Final Report

Design and Development of an Autonomous Underwater Vehicle

Team 23

AUVSI RoboSub

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Table of Contents

Table of Figures

Table of Tables

Abstract

The goal of Team 23 was to represent the FAMU/FSU College of Engineering in the 19th annual AUVSI RoboSub competition, which occurs from July 25th to July 31st of 2016. This will be accomplished through the design, development, and extensive testing of an autonomous sub which meets all of the competition requirements provided by the AUVSI RoboSub competition. The particular aspects of design that the mechanical team will work on are a redesign of the hull, torpedo design and actuation, and the gripper mechanism. All of these categories are necessary to complete tasks required of the AUV in the RoboSub competition.

In addition to the mechanical engineering team electrical engineering team 4 will also be working on the AUVSI RoboSub project. While the two teams will be assisting each other in the development of various subsystems required for the AUV, team 4 will be more focused on the navigation and vision systems for the sub while team 23 focuses more on the mechanical subsystems. This collaboration of work will give the teams the best chance at sending a sub to compete in competition.

Acknowledgements

We would like to thank the people who have helped us thus far and the ones who plan to help us in the future. This includes Kim Hinckley at the Morcom pool for letting us use FSU's dive pool for testing. Dr. Gupta and Dr. Shih for guidance and constructive criticism throughout the project and the course. Dr. Clark for pushing us to set high goals and achieve them. Dr. Harvey and Dr. Hooker for their support and suggestions and the ME and ECE department for funding our senior design project.

1. Introduction

Team 23 of mechanical engineering senior design is working towards competition in the 2016 AUVSI RoboSub competition. This competition requires teams to design and build a fully autonomous vehicle that can complete several tasks to test the vehicles abilities. This project is a continuation of several years of senior design teams at the FAMU/FSU College of Engineering. Team 23 was given a vehicle that was created by previous years' teams and includes several components including thrusters, cameras, and hardware. In addition to the mechanical engineering led team there is an electrical engineering led team that is working on software inherited from previous years. Both senior design teams are working on the same project in order to produce a vehicle for competition.

1.1. Problem Statement

The Association for Unmanned Vehicle Systems International (AUVSI) Foundation[1] and the U.S. Office of Naval Research (ONR)[2] has designed a competition to advance the development of Autonomous Underwater Vehicles (AUVs) by challenging a new generation of engineers to perform realistic missions in an underwater environment. The 19th International RoboSub Competition[3] requires the design of a vehicle that operates autonomously in a self-contained unit. The AUV will be deployed in a large salt-water pool at a Navy test facility in San Diego California. The competition has several objectives to complete which test the mechanical, electrical, and software components of the sub. These objectives consist of tasks typically required of autonomous submarines including identifying objects, picking up objects, and navigating to targets.

1.2. Design Requirements

The AVUSI Robosub competition provided guidelines for the dimensions of the AUV as well as several requirements for the subsystems to ensure contestants and the event coordinators are not harmed while the submersible is in operation. The table below highlights the weight constraints given for the competition as well as the various requirements for other subsystems.

Table 1:AUV Weight Constraints

	Bonus	Penalty
AUV Weight > 125 lbs (AUV Weight > 56.7 kg)	N/A	Disqualified!!!
125 lbs ≥ AUV Weight > 84 (56.7 kg ≥ AUV Weight > 38 kg)	N/A	Loss of 250 + 5(lb – 125) 250 + 11(kg – 56.7)
84 lbs ≥ AUV Weight > 48.5 (38 kg ≥ AUV Weight > 22 kg)	Bonus of 2(84 – lb) 4.4(38-kg)	N/A
AUV Weight ≤ 48.5 lbs (AUV Weight ≤ 22 kg)	Bonus of 80 + (48.5 – lb) 80 + 2.2(22-kg)	N/A

- The AUV weight must not exceed 125 pounds in air
- The AUV must be able to fit in a 6 feet by 3 feet by 3 feet box
- Torpedoes and markers must have a dry weight of no more than 2 pounds
- Torpedoes and markers must be able to fit into a 2 inch by 6 inch space
- Torpedoes must travel at a "safe" speed, or a speed that will not cause bruises when it strikes a person
- The vehicle must be battery powered and the battery must not have an open circuit voltage that exceeds 60V
- The vehicle must have a kill switch that can be easily accessible
- All propellers must have shrouds that surround them and have at least a 2 inch distance between the spinning disk and the edge of the prop
- The AUV needs to be buoyant by at least 0.5% of the sub's mass when it has been shut off through the kill switch

1.3. Objective

The objective over the past two semester between the teams has been to improve upon and redesign the underwater vehicle from the past year. More specifically major objectives where to improve the design of the hull and to for optimal buoyancy and ability to access electronics efficiently. Also to progress with the subsystems necessary to complete the tasks of the competition, including the pneumatic systems, comprised of the gripper mechanism and the torpedo firing system, which are both air actuated. The marker dropper and torpedo systems where improved upon from the last years design.

2. Background Research

2.1 Competition Tasks

The AUV will be operating at the SSC Pacific TRANSDEC Facility, which houses an anechoic saltwater pool. The facility is located in San Diego, CA, and the water is obtained directly from the Pacific Ocean. The underwater obstacle course will be arranged in a region with a maximum depth of 16 ft. This year, the venue will be divided into four sections, and will be running full missions in every section. There will be no practice sections for the 2016 competition until the semi-final round. For the semi-final round one half will be devoted to the semi-final runs. The other half will be devoted to teams for practice. Figure 1 is a schematic of the competition pool layout. It shows how different tasks and obstacles would be set up in the competition[4].

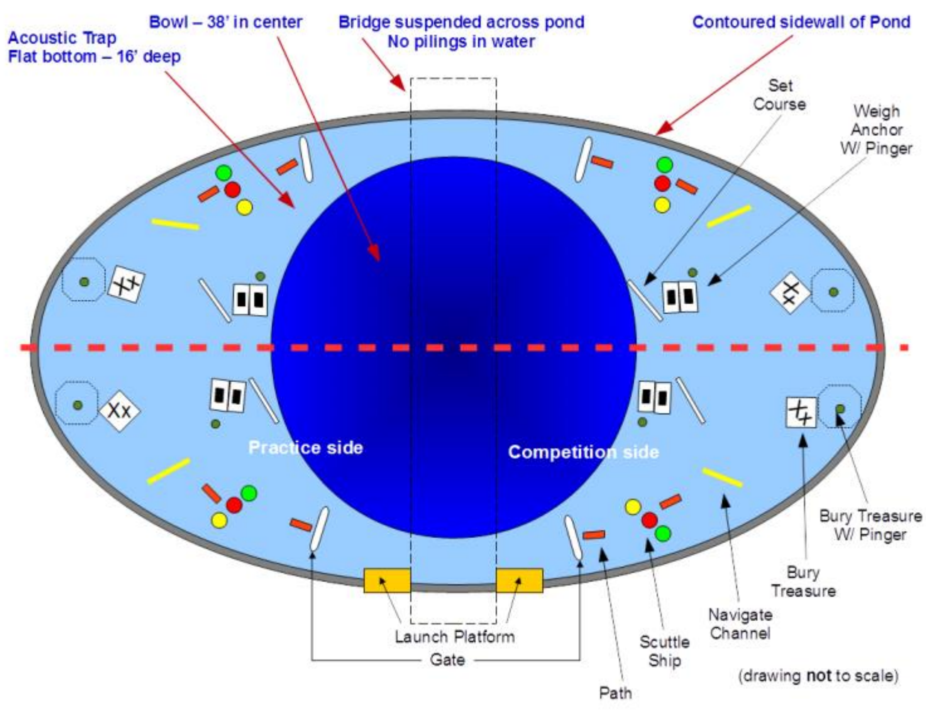

Figure 1: Competition Schematic

Examples of the various tasks the AUV needs to complete include

1. Path Marker

The path markers are 4 feet long by 6 inches wide. The path will be covered in orange colored duct tape. Each path marker will be placed directly after the current task, and point to the next task. There will be one positioned at the gate that points to the Scuttle Ship task. Positioned near the Scuttle Ship task, the next path segment will point to the Navigate Channel task. Those will be the only path segments which can be used to visually direct the vehicle.

2. Scuttle Ship

There will be two 8" buoys. One will be Red, the other will be Green. The third object will be a corrugated plastic cutout similar in size to the buoys. The cutout will be moored to the floor, and directly above the cut out, on the surface of the water, will be the silhouette of a ship. Points are awarded for touching any buoy. Additional points are awarded for touching the Red then Green buoy. Additional points are also awarded for dragging the yellow "buoy" downward pulling the ship on the surface underwater.

3. Navigate Channel

A horizontal section of 2" PVC pipe will be moored to the floor. Attached to this will be two vertical sections. Points will be awarded for passing over the obstacle. More points will be awarded for navigating with through the channel unconventionally.

4. Weigh Anchor (Bins)

This tasks consists of two black bins. A total of two markers can be dropped from each vehicle. Inside each bin will be a different anchor silhouette. One of the two bins will have a cover over the opening. Points are awarded for dropping the markers in the open bin, or on the outer edge. To obtain maximum points, the vehicle must remove the cover and drop both markers in the bin that was once covered.

5. Set Course

There will be a vertical square moored to the floor with two different size square openings. Two small openings and two large openings. A total of two torpedoes can be fired from the vehicle. On the face of the square will be a compass rose, with the directions N, S, E, W. One of the two small squares will be covered. Points will be awarded for firing the torpedo through any of the openings. More points will be awarded for firing torpedoes in the correct course heading. Maximum points will be awarded for removing the cover, and firing torpedoes through the small openings in the correct order.

6. Bury Treasure

This task consists of an acoustic pinger located off the floor of the pool. Placed directly above the pinger, on a tower, are two gold doubloons. Floating above the pinger on the surface will be an octagon representing the island. In order to obtain full points for the octagon, the vehicle must surface fully inside the octagon.

Located next to the pinger/tower is a large flat table. On the table there will be two "X"s. Maximum points are awarded for placing each of the objects near it’s associated X.

2.2 State of the Art

During the initial phases of design and development of an original robotic submersible, much research was done on other teams, both through FAMU/FSU and outside teams. More specifically, the teams that performed well in the AUVSI Robosub competition for previous years provided a great starting point for design ideas. The prototype for the 2016 design mimicked San Diego State University's 2015 team's frame[5]. As you can see in the figure below, the frame is very similar to the design that is implemented in the current FAMU/FSU design.

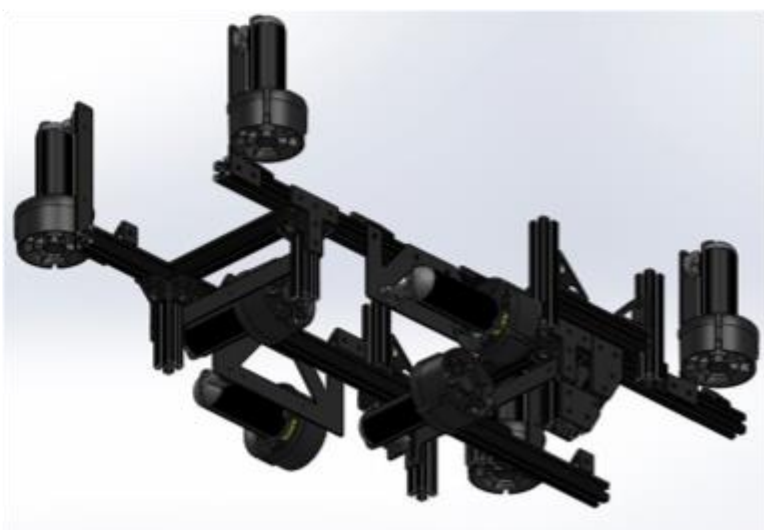

Figure 2: San Diego State University's frame

2.3 FAMU/FSU COE Past Experiences

The design and development of the autonomous submersible was aided by the previous experiences and designs from past FAMU/FSU teams. The hull utilized by the 2015 robosub team provided a template for the current hull that is utilized for the 2016 team. While the current design is fabricated from a different material as the 2015 team's hull, the hull shape and design remains consistent, due to successful waterproof tests acquired from the 2015 team.

The internal electronics within the 2015 submersible are also still utilized within the current submersible. The arduino MEGA, motor controllers, and thrusters are still utilized in the current design because they were functional for the 2015 team. Other subsystems and electronics, such as the marker dropper and zotac CPU, were modified from last year's team. The zotac utilized in the current robosub is a newer model than the previous zotac, yet it performs the same tasks. This also led to the design and development of further subsystems, organized in a similar fashion to the 2015 robosub team.

