air, the juggler may do something, maybe read a book or get a glass of water. The same idea applies to a computer, but instead of objects, they are tasks. All the juggler must do is check every once in awhile if it should catch, redirect, and throw the object. The computer on the other hand would notice it needs to do something, compute it, then wait for the next task. So instead of having a linear block of code, the computer can do something while waiting for another task. This is useful, for the I2C communication which is slower than the computer, and in the networking applications such as the juggler getting a glass of water while waiting on an object to be thrown to it.

In the case of the submarine, the things to be juggled are the PID loop computations, the I2C commands, update commands, motor commands, data reads, RAM reads, USB file read and writes, network communication, and the most useful and easiest to grasp timers.

The whole idea of threading was not delved into nor was it anticipated until the development of the motor manager. Which showed the programmers that there needed to be a while loop always computing the PID and calculating the next move, however accessing the parameter to change to move the sub was the determining factor for creating a thread.

3.) Newest Design

3.1) Introduction

The current design is in the fabrication process implementing the changes discussed in the previous section. Along the way much testing will need to be done to ensure desired results.

3.2) Thruster Layout

The orientation of the motors needs to correlate with the motor module in programming. This lead to this design, the plane motors create a stable platform while the yaw turning motors and translating motors may tilt the sub, the program can counteract these movements. Forward motor as seen will pitch the sub downward, however the program will engage the forward plane thrusts more to counteract this pitch. Same can be said about the 2 rotation thrusters, when these engage, the roll of the sub will change, however the plane thrusters can counteract these movements.

With the given positioning, and the motor control algorithm, the sub will be able to move through the water as the main abstract drive will intend it to.

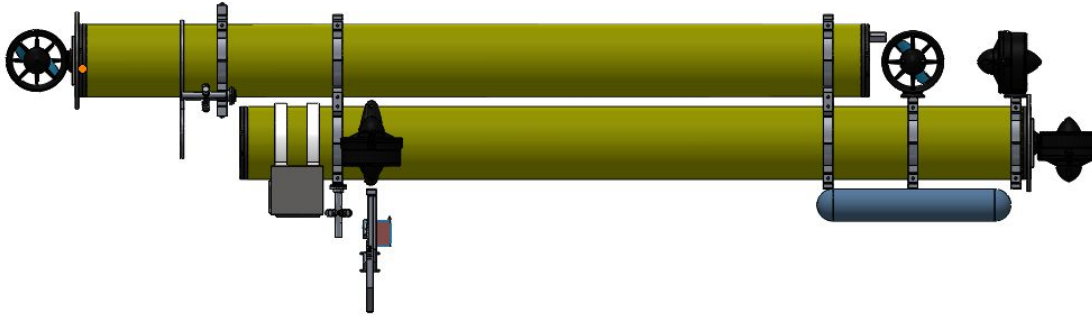


Figure 3.2 : Current turbine mounting positions.

3.3) Hull Design and External Brackets

Currently, the hull is a two-tube system held together by U- and X- shaped brackets. The decision to shift to two tubes instead of a larger diameter one is detailed above in Section 2.3. This design allows for optimal layout of all external and internal systems; depending on total weights of the subsystems, they can be rearranged in order to provide the most balanced arrangement as well as having it be neutrally buoyant in the right orientation. Ideally, the layout would be such that the submarine is horizontal and any force exerted in a specific (translational) direction would not result in any rotational force (torque), which eases the calculations necessary for movement of the submarine. The hull material is rigid ABS plastic intended for use in medium- to high-pressure irrigation systems and so fits the current usage well; no issues are expected from overpressure of the tubes, and the forces exerted on them are nowhere near breakage point

Also the team has designed the front and back brackets as is shown below, which is used to mount thrusters, the brackets is attached to the end caps, so that it is easily to remove from the sub when the team needs to replace the interior components.

The external brackets were designed with the idea in mind that various components could be easily mounted to it without drastic design changes; whereas other submarines are shown to require unique mounting systems for each component, this frame reduces time spent on design of such systems as long as a standard distance between attachment points (110mm) is used. The current frame is expected to be 3D printed to reduce labor time as well as waste material that would be generated from traditional subtractive manufacturing; in addition, since the frame does not undergo high stresses, the strength of metal is not needed and weight is saved. There are two types of bracket currently used, the U-type and X-type. Both can be used in any combination for any linear amount of tubes; the design of the submarine as-is only calls for one X-type per set, however. The brackets are tied together with figure-8 shaped “keys” which slot into grooves on the mating surfaces.

