2016 AUVSI Robosub Competition
2016 NAU Robosub Team

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Final Project Concept: The Submarine Trident

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Mechanical Engineering Design I – Fall 2015, Team 09

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1) Introduction

The Association for Unmanned Vehicle Systems International (AUVSI) hosts an annual autonomous underwater vehicle competition. The NAU AUVSI Robosub team is of senior mechanical and electrical engineers who are tasked with entering and competing in 2016 as a senior design project. This is the first year that NAU will be competing in the competition. In order to meet the deadline and have a competitive design it is vital to make the necessary decisions and ensure that the best components are adequate. This report goes over how the team came to the current design and the process of each step as well as current issues and future plans of the finalized design. Included in the explanation will be a decision on each of the components that will be used in the final design along with the reasons it was chosen.

2) 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. All of the tasks can be referenced in table 1 or appendix D. 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.

3) 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.

4) Functional Diagram

The purpose of creating a functional diagram is to understand the relationships of the parts for the submarine. The part tying all of the submarine systems together is the control system which is comprised of a computer core, with various boards. The propulsion system is comprised of a kill Switch, Motor Power Source, motor controllers, and thrusters. Another part of the competition is to have a torpedo launching system. The Torpedo system has to work with the control system and Image Processing to hit targets. The team though the sub would have 2 different power sources, one for engine power, and one for control system power; this allows the power ground to be separate from control ground. The separated power supplies technique is also employed by another university team. There are multiple sensors the sub will use such as pressure, orientation, and acoustic sensors. All these sensors will allow the sub to know where it is at, and where it needs to go. The sub will need a clasping system in order to pick up certain objects and put them into bins as for one of the tasks in the competition. All obstacles and tasks are mostly color coded, meaning that an essential part of the competition is using a color camera. This allows the sub to identify and complete tasks. The submarine will have to incorporate all these systems together to make a fully functional sub ready to compete in competition.

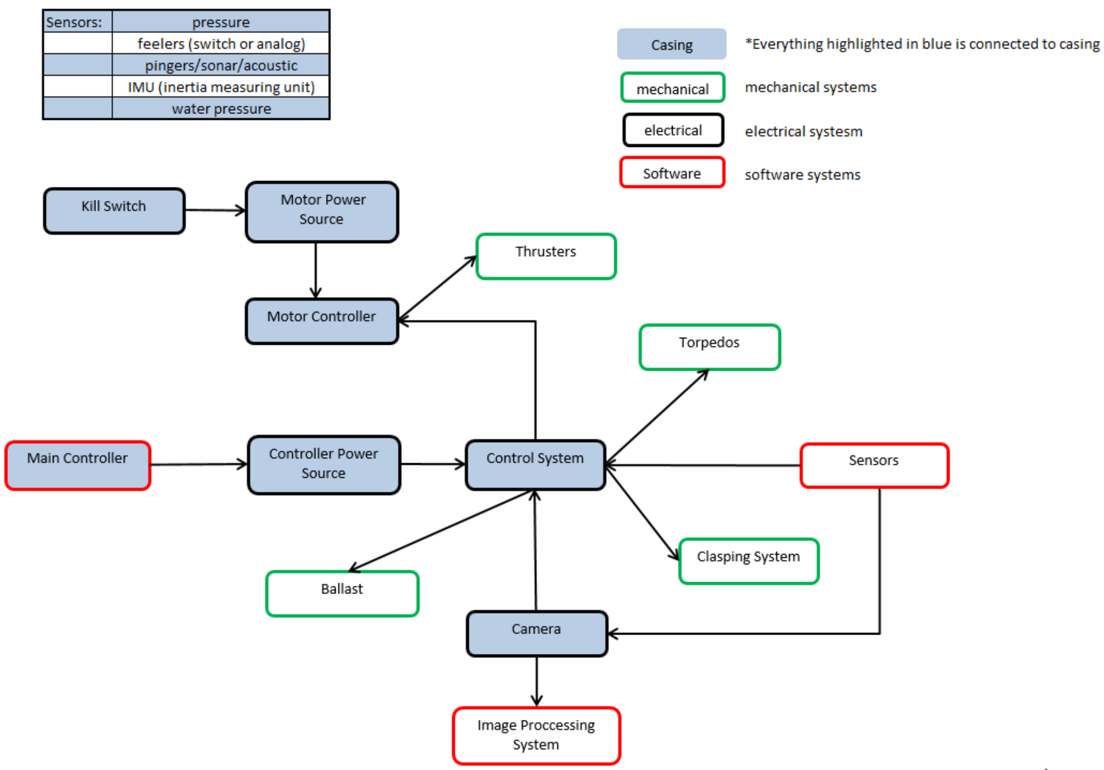

Figure 4 : Functional diagram of sub

5) Criteria

One of the first steps in completing the Robosub is to determine which components will be needed within the project and to come up with a way to determine which design option for each component should be selected. To gain a better idea for what components to use, the team looked at reports submitted by past competitors. The components that were chosen to look at in this project are as follows:

- Thruster
- Power Source
- Ballast
- Computer/Controller
- Torpedoes
- Clasping System
- Frame
- Camera
- Acoustic Sensors
- Pressure Sensors
- Inertial Measurement Unit
- Orientation Sensors
- Software Language

For each of the components listed above there are several different design options that will be discussed. In order to determine which option is the best for the Robosub, a set of criteria was created for analysis in order to compare different options side by side. To create the list of criteria for each of these component options, the constraints for the competition were considered. Criteria such as size, weight, and cost were relevant for almost every component. In addition to these criteria, specific functionality criteria was determined for each item to ensure that the robot will complete the tasks required for the competition.

6) Concept Generation

After knowing the general idea of what our project entails, the team figured options for the submarine Trident. This process includes studying other teams designs, other research and searching for components. Following is the culmination of the team's thoughts on certain subsystems and components that will comprise of.

6.1) Thrusters

The thruster design and configuration has been changed since the last design iteration due to a rethinking of the systems. The team has decided to forego the SparkFun pumps in favor of at least six BlueRobotics T100 thrusters due to the increased thrust power they provide as well as a more convenient method of mounting. The pumps were designed to be simply immersed in water and have tubes connected to them; the thrusters actually have specially-designed threaded inserts and a mount to aid in attachment to flat surfaces, with preset angles and positions to ensure a straight mount.

The thruster positions were moved to improve the balance of the submarine, as well as more effectively move the sub in terms of generating less torque during motion. The minimization of torque would allow for less correction and higher energy efficiency in doing so. The submarine movement functions are better due to a more balanced scheme and can effectively navigate (translationally as well as rotationally) with little or less need for compensation of undesirable movement.

Figure 6.1: T100 Thruster

6.2) Power Source

The entire Robosub system is reliant upon the power source to keep everything functioning and as such is a very important component for the machine, There were a few different options that were considered for the project including lithium ion, lithium polymer, and lead acid batteries. When comparing these different design options the weight and size requirements must be taken into consideration in order to meet the requirements of the competition as well as the cost.

Lithium ion as well as lithium polymer batteries are very light and compact compared to other batteries on the market today making them suitable for the constraints of the project. Lead acid batteries were considered due to their low cost and accessibility, however, they take up much more space and weight. Because the volume to power output ratio for the lead batteries, they also have much lower power than the other two alternatives. Therefore, lead acid has been ruled out. When comparing lithium ion to lithium polymer they are similar, however the lithium polymer is lighter with a lower power output per volume. Another downside of the lithium polymer is that it is the most expensive power source. When weighting the two design options against each other, the relative weighting system in Table 5.2 showed that the amount of power supplied was the most important factor, meaning that lithium ion was the best option. In combination with the cost benefit, the lithium ion option was decided to be the best option for the Robosub.

Figure 6.2: Power source

6.3) Ballast

Initially, the team had wanted to use a bladder system for the ballast. This idea won out over pressurized tanks and purely physical ballast (weights); this was due to a low cost for the bladders, low weight, and ease of positioning. The bladder could be positioned virtually anywhere as long as the submarine was still balanced.

However, the bladder and the entirety of the ballast system was deemed superfluous and was removed from THE preliminary design. This was due to the thruster system being capable of keeping the submarine submerged at a much lower level of complexity and could be easily implemented. If the bladder design had been kept, there would have to be space dedicated to the bladder and making sure it did not interfere with the function of the sub overall. Since the thrusters will be used for balancing and motion, the bladder design would have just added unnecessary complexity to the final design, and no pitch or roll control as compared to the prop design.