Most importantly, the code created by the 2015 team is still functional for the current submersible. This provided an advantage by supplying code to previous subsystems, which allowed them to be functional again for the current design. Furthermore, the code provided a template on how to proceed with the creation of new code for the subsystems that were to be unique to the 2016 design.

3. Concept Generation

A house of quality matrix (HOQ) was used to help determine what tasks the team should focus on. The HOQ can be seen in figure 3. From the HOQ it was found that the hull, image processing, and torpedo mechanism as the major tasks to complete for the project. Based off the HOQ it was decided that the ME senior design team focused on the redesign of the hull and the torpedo subsystem while the ECE senior design team would take on the image processing. In addition to these the ME team also worked on the marker dropper subsystem and the power systems for the electronics.

Legend:

Correlation

- 1: Low
- 3: Medium
- 9: High

EC's of High Importance:

1. Sensing
2. Electronics Housing
3. Torpedo Mechanism

		Engineering Characteristics									
Units		ft^3	lbf	lbf	N/A	lbf	N/A	N/A	N/A	N/A	N/A
Customer Requirements	Importance Weight Factor	Dimensions	Buoyancy	Weight	Material	Thrust	Sensing	Frame	Electronics Housing	Torpedo Propulsion system	Gripper mechanism
Cost - $2000 budget	5	1			1	1	9		3	1	1
Accessablity - easy to access components	4	3		3				3	9		
dimensions do not exceed 6x3x3 feet	3	9	9	9				3	3	1	1
Durability	4				9			3	3	1	
Shoot a target with torpedoes	4						3	3		9	
Place markers in bins	4						3				9
Waterproof	5				3			1	9		
Detect frequencies between 20-45kHz	5						9				
Navigation through obstacles	5	3	3	1		9	9	1	1		
Do not harm testers	5			3	1	1	1	1	3	9	3
Raw Score		59	42	59	61	55	164	60	137	93	59
Relative Weight %		7%	5%	7%	8%	7%	21%	8%	17%	12%	7%
Rank Order							1		2		3

Figure 3: House of Quality Matrix

3.1 Hull

One of the very first tasks of the project was a test of the hull to evaluate the buoyancy, stability, and waterproof of the hull. After discovering the hull was much too buoyant and very difficult to access the electronics it was decided to redesign the hull. Because the original hull was still functional and a new design would take several months it was decided to save the original as a backup. More complex designs were investigated that gave the AUV a more streamlined profile however fabrication would be more complicated and time consuming. Realizing that the original hull was quite stable when submerged it was decided to design a hull that would keep the general shape of the original hull but reduce the size of it for buoyancy effects. This approach had the added benefit of easy compatibility with existing components, subsystems, and hardware. This saves both time and money over the course of the project.

The old frame was useful because of its modular 8020 bars but it was assembled poorly due to weak fasteners and brackets. Furthermore the location of several components on the frame such as cameras and thrusters beneath the AUV was inconvenient because it prevented the sub from lying flat. This not only made it cumbersome to work with but also created drag in the water. In addition to these problems the entire frame was mounted to the hull with just one bracket which made it very unstable. When conceptualizing a new frame a design was sought that was compatible with existing hardware but fixed the problems listed above.

3.2 Power System

Table 2: System Power Requirements

Components	Max Current (A)	Ave. Current (A)	Voltage Required (V)
Zotac PC Board	3.5	1.5	19.0
Arduino UNO	0.75	0.5	7.0 - 12.0
Arduino Mega	0.75	0.5	7.0 - 12.0
Motor Controllers	2.0	1.5	5.0
IMU	0.075	0.060	3.5 - 16.0
Thrusters	12.0	3.0	19.1
Depth Sensor	0.020	0.012	8.0 - 11.0

In order to choose a battery for the AUV, it was first important to collect the power specifications that each component uses. The battery needs to be as compact as possible as to not take up to much of the limited space inside of the hull, but also be powerful enough to power all of the electronics for a specific period of time. The data collected about each component was put into a table that can be seen above.

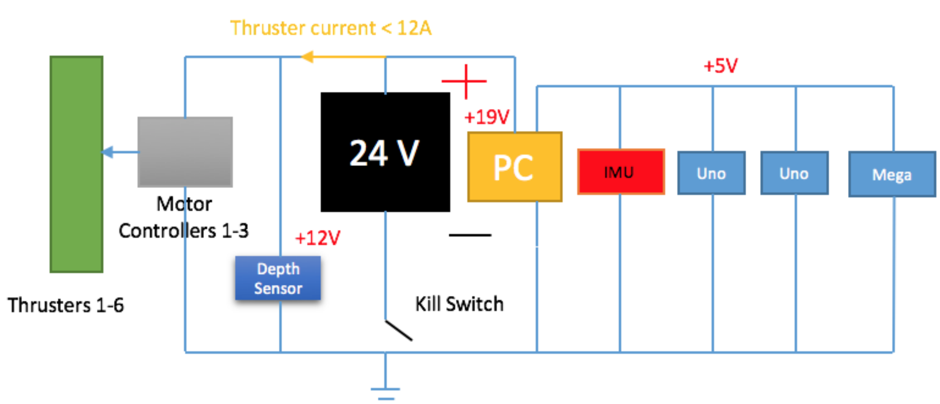

Figure 4: Power systems schematic

Based off of the research that was collected from the table above, research was then done on different types of batteries to see which would be the most ideal for this project. The team began with multiple batteries to power all the systems but this was quickly determined to be inefficient as the batteries would take up to much space and created an excess of unnecessary weight. The best option was a single battery to power all of the systems. This can be done by using step down voltage regulators that allow the proper voltage to reach the necessary components. The MPU required 19V so it was determined a 24V battery would be sufficient. It was also determined to use two identical 12V batteries to achieve the voltage as it allowed the weight to be evenly distributed inside of the hull as the battery was the heaviest of all of the components. The figure above shows the circuit diagram of the AUV as well as the necessary voltages required by each component.

3.3 Pneumatic System

The previous pneumatic system was damaged due to age and various failures. The goal in the new system is to replicate previous system functionality while making repairs and improvements where needed. In this course all of the old parts were researched and specifications were found. By using the same air systems connectivity and pressures the functionality can be restored. The only major addition to this design is a new separate tube and valve in order to control the pneumatic gripping mechanism newly purchased by the teams.

3.4 Marker Dropper

The existing marker dropping mechanism from a previous years' team was well designed and simple. An initial test of this mechanism found that the motor was broken but the remainder of it was still functional. To reduce complexity and allow for more resources on other components this design was kept and a waterproof servo was bought that mounted onto the existing mechanism.

4. Final Design

4.1 Hull

It was decided to redesign the hull to reduce buoyancy and size in addition to make it more accessible. The inherited hull was ½ inch aluminum and was too large which led to over buoyancy and forced the thrusters to hold the sub underwater. Additionally the sub was sealed by 16 bolts going through the aluminum and attaching to a flange on the hull. This caused the acrylic to slowly crack as the lid was attached and took too much time.

The new hull is constructed from ¼ inch stainless steel welded to form a box measuring 12" x 18" x 5". Six panels where cut using a cnc waterjet machine. 15 holes were drilled for electrical penetrations and 18 holes were tapped for bolting on hardware. Six stainless steel adjustable toggle latches are bolted to the side of the hull to clamp the lid down to form a watertight seal. The toggle latches grab stainless steel hooks which are bolted to an aluminum lid which provides even compression across the acrylic lid. These latches make process of sealing the hull very quick, easy, and more importantly consistent. A rubber seal is fit over the rim of the hull and joined together using glue to form the rectangular shape of the hull. Figure 1 below shows an exploded view of the hull and Figure 2 shows an assembled view.

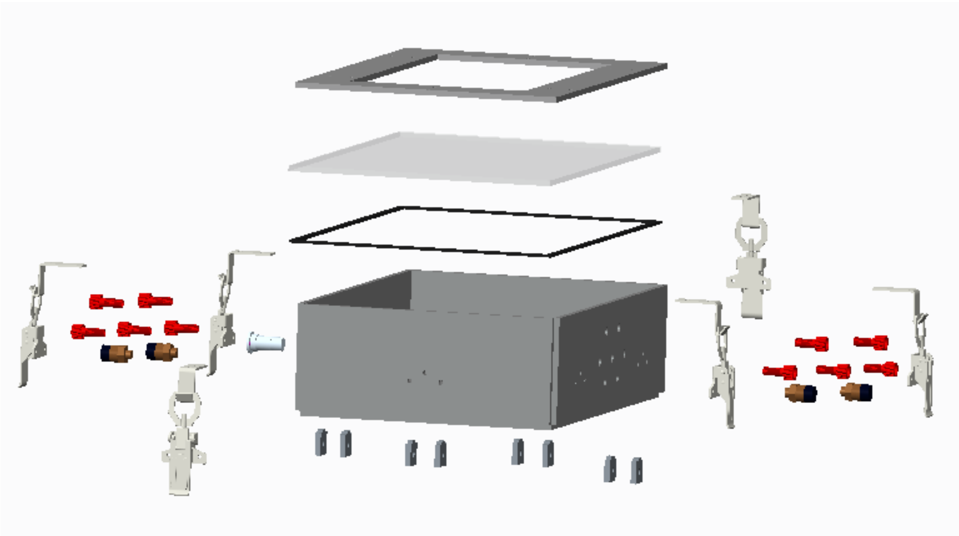

Figure 5: Exploded View of the hull

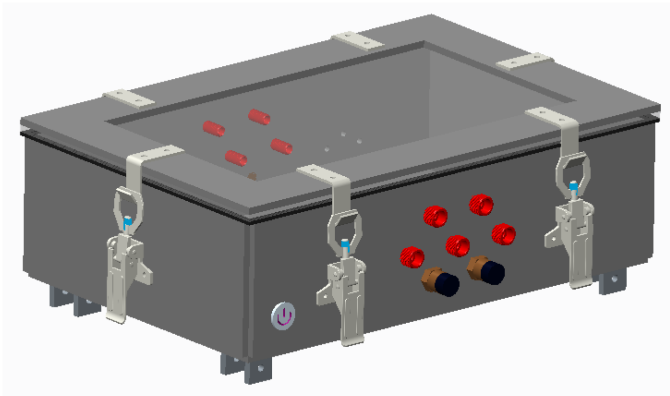

Figure 6: CAD of assembled hull

The frame is composed of 8020 extruded aluminum which was cut to size by the distributor. The frame uses two 34 inch 10 series bars in the long direction and several 8 inch 10 series bars for support and hardware. The frame is assembled using a variety of t-slot fasteners. The entire frame can be assembled and attached to the hull with an Allen wrench. The CAD of the frame can be seen below in figure 3. The general shape of the hull and frame is very similar to the original to allow for compatibility with software. Additionally the original hull and frame were kept as a backup should any problems arise with the new hull and frame. The physical hull and frame assembly can be seen in figure 8.

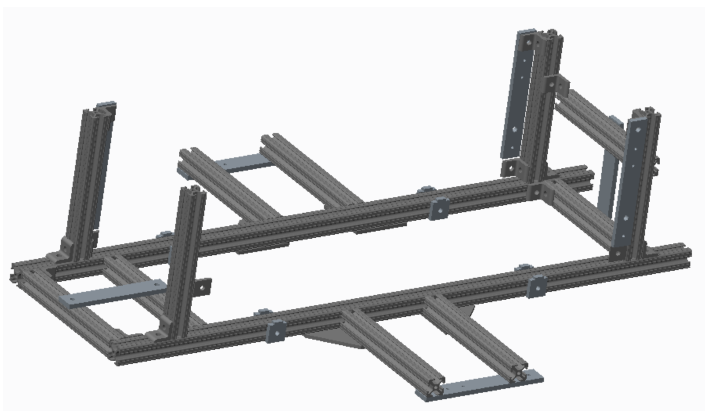

Figure 7: Framing for hull

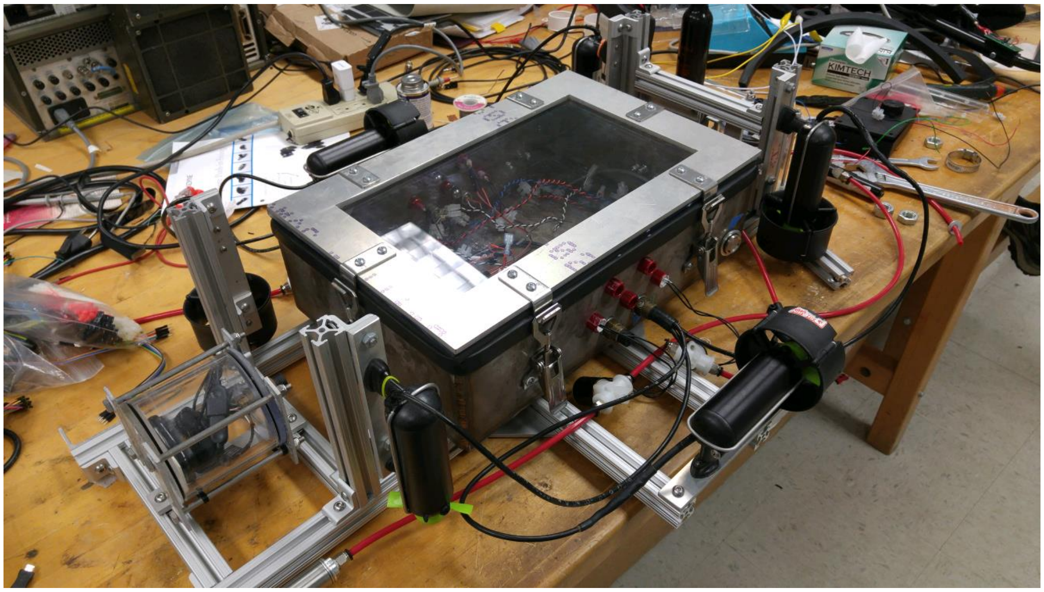

Figure 8: Physical Hull and Frame

A finite element model was created to test the pressure load experienced at a depth of 20 feet of water. The hull had a factor of safety of 1.44 with the principle stresses seen in the contour plot. Additionally many of the high stresses are stress concentrations that are not there in the real hull because of welding, bolts, and additional hardware.