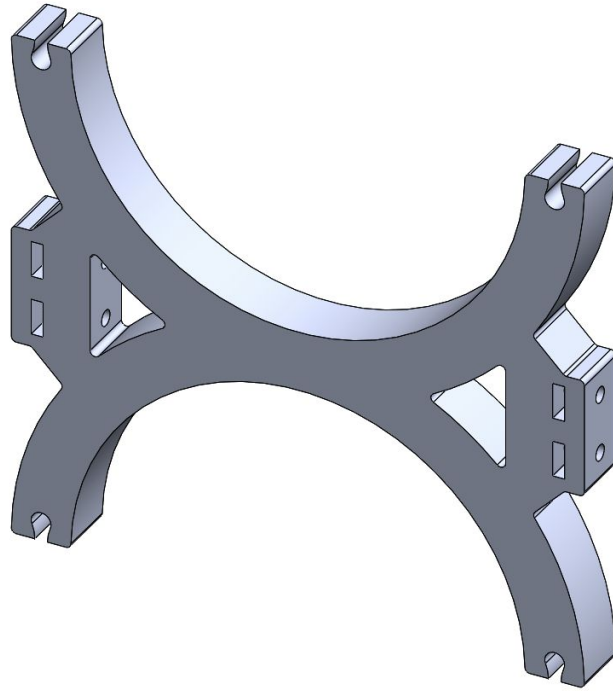


Figure 3.3.1: X-type bracket

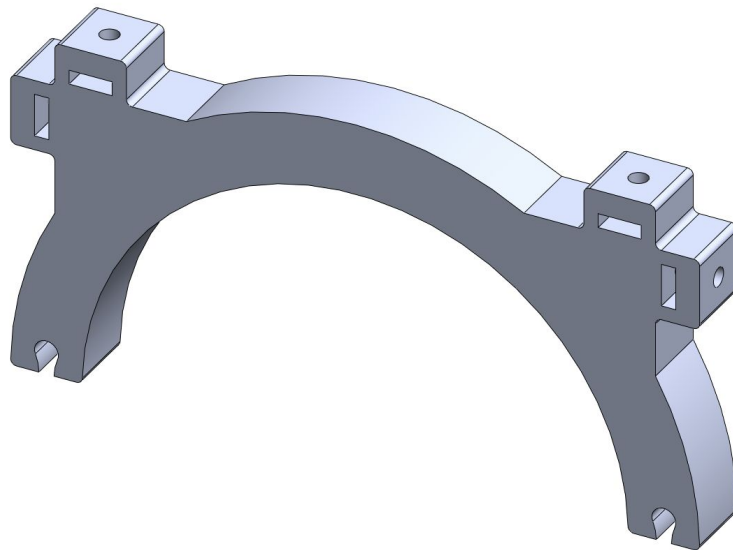


Figure 3.3.2: U-type bracket

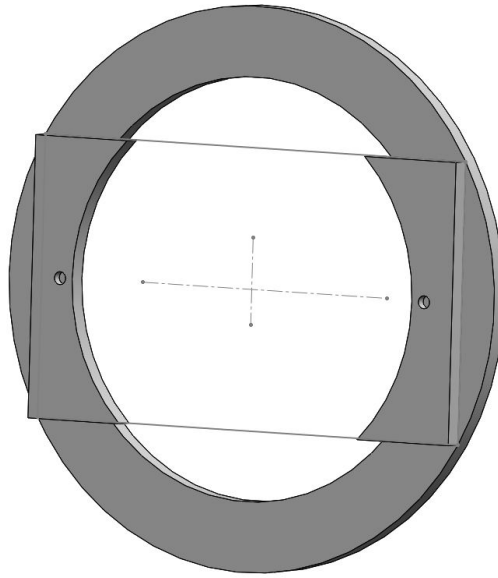


Figure 3.3.3: front and back bracket design

3.4) Camera Box

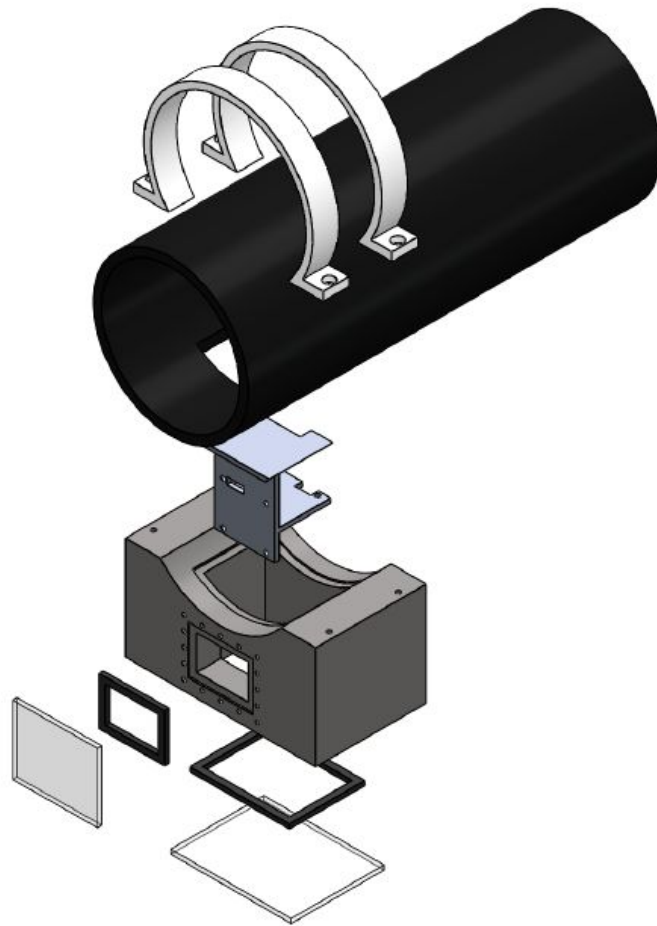


Figure 3.4.1: Semi-final camera box design

The most recent design for the camera box again changed the means by which the acrylic windows will be attached to the PVC box. Because the PVC material used in the construction of the box is so brittle, it was deemed too risky to tap the screw holes needed for the mechanical fasteners. Without a mechanical means to ensure a tight fit between the surfaces and the gaskets, the gasket will not function properly. As a result of this complication, the design was changed back to using adhesives to seal the acrylic window to the PVC box without a gasket. Research online determined that a consumer epoxy, Weld-on 40 (called an “acrylic cement”), would be able to create a water-tight seal. In addition, silicone sealant will be applied to the outer edge between the acrylic and the PVC (see figure 3.4.2)

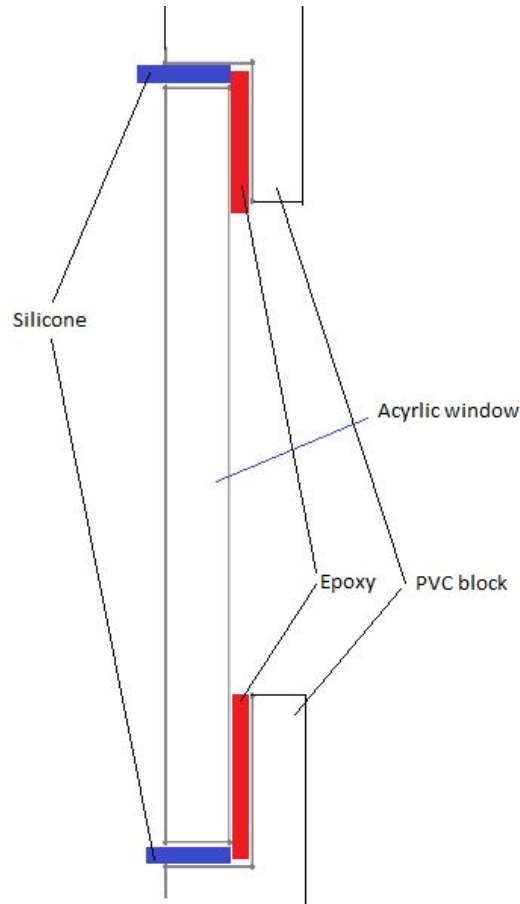


Figure 3.4.2: Side view diagram of epoxy seal for acrylic window

Otherwise, the design has not changed and is ready to be completed. The rubber seal between the PVC block and the hull has remained as the C-clamps will still be implemented thus ensured a water-tight seal. PVC cement or silicone sealant will be added to the extra surface between the block and the hull to completely ensure that the seal is water-tight.

3.5) End caps

The main concern with designing the end caps to fit on all four ends of the tubes was to create a system which would allow for easy access to the electronics within the submarine. Another consideration was to make at least one end cap out that would help allow for the heat from all the electronics to escape the system. The design chosen for these requirements is the O-ring assembly shown below with the use of an aluminum cap fastened directly onto the end. The aluminum cap was chosen because it will allow for some of the heat to be removed from the sub by making direct contact with the cap and the batteries used. It can be seen in the picture that the end cap uses 3 gaskets to prevent the water from entering including the gasket placed at the contact surface for the aluminum end cap.



Figure 3.5.1: Blue Robotics O-Ring End Cap Seal

Another reason to use the aluminum end cap is that it allows for holes to be easily machined in order to create through ports for the cables in the system. There will be one cable, DB25, that will need to be connected between the two separate tubes as well as multiple tubes going out of each tube. The figure below shows all of the cables that will come out of the top and bottom tubes at both the front and the back. The cables that are shown inside of a red box are the cables that are used for testing purposes and are removable. Once the sub is in the final competition, these cables will no longer be needed. The external power source that is being used for testing will be replaced and the ethernet will not be used.

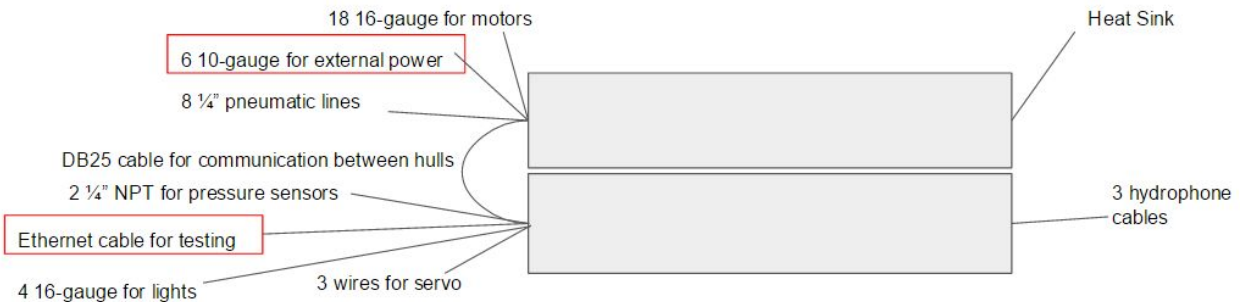


Figure 3.5.2: Through Ports Diagram for Cables in the Tubes

Below is a picture of a cable penetrator that Blue Robotics makes for their thruster cables. This system may be implemented into the design to provide an easy way to seal the cable entrances in the end caps. Below, a diagram of how the cable penetrator works by using a hollow screw with a gasket can be seen. This option is available in the pre-machined thruster cable size, or as a blank piece that can be drilled out to the desired cable size.

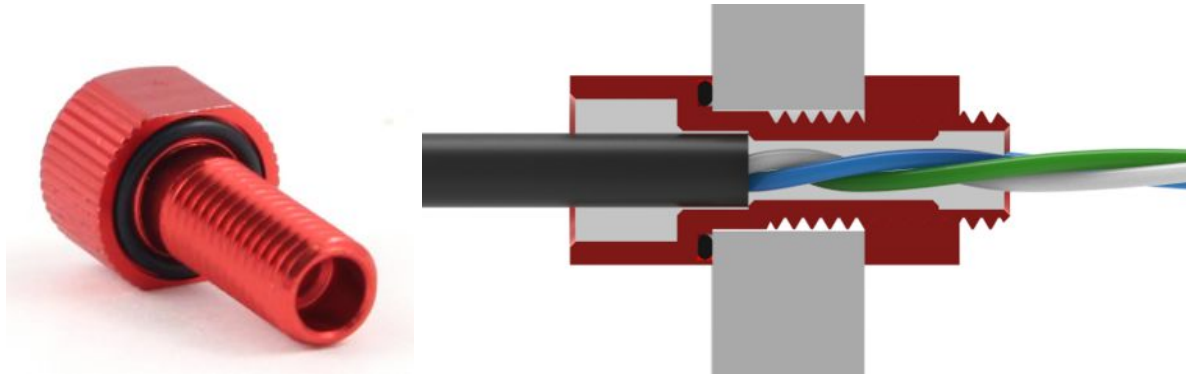


Figure 3.5.3:BlueRobotics Cable Penetrator

3.6) Clasp Design

The current clasp design is made to be robust yet easily expandable. Due to the simple 2D-profile design, it would be possible to make the parts from sheet or machined material (preferably aluminum, possibly steel or polymer) for increased strength in the unlikely case that it is needed. The clasp is designed to have a slim profile to fit as directly behind the camera box (detailed in Section 3.4) as possible in order to reduce parallax and reduce/ease the work done in programming the manipulation system. The system can also use both a servomotor and a pneumatic actuator; despite being currently designed for the former, it can be easily retrofitted with an assembly which replaces the sliding pin-in-slot linkage with one that is attached to the actuator. Attaching the clasp is a matter of putting bolts through the two mount holes on the lower frame and securing it to the versatile brackets on the hull. From there, wires from the servomotor or pneumatic actuator can be run into the hull through the back through ports.

3.7) Torpedo Design

The new torpedo design is still to use a compressed air tank to power the torpedo pneumatically for the launching system, which creates a force strong enough to drive the torpedo and the pneumatics, and can also be used for other systems included in the sub design such as the clamping system and release of the markers. The main change in the design is to add 3 ball plungers screwed inside of the torpedo tubes, as is shown in Fig.3.5, the purpose of using the ball plunger is considering the ball plunger has a spring system, which can lock the torpedo inside of the tube, so when the sub is underwater, the pressure of the water won't move the torpedo. The back torpedo connector would be permanently attached to the frame and have a ¼ inch standard pipe threading to attach the tube from the pressurized tank to a solenoid. To fire a torpedo, a pneumatic solenoid will engage to release compressed air, which unlocks the ball plungers and shoots the torpedo.