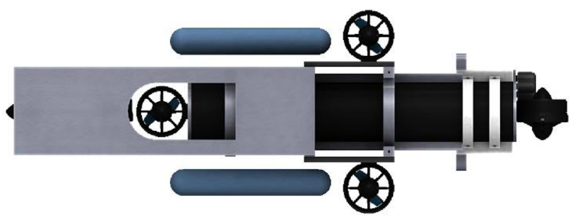

Figure 6.3.1: Thruster“ballast” (Top view of submarine)

Figure 6.3.2: Bladder ballast

6.4) Computer/Controller

The computer selection is very important part, since this is the main controller and the root of the submarines autonomy. The team considered four computers in the beginning of the semester and have narrowed the team’s consideration down to two of them. The ODROID-XU4 and the Raspberry Pi B+. There are several criteria that were important more so than others, this can be seen in the table in appendix A. The sub design may pair these two computer together to accomplish different tasks, or pairing them with Arduino microcontrollers to achieve tasks.

RAM size was especially important, since the computer will be doing image processing. For instance, the sub needs to follow a colored path on the bottom of the pool that will lead the submarine to the next task. Image allocation will require a large amount of RAM. Along with storing images in memory, the computer will need to access the image processing algorithms and variables which take up memory. Although the team doesn't know at this time exactly how much memory each item will consume, a prediction is that the above mentioned items will at use least 1-2 GBs of RAM. It would be an advantage to acquire faster RAM speeds, such as DDR2 or DDR3 RAM. DDR stands for Double Data Rate and works on the falling edge and rising edge of the clock cycle. DDR2 is double of DDR and DDR3 is double of DDR2. The ODROID-XU4. The Raspberry Pi B+ contains DDR2. The RAM size can be seen in the table in appendix A in the raw score column for each computer.

The clock speed and number of cores was also an important criteria to consider. The number of cores was especially important since the sub is running tasks in parallel (parallel processing), which can be made possible utilizing multiple cores. For instance, one core can be used for just image processing and another core can be used to handle algorithms and signals from other sensors (ping detectors, etc.). A third core (in the case of the ODROID, with 8 cores) can be used to control the motors. These tasks can all be done at the same time. The number of cores for each computer can be seen in the table.

The Analog to Digital Convertor pins are also important to consider when deciding which computer to choose. ADC connections are important since the sub is going to be sensing many continuous analog signals during the entire competition and converting them to discrete digital data which the submarine will use (along with code) to make autonomous decisions. There are several factors that go into choosing the right ADC connection which are not shown in the decision matrix. The ADC to sample data at a fast enough rate for the sonar, so the submarine can accurately and with high resolution detect and make an accurate decision. If the ADC is sampling at too slow of a rate, the submarine may make an incorrect decision, since important information may be missed that it needs to compute its next move. The number of ADC pins is also considered since there are many sensors working together. The number of ADC pins per computer can be seen in the table in appendix A. The Raspberry Pi B+ does not have any ADC pins, so if the sub use this, it would need a separate ADC circuit. This circuit could possibly be constructed using an Arduino microcontroller board. The team has also emailed the ODROID manufacturer to find out the ADC speed, which is 10ksps (kilosamples per second), which may not be fast enough for the sub's sonar needs.

Figure 6.4 Odroid-xu4

During this past semester the team has been using a MacBook pro for prototyping. The MacBook has been tethered to the camera and motor controllers through USB. The team have achieved some basic line following algorithms with this setup, but the chosen computer setup should be on board the submarine. All considerations the ODROID seems a very desirable computer, aside from the ADC.

6.5) Torpedoes

Three different concepts for the torpedo system were initially considered, all using different firing methods with the same shell design. The first concept was to use a small DC motor which will fit inside the torpedo and propel it through the water. Other ideas were to use a spring loaded mechanical system or a CO2 cartridge to launch the torpedo. The spring loaded torpedo was ruled out because of the risk of it falling short of the target due to lack of control and driving force. The problems arising with the DC motor to propel the torpedo are not having a strong enough force and increasing system complexity. The initial decision matrix for the torpedoes system can be seen in Appendix A.

A fourth and final option is to use a compressed air tank to power the torpedo pneumatically was created based on these initial design options. The use of the compressed air is easy control, creates a force strong enough to drive the torpedo and the pneumatics 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 design chosen for the torpedo. The metal tube inside of the blue torpedo shell will 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 the torpedo. Activation of the solenoid will launch the torpedo with air, releasing from the tube to be fired in the desired direction.

To fire a torpedo, a pneumatic solenoid will engage to release compressed air. This will push the torpedo off the snug fit of the tube, thereby releasing the torpedo. 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.

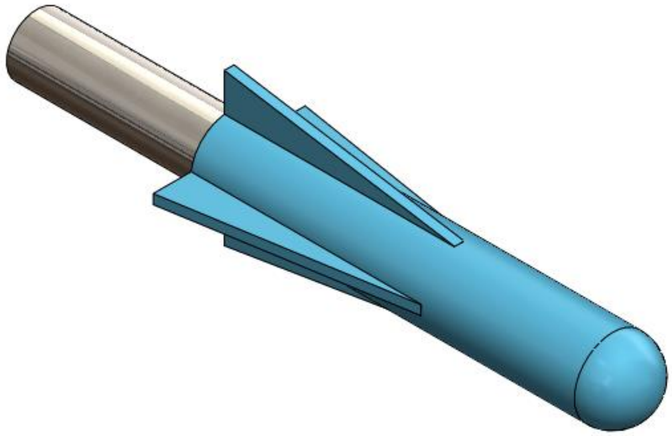

Figure 6.5: Pneumatic Torpedo

6.6) Clasping System

The sub will use a clasping system in the submarine to interact with the bins and PVC structure obstacle. A gripper with a large range of travel will be needed to reach the object that it must move. An initial idea was to not have actuators but use stationary struts to interact with the required obstacles. A major advantage of the claw is that it does not depend solely on the subs thrusters to move the obstacle; instead, the claw itself can actuate and save the stress of trying to change the position of the whole sub to apply the necessary force to move an object.

There are two types of the clasping systems actuators. The first system is actuated with a pneumatic cylinder, which is powered by compressed air and opened with a spring-return system. The second system is a hydraulic gripper, using water pressure to power the clasp instead of air pressure. After evaluating the options, the team decided to use the pneumatic system for the sub design based on other teams' previous design experience, which yielded good results. The pneumatic system can also combine with the torpedoes system reducing the extra control electrical system. The resulting pneumatic air piston is actuated with a 5 port, 2 position air solenoid. This solenoid allows the pneumatic system to either fully open or fully close with all force derived from the pneumatic system's main air tank.

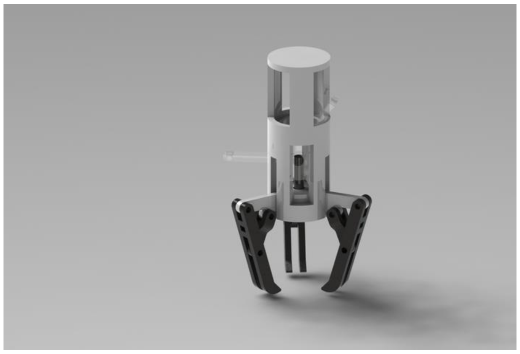

Figure 6.6 : Clasping system

6.7) Camera

In order to complete all of the tasks of the competition, the submarine will need to capture images using a camera. The main computer board will process the images using image processing algorithms. The sub will need a camera with a high enough resolution in order to create detailed pictures, however this may slow down the image processing. If the image processing becomes too slow, then the code can programmatically decrease the resolution of the camera. The program cannot increase the resolution beyond its max resolution, so that is an important criterion to consider when picking a camera. The size and power usage are also important criteria. The camera must into a small area, and the sub has a limited supply of power onboard. After weighing all the criteria, out of three options, the final decision was the 8Mp Logitech HD Portable 1080p Webcam c615.

After doing more research about the main tasks of the competition, the team has decided to go with two cameras. Both of these cameras have a large count per pixel and works on Linux OS. One of these cameras will be pointing downward. This camera has a fish-lens with 175 degree view and 4Mp, to acquire targets without moving the sub. The other one will pointing forward with a 75 degree view and use 8Mp; this one will be good to acquire targets and their distance. Using the known focal length of this camera and the known width and height of obstacles, it is possible to calculate relative distances and then rudimentarily determine rough distances to targets the sub needs to move to.

Figure 6.7: 8Mp Logitech HD Portable 1080p Webcam c615.

6.8) Acoustic Sensors

This is an essential element of the robot submarine competition. The last obstacle of the competition is to find an acoustic beacon which has PVC structures above it. Once the submarine finds the acoustic pinger, then the submarine may complete the last task of moving these structures. Without finding the pinger, it will almost be impossible to finish this obstacle. However, it is one of the few subsystems that can't normally be acquired within budget constraints. The team will have to consider making them to stay within budget. Also, market waterborne acoustic data cruncher, don't exist. Commercially available sonar are fish finders, and heavy duty scientific sensors. However, the fish finders can't be tuned to look for a particular frequency and the scientific equipment is too expensive, so it wouldn't be able to locate the beacon. This eliminated the option of hacking a fish finder or scientific equipment. The acoustic subsystem is an entire EE capstone at some competing colleges. Quick solutions that will work are needed. This means having the base functionality of finding an acoustic pinger and telling the sub what to do.