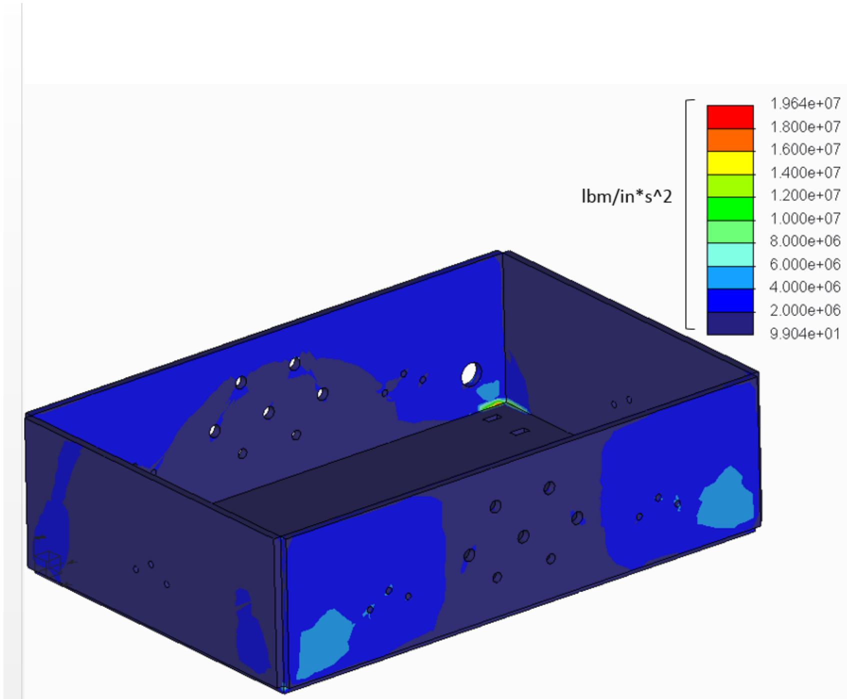

Figure 9: FEA of hull

4.2 Electronics

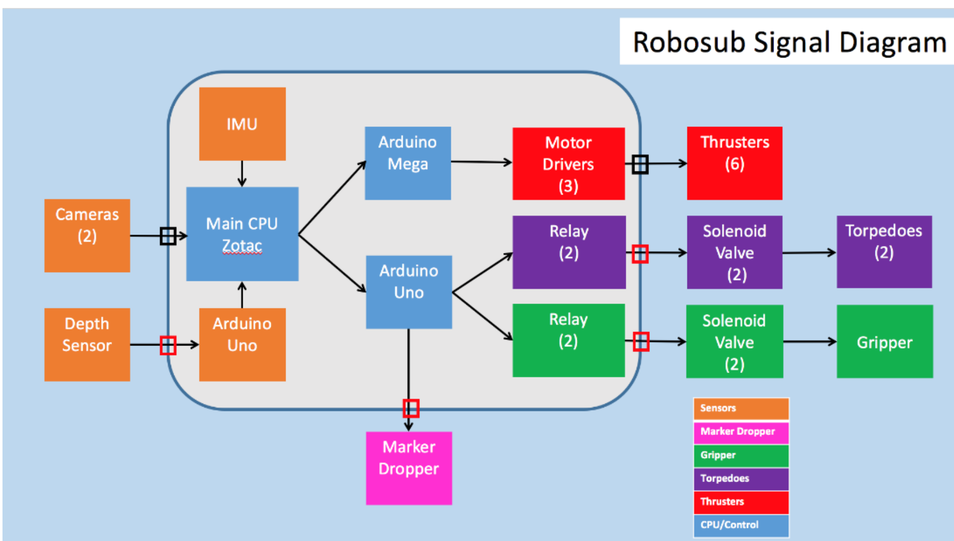

Figure 10: Signal Flow Diagram

While the mechanical systems of the AUV are important, they would not be functional without electronics to control them. There is a lot of communication going on between different periperals that allow the AUV to complete its different tasks. The signal flow diagram show in the figure above shows how everything is connected and communicates with one another.

4.2.1 Main CPU

In order to integrate all of the subs functions to communicate with one another a main processing unit is needed. The Zotac computer, shown in figure 10, acts as the main processing unit for the AUV. As the MPU, the Zotac is essentially the sub's "brain" and is responsible for most of the high-level communication. The Zotac is where the image processing takes place which then communicates to other peripherals of the sub. The reason the team decided to go with the Zotac Mini PC is that it allowed us to have more then enough processing power for the tasks we needed to complete with lenty to spare if anything ever needed to be added in upcoming years. The Zotac also gave wireless screen sharing capability which allowed it to be monitored and controller from on land via a laptop while the AUV was underwater. The MPU interfaces with one Arduino Mega and two Arduino UNO microcontrollers. The Zotac makes use of its USB ports to establish bidirectional UART serial communication links with the microcontrollers. The information is sent to the Arduinos to control various hardware such as the thrusters, and depth sensor. The Arduinos also regularly update the MPU with necessary mapping and control data such as current latitude readings and acceleration readings as well as relative depth readings which helps process the instructions and commands. The serial communication links are opened at a baud rate of 19,200 bits/s and zero parity. The Zotac computer also utilizes two Logitech webcams connected via USB for vision information. The MPU receives power from an external 19V/ 4mA universal laptop battery. The Zotac also acts as a power source to the microcontrollers and IMU.

- CPU Intel Core i32330M Processor (2.2 GHz, dual Core)
- Chipset Intel HM65 Express
- Memory: 2 X 204pin DDR31333 SODIMM Slots, Max Capacity of 16GB
- Hard Drive: Supports 1 X 2.5Inch SATA 6.0 GB/s Hard Drive
- Ports:4XUSB2.0Ports(1front,2rear,1top);2XUSB3.0Ports;1X
- WiFi Antenna Connector; 1 X DVI Port; 1 X HDMI Port; 1xOptical S/PDIF Out; 1 X RJ45 LAN Port; Audio I/O Jacks
- Card Reader: 6In1 Card Reader, Supports MMC/ SD/ SDHC/ MS/ MS Pro/ xD
- LAN: Integrated Gigabit
  Ethernet Controller;
  802.11n/g/b Wireless LAN; Bluetooth 3.0

Figure 11: Zotac Mini Computer

4.2.2 Microcontrollers

There are many different kind of microcontrollers that could have been used for this project. In the end, after analyzing a couple different brands, the team decided to go with the use of Arduino Microcontrollers. The reason for this choice came down to a few factors. Arduinos allowed easy communication for our subsystems and also had the most amount of output pins for its price which meant that fewer microcontrollers were needed for the project.

Figure 12: Arduino Mega

The Arduino Mega microcontroller, shown above in Figure 11, is the main control for the thrusters. It is responsible for interfacing with the motor controllers that control the thrusters, which are connected to the Zotac. The Arduino Mega microcontroller communicates with the Zotac computer through a UART serial link, which is channeled through the USB ports of both devices. The serial communication link sports an effective baud rate of 19200 bit/s to ensure data is transmitted quickly yet effectively. Each motor controllers supplies voltage to two thrusters each. These motor controllers therefore require the use of six pins on the Mega, two of which must be analog (PWM) pins in order to have variable control of the speed the thruster propellers are rotating. The Arduino Mega receives power from the MPU through the USB connection. Each of the three motor controllers are supplied with a maximum of 14.8V as input from the thruster and motor controller power system.

Figure 13: Arduino UNO

The Arduino UNOs, shown in figure 12, are useful in controlling parts of the sub that have to deal with each task it has to perform. One of the UNOs acts as the main microcontroller for the Depth Sensor. The microcontroller interfaces with the MPU via a UART serial communication link channeled through the USB port. The Arduino UNOs receive power from the USB connection to the MPU. The microcontroller is supplied with 12 V. The Arduino Uno then reads an analog voltage output for the depth sensor. It communicates the data from the sensor to the Zotac.

The other UNO controls the actuation valves for the air tank which is important for torpedo and gripper tasks. The UNO receives the image processing from the Zotac which then activates one of the pins on the microcontroller. The signal sends the necessary voltage to open the desired valve releasing the air pressure which will either fire a torpedo or open and close the gripper.

4.2.3 IMU

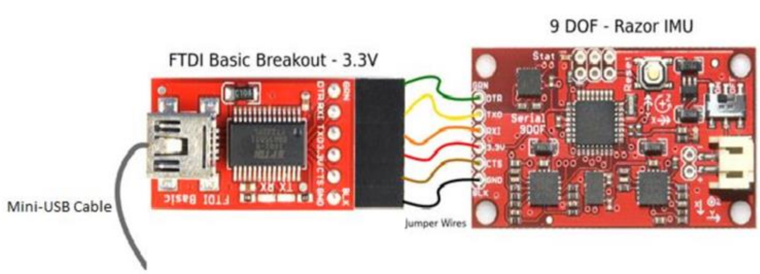

Figure 14: Sparkfun Razor IMU

The Sparkfun Razor IMU, shown above in Figure 13, is a sensor that is used to determine current angular velocity data, which will valuable in describing the AUV's current state of balance and movement.

The IMU directly interfaces with the Zotac PC via the FTDI Breakout Board, which is connected through a mini USB connection. The RazorIMU is therefore supplied with the ideal voltage and current flow to operate by connecting the 3.3V and GND pins from the Breakout Board to the respective 3.3V and GND pins on the IMU.

4.2.4 Motor Controllers

There are three L298 H-Bridge motor controllers that were used in the AUV, both of which were very similar. It was decided to stick with the motor controllers left from the previous years team because of their availability and proven effectiveness. The motor controller used is the CanaKit driver, shown in Figure 14, with the following specifications:

- Motor supply: 6 to 35 VDC
- Output Power: Up to 2 A each or 4 A if bridged together
- Onboard Power Resistors Provided for Current Limit
- Enable and Direction Control Pins
- Power-On LED indicator
- 4 Direction LED indicators

Figure 15: L298 H-Bridge Motor Controller

4.2.5 Battery System

Figure 16: Power Sonic 12V battery

The battery the team went with is shown in the figure above. It is a 12V 9 mAh rechargeable lead acid battery. By combining two of these in series the team was able to achieve the necessary voltage to power all of the systems in the AUV. This battery has a max output current of 2.7A which is well within the parameters the team came up with in the concept design. This battery allows the team to control the AUV in water for multiple hours before recharging it. The lead acid battery also gives safer usage then a typical li-po battery.

4.2.6 Cameras

The camera system was adopted from the previous year's team. The vision system will use two C615 webcams which are shown below in Figure 16. One webcam will be positioned horizontally in the front of the AUV. The other webcam will be placed in the back and facing down. The horizontal webcam will function with detecting the Gate and maneuvering the structure. The bottom facing webcam will detect the path segments on the floor of the pool. Each webcam is powered by USB so no external power adapter will be necessary. The following are the camera specifications that they provided.