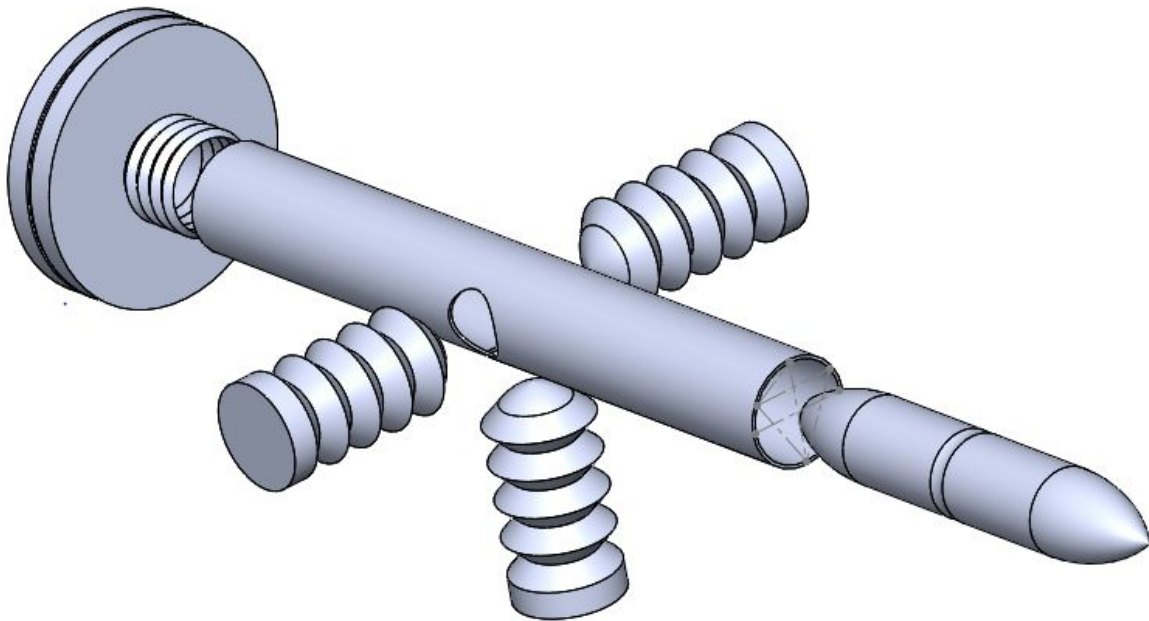


Figure 3.7: Torpedo design

3.8) Light Structure

The model of the light structure has two holes for the LED lights. The maximum depth for the light is 500 ft; the lamp has 3 ultra-bright (30 lumen) LEDs which are also powered by an aux board. This type of solid work design commonly is referred to as LED light. This form of light is usually a two-lead semiconductor source of light. It is usually a p-n junction diode that basically emits light when it is activated. When suitable voltage is applied specifically to the leads, the electrons and electron holes are able to recombine within the device, which leads to the emission of energy that is in form of photons. The effect is usually referred to as electroluminescence. The advantages of the light is the board has a plug and play replacement, which makes it easier to replace and thicker for stability purpose. Also it can sustain heat among other factors. These factors fits for the expectation of robosub design.

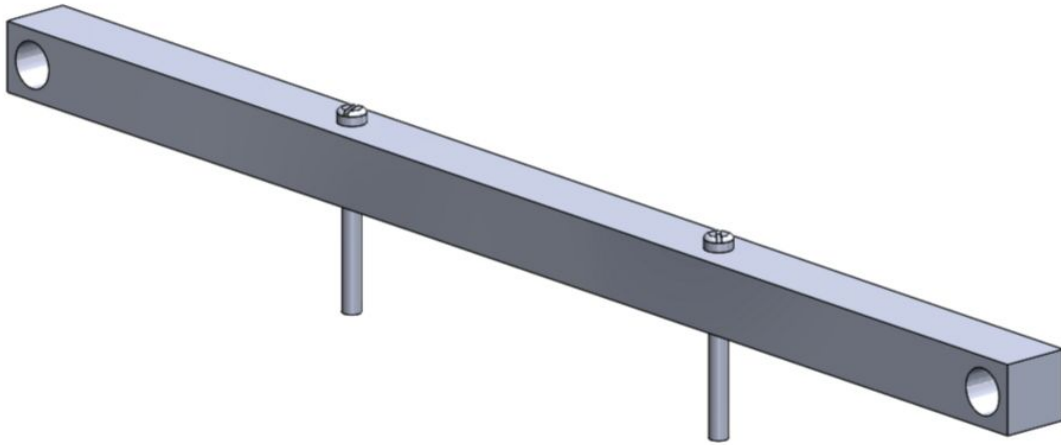


Figure 3.8.1: Light frame

3.9) Internal Frame

The new design of sub has two tubes because there are a lot of hardware. The first tube is the high power tube, this tube will be oriented on the top. The other tube will be in the bottom. It will contain the sensitive electronics (See figure 3.9.1)

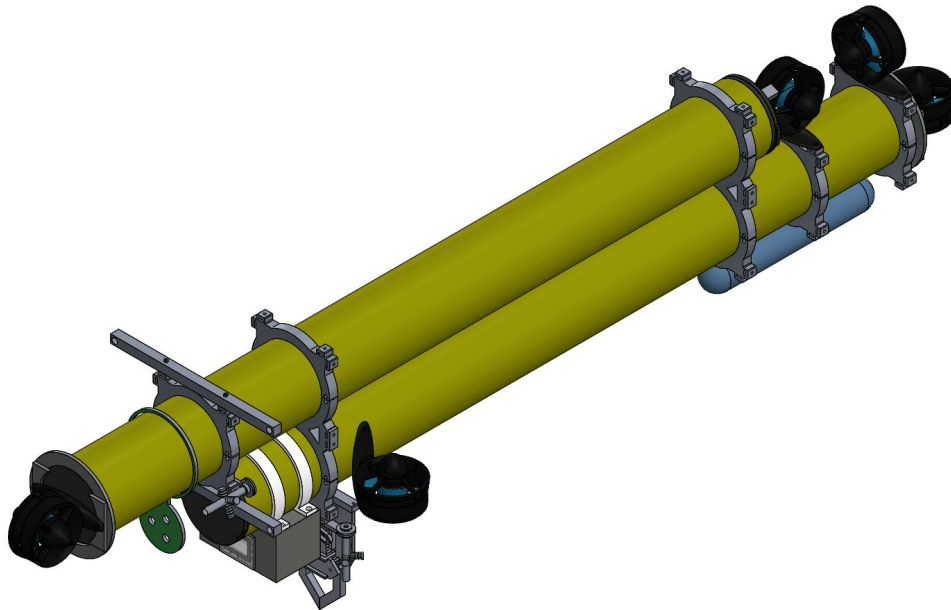


Figure 3.9.1: Both tubes contain electronics

making water detectors to detect any water leaking to avoid any damages to the sub as well as for the safety to produce the lithium battery. the sub will have five water detectors. Two of them will be on the upper tube, the first one will be on the front and the other one will be in the back. The other three will be in the bottom, two of them will be oriented as the first two water detectors, and the third will close to the camera box hole.

Making multiple sections for different parts will make it easier to change any part has a problem. The sections we made for the high power tube are, main motor batteries towards the front, buck and electric speed controllers (ESCs) in the middle, and solenoids and connectors in back. For sensitive electronics tube on the bottom we put sonar and Raspberry Pi (RPI) and boards towards the front, Hubs in the middle, small batteries and connectors in the back (See *Figure 3.9.2*).

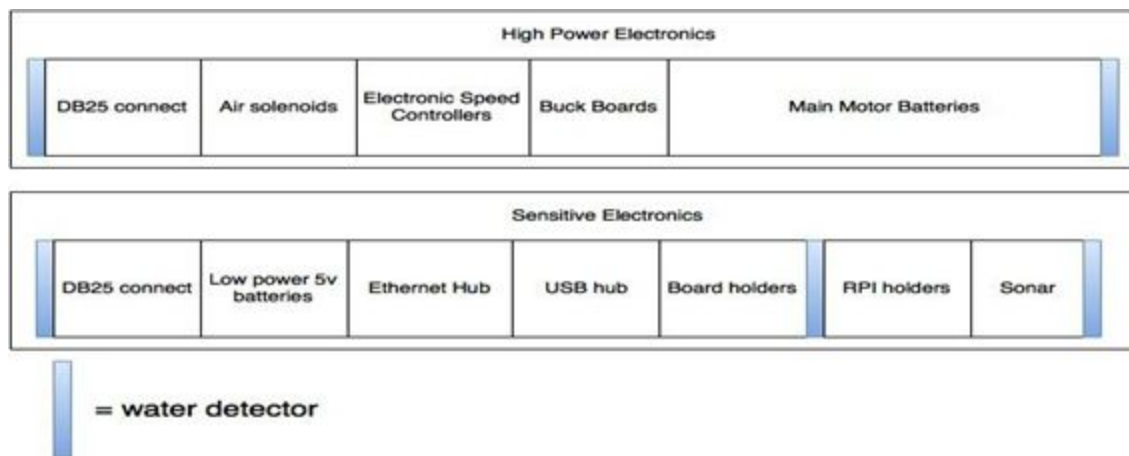


Figure 3.9.2

Since the sections are very complicated to manufacture, we have to use 3D printers to manufacture them. Each section has a big enough gap to avoid the heat and any electrical faults. Each section has two holes on the top and in the bottom, in order to attach all the sections to install them in the sub.the average of thickness for each part is one inch, to give enough room for the wires (See *Figure 3.9.3*).