The most important criteria for this system is the sampling speed, the minimal frequency that the circuit will need to sample at is 50 Kilohertz. It is known in the subject of digital signal processing (DSP) that the circuit will need to sample above the nyquist frequency of the maximum frequency that the system will detect. This means that the sub would need a system that would at minimum sample at 50 Kilo Samples per Second (Ksps) The higher the sampling rate is, the better the resolution, and the better the accuracy with the receiving signal. However higher sampling hardware is expensive, leading the engineering balancing act. Needless to say, the team has to design, program, and test to complete this part of the submarine.

The passive sonar system is comprised of: hydrophones, operational amplifiers, Analog to Digital Converters, and algorithms to crunch the data what the program is looking at. Below is the hydrophone the team intends to use, the Aquarian Audio H1c.

Figure 6.8: Acoustic sensors

6.9) Pressure Sensors

Obtaining depth measurements throughout the competition is necessary for the sub to have an understanding of its exact position in the tank. The team has looked into three different options for the pressure sensor, with the criteria being cost and accuracy. The first two sensors looked at were the TD-H80 and the Stevens SDX. These two are completely submersible pressure sensors and are ideal. However, the high price of these sensors led to add another option, the Omega PX309, with a non-submersible design. The PX309 has the benefit of substantially reduced cost with the drawback of needing to be mounted inside the body of the sub with just a small port going through to the exterior.

From the decision matrix (App. A, table 6.9), one can see that the PX309's substantial reduction in cost (almost half vs the Stevens SDX) outweighs the benefits brought from the submersible SDX and TD-H80 options. The main issue with this new design then becomes mounting the PX309 such that the port is on the outside of the sub while the rest of the device is inside. This will most likely be accomplished with a drilled hole in the body of the sub, as well as liberal application of liquid silicone adhesives to make sure the porthole is water tight.

Figure 6.9: Omega PX309 Pressure Sensor

6.10) Inertial Measurement Unit

In order to determine its position in three spatial axes, the group decided to buy an Inertial Measurement Unit (IMU). This is a sensor package that contains accelerometers to assess change in velocity, gyroscopes to determine change in orientation, as well a magnetometer (compass) to further understand the exact orientation. Buying one of these packages instead of creating one from scratch will save the team valuable time to concentrate on less commercially developed functionalities.

There are several sensor packages the team was considering. They all contain an accelerometer, a magnetometer, and a gyroscope. The three considered are the SBG Ellipse-A: Miniature AHRS, ATMEL AVR 4018: Inertial Two (ATAVRSBIN2), and the Sparkfun 9 Degrees of Freedom - Razor IMU. The Sparkfun both contains I2C address protocol busses which will make communication with the Odroid board easier. The SBG and ATMEL sensor packages use different protocols which will the team can communicate with but it may be more difficult for programming.

The decision matrix (App. A, table 6.10) shows that the low cost and high accuracy (low range) of the gyroscopes and accelerometers in the ATMEL ATAVRSBIN2 make it appear to be the best choice for the group. The low ranges which might be a problem in a more quickly changing environment will actually serve to give the design more accurate readings in this slow-changing, underwater environment. The SBG Ellipse-A features a highly durable, enclosed package, a feature that the other parts do not have. However, this advantage was vastly overshadowed by the 2 magnitude price difference.

In the end the Sparkfun Razor IMU was chosen primarily because of its I2C compatibility with the rest of the electronic systems. The slight differences in accuracy and cost from the ATMEL device are far outweighed by this critical system compatibility. Simply put, a device without I2C compatibility is not a viable option, so the Sparkfun RAZOR IMU will be the group’s final design choice.

Another reason for this decision is the extremely low cost of the ATMEL unit does give some credence to several online posts that claim the unit is highly unreliable due to its cheap parts and manufacturing. The RAZOR's online reviews do appear to be more positive, though some defects have been reported. Ideally, a professional model like the SBG unit or one of its competitors who design IMUs specifically for this type of application would be used, but the cost is just too far out of budget to justify so much expenditure on one small sensor system. It seems the hobbyist device will have to suffice for this less-than-critical functionality.

Figure 6.10:Sparkfun 9dof RAZOR Inertial Measurement Unit

6.11) Software Language

The main computer will be running a program to control the submarine. However, there are many languages and they all have their benefits and detriments. It is known that the team's program will most likely utilize some parallel processing, whether it be threaded or multi-process with a communication interlink between the processes. It is also known running the program on a 32 bit machine is desirable. This means that a programming language that can run with the Operating System (OS) is needed. The team is also mostly Mechanical Engineers (ME), who haven't had much experience with programming, and this project is programming intensive. With this in mind, a language that was easy to learn so that the ME's can help with programing was wanted.

Information was gathered about the programming languages by talking to multiple Computer Science (CS) professors at NAU and other CS students. With this information, a decision was reached to use Python. Matlab might have won, if it was compatible with 32bit Linux; however, it is not. C++ was also considered, but none of the team members have experience with it. With C++, the program wouldn't need to wrap visual libraries, but it doesn't have automatic garbage collecting, which might be bad for beginner programmers like us. Java has great threading abilities which would allow the team to utilize the multiple cores of the Odroid, however, it's a slightly more advanced language and with the team's lack of programming power, the team will need an easier language.

Python was chosen because it's easy to use, and there's a great online community for help. Python does lag a little in threading abilities as it can thread but it's not true parallel processing. But there is a work around, in industry people make multiple running instances of many programs. These programs run simultaneously which can work around Python's linear processing design. The programs talk through a network socket, which allows not just multiple processes running on the same machine to run together, but if needed other computers can be hooked up and they would all be able to communicate through the same socket protocol. This is a great advantage and if the team finds the algorithms the computers are running are draining resource. With this setup, the sub can easily network many computers together and it would be easily implemented the same program without too many added difficulties. Please reference Table 5.12 in Appendix A for the decision matrix on languages.

Figure 6.11: Python logo

7) Final Concept Generation

After prototyping and initial research for concepts, the team devised a final concept that is within budget. Following are details about the prototype and the final concept for the Trident submarine.

7.1) Electrical System Prototype

In order to test the image processing algorithms and motor controllers, a board was created with electronics for a prototype of the submarine to be tethered too. The board was made from recycled metal from a projector television. The phidgets that were generously donated from Carl Hayden High School, a recycled computer power supply, a USB hub and a terminal block were attached to this board. The phidgets went the USB hub via mini-USB and then to a MacBook Pro. The MacBook Pro also had a camera connected to another USB port. The recycled computer power was ran to the terminal block where the phidgets could get power and then go to the liquid pumps. This setup was equipped with long USB extender cables and long wires so a tether could be created when testing. This circuit described can be seen in the motor controller system. The difference is the prototype was wired for only 2 liquid pumps, and there was no fuse on the battery; DC power coming off the computer power supply was also used instead of batteries.

7.2) Mechanical System Prototype

For the first physical prototype, the team wanted to test only three systems: Flotation/waterproofing, path/line-following, and thruster mount prototype.

Since the BlueRobotics (BR) thrusters had yet been made usable due to hardware and programming limitations, the choice was made to use bilge pumps (BP) to simulate the thrusters. As the BP were intended to be simply placed in water with a tube leading to a non-flooded area, they did not have a mounting system available; a large bracket was designed to hold them. Initially, the design called for two rectangular through-holes through which hose clamps would be threaded; due to a malfunction in either the model or the printing process, these holes were not present. As a result, the BP had to be oriented slightly differently and the hose clamps were fastened between the mounting system and the main body of the submarine.

The path/line following system was mostly software-based. The mechanical involvement in this was very little. The team bought a sheet of transparent plastic, cut it to size, and mounted it on the front of the sub. Unfortunately, it was discovered that the plastic was frosted and too opaque to be usable after installation. The team then made the decision to use resalable plastic bags to temporarily house the camera until a better solution could be found.

Waterproofing was a very simple process. Due to the design of the sub at that stage, there could only be two points of failure: The front camera window and the rear pipe plug. The team encountered problems with neither of these and the test was deemed a success.

7.3) Program system prototype

In order for the team to get a small taste of the programming needed for the submarine, they were tasked with commanding the submarine to follow a line under water. This required the integration of multiple libraries: open CV, Phidget MC, and Numpy. Importing libraries proved difficult possible. The team then had to tie the phidget controllers to the algorithms set up by Object Oriented (OO) phidget code. The code then discerns an orange line under water and depending on how far off the submarine is from the line, engages the motors with proportional power. Tethering the submarine did affect the coefficients of proportionality that the submarine was seeing in its algorithm. However the team finally proved that the sub can indeed follow a line.