- Full HD 1080p video capture (up to 1920 x 1080 pixels) with recommended system
  HD video calling (1280 x 720 pixels) with recommended system
- Logitech Fluid CrystalTM Technology Autofocus
  Photos: Up to 8 megapixels (software enhanced)
- Hi Speed USB 2.0 certified (recommended)

Figure 17: Logitech Webcam

4.3 Pneumatic System/Torpedoes

The pneumatic system, which includes the air valves, air tank, tubing and piston, has been redesigned this year. The original air system had all the aforementioned components, however, due to time the systems had deteriorated and required updating. In principal, this redesign was more of a replacement rather than an outright new system. Therefore each piece was set to emulate the previous systems specifications with any improvements, however marginal, that could be afforded. In the repurchase of the air tank, the new tank is the same type used in recreational, compressed air guns, and both versions share the same size and limits. The air valves used are newer models of the original air valves. Additionally there was a new valve purchased for the use of the pneumatic gripping mechanism. The updated tubing shares the same diametral size as the previous tubing, however also has a significant increase in strength over the previous years as well as lessened but comparable flexibility. The new tubing was chosen for this due to the fact that the old tubing experienced a cut or rupture that motivated its replacement. The final addition to the pneumatic system is the torpedo. The design of this was taken both from the old systems unsuccessful design and modified with designs used for toy torpedoes. This system fixed the previous issue of the torpedo floating to the surface immediately after firing by changing the behavior to better represent a standard projectile motion. This was accomplished by changing the material to a high density rubber that had a rapid fabrication process.

The torpedo was built in four steps. The initial step is the development of the CAD model. Taking designs of real world torpedoes and rubber torpedo pool toys an initial design is made. Upon completion of the CAD model the file is saved as a stereolithograph at relatively high constraints. The stereolithograph is moved to a slicing software such as makerware to prepare it for the 3D printer. In the software it is important to take into account build tray limits and part orientation, it should be oriented vertically to reduce potential model errors during printing. The model is printed out of ABS plastic and with any infill density. The finished 3D printed part once finished is post processed using increasingly fine grits of sandpaper to produce a smooth surface finish to ensure the part will be better streamlined. The third step in the fabrication is development of a two-part plaster mold. In setting up this mold it is important to consider the shape of the part and the orientation of the pour spouts, the mold material will not completely fill the mold if airways are not located at the highest parts of the designed piece. In order to cast this mold a basin to hold the wet plaster is required. In general cardboard is used with hot glue sealing cracks to prevent leaks. Additionally, a stand may be used to suspend the part within the basis to ensure a consistent height, this can be done with a piece of hot glue. Before pouring the plaster both the mold and the torpedo must be coated in wax or some other seal releasing agent to ensure separation of the piece from the mold, this must be done every time the mold is used and between each mold half during fabrication. After pouring the first half of the plaster into the mold, when the plaster begins to thicken, notches are made in the piece to create places for the two mold halves to lock together. At any point the plaster mold edited through the use of a scalpel to carve away any problem areas. The final step in the manufacture of the torpedo is to pour the mold material into the mold. The material used is Simpact 85A urethane rubber purchased from Smooth-on, it used an 1:0.85 mixing ratio by mass which therefore requires a scale to measure properly. Though not required, it should be handled with nitrile gloves to minimize skin contact. This material has a very short pot life of only about 4 minutes, and as such requires rapid mixing and pouring. Once poured the material is given forty eight hours to cure fully before releasing the mold to ensure the part does not tear. Final touches to clean the part are made using a scalpel and sandpaper.

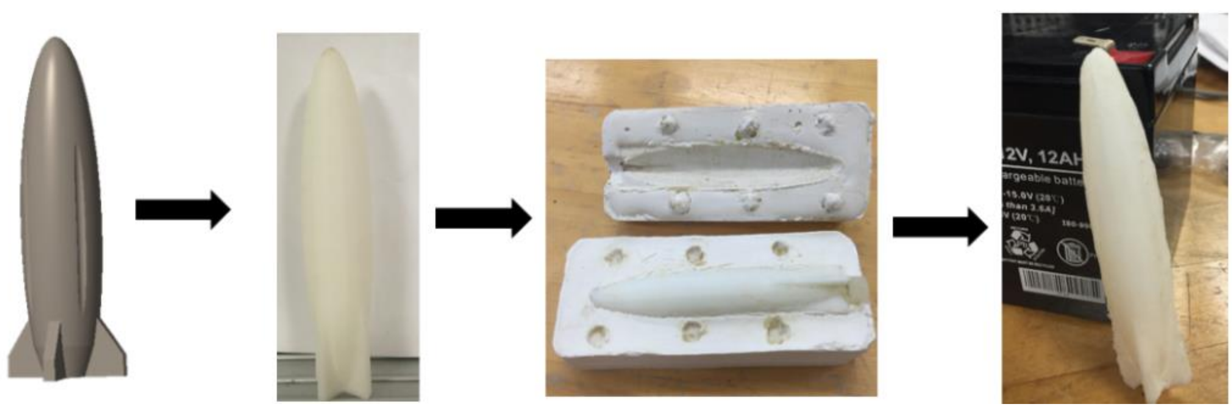

Figure 18: Torpedo Process

This process in its entirety takes a minimum of three days. Though it seems highly involved it was made to mimic the injection mold process used by most companies which work with polymers as well as sculpting techniques. If this was every required to be mass produced an assembly line could easily complete many of these in a short time frame. One possible way for this process to be improved is to rather than designing a torpedo first and creating a plaster mold a direct mold design can 3D printed and used to fabricate the torpedo. This would slow prototype editing and active model adjustment but could improve mold durability and accuracy of a well established design.

4.4 Marker Dropper

The marker dropper was edited from a previous year's designed prototype. The primary issues with this design is the fact that it lacked a method for waterproofing its actuator, which was a basic DC motor with no encoder. The frame for this system was salvageable in that it had established guides from for the round markers to follow and a mounting platform for both an actuator and the frame. The final version of this utilized a change in the actuator. The replacement piece was a waterproof servo motor with comparable size to the previous actuator. The system came with a usable servo arm which had sufficient size to optionally prevent or allow the markers to fall. To allow this new system to operate as expected the mounting bracket was adjusted to fit the new servo and tested. It proved to work as expected.

Figure 19: Marker Dropper

The marker dropper is made out of two aluminum 6061 parallel plates that contain a curved guide track. Both the curved boundaries of the guide track and the containing plates can be cut and drilled using a waterjet cnc machine. Spacers are located between the bars of the guides and plates held in place by the screws and lock nuts that hold the frame together. The spacing is adjusted by the addition of washers along these same shafts. This is mounted to the frame by an 80-20 piece of aluminum. A waterproof servo is held in the window of the aluminum plate with a standard servo arm and held in place with the servo mounting screws that came with the servo.

This subsystem has a very simple design that can be manufactured and assembled easily within a few hours. One of the best qualities of this design is its open air set up, which allows for easy testing and does not require any external water sealing. If this system were to be redesigned it may be beneficial to replace the curved guide rails with individual tubes to contain the markers. This would ensure that the markers stay in place during transit which may be an issue that arises that we are as of now unaware of due to the lack of extensive testing. This change would likely not affect the manufacturing or assembly time.

5. Design of Experiment

5.1 Waterproof Test

Waterproof testing was done under certain criteria to prove that the redesigned hull and frame system is watertight. Each test follows an order that only continues if the previous test does not fail. Additionally during testing paper towels are placed in the hull in order to identify where a leak occurs. The testing was done by first sinking the hull and checking for catastrophic failure, denoted by immediate rapid water flowing inside the hull. The second test fully submerges the sub for ten minutes, which allows time for slow leaks to appear. The third round of testing involves moving the sub in the water and changing its orientation so that leaks that may spring up due to different conditions can be identified. This range of testing is done three times with the lid removed and resealed between each test to ensure a good seal at various conditions. If any of these criteria fails the team alters the waterproofing and retests. The final after all has been sealed at shallow waters is retested 16 feet under the surface to ensure that pressure increase does cause water to breach the hull.

Figure 19: Waterproof Test

5.2 Thrusters

Thruster testing was one of the first tests performed in the fall semester. A preliminary lab test was conducted to ensure that not only the thrusters were functioning but also to ensure the functionality of supporting systems such as batteries, motor drivers, and software needed to operate the thrusters.

5.3 Pneumatic System

Pneumatic system testing is critical for both the marker dropper and torpedo firing. The majority of the components necessary to operate the pneumatic system were inherited with the old AUV however nearly all of these components were broken beyond repair. To conduct a test of this system several components had to be replaced including: a compressed air tank, air tubing, solenoid valves, air pistons, and electrical relays. Once these items were replaced and assembled a dry test in the lab was conducted that tested the torpedo firing system.

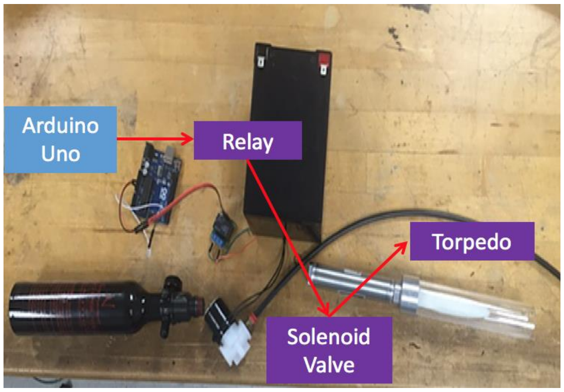

Figure 20: Pneumatics Test

5.4 Marker Dropper

The marker dropper testing was performed in two stages, the first stage was the individual subsystem test, and the second is the total subsystem integration test. The first test involved both testing of the code with markers being dropped in air and in water. The water tests were performed in a small bath of water and the frame was completely submerged. This test was successful upon the first instance of the new actuators implementation. The secondary test was performed when the full hull and frame assembly was together. Finally the actuation is tested in code to determine if the drop is successful at full scale.

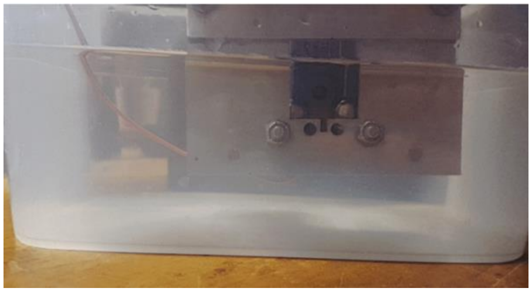

Figure 21: Marker Dropper Test

6. Environmental Considerations and Ethics

When conducting experiments with the submersible autonomous vehicle, it is important to evaluate the environmental and safety hazards while testing. The environmental issues are minimal and almost nonexistent, considering the testing is performed within a controlled environment. However, a potential environmental hazard of the submersible would be the malfunction and detachment of components within a large body of water. Also, if the submersible is not waterproof, the electronics will malfunction and could leak battery acid within the water, causing damage to the environment. The safety issues regarding the sub are minimal as well. If the sub is not waterproof, the components could potentially shock and injure individuals within the sub's vicinity. Furthermore, when testing with compressed air, it is imperative to use caution within its testing vicinity. When launching projectiles such as torpedoes, there is a possibility that one of the projectiles could impact and injure an individual. Therefore, the submersible is tested to be waterproof before electronics are inserted to ensure that the sub is both environmentally friendly and safe to test.

7. Project Management

7.1. Schedule

Designing and developing an autonomous underwater vehicle is most definitely a multidiscipline project that has numerous aspects to consider. Throughout the two semesters the team embarked on the project, the use of Gantt charts was helpful but did not keep the team's completion of task's on time but became a consistent reminder of the critical path necessary to follow to complete the project. As the Gantt charts were revised between deliverables and presentation they became more of a way to keep track of what still needed to get done instead of when it needed to be done.

7.2. Resources

The team was given a large range of resources in the design and manufacture of the individual subsystems. Both the college of engineering machine shop as well as its machinists were vital in the fabrication of the hull. The machinists offered the team several design suggestions that would allow the hull to be produced more easily and reliably. The facilities which were primarily utilized were the electrical engineering senior design lab and secondarily the STRIDE laboratory facilities. The electrical engineering lab was used to house, assemble, and prototype all systems on the submersible; also serving as a meeting and planning area for the team. Most of the work done on the sub was done in the electrical engineering lab with tools provided either by the laboratory or by team members. The STRIDE laboratory was only used by the team members employed in said lab, and this facility was only used for torpedo fabrication and a few select resources that it had readily available. The team also had access to a 3D printer and various testing electronics, such as touch screens and microcontrollers, provided by one of the team members. Additional resources include the various advising from professors, mainly Dr. Clark, and the senior design instructor Dr. Gupta. The primary advisor, Dr. Clark, assisted the team by guiding them in resource selection, project goal hierarchy, and improved communication techniques.

7.3. Procurement

The Robosub senior design project was allotted $2000 dollars total over the course of two semesters as a budget. In order to meet these budget requirements the team realized the budget had to be properly managed in order to insure the proper funding throughout the project. For example some of the components that are on the sub which have been used over the years like the BTD150 thrusters and Seacon ports could use some replacement, but given they're high expense that was not a priority. The project is comprised of many different subsystems, so for simplicity categories have been broken down into the main areas seen in the pie chart below. An absolute bill of materials of materials is included in the Appendix A.