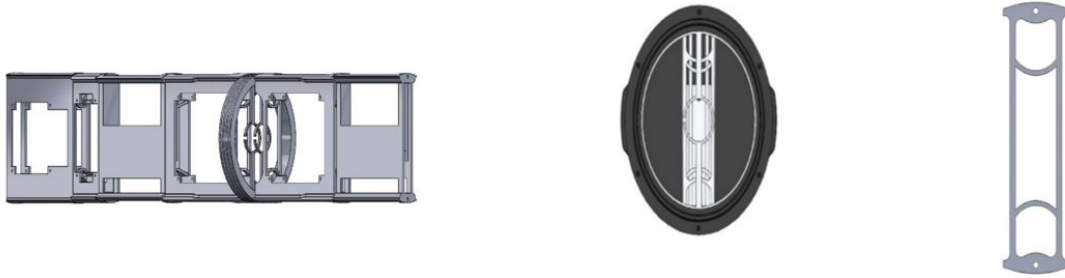


Figure 3.9.3

The electronic speed controllers (ESC's) will generate a lot of heat inside the sub. This heat might affect a lot of the sub's parts such as the wires and the lithium batteries. We have made heatsinks to absorb the heat. Even though it was not enough because the sub is closed. As well as the insulation because of the type material that is the tube is made of. We made the end caps to be aluminum in order to reduce the amount of the heat.

3.10) Electricals and control system

3.10.1) Sensitive Circuit

During development of the main control circuitry, the electrical engineers encountered many obstacles, and have designed around them. This portion of the circuit is currently comprised of the main computers, cameras, the Arduinos, the IMU, and the sonar circuit. Some components were bought while others were designed, built and tested. A concern is the high inductance from the power portion of the circuit power spiking the ground of the sensitive circuitry. Another concern is the noise from the 5V batteries regulators affecting the sonar circuit. The sonar board development is postponed until a majority of the sub working. The circuit design may isolate power from the sensitive portions once the majority of the sub is mostly done, the sub will still work, but most likely will not allow the sonar circuit to work as is. An overview diagram of the Sensitive Circuit is below, details of individual boards are in Appendix E.

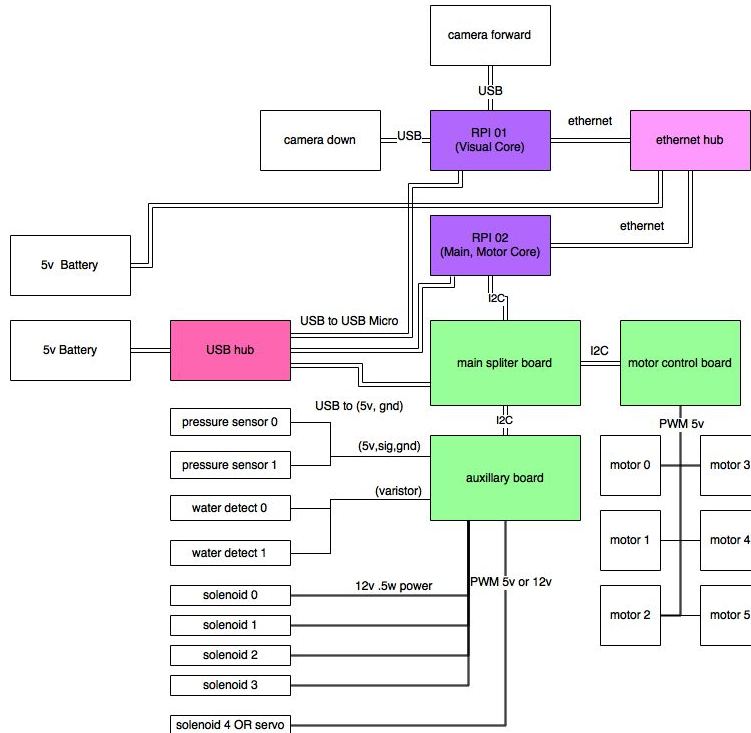


Figure 3.10.1.1 Overview of sensitive circuitry.

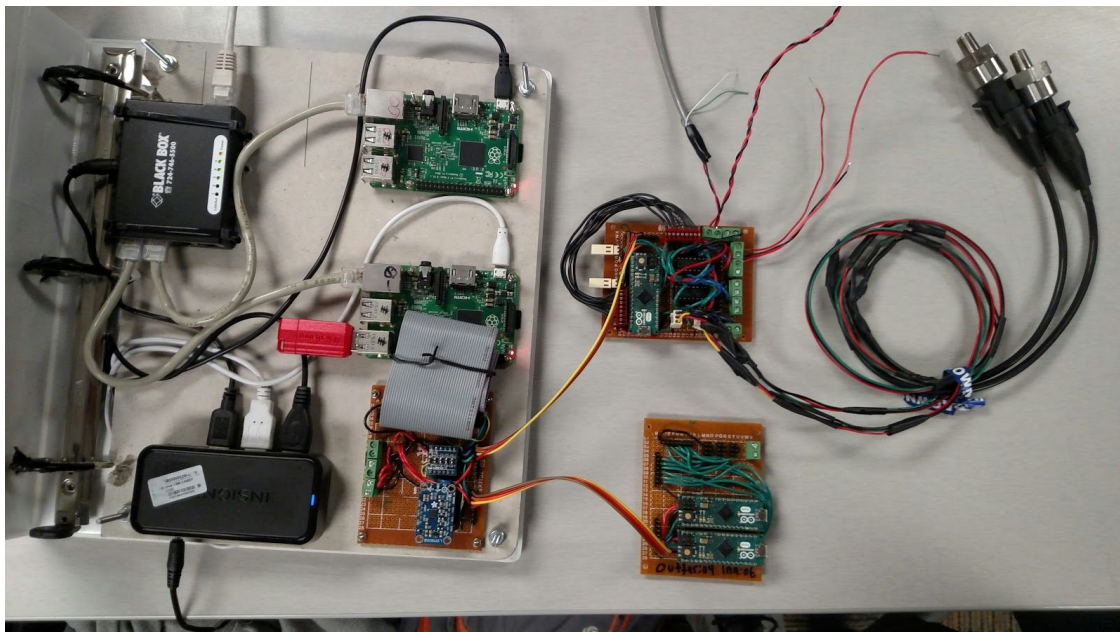


Figure 3.10.1.2 Test setup of sensitive electronics system.

3.10.2) Power Circuit

The power portion of the sub requires the control of roughly 1 Kilowatt of power, this is quite the task given our limited space. The Power portion uses ESCs to convert DC power from the batteries to 3 phase motor output to our water turbines. Other high power portions include the H-bridges powering the Solenoids and servos for the torpedo and clasp system. The ESCs require a constant source of 5V power which are supplied from 2 buck converters which are being supplied by the main motor batteries. The main motor batteries are meant for the powering the motors and the ESCs. The main motor batteries can be shut off with a relay system which is activated by a waterproof switch on the outside of the sub. This circuit has been tested with an individual motor set up and does work.

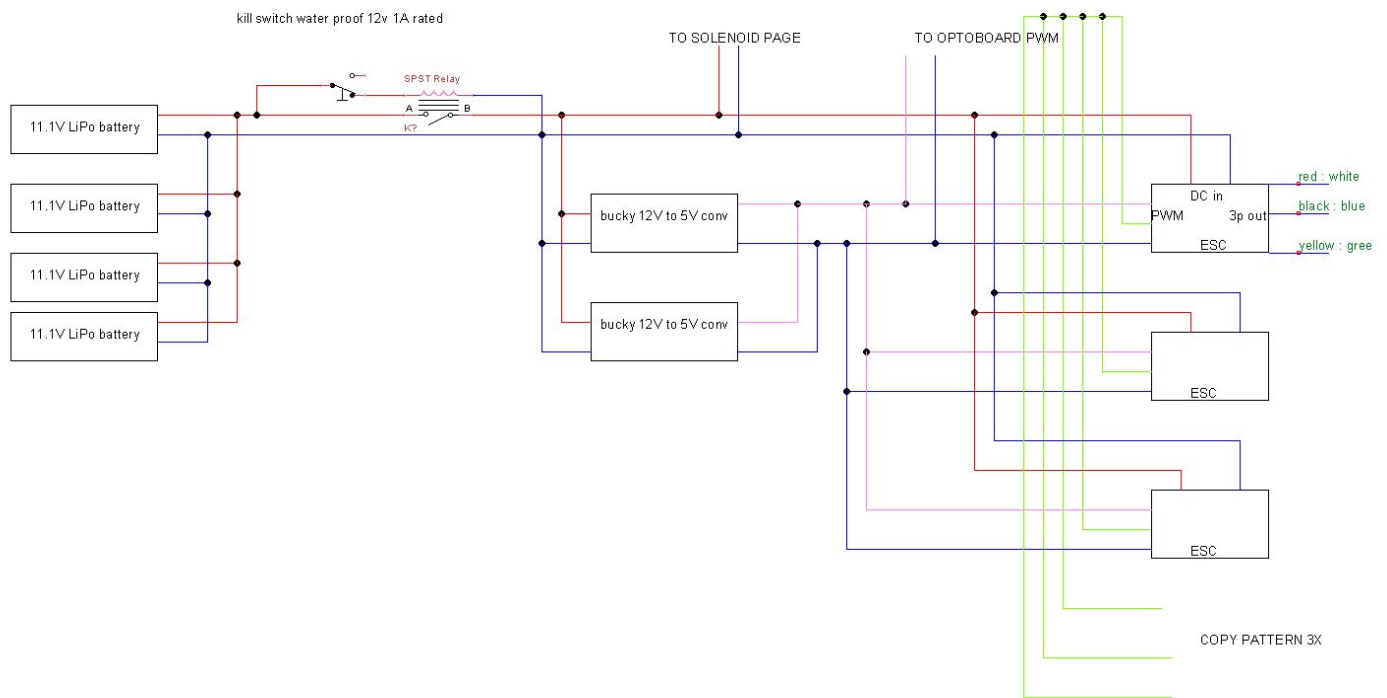


Figure 3.10.2.1 Overview of power circuitry.