7.4) Frame

One of the driving forces behind designing the frame was a desire to have it be modular, easily-expandable, and easy to mount components onto. This desire materialized in the form of a bracket system which lends itself to fairly easy fabrication and assembly, and is easy to customize to various roles. The form of the bracket, shown below, provides ample robust attachment points on the top, bottom, left, and right, as well as plenty of areas to attach non-standard parts to. The posts and arc allow larger mounted components to be offset in the case that certain smaller components such as the passive sonar array need to be attached directly to or close to the main submarine tube. There is also an option to attach solid plates or lattice structures which are made of lightweight plastic or thin metal sheets. If large area components need to be mounted, component size is smaller than the distance between posts, or components require multiple attachment points, then the team may use these plates for easier mounting.

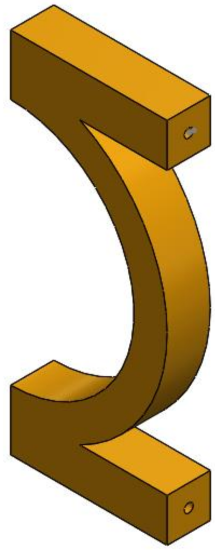

Figure 7.4: Frame Bracket

The thruster mounts can be easily attached to the sides of the brackets, minimally interfering with the function of the other mounted components. By using the brackets, it would be possible to rigidly attach the thrusters and position them accurately at specific angles instead of having to deal with attaching them to a rounded surface, such as the main tube.

The camera enclosure has a similar mounting system, but was custom-designed to fit closer to the main body of the sub. Theoretically, the camera mount system can be merged or adapted to the modular brackets. This would enable the team to use less custom hardware and save on time and costs of development and implementation. The camera mounting box also holds the downward facing fisheye lens camera and the forward facing hydrophone array. This setup leads to minimal electrical interference from most of the power intensive device such as the motors and batteries.

The air tank holders would require custom adapters to fit onto the bracket; in doing so, the bulky undercarriage box could be eliminated, heavily simplified, or relocated. Theoretically, these adapters could be ignored in favor of adhesives or other components fixing the tanks in place.

7.5) Electrical System

The electrical system is vast and is the control backbone to the autonomy of the entire sub. There are vast systems in place and all the details will be ironed out once assembly gets going next semester. However, the main concept is quite simple: there's a main controller center that runs everything. This main controller connects the motors, pneumatics and sensors. Two of the systems are output systems, while the other one is input. The sensor system is the feedback from the physical interactions from the real world; this includes the IMU, cameras, pressure sensors, and the acoustic sensor system. while the motors and actuators will be able to perform the actions the sub needs to do in order to complete tasks.

An overview of the entire system is shown in the figure 6.4. Details on each sub system can be found in appendix B. These details include the exact serial connection in between systems and the low level system setup of the hydrophone circuit.

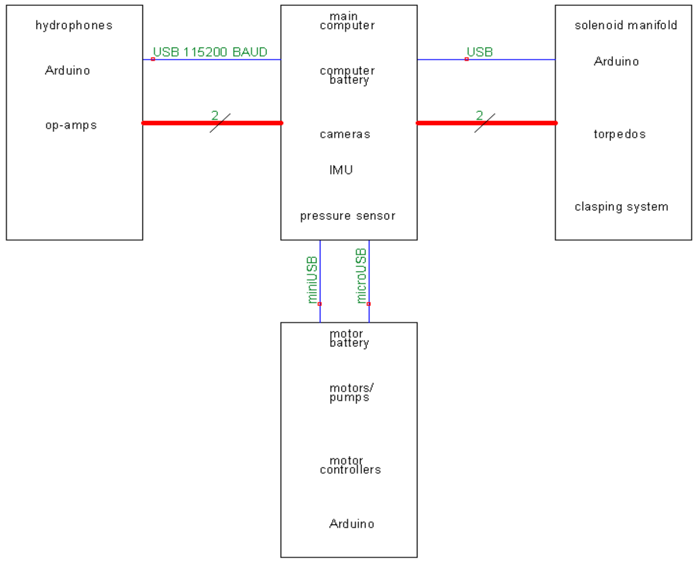

Figure 7.5 Overall Electrical System

7.6) Programming

An overview of the subs main routine is shown in the figure below and shows how the submarine will power up after power is engaged. This will prompt the OS to boot up in the main computer, there will be multiple programs that will start talking to each other through the internet socket. This will have to be programmatically coordinated upon startup of the programs.

The main idea is that once full initialization is done, the submarine starts to look for the first obstacle from a database of obstacles that it can search through. This first obstacle is the first one that the sub should see such as the line on the floor of the pool or the first gate to go through. Image processing is statistical when a program is trying to identify an object. Parameters to detecting algorithms utilized by an image processor may alter the amount of contrast that an edge detecting function may deem to be an edge. The team references some of these parameters as skepticism, which means changing what the computer detects as an object. The program will start with a high skepticism of an image it has retrieved then lower the skepticism in order to find a target. This algorithm can be made more efficient in the future. If the program changes the skepticism of the image fully, then the sub will move and try and look at a different location. This movement that will occur is yet to be determined. The sub could dive deeper or go in a spiral pattern until it does recognize, or a combination of both.

The sub will then find the first or next obstacle that the program is trying to look for from the database and then will orient the submarine to do that task. It will then run a module of commands that the team will devise from testing in order to complete the task. There could be an error in running the task, if this does occur the submarine will try to get back into position to try the current obstacle again. The team perceive errors happening around the PVC structure moving obstacle, perhaps during the marker drop point, and a slight possibility during the torpedo shot. When the program has completed all the tasks, the submarine will surface, therefore completing the competition. Note that the boxes are colored denoting what colour of LED the sub will be flashing to give visual feedback of what is happening..

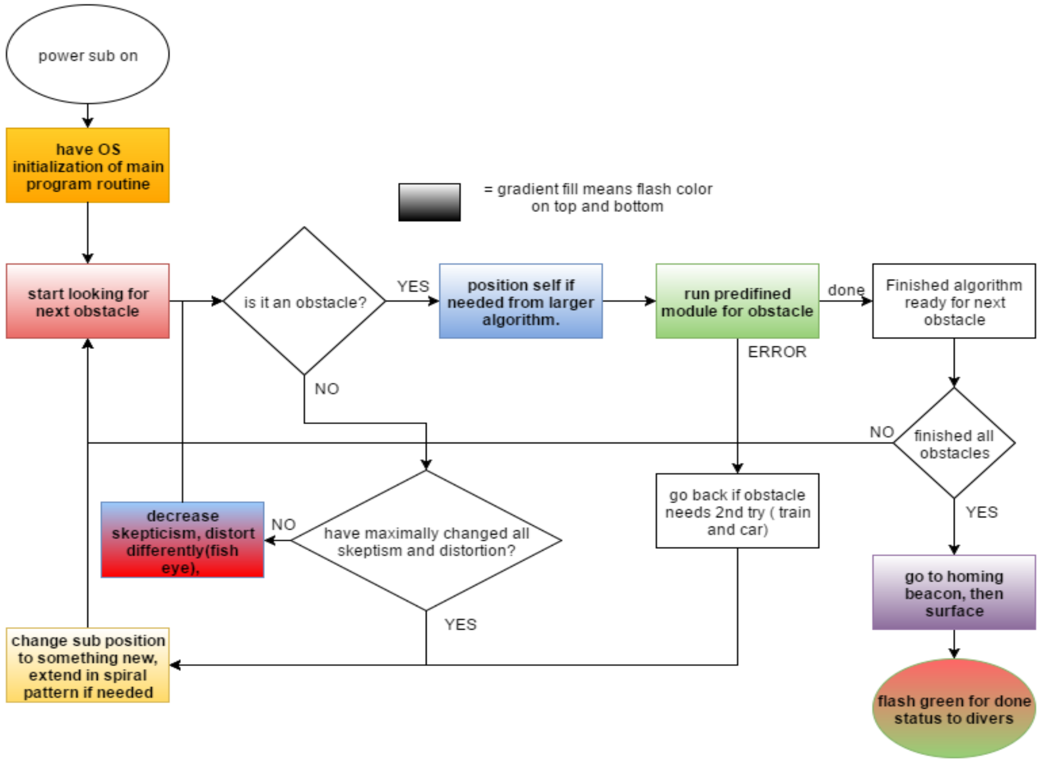

Figure 7.6: Main submarine algorithm routine

7.7) Passive Sonar System

The sub will look for the acoustic pingers underneath the PVC structures that it will need to move for the competition. There are 2 possible ways to detect the angle that the pingers are at relative to the sub: time delay of duty cycle or calculating the phase difference in the received acoustic signal. The team choose to go with determining the phase difference, for higher accuracy and ease of computation. If you look at the main sub design, the hydrophones are placed in such a way that there will be no physical wave aliasing, so the program can always determine the direction the sound is coming from. The wave coming off the pinger is detected in the nano to micro volt range and is amplified through opamps that have enough gain at 25 Khz that the ADC on the Arduino Duo will be able to read the voltages. These values are then stored and sent serially to the main computer for computation. Using the algorithm devised in the diagram, the sub will be able to figure it's relative angle of attack onto the pinger. A preliminary circuit design is proposed in (App B Figure B.3). Some specifications of the elements will have be developed further, to account for countering sensor saturation, increasing high frequency gain, minimizing unwanted capacitance, and avoiding extraneous circuit noise.