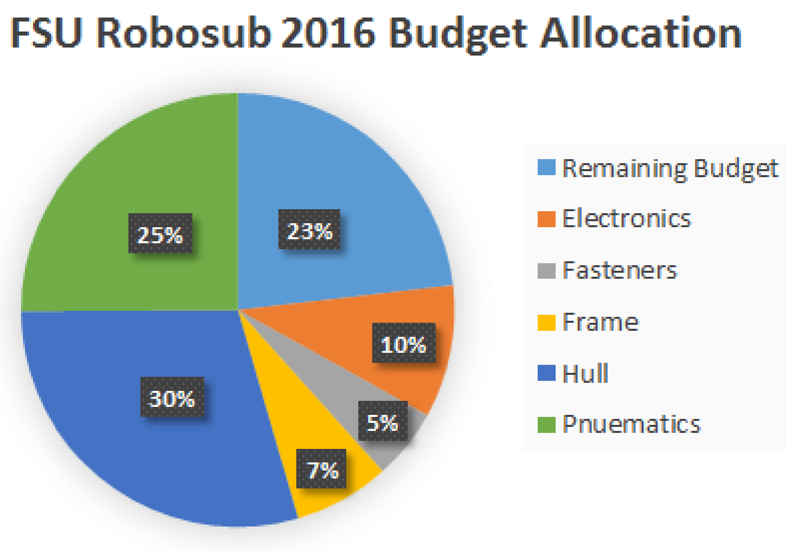

Figure 20: Robosub 2016 Total Cost Breakdown

In general, up to now the majority of the budget has been spent on the fabrication of the new hull equating to 30% of the total budget which comes out to $590. These cost when mainly to the purchases of raw materials, including the stainless steel for the hull, aluminum for the lid, and also the stainless steel toggle latches for enclosing. These were some of the more expensive items necessary to improve the design of the Robosub. The pneumatic system has made a lot of progress and was a large focus while the new hull has been under construction. Many items were required to get the pneumatics up and running which include the torpedoes firing and gripper actuation. Some of the items that have been purchased for these systems were the compressed air tank, pneumatic actuator, solenoid valves, and of course the hose and waterproof connections to tie it all together. Seen in the pie chart this has contributed to 25% of the total budget coming down to roughly $500. The three remaining categories including the electronics, fasteners, and frame go hand in hand with the major components of the submersible. The frame can be elaborated upon to include more subsystems if needed which require additional electronics and fasteners for integration. These categories grow together with progression of the project each contributing between 5% and 10% of the budget which is about $150 each.

Of the $2000 dollars, $1000 was designated for FSU vendors while the other $1000 was to be spent for non-FSU vendors. Due to the nature of the project the majority of components that were necessary to order were from non-FSU vendors, so that side of the budget was first to go. For the other half of the budget one of the team members had to make the purchases for the team and the AME would reimburse the team. Though this was a simply transition the amount of time required to reimburse the team was not ideal, but unavoidable. The budget was spent wisely and on only parts and components that were essential. Having a budget of $2000 dollars worked, due to the fact that many of the more expensive system components from the previous years design were salvaged while the other more degredated, less expensive components were affordable enough to replace. Although with some addition funding some of the thrusters and seacon ports could have been replaced which the sub would have benefited from.

7.4. Communication

The primary form of communication between the team members was through GroupMe, a phone application that eases communication between larger groups, which allowed the team to efficiently remain in contact with each other throughout the duration of the project. For communication with various advisors the team generally communicated through email and by verbal communication. Getting in contact with the team’s advisor, Dr. Clark, proved to be a simple task for the team as several members already had regular contact with him throughout the school week. The most difficult challenges team 23 faced in terms of communication was trying to determine where the ECE Robosub team stood.

The team held meetings in the ECE senior design lab twice a week to focus on various goals the team set for themselves for each week. Periodically representatives from the other robosub team would join to collaborate on various tasks that the two teams were working on. Meetings with the team's advisor happened roughly every two weeks at the beginning of the semester and gradually trailed off as the team picked up pace while developing various subsystems. Meetings with the instructor, Dr. Gupta, were held every few weeks as an update on where the team stood in terms of completion of the project.

8. Conclusion

Given the testing and research of the three subsystems that the mechanical engineering led group is responsible for the next steps have been made clear. The testing revealed that the current hull is functional but not optimized for the design. However, the upfront cost, both economically and time wise, are great if the group were to scrap this design in favor of another, given our low budget and the rapidly approaching competition these factors are critical. Therefore, the decision was made to generate alterations to the current hull to improve its performance in testing. Ideas may be taken from the other designs in this process however at its core the hull will be the same piece. The old gripping mechanism has been analyzed however since it was never functional the team will simply be starting from scratch with a new system. In order to reduce strain on the electronics and to easily apply a continual force the choice was made to make the mechanism air actuated and in order to prevent interference with the camera it will hag far below the sub. The competition has yet to release the specific tasks that the gripper should accomplish a holding mechanism has yet to be conceptualized fully because of this the design has been slightly delayed. The torpedo system has yet to be tested by this year's team due to rusted parts however based on old video it was at one point functional. For this reason, the air compression system will remain largely unchanged and simply reconstructed with replacement parts. The torpedoes themselves on the other hand will need to be updated. Based on the video evidence the projectile is too buoyant to meet competition task standards therefore a new design is needed. The process of this new design will be iterative using 3D printing for the purposed of rapid prototyping. This in hand with buoyancy testing will allow the team to produce several options that will best achieve performance standards. Overall the current sub is close but falling just short of competition standards. For this reason, our work is focused on small but critical updates to the submersible to bring it to the level it needs to be at to work successfully.

9. References

[1] "Home - Foundation." Home - Foundation. N.p., n.d. Web. 30 Oct. 2015. <http://www.auvsifoundation.org/home>.

[2] "Directorates." *Office of Naval Research Home Page*. Web. 08 Apr. 2016.

[3] "RoboSub - Foundation." *RoboSub - Foundation*. Web. 08 Apr. 2016.

[4] Robosub, Preliminary Mission And Scoring, and 12 December 2015. *Preliminary Mission and Scoring A Pirate's Life for Thee* (n.d.): n. pag. Web.

[5] "President Obama Congratulates Mechatronics for Their 2015 RoboSub Win." *SDSU Mechatronics Club*. Web. 08 Apr. 2016. <http://www.sdsumechatronics.org/>.

10. Appendix

Appendix A- Bill of Materials

Item Description	Quantity	Unit Price	Total Cost	Subsystem
Arduino Uno R3 (Atmega328 - assembled) PID: 50	1	24.95	24.95	electronics
Connector/Adaptor: A Pair of Tamiya Connectors (Male + Female)	2	2.95	5.90	electronics
Custom NiMH Battery Pack: 24V 2200mAh (20XAA) Battery with Thermistor and Polyswitch	1	43.95	43.95	electronics
Universal Smart Charger (2A) for 19.2-24V NiMH/ NiCd Battery Packs with Tamiya Connector*	1	26.95	26.95	electronics
IP68 Waterproof LED Push Button Switch	1	22.99	22.99	electronics
Pololu Basic SPDT Relay Carrier with 12VDC Relay (Assembled)	4	4.95	19.80	electronics
Pololu 12V Step-Up Voltage Regulator U3V12F12	4	3.95	15.80	electronics
Savox SW-0231MG Waterproof High Torque STD Metal Gear Digital Servo plus FREE Aluminum Servo Horn	1	36.95	36.95	electronics
M10-1.5 DIN 1587 A2 Stainless Steel Acorn Nut	10	1.43	14.30	fasteners
Loctite 4G Control Gel Super Glue	1	2.98	2.98	fasteners
Sheet metal screw, pan head #6 x 1" (6 per pack)	3	1.18	3.54	fasteners

1/4-20 x 3/4" button head screws (2 per pack)	4	1.85	7.40	fasteners
1/4-20 Hex Nuts	8	0.06	0.48	fasteners
J-B Weld 50172 MarineWeld Marine Adhesive Epoxy Syringe - Dries White - 25ml	2	7.99	15.98	fasteners
Zinc-Plated Steel Pan Head Phillips Machine Screw, 10-32 Thread, 1/4" Length, packs of 100	1	3.93	3.93	fasteners
Dixon Valve TTB75 PTFE Industrial Sealant Tape, -212 to 500 Degree F Temperature Range, 3.5mil Thick, 520" Lengt	1	2.53	2.53	fasteners
Military Grade Pipe Thread Sealant Tape, 14 yd L X 1" W, .0032" Thickness, 1.2 G/CC Density	1	8.72	8.72	fasteners
Pressure-Sealing Washer for Screws and Bolts, Zinc-Plated Steel, No. 10 Screw Size, 0.180" ID, 0.443" OD, packs of 10	2	9.34	18.68	fasteners
Pressure-Sealing Washer for Screws and Bolts, Zinc-Plated Steel, 1/4" Screw Size, 0.240" ID, 0.505" OD, packs of 10	1	9.34	9.34	fasteners
Pressure-Sealing Washer for Nuts and Washers, Zinc-Plated Steel, 3/4" Screw Size, 0.765" ID, 1.375" OD, packs of 1	1	3.86	3.86	fasteners

Pressure-Sealing Washer for Nuts and Washers, Zinc-Plated Steel, 7/16" Screw Size, 0.447" ID, 0.906" OD, packs of 5	1	14.16	14.16	fasteners
1" Single T-Slotted Framing Extrusion, 10' Long This product ships via motor freight.	2	31.59	63.18	frame
90 Degree Plate, 3" Long for 1" High Single Profile Aluminum T-Slotted Framing Extrusion	4	8.47	33.88	frame
Bracket, 1" Long for 1" High Single Profile Aluminum T-Slotted Framing Extrusion	8	5.79	46.32	frame
Acrylic Extruded Clear Sheet (Thicknes: 1/4'', Sheet Size: 24'' x 48")	1	58.71	58.71	hull
03-1692SS: Catch Plate for Toggle Latch Stainless Steel (Natural)	6	2.98	17.88	hull
Window weatherstrip (Part Number: 70-1192-52)	6	4.40	26.40	hull
Size 110 GN831.1-IN TOGGLE LATCH S.S. (Item Code: 110EGNL)	6	20.56	123.36	hull
Multipurpose 304 Stainless Steel Sheet, .250" Thick, 12" x 18" (Product # 8983K251)	2	69.95	139.90	hull
Multipurpose 304 Stainless Steel Sheet, .250" Thick,	2	26.23	52.46	hull

6" x 12" (Product # 8983K221)				
Multipurpose 6061 Aluminum, 1/4" Thick x 2" Width x 6' Length (Product # 8975K71)	1	20.10	20.10	hull
Impact-Resistant Polycarbonate Sheet, 1/4" Thick, 12" x 24", Clear	1	27.72	27.72	hull
Cable Penetrator for 6mm Cable (SKU: PENETRATOR-10-25-A-R2 Categories: Cable Penetrators)	12	3.00	36.00	hull
Aluminum 6061-T651 Bare Plate 0.25" Cut to: 13" x 19"	1	74.10	74.10	hull
Weather- and Abrasion-Rst Foam Sheet, Blended EPDM, Soft, 1/4" Thickness, 42" WD, 1' LG	1	11.25	11.25	hull
100' Box (1/4 OD x 1/8 ID Tubing) (Part #: PU-250-3)	1	45.90	45.90	pneumatics
Pneumatic fitting, straight, 1/4" tube, press-in, 1/8" NPT male (am-2011)	16	2.00	32.00	pneumatics
Airtac HFY; Double Acting Pneumatic Air Gripper - HFY 16	1	50.80	50.80	pneumatics
Miniature Male Straight Adapter (Internal and External Hex). Model Number: OM-AIR-M22250105-5PK	2	14.75	29.50	pneumatics
Female Stabilizer Regulator, Low Pressure	2	98.00	196.00	pneumatics

(PPSP010LP) (Black, 0-200psi)				
1/8" 12V DC Electric Plastic Solenoid Valve	4	16.99	67.96	pneumatics
Ninja Air Aluminum HPA N2 Paintball Tank 3000psi	1	59.95	59.95	pneumatics
Miniature Male Straight Adapter (Internal Hex) OM-AIR-M222A0405-5PK (M5 Thread 1/4' Tube OD)	1	19.75	19.75	pneumatics