3.10.3) Main Splitboard

The Sub uses an I2C interface to communicate with all its sub systems, which can connect to other boards with this board. This board is mostly a routing board with a voltage signal transform board, which would have been a waste of space, so this board also incorporated

the IMU with it. The Main split board also serves as a way to power the Arduino boards which need the regulated power from the battery packs. This Board can be expanded, and is about 70% full. The schematic of the splitter board can be found in Appendix E.

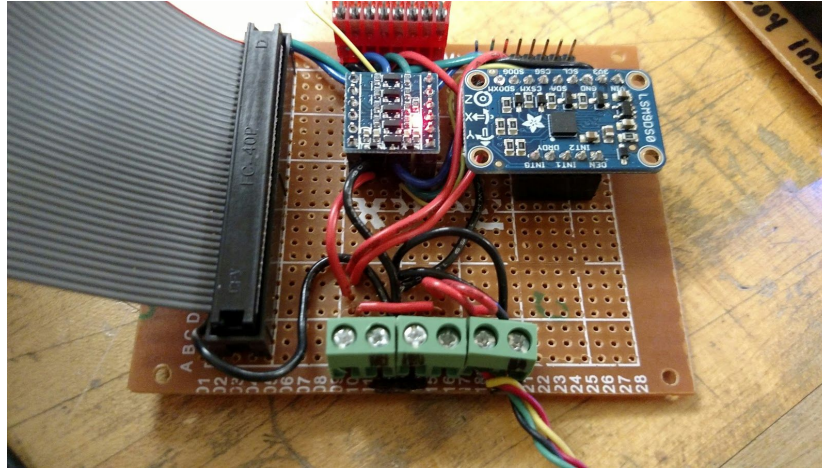


Figure 3.10.3 : Splitter board

3.10.4) Auxiliary Board

This Board Holds many functions and has been called the auxiliary board accordingly. It is responsible for the water detecting circuit, the pressure transducing circuit, turning on the lights and activating the solenoids and servos on the submarine. This circuit is just about at full capacity. If the sub needs any more functionality, another auxiliary circuit with the I2C interface can be added easily and it would work the same. In the following years, other engineering teams can develop a battery monitoring circuit. The detailed circuit diagram can be found in Appendix E. The team also devised a water detecting circuit that will be implemented in the sub incase one of our seals fail. A picture of how the water detector works can be found in Appendix B

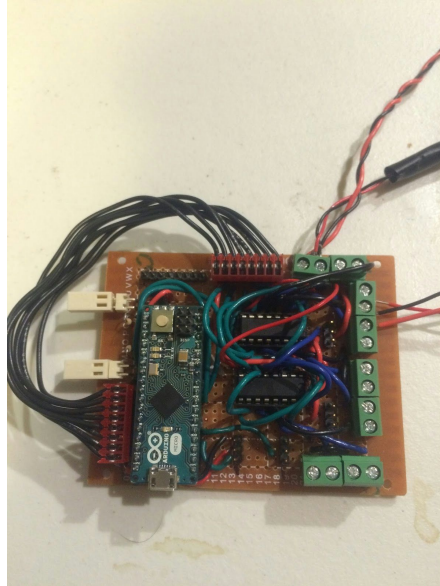


Figure 3.10.4 : Auxiliary board

3.9.5) Motor Control

The ESCs take a PWM signal and convert the DC power to 3 phase power. The point of the following circuit is to take an I2C command and translate that command into a PWM signal and then splice that signal with power for the ESCs to operate the motors. The Raspberry Pis (RPI) couldn't be directly used for PWM because an RPI may only provide 1 or 2 PWM signals each. With the 2 RPI's it's impossible to control 6 motors, nor would it be optimal to do so. Instead the current design goes with 2 arduinos controlling 6 motors. An engineering measure was to be safe with the servo output to the motors and not tax one Arduino with 6 interrupt loops, so the computation is divided. In this manner, the motors won't have a chance to lag due to internal computation time. A detailed schematic is in Appendix E. The following picture is the board the sub has right now for controlling the ESCs

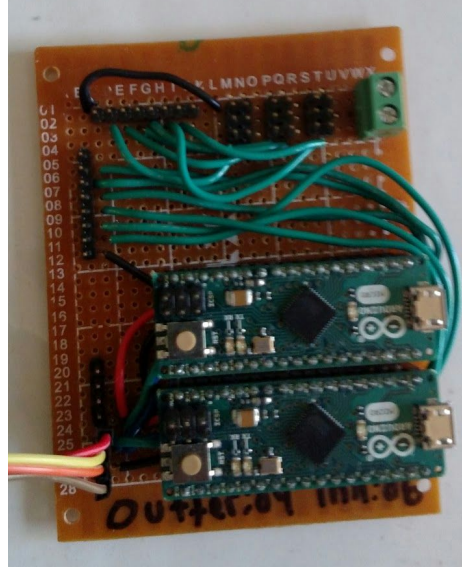


Figure 3.9.5: Motor Board to ESCs

3.11) Software

3.11.1) Overview

One of the most important aspects of the submarine is the code. The Trident needs to be autonomous, which requires a different level of programming than what the electrical engineers on the team are used to. This is a large design and engineering task. There are many parts that make up the submarine. Not only that, but the multiplatform and multitask nature of the overall sub, means that the Trident needs thread and queue managers. It wasn't known that the programs would need threads until development, but it was known there would be multicore capabilities early on.

There's a saying about what threading is in software from Dr. Otte in the NAU CS department, "Why shoot one foot, when you can shoot both feet at the same time with threading?" This just about sums up the frustrations of the learning curve the electrical engineers are experiencing, regardless, there is progress. Threading is a way to make a program quicker by allowing IO and timing holdups to be circumnavigated and to allow a core to work on other assignments. The concept is easy, but the code is quite difficult. So difficult, that the electrical engineers were not allowed to take a class with these topics because they were deemed too advanced. There has been progress on code that is threaded and multicore, with multiplatform code being developed soon. However, the multicore manager, and cross platform manager needs to be made custom for every module, which is creating issues.

Python is an easy language to learn, and is easy on syntax. It allows for quicker progress on code than other languages, even if it's not the quickest running code, there will be more sluggish code to show for all the effort this year.

3.11.2) Visual Module

The basics of this module are explained in section 2.11.2. There are two major improvements being implemented in visual module. The first is a threshold being applied to the image immediately after the image is captured. This threshold is ultimately an extreme simplification of the image. The threshold generalizes and then classifies all 256 possible pixel values into a much smaller number of possible pixel values based on function parameters and conditions set in the code. Currently our algorithm loops through every other pixel value (128 times) as a parameter for the openCV threshold function and for each attempt all conditions are checked, such as the edge detection algorithm (step in the line detection process) will run for that given pixel threshold, and then also for the next threshold pixel value. Until we have the the right conditions to find the colored line we looking for. What this means is that it can sometimes take up to 3 or 4 seconds before a line is detected, which is extremely slow in terms of computing efficiency and complexity.



Figure 3.11.2.1 Thresholding Step

The second main improvement is a blurring effect added right before the edge detection function is applied. This is also a built-in function in openCV created to blur any excess and unwanted noise out of a binary image, so by the time image gets to it there are only two color channels.