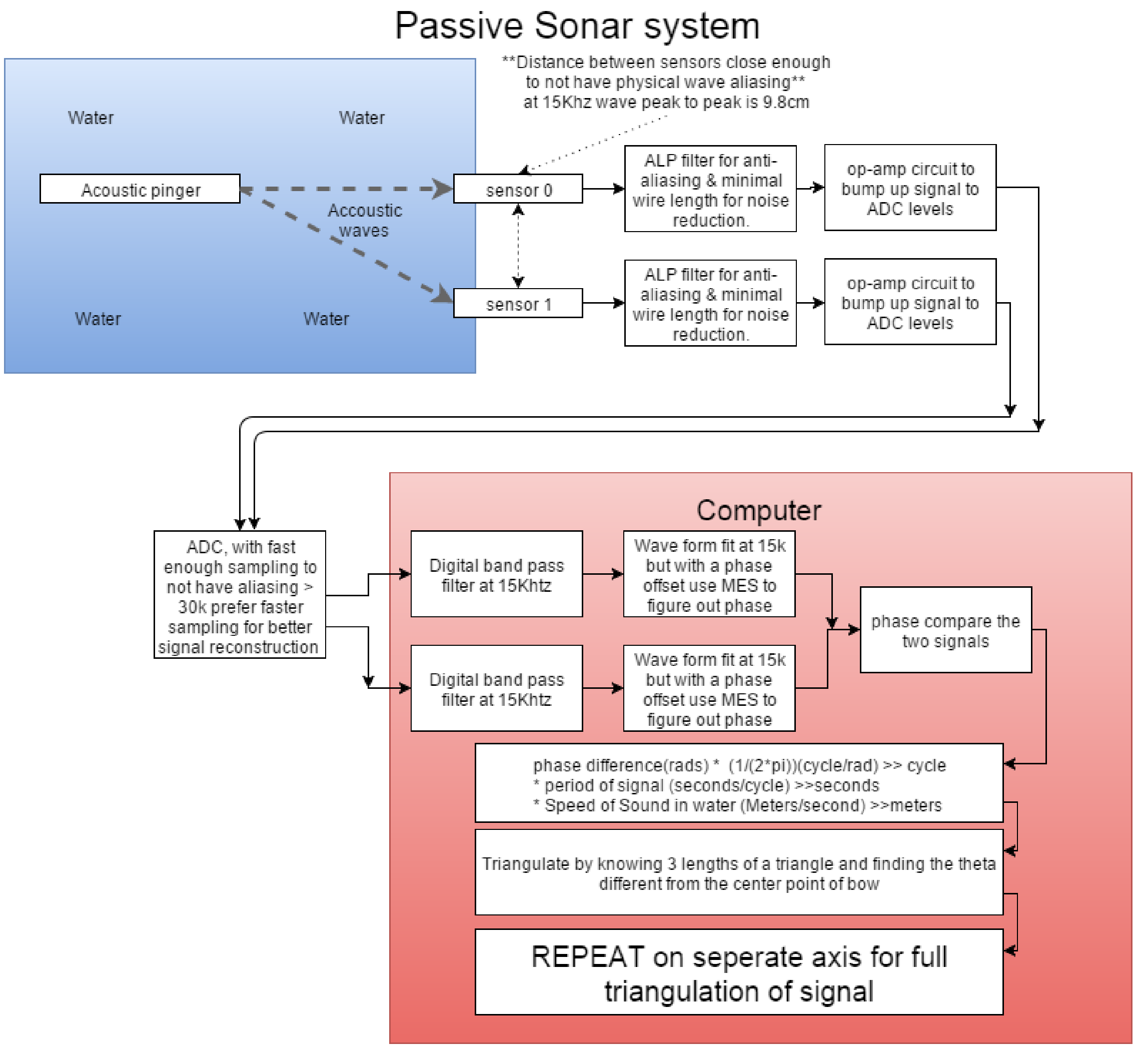

Figure 7.7: Passive Sonar Array

7.8) Main Concept

The main concept of this design is to use the modular, skeletal frame to attach all of the needed components and any parts necessary to mount the components. Having these skeletal "ribs" will allow ease of design change and implementation of any new parts as the team deems necessary in the construction and troubleshooting process.

The initial design involves strategic placement of the six thrusters such that each thruster (with the exception of the two used for buoyancy control) is able to exert its force without inducing a moment on the sub, thus making each direction of translation actuated by an independent thruster. If this design is able to pass trials ensuring it works as intended, it will make the programming work much easier as the sub will have few rotational challenges to overcome

The next important aspect of the design is internal housing. It will hold all the components which cannot be exposed to water. This includes the batteries, computer, IMU, pressure sensor, and all electrical subsystems (switches, adaptors, etc.). There will be waterproof through ports on the internal housing to run wiring from the inside to sensors and systems on the outside of the main housing. The camera will need to be connected through one of these through port connections.

Initially the camera was going to be placed inside the internal housing, but further development led to the design of an external box mounted towards the front of the sub. This box will contain both the lower definition fisheye lens oriented downward and the higher definition 8Mp lens oriented forward. This will allow the team to modify the camera configuration without taking the whole internal electrical system apart.

The hydrophone array is oriented forward at the front of the sub to facilitate easy location of the pinger. Likewise the torpedoes are oriented forward such that the camera is able to see where they are pointed, thus making aiming them as easy as aiming the sub itself. The tanks for the pneumatic systems are oriented on either side of the sub so that the buoyant forces created by them do not rotate the sub.

The orientation of the clamping and marker dropping systems are less important than the systems mentioned above. As such, they are oriented in places that they can easily fit, and that are on or near the center of gravity of the sub. These systems are subject to change as the group moves forward on more critical orientation issues like thrusters and torpedoes.

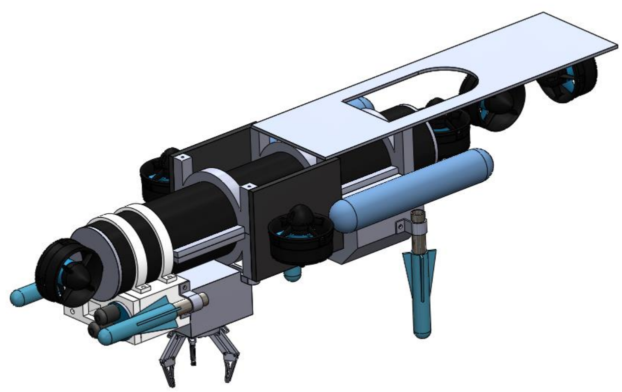

Figure 7.8 : Main Concept Trident submarine

7.9) Bill of Materials

One of the largest project constraints the team had was the budget. Initially the sub had a budget endowed with $2,000 from the engineering college. After finishing the design, the team realized that the sub was over budget. However with the much needed donation from Orbital ATK, the team will be able to buy all the parts needed to accomplish all of the tasks. Based on calculations obtained so far, costs will be below the maximum of budget for the year with a buffer zone. The bill was broken into six different sections: electrical control, Hydrophones, Motors & batteries, Pneumatic, Frame & other mechanical, and registration cost. One may see that the motor control is the most expensive section of the budget. Below you can see the breakdown of the costs of various systems; details of the breakdown are in Appendix C. The team is below the maximum budget of $4,500 for the year.

Table 7.1 Breakdown of total costs

Electrical Control	*$577.98*
Hydrophones	*$446.19*
Motors and Batteries	*$1,040.21*
Pneumatics	*$702.30*
Frame and other Mechanical	*$389.00*
Registration cost	*$750.00*
TOTAL PROJECT COST	***$3,905.68***

8) Conclusion

The NAU robosub team has now developed a complete design for its entry into the AUVSI robosub competition. Having completed a functional diagram (Figure 4) and compiled criteria for each functionality, the team was able to make final design decisions for each system;

- Blue Robotics thrusters were chosen for their relatively low cost and design created specifically for this application
- Lithium polymer batteries were chosen for their high capacity to volume ratio
- The idea of using a ballast was thrown out in favor of using a buoyant overall design with downward thrusters actively negating this buoyancy force
- The ODROID computer was chosen for its high RAM and ADC compatibility
- Compressed air or CO2 powered torpedoes were chosen for their lack of complex mechanical systems and consequential reliability and accuracy
- A pneumatic clamp was chosen for its ease of integration with the torpedo system as well as its reliability and simplicity
- A 175 degree, 4 Mp camera was chosen as the downward facing camera for following the line and acquiring close targets
- A 70 degree, 8 Mp camera was chosen to be forward facing for acquiring long distance targets
- Aquarian Audio's H1c was chosen as an acoustic sensor to find pingers in the competition
- Omega's PX309 was chosen for its low cost acceptable accuracy
- Sparkfun's 9-dof razor IMU was chosen for its low cost and I2C compatibility

- Python programming language was chosen for its extensive library, ease of learning, and extensive community support

After making these critical design choices, a prototype was developed to test one of the sub's most important systems: its ability to use a camera and thrusters to navigate autonomously. This prototype, while still tethered due to the need to use an external laptop instead of the final design's internal ODROID, was able to show the ability of the sub to perform this basic function by actuating the subs body around a line, adjusting for any skew the camera picked up.