Appendix B- Operating Code

B.1 Thruster Control Code

Version 3

```
- 1.0 : initial code to map pins from mega to motor controllers
- 1.1 : added speed control for each thruster
- 2.0 : code can now work as remote controller for individual thrusters
- 3.0 : group vertical movement together from one command
- 3.1 : added kill command for individual thrusters and kill command for enitre system

Description: This program allows the user to input serial commands to control the sub as
a remote control vehicle. this is useful for testing the mechanical systems if the sub
as well as demonstrating the capabilities. There are multiple iterations of this code that
have been worked through and the current options that this code can accomplish are listed
above.
*/
/* A pin guide for connecting the mega to the three motor controllers are as declared below.
The declarations are split into the three controllers so that it is easier to follow the wiring.
To minimize confusion, the variable names used match those
on the actual motor controller.
*/

/* Motor Controller I */

const int MOTIV_1_EN1 = 5;
const int MOTIV_1_I1 = 40;
const int MOTIV_1_I2 = 41;
const int MOTIV_2_EN2 = 6;
const int MOTIV_2_I3 = 36;
const int MOTIV_2_I4 = 37;

/* Motor Controller II */

const int MOTII_1_EN1 = 3;
const int MOTII_1_I1 = 32;
const int MOTII_1_I2 = 33;
const int MOTII_2_EN2 = 2;
const int MOTII_2_I3 = 28;
const int MOTII_2_I4 = 29;


/* Motor Controller III */

const int MOTIII_1_EN1 = 8;
const int MOTIII_1_I1 = 46;
const int MOTIII_1_I2 = 47;
const int MOTIII_2_EN2 = 9;
const int MOTIII_2_I3 = 50;
const int MOTIII_2_I4 = 51;
```

```
//const int zeroBits = 0;
//const int prescaler = 3; // 2 for 4kHz, 3 for default of 490Hz

//int names are postions of thrusters
int motordata;
int rightSide = 0;
int leftSide = 0;
int backLeft = 0;
int backRight = 0;
int frontLeft = 0;
int frontRight = 0;

/* Sub thruster layout and control input (FORWARD/REVERSE)

  (2/3)_____________(2/3)
     |                  |
     |                  |
     |                  |
 (4/6)|                 |(1/5)
     |                  |
     |                  |
     |                  |
     |                  |
  (2/3)_____________(2/3)


Sub Thruster shut off input (7 kills all at once)

    (e)_____________(f)
     |                |
     |                |
     |                |
  (d)|                |(a)
     |                |
     |                |
     |                |
     |                |
    (b)_____________(c)

*/
void setup()
{
// change PWM frequency
/* TCCR1B = TCCR1B & zeroBits;
TCCR2B = TCCR2B & zeroBits;
TCCR3B = TCCR3B & zeroBits;
TCCR4B = TCCR4B & zeroBits;
TCCR1B = TCCR1B | prescaler;
TCCR2B = TCCR2B | prescaler;
```

```
TCCR3B = TCCR3B | prescaler;
TCCR4B = TCCR4B | prescaler; */

Serial.begin(9600); // serial comm. thru USB with Zotac
Serial.println("Ready");
Serial.println("select input ");

//set all motor controllers to output to thrusters
pinMode(MOTII_2_EN2, OUTPUT);
pinMode(MOTII_2_I3, OUTPUT);
pinMode(MOTII_2_I4, OUTPUT);
pinMode(MOTII_1_EN1, OUTPUT);
pinMode(MOTII_1_I1, OUTPUT);
pinMode(MOTII_1_I2, OUTPUT);
pinMode(MOTIII_1_EN1, OUTPUT);
pinMode(MOTIII_1_I1, OUTPUT);
pinMode(MOTIII_1_I2, OUTPUT);
pinMode(MOTIII_2_EN2, OUTPUT);
pinMode(MOTIII_2_I3, OUTPUT);
pinMode(MOTIII_2_I4, OUTPUT);
pinMode(MOTIV_1_EN1, OUTPUT);
pinMode(MOTIV_1_I1, OUTPUT);
pinMode(MOTIV_1_I2, OUTPUT);
pinMode(MOTIV_2_EN2, OUTPUT);
pinMode(MOTIV_2_I3, OUTPUT);
pinMode(MOTIV_2_I4, OUTPUT);

//thrusters off at initial initation of code
digitalWrite(MOTII_2_EN2, LOW);
digitalWrite(MOTII_2_I3, LOW);
digitalWrite(MOTII_2_I4, LOW);
digitalWrite(MOTII_1_EN1, LOW);
digitalWrite(MOTII_1_I1, LOW);
digitalWrite(MOTII_1_I2, LOW);
digitalWrite(MOTIII_1_EN1, LOW);
digitalWrite(MOTIII_1_I1, LOW);
digitalWrite(MOTIII_1_I2, LOW);
digitalWrite(MOTIII_2_EN2, LOW);
digitalWrite(MOTIII_2_I3, LOW);
digitalWrite(MOTIII_2_I4, LOW);
digitalWrite(MOTIV_1_EN1, LOW);
digitalWrite(MOTIV_1_I1, LOW);
digitalWrite(MOTIV_1_I2, LOW);
digitalWrite(MOTIV_2_EN2, LOW);
digitalWrite(MOTIV_2_I3, LOW);
digitalWrite(MOTIV_2_I4, LOW);
}

void loop()
{
```

```
if (Serial.available() > 0)
{
motordata = Serial.read();

if(motordata == '1') // Keyboard input 1
{
Serial.println("Moving right forward");
rightSide = 50; //thruster speed
if(rightSide == 0)
{
analogWrite(MOTII_2_EN2, rightSide);
digitalWrite(MOTII_2_I3, LOW);
digitalWrite(MOTII_2_I4, LOW);
}

else
{
rightSide = constrain(rightSide, 25, 238);
analogWrite(MOTII_2_EN2, rightSide);
digitalWrite(MOTII_2_I3, LOW);
digitalWrite(MOTII_2_I4, HIGH);
}
}
if(motordata == '5') // Keyboard input 5
{
Serial.println("Moving right backwards");
rightSide = 50; //thruster speed
if(rightSide == 0)
{
analogWrite(MOTII_2_EN2, rightSide);
digitalWrite(MOTII_2_I3, LOW);
digitalWrite(MOTII_2_I4, LOW);
}
else{
rightSide = constrain(rightSide, 25, 238);
analogWrite(MOTII_2_EN2, rightSide);
digitalWrite(MOTII_2_I3, HIGH);
digitalWrite(MOTII_2_I4, HIGH4
;
}
}


if(motordata == '6') // Keyboard input 6
{
Serial.println("Moving left backwards");
leftSide = 50; //thruster speed
if(leftSide == 0)
{
analogWrite(MOTII_1_EN1, leftSide);
```

```
digitalWrite(MOTII_1_I1, LOW);
digitalWrite(MOTII_1_I2, LOW);
}
else{
leftSide = constrain(leftSide, 25, 238);
analogWrite(MOTII_1_EN1, leftSide);
digitalWrite(MOTII_1_I1, HIGH);
digitalWrite(MOTII_1_I2, LOW);
}
}

if(motordata == '2') // Keyboard input 2
{
Serial.println("Moving Vertical UP");
backLeft = 50; //thruster speed
backRight = 50; //thruster speed
frontLeft = 50; //thruster speed
frontRight = 50; //thruster speed

if(backLeft == 0)
{
analogWrite(MOTIV_1_EN1, backLeft);
digitalWrite(MOTIV_1_I1, LOW);
digitalWrite(MOTIV_1_I2, LOW);
}


else
{
backLeft = constrain(backLeft, 25, 155);
analogWrite(MOTIV_1_EN1, backLeft);
digitalWrite(MOTIV_1_I1, LOW);
digitalWrite(MOTIV_1_I2, HIGH);
}

if(backRight == 0)
{
analogWrite(MOTIV_2_EN2, backRight);
digitalWrite(MOTIV_2_I3, LOW);
digitalWrite(MOTIV_2_I4, LOW);
}



else
{
backRight = constrain(backRight, 25, 155);
analogWrite(MOTIV_2_EN2, backRight);
digitalWrite(MOTIV_2_I3, LOW);
digitalWrite(MOTIV_2_I4, HIGH);
```

```
}
if(frontLeft == 0)
{
analogWrite(MOTIII_1_EN1, frontLeft);
digitalWrite(MOTIII_1_I1, LOW);
digitalWrite(MOTIII_1_I2, LOW);
}



else
{
frontLeft = constrain(frontLeft, 25, 155);
analogWrite(MOTIII_1_EN1, frontLeft);
digitalWrite(MOTIII_1_I1, HIGH);
digitalWrite(MOTIII_1_I2, LOW);
}
if(frontRight == 0)
{
analogWrite(MOTIII_2_EN2, frontRight);
digitalWrite(MOTIII_2_I3, LOW);
digitalWrite(MOTIII_2_I4, LOW);
}


else
{
frontRight = constrain(frontRight, 25, 155);
analogWrite(MOTIII_2_EN2, frontRight);
digitalWrite(MOTIII_2_I3, LOW);
digitalWrite(MOTIII_2_I4, HIGH);
}
}

if(motordata == '3') // Keyboard input 3
{
Serial.println("Moving Vertical Down");
backLeft = 50; //thruster speed
backRight = 50; //thruster speed
frontLeft = 50; //thruster speed
frontRight = 50; //thruster speed

if(backLeft == 0)
{
analogWrite(MOTIV_1_EN1, backLeft);
digitalWrite(MOTIV_1_I1, LOW);
digitalWrite(MOTIV_1_I2, LOW);
}

else
```

```
{
backLeft = constrain(backLeft, 25, 155);
analogWrite(MOTIV_1_EN1, backLeft);
digitalWrite(MOTIV_1_I1, HIGH);
digitalWrite(MOTIV_1_I2, LOW);
}


if(backRight == 0)
{
analogWrite(MOTIV_2_EN2, backRight);
digitalWrite(MOTIV_2_I3, LOW);
digitalWrite(MOTIV_2_I4, LOW);
}

else
{
backRight = constrain(backRight, 25, 155);
analogWrite(MOTIV_2_EN2, backRight);
digitalWrite(MOTIV_2_I3, HIGH);
digitalWrite(MOTIV_2_I4, LOW);
}


if(frontLeft == 0)
{
analogWrite(MOTIII_1_EN1, frontLeft);
digitalWrite(MOTIII_1_I1, LOW);
digitalWrite(MOTIII_1_I2, LOW);
}

else
{
frontLeft = constrain(frontLeft, 25, 155);
analogWrite(MOTIII_1_EN1, frontLeft);
digitalWrite(MOTIII_1_I1, LOW);
digitalWrite(MOTIII_1_I2, HIGH);
}


if(frontRight == 0)
{
analogWrite(MOTIII_2_EN2, frontRight);
digitalWrite(MOTIII_2_I3, LOW);
digitalWrite(MOTIII_2_I4, LOW);
}

else
{
```

```
frontRight = constrain(frontRight, 25, 155);
analogWrite(MOTIII_2_EN2, frontRight);
digitalWrite(MOTIII_2_I3, HIGH);
digitalWrite(MOTIII_2_I4, LOW);
}
}

if(motordata == '4') // Keyboard input 4
{
Serial.println("Moving left forward");
leftSide = 50; //thruster speed
if(leftSide == 0)
{
analogWrite(MOTII_1_EN1, leftSide);
digitalWrite(MOTII_1_I1, LOW);
digitalWrite(MOTII_1_I2, LOW);
}

else
{
leftSide = constrain(leftSide, 25, 238);
analogWrite(MOTII_1_EN1, leftSide);
digitalWrite(MOTII_1_I1, LOW);
digitalWrite(MOTII_1_I2, HIGH);
}
}
/* Bottom Front thruster, which is connected to MOTIII_1 */


if(motordata == '7') // Keyboard input 7
{
Serial.println("Shutting Off");

digitalWrite(MOTII_2_I3, LOW); //right
digitalWrite(MOTII_2_I4, LOW);

digitalWrite(MOTIV_1_I1, LOW); //back left
digitalWrite(MOTIV_1_I2, LOW);

digitalWrite(MOTIV_2_I3, LOW); //back right
digitalWrite(MOTIV_2_I4, LOW);

digitalWrite(MOTII_1_I1, LOW); //left
digitalWrite(MOTII_1_I2, LOW);

digitalWrite(MOTIII_1_I1, LOW); //front left
digitalWrite(MOTIII_1_I2, LOW);

digitalWrite(MOTIII_2_I3, LOW); //front right
digitalWrite(MOTIII_2_I4, LOW);
```

```
}


if(motordata == 'a') // Keyboard input a
{
Serial.println("Shutting Off Right");
digitalWrite(MOTII_2_I3, LOW); //right
digitalWrite(MOTII_2_I4, LOW);
}

if(motordata == 'b') // Keyboard input b
{
Serial.println("Shutting Off Back Left");
digitalWrite(MOTIV_1_I1, LOW); //back left
digitalWrite(MOTIV_1_I2, LOW);
}

if(motordata == 'c') // Keyboard input c
{
Serial.println("Shutting Off Right");
digitalWrite(MOTIV_2_I3, LOW); //back right
digitalWrite(MOTIV_2_I4, LOW);
}

if(motordata == 'd') // Keyboard input d
{
Serial.println("Shutting Off Left");
digitalWrite(MOTII_1_I1, LOW); //left
digitalWrite(MOTII_1_I2, LOW);
}


if(motordata == 'e') // Keyboard input e
{
Serial.println("Shutting Off Front Left");
digitalWrite(MOTIII_1_I1, LOW); //front left
digitalWrite(MOTIII_1_I2, LOW);
}

if(motordata == 'f') // Keyboard input f
{
Serial.println("Shutting Off Front Right");
digitalWrite(MOTIII_2_I3, LOW); //front right
digitalWrite(MOTIII_2_I4, LOW);
}
 }
}
```