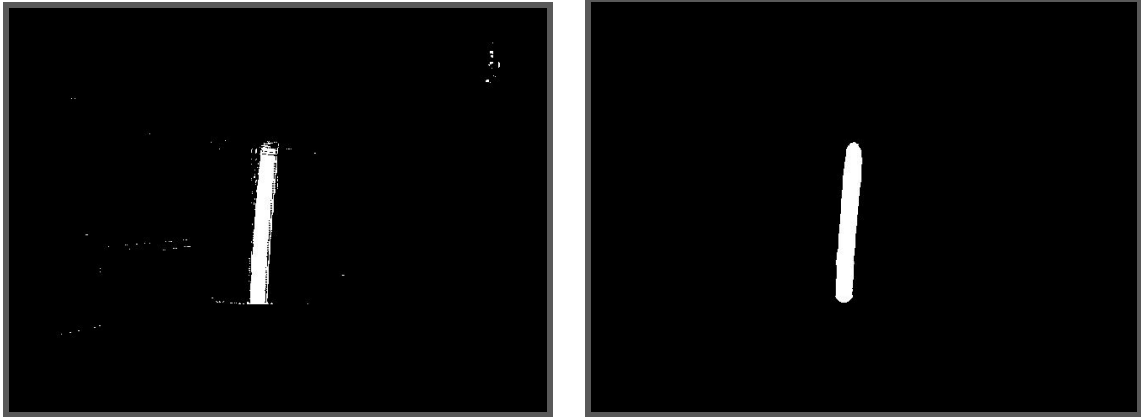


Figure 3.11.2.2: Blurring Excess Noise

3.11.3) Motor Module

The class for the Motor Module is complete with try and catch statements. This easily allows for the sub to be controlled once the main abstract drive finds what to do with the lines the sub detects. This module would have to be expanded if future development of the sub calls for more motors.

3.11.4) Auxiliary Module

The class for the auxiliary module communicates with the arduino through I2C statements. The pressure are a simple analog read on the arduino and then use I2C read statements in the python code to get the data. In the python code I2C write statements can be used to activate solenoids, which will be used for the torpedos on the submarine. The solenoids are attached to digital output pins on the arduino. The water detection circuits are attached to analog read pins, and the python can read the data with I2C read statements.

3.11.5) Main Abstract Drive

As mentioned earlier, there is not yet a final main program. The pieces are still being testing individually. Placing all the pieces together will be a final step. A piece of this puzzle that will most definitely need improvement for the main program to work smoothly will be the visual module. The visual module is currently detecting lines fairly slowly. So from image to image if there is 3 seconds of drift where the sub over corrected the camera may not even be able to see the line anymore. Ultimately the time for process of image detection and turning this into useful information and sending that information to the motors, needs to be decreased. Not to mention the motors also receive information from the IMU, and auxiliary board on what to do through the Raspberry Pis of course, but these operations are not as slow.

3.11.6) Multi-Platform Manager

There is one main core that is running all the other cores. The cores and threads from those cores communicate to the main core by means of a queue bridge which can be networked or on the local machine. A queue is a data type in programming which allows for synchronous data to be computed. This means the data isn't corrupted by accessing one piece by 2 running cursors.

The sub will be partitioned to compute different things simultaneously, thereby creating an actual working machine.

1.) main manager: this dishes out commands to the visual core and the motor core and is the link between where the sub needs to go and how the motors are going to get there. This includes how the sub should move when encountering an obstacle.

2.) PID core 1 (motor manager): This core is getting the most recent data from the IMU portion and calculating the new Proportional Integral Derivative (PID) set point for each motor. Once the new set point for each motor have been calculated and superimposed, the motors are updated through an I2C command.

3.) PID core 2: This core is accessed by the 1st PID core and will burn the PID calculation load from both ends in order to get the results quicker. While not calculating the PID, it will be crunching the statistics from the IMU if possible. This core might not be utilized other than the PID calculation.

4.) IMU core: This core needs to be independent and be perfectly timed in order to not have terrible gyro drift. This core access the I2C line which the PID cores access too, which makes IO for the RPI difficult. This needs to be an independent core because the I2C Python library is not fully efficient which makes threading the portion of the motor control

5-8.) Visual Core: 1 RPI is dedicated as the visual core. This is needed because the internal libraries are C-wrapped and already implement an multicore and multithreaded computation of the image crunching. Some programming time will be needed in order to optimize the code in order to make image crunching faster which will be detailed in the visual module section.

3.11.7) Thread Manager

There will be threads which allow the sub to have timers that que the sub to do tasks and take control. Not only wil threads do that, but they allow the backbone communication between the cores, without too much unlinear overhead one each core. This means the cores will be quicker will receiving commands even during mid execution of large tasks. This is useful for

some tasks such as the re-calibrating of the IMU and during mid move. This allows for more precise movements because the cores aren't lagging from waiting for commands but are executing and will immediately un-execute to see if they should or shouldn't keep going with a movement.

The best and main reason for threads though is the backbone of multi-core processing and multi-platform processing. Without these threads, the code would be even more difficult to execute and write.

4.) Future Progress

4.1) Introduction

Progress on the sub is ongoing and will continue. Many obstacles have been overcome and many new ones are being considered. What follows is a breakdown of the group's vision for the robo-sub's completion, including time frames and perceived issues.

4.2) Schedule for sub

The team believes that testing of the sub can start in 6 weeks. This will start the actual testing phase. Once the robo-sub is able to be tested in the water, the group will have the most accurate metric of where it stands in terms of the abilities the sub has to complete the tasks in competition. This will also represent the end of most of mechanical fabrication and beginning of the in-depth software troubleshooting. Hopefully, the remaining 3 weeks will see a sub close to ready for the competition.

4.3) Tasks in Progress and Future Plans

Enough brackets need to be fabricated to attach all of the thrusters and other subsystems to the submarine; the brackets need to be rigid and strong enough to withstand not only those forces exerted while underwater, but also of storage and transportation.

For the camera box, the acrylic needs to be cut to window sizes, the internal mount needs to be 3D printed, and the whole rig needs to be put together. Without any last minute design changes, this should be able to be completed in a relatively short time as there won't be much waiting on the shop to complete tasks as there was with getting the PVC block milled.

The clasp needs to have a finalized design; it needs to be able to smoothly toggle between the open and closed positions. In addition, a suitable servomotor needs to be chosen and waterproofed up to the depth used in the competition. In the case that a servomotor cannot be made to actuate the clasp, a pneumatic system needs to be designed and incorporated into the clasp mechanism.

The electrical engineers will have mostly programming and program integration for the rest of the duration of construction. There will be some wire running and circuit creating, however the design is 99% done electrically. There might be some schematic change up once assembly is fully underway, but proto-boarding should have eliminated most errors in our schematics.

A large issue still yet to tackle as mentioned earlier will be still creating useful information out of captured images for the motors in a timely manner. Since the image detection will be how the sub determines direction from task to task, this an important piece in the sub's operation.

4.4) Gantt Chart

week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Hardware Review																
Client Meeting																
Staff Meeting																
Midpoint Presentaion and Report																
Concept Generation and Selection																
Concept Prototype																
Prototype Testing																
Project Webpage																
Functional Diagram																
Criteria																
Final Hardware Review																
Walkthrough Presentations																
UGRADS Presentation and Final Report																
Submit Operations Manual																

4.5) Bill of Materials

The sub costs are right below the limit for our allotted budget of \$4,500. If the electrical engineers do not develop the sonar board, the sub cost for this year will be \$800 below budget. A detailed list of each section cost can be found in Appendix D.

Table 4.5 : Overall Costs

Section	Costs
Electrical Control	\$492.41
passive sonar	\$842.43
Motors and Batteries	\$1,193.42
Pneumatics	\$498.22
Frame and other Mechanical	\$326.88
Camera Box and Others	\$291.20
Torpedos and Lights	\$91.55
Registration Cost	\$750.00
TOTAL PROJECT COST	\$4,486.11

5.) Conclusion

The Robosub design has undergone many changes since its initial conception. Accounting for electronics space and heat dispersion had led to the necessity for two hulls instead of one. The clamp was significantly simplified to be planar. The torpedoes and markers were made smaller and more streamlined. Endcap and thru port designs were fully fleshed out. As each functionality is being fabricated, the design is changing based on complications and new design ideas. The designs that the team has now have been considered from a more grounded standpoint with more realistic ideas of what can be made in the shop from what parts can be acquired. The team's design, as shown here, is quite different from the design just 3 months ago. However, because of experience in fabricating these parts and functionalities, the team's current design is much closer to what will be put in the water at the competition and will undergo few, if any, changes.

The team is going to need more time to fully finish the sub, however there will be a sub in the water, ready to test, in 6 weeks. Looking at other schools teams, it can be deduced this will be a multiple year project that the NAU engineering department will continue and improve upon.