The final step in the build up to actually developing a sub for competition was creating a final design. This involved building a CAD model using SOLIDWORKS and Blender modelling software. The final design includes all of the aforementioned mechanical and electrical systems. Some tweaks may have to be made (mainly thruster placement), but such decisions can only be made once the team starts building the sub and can see exactly how these systems interact and what problems arise.

The final design also involves a huge range of electrical and programming subsystems, including electrical and programming maps. Figure 7.6 shows how the sub will run its programs, but many lines of code will still have to be developed to implement these critical command systems. Figure 7.4 shows the electrical mapping and generally describes how all of the sensors and mechanical systems will be connected to the computer and batteries.

The last step in creating this design was to build a Bill of Materials to assess costs. Table 7.1 gives a breakdown of total costs and shows that the team is currently within budget and even has some extra space if new costs are deemed necessary.

Moving forward, the group will begin to implement this overall design. Many tests will have to be run to ensure that each system is working how it was imagined to work. Troubleshooting and programming will be the main focus of the next semester of work. While the design might change in small ways such as placement of elements, small tweaks, etc., the overall idea of how the sub will operate is now well defined.

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Appendix A (Decision Matrixes)

Table A.1: Decision Matrix for Thrusters

	Design Options						
weight	**Thrusters**	sparkfun Raw	Sparkfun score	Seabotix Raw	Seabotix	Tecnadyne raw	Tecnadyne
0.16	Weight(g)	416.73	1.64	705.00	0.82	1,200.00	0.49
0.20	Cost	14.95	2.00	200.00	0.20	200.00	0.20
0.54	Thrust(N)	0.74	0.54	28.43	2.68	75.51	5.35
0.03	Power draw(w)	18.00	0.32	110.00	0.22	475.00	0.16
0.07	Volume (mm)	100.00	0.69	175.70	0.34	198.60	0.34
	Total		5.18		4.27		6.55

Table A.2: Power Decision Matrix

	Batteries						
weights		*Lithium Ion raw*	*Lithium Ion*	*Lithium Polymer raw*	*Lithium Polymer*	*Lead Acid raw*	*Lead Acid*
0.09	*Weight(kg)*	*480.00*	*0.74*	*600.00*	*0.9*	*120.00*	*0.2*
0.69	*Capacity(% bat)*	*80.00*	*5.54*	*60.00*	*4.2*	*40.00*	*2.8*
0.14	*Voltage(dv/ dt)*10min*	*1.00*	*0.1*	*1.00*	*0.1*	*1.00*	*0.1*
0.08	*cost($/kwh)*	*60.00*	*0.6*	*120.00*	*0.4*	*30.00*	*0.7*
	sum		*7.0*		*5.7*		*3.8*

Table A.3: Ballast Decision Matrix

	Design Options						
weight	**Ballast**	piston 78mm diameter Raw	piston 3"diameter score	bladder raw	bladder	dual prop/pump	dual prop/pump
0.05	dry weight (g)	924.00	0.27	1,370.00	0.41	2,400.00	0.18
0.36	Cost	169.99	1.45	19.99	2.91	2*200	2.55
0.05	pitch control (y/n)	n	0.00	n	0.00	y	0.45
0.41	water seal area	45.60	0.82	0.00	4.09	0.00	4.09
0.14	energy consumptio n(w)	5.32	1.23	9.90	0.95	950.00	0.27
	Total		3.77		8.36		7.55

Table A.4: Decision Matrix for computers

	Design Options								
weight	**Comput er/Contr oller**	ODROID Raw	ODROID score	Gizmo 2 raw	Gizmo 2	Aspire raw	Aspire E 15 E5-571-563B	raspberry pi B+ raw	raspberry pi B+
0.21	processing (GigaHtz)	8 core, 2Gh	1.67	2core, 1Gh	1.25	1core, 1.5G	0.78	1 core, .7Gh	0.63
0.30	RAM size (GigaByte s)	1G	1.20	1G	1.20	6G	2.99	.512G	0.30
0.07	bulkyness (largest dim M.)	0.08	0.62	101.60	0.62	381.00	0.07	85.00	0.62
0.03	Weight (g)	131.00	0.23	0.75	0.23	2,499.29	0.03	59.00	0.23
0.02	Volume (cm*cm*c m)	104.63	0.17	262.19	0.10	2,458.06	0.02	80.92	0.17
0.16	ADC pins 5V #	3pin	0.63	0.00	0.48	0.00	0.16	0.00	0.16
0.12	Dig I/O pins #	40pins	0.87	12.00	0.27	0.00	0.12	40pins	1.24
0.10	Cost	74.00	0.92	199.00	0.67	399.00	0.29	29.95	0.96
	sum		6.31		4.83		4.46		4.31

Table A.5: Torpedo Decision Matrix

	Design Options						
weight	**Torpedoes**	CO2 Raw	CO2 score	spring loaded raw	Spring loaded	internal motor raw	**Internal Motor**
0.28	Launch force(kg*m/s^2)	46.57	1.42	445.00	2.55	2.08	0.57
0.16	Weight(kg)	0.20	1.41	0.27	0.94	0.31	0.47
0.27	Accuracy(m)	0.50	1.62	1.00	0.54	0.30	2.43
0.29	Range(m)	2.00	0.87	1.50	0.87	2.50	2.61
	total		5.32		4.90		**6.08**

Table A.6 : Clasping Decision Matrix

		Design Options			
Weight	**Clasping System**	Clamp Raw	Clamp score	hooks raw	Hooks
0.41	Clamping Force (N)	40.00	3.69	24.00	2.87
0.12	Clearance (m)	2.50	0.46	2.50	0.46
0.39	Carrying Load (m)	10.00	3.10	9.00	2.72
0.09	Cost (USD)	100.00	0.26	50.00	0.70
	total		7.51		6.74

Table A.7 : Camera Decision Matrix

			Design Options				
weight	**Camera**	8Mp web camera Raw	8Mp webcamera	cognex raw	cognex	some DSLR Raw	some DSLR
0.280	Resolution(Mp)	8.00	1.12	4Mp	0.56	16Mp	2.24
0.258	Size(cm*cm*cm)	60.00	2.06	130.00	1.29	320.00	0.26
0.293	Power(mW)	40.00	2.34	200mw	0.59	50mw	2.34
0.065	Cost (USD)	40.00	0.65	800.00	0.07	600.00	0.20
	total		6.18		2.50		5.04

Table A.8 :Decision Matrix on Acoustic

			Design Options				
weight	**acoustic sensors**	UT w/OD raw	UT w/Odroid	UT w/Ard raw	UT w/Arduino	custom ADC board raw	custom ADC board
0.17	cost	200.00	1.67	250.00	1.00	400.00	0.33
0.07	added Weight (g)	0g	0.69	30g	0.48	50g	0.34
0.48	sampling speed (Ksps)	300 Ksps	1.44	100Ksps	0.48	1000 ksps	4.81
0.17	com speed (Baud)	1.5G	1.69	12,400.00	0.84	12,400.00	0.84
0.11	added power(Wm)	0.00	1.14	200mW	0.91	450mW	0.17
	sum		6.63		3.72		6.50

Table A.9: Decision Matrix for Pressure Sensor

Design Options						
pressure sensors	TD-H80 raw	TD-H80 score	Stevens SDX raw	Stevens SDX	Omega PX309	Omega PX309
Accuracy	0.5%	1.78	.25%	6.22	.25%	6.22
Cost	300	0.56	312	0.67	175	.95
Totals		2.33		6.88		7.17

Table A.10: IMU Decision Matrix

Design Options						
IMU	Sparkfun 9-dof Razor IMU raw	Sparkfun 9-dof Razor IMU score	Atmel ATAVRSBIN2 raw	Atmel ATAVRSBIN2	SBG Ellipse-A raw	SBG Ellipse-A
Range (acc)	16g	1.83	8g	3.29	8g	3.29
Range (gyro)	300 rad/s	4.03	250 rad/s	5.60	450 rad/s	2.30
Cost	74	0.06	33	0.44	2000	.1
Totals		5.91		9.34		5.694