B.2 Pneumatic Actuator Code (Torpedo/ Gripper)

```
#include "Arduino.h"

//Define LED pin for debugging
#define LED 13 //set LED pin



/*****WARNING: DO NOT USE LED EXCEPT FOR DEBUGGING! LED pin is
used for controlling valves and LED toggling will interfere with
proper functioning of the valves*****/


//Define motor controller pins
//Digital pins 2-13 used on Arduino Uno


//Left side goes to high pins1
//Claw pressurize is lower numbered pins of white md -- claw close


//Claw pressurize valve
#define MD2_IN1 10  //Motor driver IN1 pin to Arduino pin 10
#define MD2_ENA 9  //Motor driver ENA (enable) pin to Arduino pin 9
#define MD2_IN2 8  //Motor driver IN2 pin to Arduino pin 8


//Claw release valve
#define MD2_IN3 13  //Motor driver IN1 pin to Arduino pin 13
#define MD2_ENB 12  //Motor driver ENA (enable) pin to Arduino pin 12
#define MD2_IN4 1  //Motor driver IN2 pin to Arduino pin 1


//Right Torpedo
#define MD1_IN1 4  //Motor driver IN1 pin to Arduino pin 4
#define MD1_ENA 3  //Motor driver ENA (enable) pin to Arduino pin 3
#define MD1_IN2 2 //Motor driver IN2 pin to Arduino pin 2


//Left Torpedo
#define MD1_IN3 7 //Motor driver IN1 pin to Arduino pin 7
#define MD1_ENB 6 //Motor driver ENA (enable) pin to Arduino pin 6
#define MD1_IN4 5 //Motor driver IN2 pin to Arduino pin 5


//Torpedo release time
#define TORPEDO_DELAY 0.5
```

```
//function prototypes
void setPins();
void actuatorSelector(int selector);
void torpedoDelay();
void setPins(){ //Sets pins to output and initializes them for all actuators


  //Set LED pin to output for debugging
  pinMode(LED,OUTPUT);
  digitalWrite(LED,LOW);

  //Right Torpedo
  //Set motor driver pins to output
  pinMode(MD1_IN1,OUTPUT);
  pinMode(MD1_ENA,OUTPUT);
  pinMode(MD1_IN2,OUTPUT);

  //Initialize motor driver pins to closed
  digitalWrite(MD1_IN1,HIGH);
  digitalWrite(MD1_ENA,LOW); //Enable controls valve state LOW (Closed) HIGH (Open)
  digitalWrite(MD1_IN2,LOW);


  //Left Torpedo
  //Set motor driver pins to output
  pinMode(MD1_IN3,OUTPUT);
  pinMode(MD1_ENB,OUTPUT);
  pinMode(MD1_IN4,OUTPUT);

  //Initialize motor driver pins to closed
  digitalWrite(MD1_IN3,HIGH);
  digitalWrite(MD1_ENB,LOW); //Enable controls valve state LOW (Closed) HIGH (Open)
  digitalWrite(MD1_IN4,LOW);


  //Claw close
  //Set motor driver pins to output
  pinMode(MD2_IN1,OUTPUT);
  pinMode(MD2_ENA,OUTPUT);
  pinMode(MD2_IN2,OUTPUT);

  //Initialize motor driver pins to closed
  digitalWrite(MD2_IN1,HIGH);
  digitalWrite(MD2_ENA,LOW); //Enable controls valve state LOW (Closed) HIGH (Open)
  digitalWrite(MD2_IN2,LOW);


  //Right Torpedo
  //Set motor driver pins to output
  pinMode(MD2_IN3,OUTPUT);
```

```
  pinMode(MD2_ENB,OUTPUT);
  pinMode(MD2_IN4,OUTPUT);

  //Initialize motor driver pins to closed
  digitalWrite(MD2_IN3,HIGH);
  digitalWrite(MD2_ENB,LOW); //Enable controls valve state LOW (Closed) HIGH (Open)
  digitalWrite(MD2_IN4,LOW);
}


void actuatorSelector(int selector){
  //Interprets command given from serial stream
  //Example command: 11
  //              ^^
  //              ||________________________
  //              |                        |
  //         [device #]    [command: (1) claw close/fire (0) claw open]
  //
  // devices: 1=left torpedo, 2=right torpedo, 3=claw
  switch(selector){
  default:
    Serial.print("Invalid input\n");
   break;


    //fire right torpedo
  case 11:
    Serial.print("New state: fire right torpedo! \n");
    //digitalWrite(LED,HIGH);
    digitalWrite(MD1_ENA,HIGH); //fire torpedo
    torpedoDelay(); //wait for torpedo release
    //digitalWrite(LED,LOW);
    digitalWrite(MD1_ENA,LOW); //close torpedo valve
    break;

    //fire left torpedo
  case 21:
    Serial.print("New state: fire left torpedo! \n");
    //digitalWrite(LED,HIGH);
    digitalWrite(MD1_ENB,HIGH); //fire torpedo
    torpedoDelay(); //wait for torpedo
    //digitalWrite(LED,LOW);
    digitalWrite(MD1_ENB,LOW); //close torpedo valve
    break;


    //open claw
  case 30:
   Serial.print("New state: open claw \n");
    //digitalWrite(LED,LOW);
```

```
    digitalWrite(MD2_ENA,LOW); //close claw pressure valve
    digitalWrite(MD2_ENB,HIGH); //open claw release valve
    break;
    //close claw
  case 31:
    Serial.print("New state: close claw \n");
    //digitalWrite(LED,HIGH);
    digitalWrite(MD2_ENA,HIGH); //open claw pressure valve
    digitalWrite(MD2_ENB,LOW); //close claw release valve
    break;
  }

}

void torpedoDelay(){delay(TORPEDO_DELAY*1000); /*(delay for time TORPEDO_DELAY)*/}
```

B.3 Marker Dropper

```
#include <Servo.h>

Servo myservo;  // create servo object to control a servo

int pos = 0;
int servodata;

void setup()  {

Serial.begin(9600);
Serial.println("Ready");
Serial.println("select input ");

myservo.attach(9); // attatch servo to arduino pin 9

}

void loop()
{
  if (Serial.available() > 0)
  {
   servodata = Serial.read();


    if(servodata == '1') // Keyboard inout 1
    {
      Serial.println("Object Detected");
      Serial.println("Dropping Left Marker");
     for(pos = 90; pos < 120; pos += 1)  // goes from 90 degrees to 120 degrees
  {                                  // in steps of 1 degree
    myservo.write(pos);              // tell servo to go to position in variable 'pos'
    delay(10);                       // waits 5ms for the servo to reach the position
```

```
}
for(pos = 120; pos>=90; pos-=1)     // goes from 120 degrees to 90 degrees
{
  myservo.write(pos);              // tell servo to go to position in variable 'pos'
  delay(10);                       // waits 15ms for the servo to reach the position
}
  }
    else if(servodata == '2') // Keyboard input 2
  {
    Serial.println("Object Detected");
    Serial.println("Dropping Right Marker");
   for(pos = 90; pos > 60; pos -= 1)  // goes from 90 degrees to 60 degrees
{                                  // in steps of 1 degree
  myservo.write(pos);              // tell servo to go to position in variable 'pos'
  delay(5);                        // waits 15ms for the servo to reach the position
}
for(pos = 60; pos<=90; pos+=1)     // goes from 60 degrees to 90 degrees
{
  myservo.write(pos);              // tell servo to go to position in variable 'pos'
  delay(5);                        // waits 5ms for the servo to reach the position
}
  }

  Serial.println();    // End the line
}
}
```

Appendix C- Operations Manual

Operations Manual

Design and Development of an Autonomous Underwater Vehicle

Team 23

AUVSI Robosub

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4/1/2016

Table of Contents

Table of Figures

Table of Tables

Abstract

The goal of Team 23 is to represent the FAMU/FSU College of Engineering in the 19th annual AUVSI Robosub competition, which occurs from July 25th to July 31st of 2016. This will be accomplished through the design, development, and extensive testing of a modular sub which meets all of the competition requirements provided by the AUVSI Robosub competition. The work process is described in the manual below as well as operation instructions for the submersible.

Team 23 was not the only team working on the Robosub this year, team 4 of the ECE teams also worked to reach the goal of reaching the competition this year. This manual will combine the progress of both teams into one central document to make it easier to follow all the information there is to know about the submersible.

Acknowledgements

We would like to thank the people who have helped us thus far and the ones who plan to help us in the future. This includes Kim Hinckley at the Morcom pool for letting us use FSU's dive pool for testing. Dr. Gupta and Dr. Shih for guidance and constructive criticism throughout the project and the course. Dr. Clark for pushing us to set high goals and achieve them. Dr. Harvey and Dr. Hooker for their support and suggestions and the ME and ECE department for funding our senior design project.

Functional Analysis

Electrical Function

The intended function of this project is to design an autonomous underwater vehicle, or AUV. In order to accomplish this several components needed to be addressed: the main electronics (the CPU), a waterproof electronics housing (hull), cameras and thrusters for navigation, and the mechanical components of subsystems to perform various tasks such as the marker dropper, gripper and torpedo firing mechanism. The major electronics hardware required to control the AUV is comprised of a main processing unit (MPU), microcontrollers, and motor drivers. Each subsystem has its own set of instructions and code which interacts with the MPU. Below is a signal diagram showing how the electronics communicate with one another in their subsystems. The legend on the upper left corner of Figure 1 organizes the components into their specific subsystems.

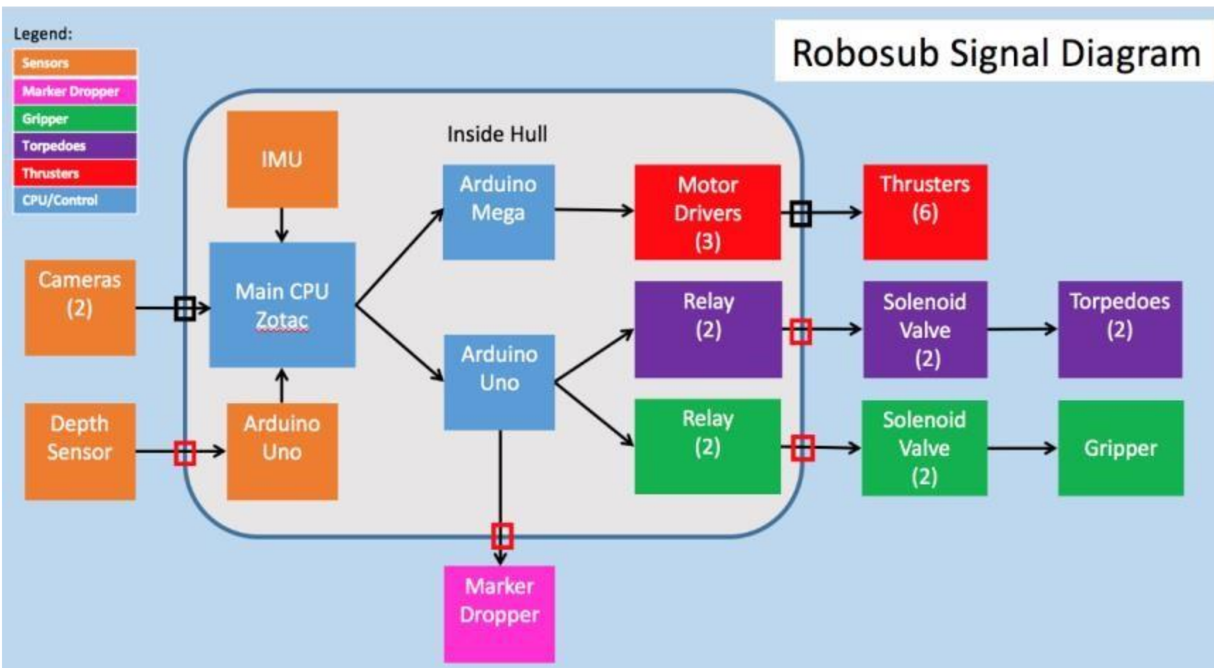

Figure 1: Signal Diagram

Mechanical Function

A well designed hull was one of the most crucial requirements for the entire project. A good balance between size and weight had to be found. The size is an important factor in that it must be large enough to hold all the electronics hardware but not but not have excess volume that caused too much buoyancy. The electronics housing is an important factor in the AUV since it will be housing all of the electronic hardware and will need to be watertight to prevent water shorting the electronics. A CAD of the hull can be seen in figure 2 below. The waterproofing will be done by using a weather strip as an o-ring around the inside of the hull. There are then six latches that put pressure on an acrylic lid. The pressure applied to the lid from the latches creates a watertight seal around the top. The housing is also important in that it is the main medium through which the heat generated by the electronics will be dissipated. If the heat dissipated is not enough, then the electronics could overheat, which could then cause small problems circuitry problems such as shorts. The final design that was chosen is shown above and is made of stainless steel. It is smaller and lighter than the previous years' hull but it solves the problem of the positive buoyancy. This hull was tested and not only passed the waterproof test, but also was designed to be slightly above neutral buoyancy so that the sub maintains its depth when the kill switch is presses and the thrusters turn off.