APPENDIX

Appendix A(section 1 & 2)

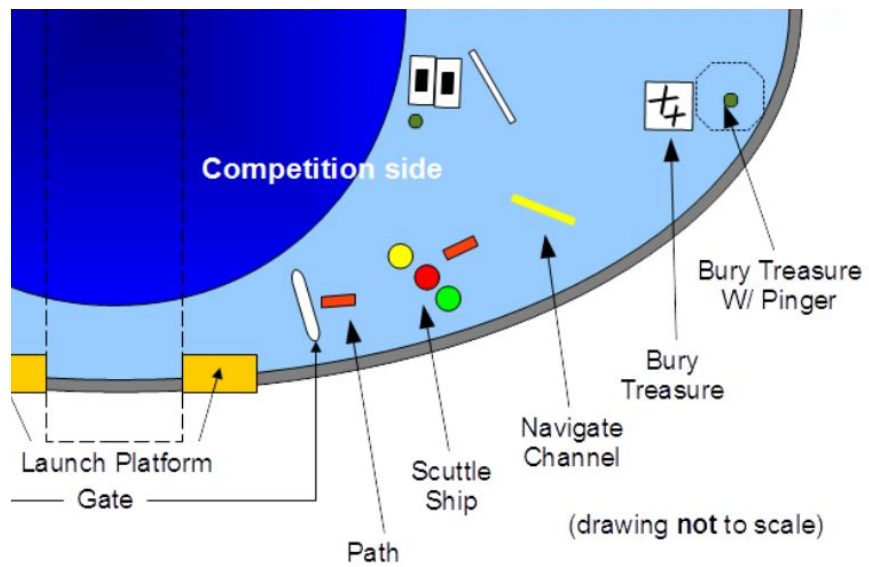


Figure A.1 : Map of the Sub Competition

Appendix B (section 3)

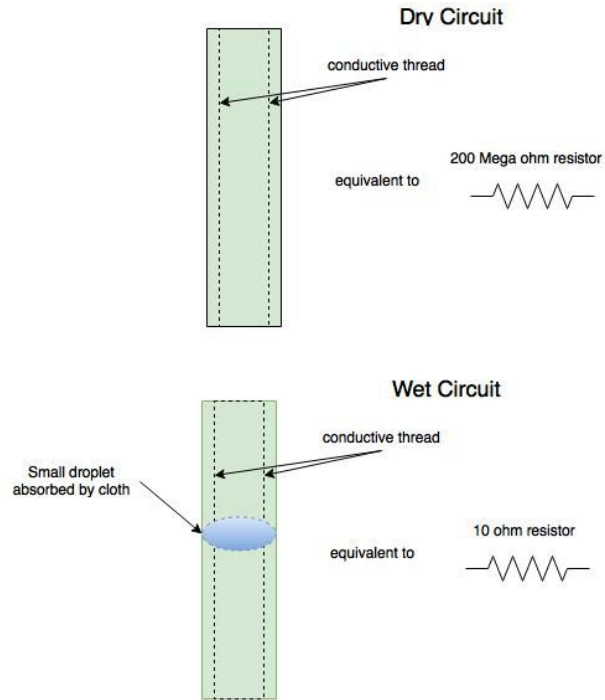


Figure A.2 : How the water detectors work

Appendix C (Bill Of Materials)

Table C.1 : Electrical Cost

Electrical Control	price	quantity	total Cost
Raspberry Pi 2	\$38.76	2	\$77.52
arduino micro	\$24.99	3	\$74.97
10/100 5-Port Switch mini ethernet switch	\$40.01	1	\$40.01
raspberry Pi 2 GPIO ribbon	\$4.95	1	\$4.95
micro USB cable	\$3.86	3	\$11.58
mini USB cable	\$2.99	1	\$2.99
USB powered hub	\$10.95	1	\$10.95
5Mp web camera(linux comp.)	\$52.00	1	\$52.00
2Mp 80degree view camera	\$45.00	1	\$45.00
2.54mm pins male	\$1.80	1	\$1.80
2.54mm socket female	\$2.08	1	\$2.08
PCB perf boards	\$3.50	3	\$10.50
4 channel voltage level shifter	\$8.22	1	\$8.22
Eyourlife Universal 30PSI Pressure Transducer	\$20.99	2	\$41.98
general op-amp	\$0.00	1	\$0.00

adafruit IMU	\$27.89	1	\$27.89
ethernet cable various lengths	\$0.00	1	\$0.00
terminals, PCB mounted	\$8.19	1	\$8.19
CS2N25MF-2.5	\$21.55	1	\$21.55
DB25-F connector	\$7.99	2	\$15.98
2-56 screws 1"	\$2.53	1	\$2.53
2-56 square nuts	\$12.73	1	\$12.73
terminal board DB25-M	\$18.99	1	\$18.99
total	x	x	\$492.41

Table C.2 : Passive Sonar

Passive Sonar Assembly	price	quantity	total Cost
H1c Hydrophone	\$129.00	3	\$387.00
ultrasonic sensor	\$18.49	1	\$18.49
arduino duo	\$39.99	1	\$39.99
op amp (584-AD8021ARZ-R7)	\$3.01	15	\$45.15
analog multiplexer (781-DG613AEY-E3)	\$0.45	4	\$1.80
various resistor and capacitors	\$200.00	1	\$200.00
PCB surface manufacturing	\$150.00	1	\$150.00
total	x	x	\$842.43

Table C.3 : Motors and Batteries

Motors and batteries	price	quantity	total Cost
11.1V (3S) LiPo Batteries	\$29.91	4	\$119.64
5v battery	\$14.99	2	\$29.98
water proof killswitch	\$10.00	1	\$10.00
100 amp relay	\$10.29	1	\$10.29
screw connectors	\$4.00	1	\$4.00
eurostyle terminal	\$3.87	1	\$3.87
battery charger	\$20.00	1	\$20.00
barrel connector to xt60 connectors	\$5.99	1	\$5.99

buck converter step down	\$6.78	2	\$13.56
DC power barrel connector(phidgets)	\$4.90	1	\$4.90
12V fans	\$7.99	2	\$15.98
16AWG, 10A, 12Vdc rated wire	\$22.95	1	\$22.95
12v water pumps	\$14.95	3	\$44.85
BlueRobotics T100 motors	\$109.00	6	\$654.00
ESC 10A 3p rated 6-17V	\$25.00	6	\$150.00
3.5mm m&fm wire bullets	\$3.87	3	\$11.61
10 gauge power wire	\$17.95	4	\$71.80
total	x	x	\$1,193.42

Table C.4 : Pneumatics

Pneumatics	price	quantity	total Cost
Empire 20oz CO2 Tank	\$20.21	1	\$20.21
solenoids 12v operation 5/3	\$24.99	1	\$24.99
solenoids 12v operation 2/1	\$15.99	5	\$79.95
1/4pneum to 1/2" NPT Female	\$7.56	2	\$15.12
1/4 pneumatic piping	\$4.00	1	\$4.00
1/4 pneumatic split 1 to 5	\$12.00	1	\$12.00
one way 1/4" valve	\$8.00	5	\$40.00
4TH22 (regulator)	\$51.95	1	\$51.95
pressure tank	\$254.28	0	\$0.00
air actuating piston *estimate*	\$250.00	1	\$250.00
total	x	x	\$498.22

Table C.5 : Frame and Other Mechanical

Frame and other Mechanical	price	quantity	total Cost
			\$0.00
3D filament	\$21.98	3	\$65.94
3D filament	\$21.98	3	\$65.94
4in ID Tube	\$7.00	1	\$7.00
Silicone Sealant	\$5.00	2	\$10.00
Fasteners	\$25.00	1	\$25.00

<i>Super Glue</i>	\$1.50	2	\$3.00
<i>PVC test structures *estimate*</i>	\$150.00	1	\$150.00
total	x	x	\$326.88

Table C.6 : Camera Box and Seals

camera box and others	price	quantity	total Cost
<i>Weld-on glue</i>	\$8.00	1	\$8.00
<i>PVC block</i>	\$36.21	1	\$36.21
<i>WTE4-ASM-R1</i>	\$29.00	4	\$116.00
<i>Aluminum End Cap (4" Series)</i>	\$22.00	4	\$88.00
<i>Weld-on #40</i>	\$42.99	1	\$42.99
total	x	x	\$291.20

Table C.7 : Torpedos and Lights

Torpedo and lights	price	quantity	total Cost
<i>Ball Plunger</i>	\$4.55	\$3.00	\$13.65
<i>Firing Tube</i>	\$7.00	\$4.00	\$28.00
<i>Flash Light</i>	\$14.95	\$2.00	\$29.90
<i>Aluminum square tube</i>	\$20.00	1	\$20.00
total	x	x	\$91.55

Appendix D (Circuit Diagrams)