Table A.11: Decision Matrix for Software Languages

	Design Options				
weight	**Software Language**	Python	Matlab	C++	Java
0.01	compiled %	0.00	0.00	0.01	0.01
0.03	community help	0.08	0.05	0.05	0.05
0.05	previous experience	0.10	0.41	0.00	0.10
0.08	visual lib wrapping	0.08	0.08	0.08	0.00
0.08	digital I/O lib wrapping	0.08	0.00	0.08	0.00
0.39	core compatibility(OR bits)	0.39	0.00	0.39	0.39
0.08	threading(4-# steps)	0.16	0.20	0.16	0.08
0.06	ease to learn	0.18	0.18	0.06	0.12
0.18	garbagecollection	0.18	0.18	0.00	0.18
0.05	visual data snapshot ease	0.11	0.16	0.05	0.08
	total	1.34	1.26	0.87	1.01

Appendix B (Circuit Diagram)

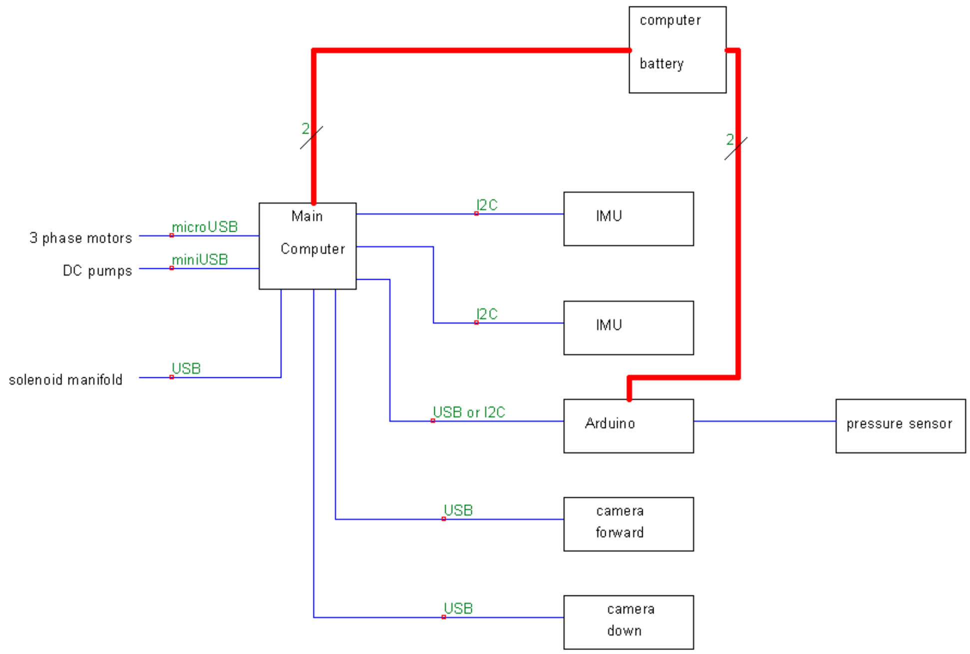

Figure B.1: Sensor system

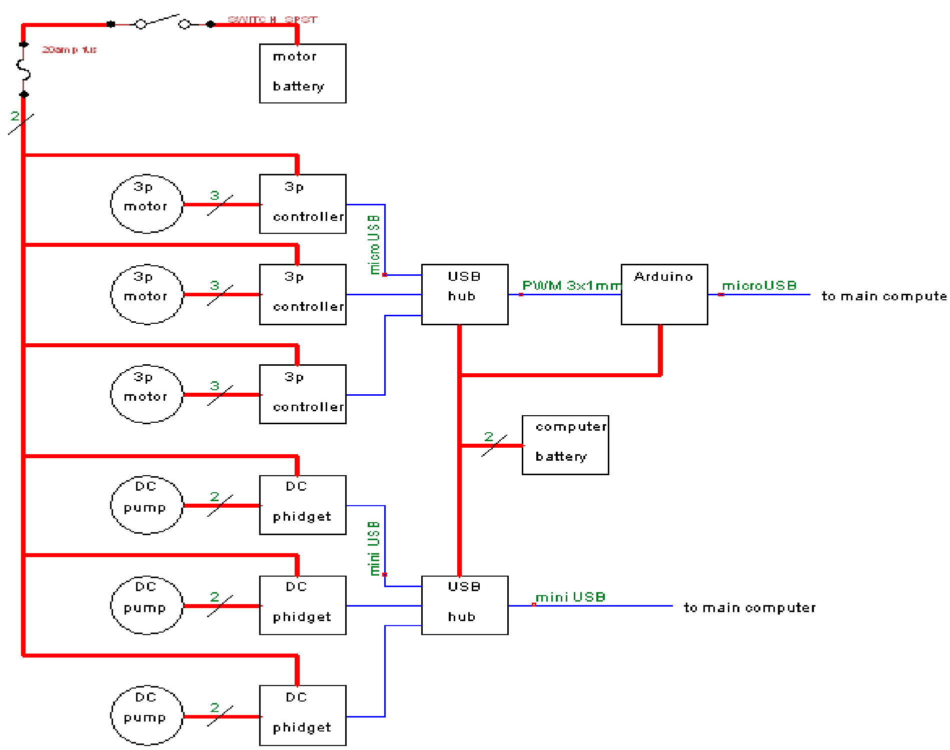

Figure B.2: Motor Controller system

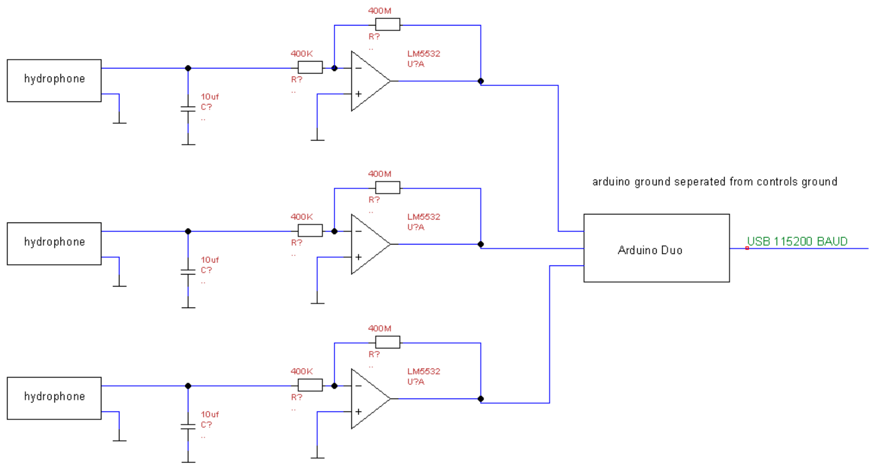

Figure B.3 Operational Amplifier Sonar Circuit

Appendix C (Bill of Materials)

Table C.1 :Electrical control

Electrical Control	Description	Reason	price	quantity	total Cost
raspberryPi 2	main controller, computer	control everything	$38,76	2	$77,52
raspberry Pi 2 GPIO ribbon	raspberry pi serial cable	this allows us to connect up peripherals to control the motors directly	$4,95	1	$4,95
micro USB cable	microUSB to USB2.0 port	power the raspberryPi2	$3,86	1	$3,86
mini USB cable	mini USB to USB 2.0 port	cable to connect to the phidget controllers	$2,99	6	$17,94
USB powered hub	expansion module for the raspberry pi	to expand the USB ports of the raspberry pi and power peripherals	$10,95	1	$10,95
5Mp webcam(linux comp.)	USB cable to webcamera (linux compatible) 5Mpixel 170 degree view, has mounting holes for easier adhesion for ME team	for image recognition, wanted the ability to upgrade the main computer to the Odroid and a raspberry pi only camera would be not designing for future expansion	$52,00	1	$52,00
8Mp 75 degree view camera	camera for looking forward on submarine	A smaller angle of collection means that more of the bits are in the forward direction meaning that forward calculations will require less manipulation and will offer greater distance readings by consolidating more pixel per angle.	$60,00	1	$60,00
2.54mm pins male	2.54mm spaced pins for components	to be able to connect up the servo plug type	$1,80	1	$1,80
2.54mm socket female	2.54 mm spaced socket for adding other components	connect voltage transfer board to the board without problems	$2,08	1	$2,08
PCB perf boards	perforated circuit board for 12cm x 8cm 2.54mm pitch dual sided universal prototyping PCB board	connect the voltage level converters, and other circuit board elements together elements to	$3,50	2	$7,00
8 channel bi dir V converter	a small board that has 8 bi-directional channels, there are boards made by Odroid, however they won't show up in time	voltage levels of the raspberry pi and Odroid are 3.3 &1.8 but to control the ESC's the computer will need this to get the board up to 5V this will also be useful for lighting up LEDs	$14,98	1	$14,98
Omega PX309 (0-30psi)	Omega, water pressure transducer	water pressure transducer to detect the level in the water that the sub is at	$175,00	1	$175,00

sparkfun IMU	IMU with I2C protocol, has easy library for use with raspberry pi	This is to determine cardinal directions, position in 3 directions and for acceleration in 6 for better submarine control	$74,95	2	$149,90
total	x	x	x	x	**$577,98**

Table C.2: Passive sonar cost

Passive sonar	Description	Reason	price	quantity	total Cost
H1c Hydrophone	hydrophones, 25nF , need G>60db representation for high frequencies	for sensing the the pinger at end of competition	$129,00	3	$387,00
arduion duo	1Msps adc, with serial usb com protocol,	fast reading adc for use with hydropones. This device is also easy to work with in terms of programming	$39,99	1	$39,99
(op-amp) 595-OPA2192IDGKT	Mouser Electronics, Op-Amp, through hole mount, low noise, small voltage differential	this is to amplify the voltage signal coming off the hydrophones into rang that the ADC will read. 4th opAmp is for the pressure transducer	$4,80	4	$19,20
10k ohm resistor	for opamp circuit function	for opamp circuit function	$0,00	10	$0,00
10M ohm resistor	for opamp circuit function	for opamp circuit function	$0,00	10	$0,00
10uF capacitor	for analog filtering of signal	for analog filtering of signal	$0,00	3	$0,00
total	x	x	x	x	**$446,19**

Table C.3: Motors and Batteries Cost

Motors and batteries	Description	Reason	price	quantity	total Cost
12v batteries	bank of batteries to hook up for increased Ahr operation	power everything motor wise	$29,91	4	$119,64
5v battery	computer batteries for computers, usb hub	power everything computer wise	$20,00	2	$40,00
DC power barrel connector(phidgets)	DC power connect 5.5mmOD 2.1mmID (pack of 6)	to power the phidget motor controllers	$4,90	1	$4,90
16AWG, 10A, 12Vdc rated wire	AWG 16, 3 spools(100') (RED,BLACK,BLUE) you have to specify the color that you want	power transmission to motors controllers	$22,95	1	$22,95
12v water pumps	water pumps to push vessel in certain directions	for prototyping the response of the system	$14,95	3	$44,85
BlueRobotics T100 motors	3P, 10A propped motors	for main thrusters	$109,00	6	$654,00
ESC 10A 3p rated	Electric Speed Control, DC to 3P MC's	need 3p, motor controllers	$25,00	6	$150,00

3.5mm m&fm wire bullets	pack of 20pairs M&FM 3.5 bullet	connect the ESC power to battery power	$3,87	1	$3,87
total	x	x	x	x	$1,040,21

Table C.4: Pneumatics cost

Pneumatics	Description	Reason	price	quantity	total Cost
solenoids 12v operation 5/3	two way valve for pulling and pushing power	for operating the clamp, and drop beacons	$24,99	3	$74,97
solenoids 12v operation 2/1	solenoid with on/off capabilities for the sub shooting torpedoes	for shooting the torpedos	$15,99	2	$31,98
¼ pneum to 1/2" NPT Female	pack of 10, 1/4"NPT to 1/4"	connect the pneumatic piping to the	$7,56	2	$15,12
1/4 pneumatic piping	1/4" tubing	for running lines to everything	$4,00	1	$4,00
1/4 pneumatic split 1 to 4			$12,00	1	$12,00
one way 1/4" valve			$8,00	1	$8,00
4TH22	125PSI max regulator and gauge 1/4"NPT		$51,95	1	$51,95
pressure tank		to hold pressure to use in the pneumatic system	$254,28	1	$254,28
air actuating piston	2 to 4" range 1/4" NPT on in/out port	actuate the claw full open and full close	$250,00	1	$250,00
total	x	x	x	x	**$702,30**

Table C.5: Frame and other Mechanical cost

Frame and other Mechanical	Description	Reason	price	quantity	total Cost
					$0,00
	1.75mm filament for 3D printing	To build frame pieces	$20,00	2	$40,00
	4in Tube	For main body	$7,00	1	$7,00
	Silicone Sealant	For water tight seals	$5,00	2	$10,00
	Fasteners	Fastening (duh)	$25,00	1	$25,00
	4in Pipe-plug		$4,00	1	$4,00
	Super Glue		$1,50	2	$3,00
estimate	through ports for wire and pneumatic tubes		$150,00	1	$150,00
estimate	Test rigs for competition		$150,00	1	$150,00
total	x	x	x	x	**$389,00**

Appendix D (Objectives)

Table D.1: Objectives

Objective	Units
Pass through gates	ft wide
Torpedo target	ft^ area
Bump target	ft^2 area
Remove lid	ft from handle
Recognize Color	Red, blue, green , etc....
Drop marker	ft from bin
Complete all tasks quickly	S

Appendix E (QFD, House of Quality, Project Plan)

Table E: QFD

	PHASE I QFD											
Customer Needs	Customer Weights (1-10)	Material Strength	Thruster Power	Power Source	Sensors Resolution	Camera Resolution	Ballast Volume	Frame Size	Connectors' Young's Mod	Computer Hardware Size	Programming	Casing Volume
Self-Functioning	10				*	*				*	*	
Finish tasks	10		*	*	*	*		*		*	*	
Kill Switch	10							*	*	*	*	
Weight	10	*	*	*	*	*	*	*		*		*
Size	10	*	*	*	*	*	*	*		*		*
Power	10		*	*		*		*	*	*		
Bouyancy	10	*	*	*			*	*		*		*
Recovery	9						*	*			*	
Water proof	10	*	*		*	*	*					*
Cost	8	*	*	*	*	*	*	*	*	*		*
Time to Finish Tasks	7	*	*					*			*	
	Raw Score	6	8	6	6	7	6	9	3	8	5	5
	Unts	Psi	W	W	Hz	MP	ft^3	ft^3	Psi	Bit	Bit	ft^3

Table E.2 : House of Quality

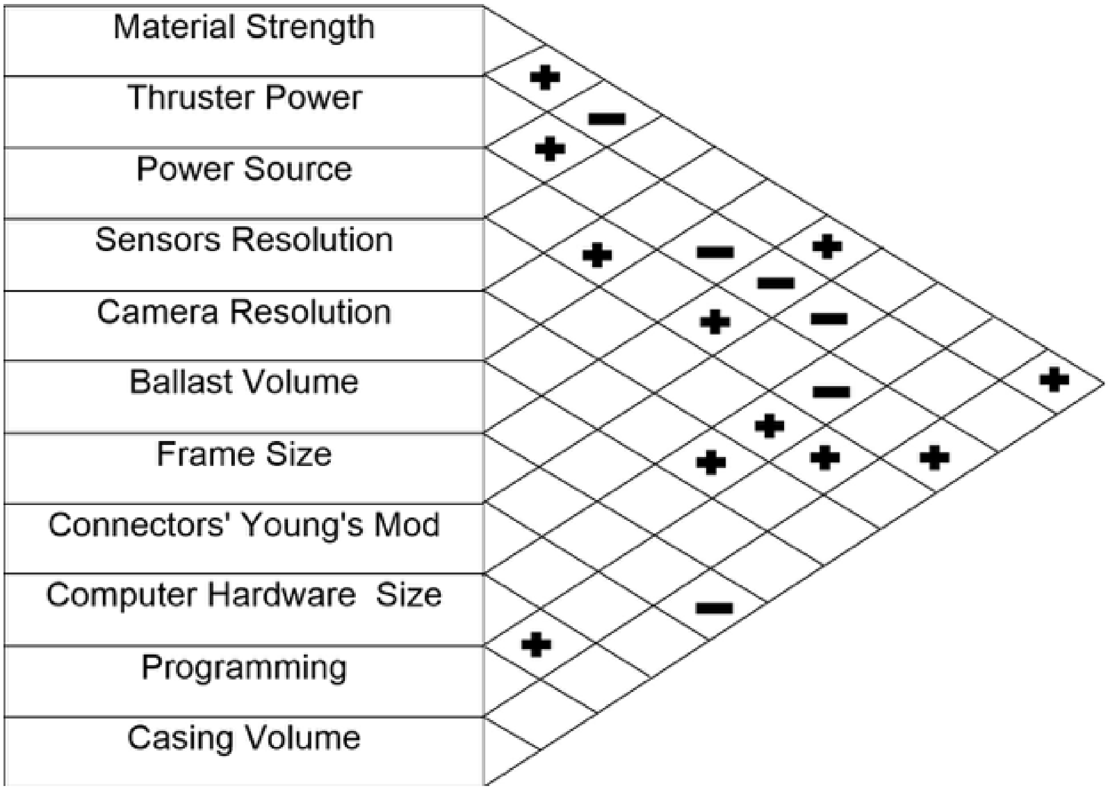

Table E.3: Project Plan