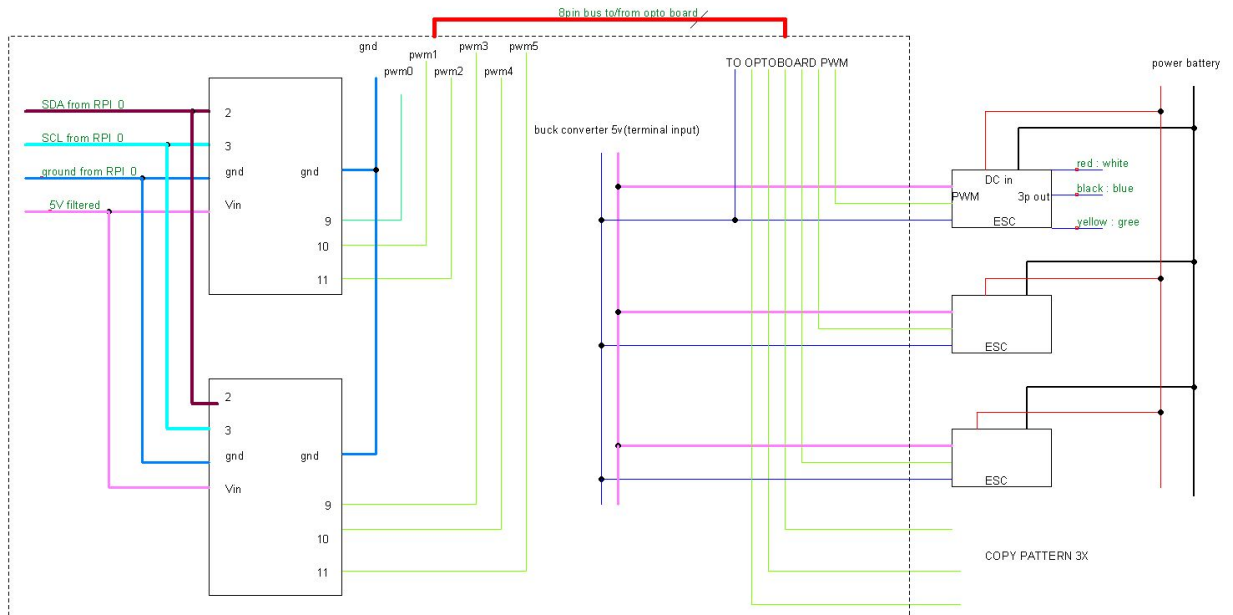


Figure E.1 : Power Circuit with arduino MCs

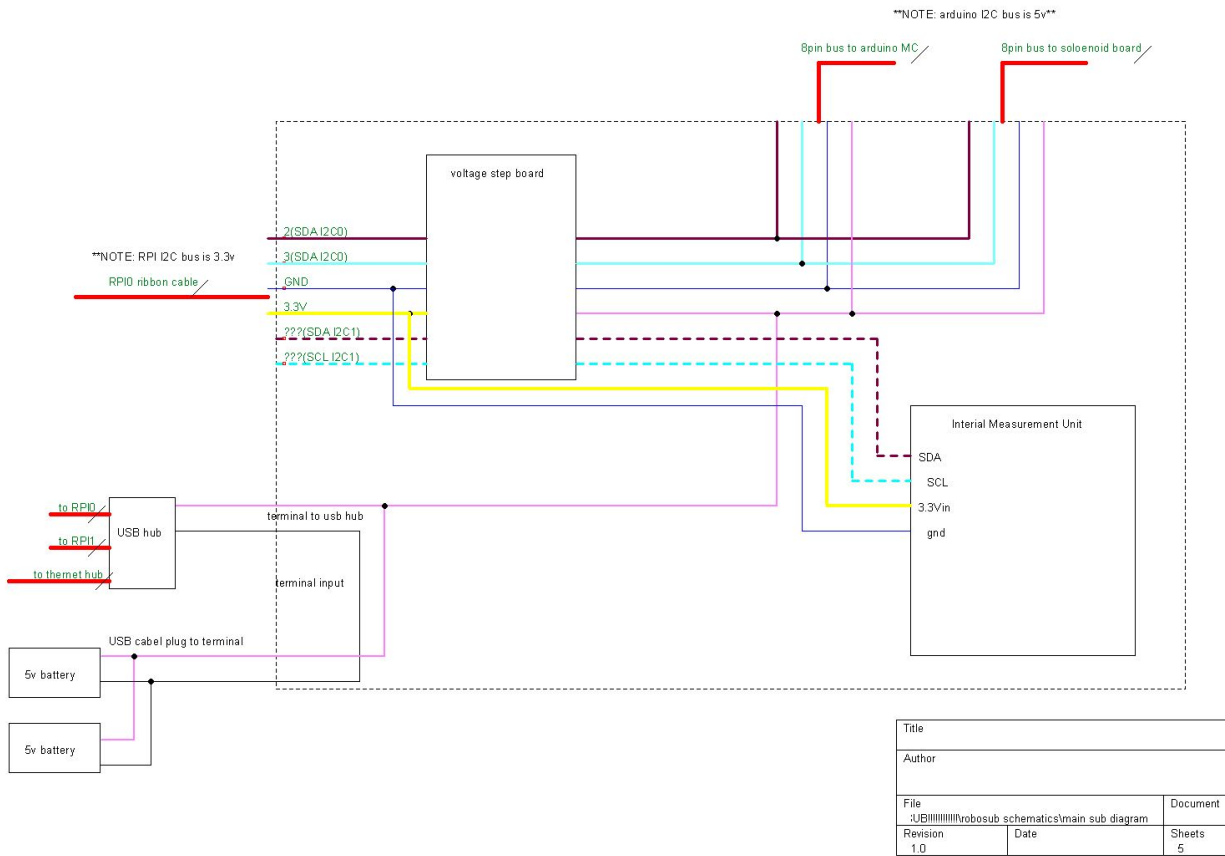


Figure E.2 : Split board

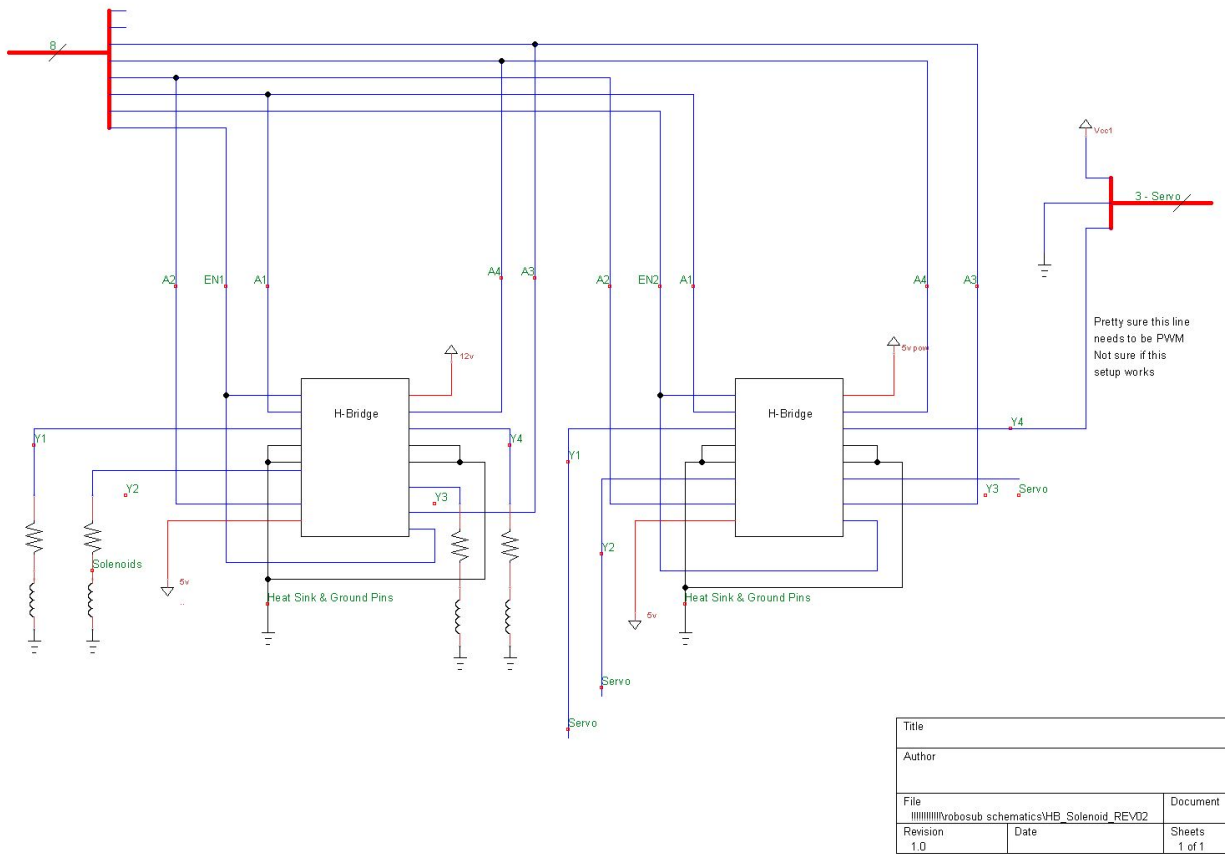


Figure E.3 Solenoid, lighting, and servo powering circuit

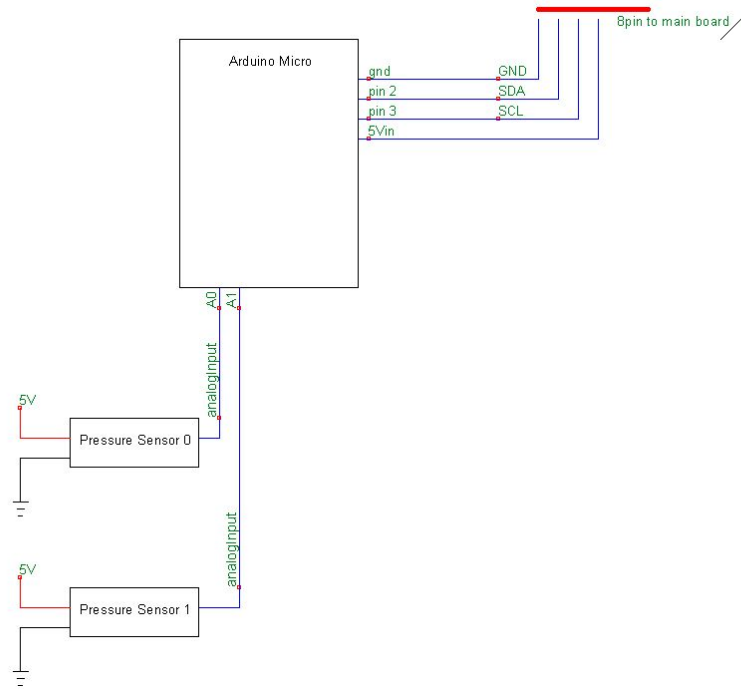


Figure E.4 Pressure, and water detecting circuit