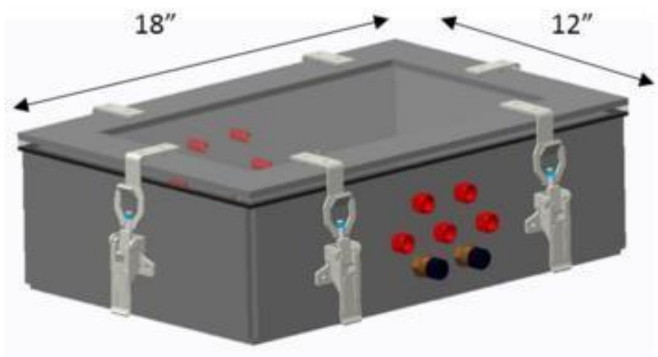

Figure 2: New Hull Design

Project Specifications

Electrical Specifications

Each controller, sensor, actuator, and thruster requires a specific voltage and current to function. To achieve this, a power system has to be designed to allow the AUV to operate for a sufficient time underwater. Table 1 shows some of the requirements needed for selected components of the AUV. The figures below also show the circuit that the battery will power.

Table 1: Battery Requirements

Components	Max Current (A)	Ave. Current (A)	Voltage Required (V)
Zotac PC Board	3.5	1.5	19.0
Arduino UNO	0.75	0.5	7.0 - 12.0
Arduino Mega	0.75	0.5	7.0 - 12.0
Motor Controllers	2.0	1.5	5.0
IMU	0.075	0.060	3.5 - 16.0
Thrusters	12.0	3.0	19.1
Depth Sensor	0.020	0.012	8.0 - 11.0

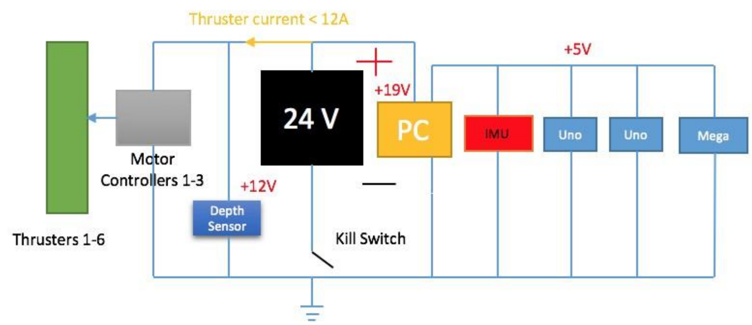

Figure 3: Battery Diagram

Figure 3 above shows the main power diagram for the AUV. The main components are all powered by a 24 V battery along with voltage regulators which cut down the power to the components that do not require as much.

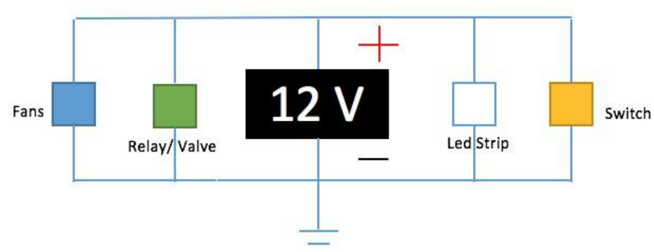

Figure 4: 12V Battery Circuit

The Figure above shows the secondary power diagram for the AUV. The functional purpose of this battery is to power the cooling fans along with the relays and air valves for the pneumatic system. This battery also serves aesthetic purposes such as powering the LEDs in the sub or lighting up the kill switch.

Main CPU

In order to integrate all of the subs functions to communicate with one another a main processing unit is need. The Zotac computer acts as the main processing unit for the AUV. As the MPU, the Zotac is essentially the sub's "brain" and is responsible for most of the high-level communication. The Zotac is where the image processing takes place which then communicates to other peripherals of the sub. The MPU interfaces with one Arduino Mega and two Arduino UNO microcontrollers. The Zotac makes use of its USB ports to establish bidirectional UART serial communication links with the microcontrollers. The information is sent to the Arduinos to control various hardware such as the thrusters, and depth sensor. The Zotac computer also utilizes two Logitech webcams connected via USB for vision information. The MPU receives power from an external 19V/ 4mA universal laptop battery. The Zotac also acts as a power source to the microcontrollers and IMU.

Figure 5: Zotac Mini Computer

Microcontrollers

Each serial device needs a "bridge" to communicate with the MPU. The Arduino UNO is a perfect solution to handle this communication. Two Arduino UNO's will be used in the AUV. Each Arduino will control a peripheral: actuators, hydrophones, etc. This will take the serial communication from each subsystem and allow control over USB from the MPU. This device was selected to be specifically used for motor control. It contains more pins to be used with all six thrusters. This allows thruster control to be sent to only one device instead of multiple Arduinos. It also allows for more processing power so that it can be directly attached to the IMU stabilizing unit. It is powered via USB and will be controlled through USB from the MPU as well.

IMU

The Inertial Measurement Unit, or IMU, is integral in maintaining the orientation of the AUV. It has nine degrees of freedom and outputs data in the x,y, and z planes. This particular IMU was a very cost effective model that was able to easily do the tasks needed with this project and communicate with the Zotac which adjusts the thrusters accordingly.

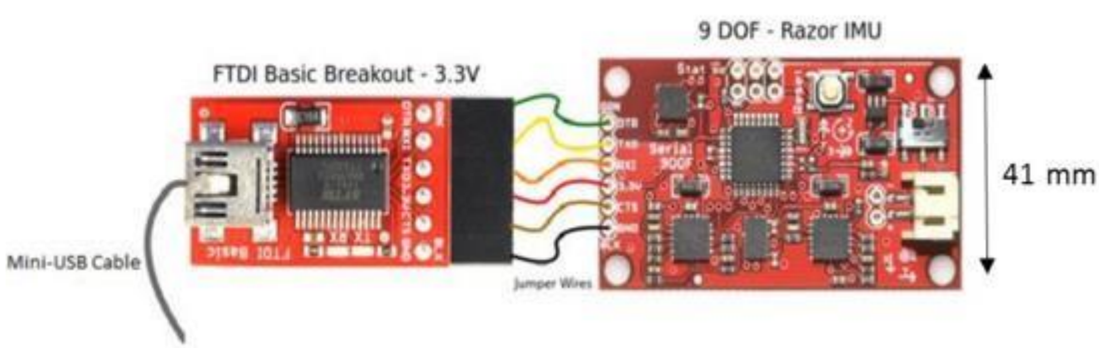

Figure 6: Sparkfun Razor IMU

Motor Controllers

There were three L298 H-Bridge motor controllers that were used in the AUV, both of which were very similar. This year the team purchases a new motor controller to replace the older model and make all of the controllers the same. The motor controller used is the CanaKit driver, with the following specifications:

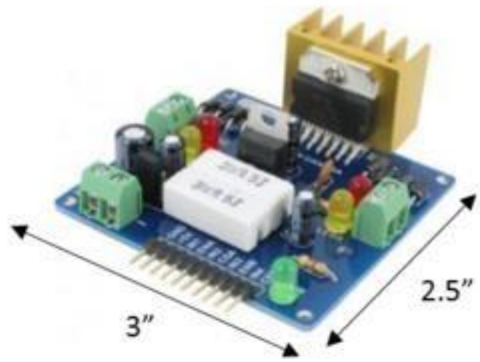

Figure 7: L298 H-Bridge motor controller

Mechanical Specifications

The hull without the frame weighs 75 lbs and displaces slightly over that to achieve a small degree of buoyancy when submerged. If needed buoyancy foam can be added to the bottom of the hull to achieve neutral buoyancy if it is too heavy. Furthermore weights can be added to the hull if it is too buoyant.

Product Assembly

There are a lot of connections that need to be made throughout the AUV in order for it to operate correctly. The signal diagram from figure 1 shows all the top level connections that need to be made, This section contains more detailed wiring diagrams as well as instructions for attaching the hardware to one another.

Mechanical Design

The mechanical design consists of the hull and frame assembly. The primary purpose of this design was to keep it simple and functional. The main idea behind the design of the hull was to achieve neutral buoyancy to put as l

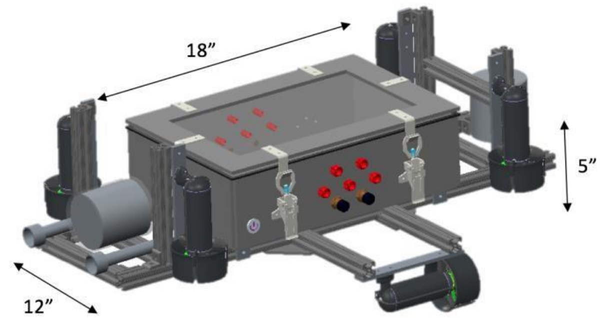

Figure 8: Hull Assembled on Frame

Gripper

The gripper mechanism must be able to grasp and continuously apply pressure to a variety of small objects throughout the course. The grip must constrain at least 3 degrees of freedom of the object throughout movement in all directions. The gripper must be controlled effectively by the microcontroller and interface with the cameras to ensure accuracy in securing a target.

Figure X shows the actuator the team has decided to go with for the gripping mechanism. This model runs off of compressed air. The camera would detect an object on the bottom of the pool and would activate an air compressor which would close the claw and keep it inside of its grip. This model will be improved upon this year by redesigning the physical gripper but keeping the same principles intact. The gripper for this AUV is mounted in the front.

Figure 9: Gripper Mechanism

Torpedo

The portion of this system that the team is focused on redesigning is the physical projectile. The problem of the floating torpedoes will invariably effect scoring during the competition. Upon investigation of an old torpedo It was found that the object is made out of either cast or machined ABS plastic that contains a metal rod in its center and a magnet to attach to the projectile system. The use of a metal rod gave structure and assisted in the attempt to correct buoyancy. With the knowledge that this had less than optimal buoyancy but the system is still designed for these to particular projectiles to fit into it the team chose to look at a manufacturing change. Figure 4 shows a remade CAD design made

to mimic the previous design. The manufacturing methods that will be used to replicate this is 3D printing. Using 3D printed ABS rapid inexpensive prototyping is available to change buoyancy based on core size and infill. This will also allow the altering of core materials with ease to produce the ideal weig5” ht addition to water.
the sub. Additionally the rapid prototyping will allow for slight shape changes to optimize trajectory in

Figure 10: Torpedo Design

Marker Dropper

The design used for the marker dropper came from a design adopted from a previous FAMU-FSU RoboSub team. The decision to continue with this design came down to its simplicity and effectiveness. The mechanical subsystem is made out of aluminum 6061 and contains a parabolic track where two steel balls will be in place. The parabolic track is bound on both sides by aluminum walls in order to prevent the markers from accidentally falling off the device. There is a servomotor that is oriented vertically downward, located directly between each of the two markers. When the camera sees the desired object the servomotor will rotate right or left to a desired angle releasing one of the two balls. After the ball is released, after a given delay, the motor will rotate back to its starting position. When the cameras see the other desired object, the motor can rotate to the same angle in the opposite direction in order to allow the second steel ball to drop into the desired bin. The servomotor will be controlled by one of the microcontrollers. The wires from the microcontroller will run to one of the Seacon ports that will run the rest of the connection to the waterproof servo.

Figure 11: Marker Dropper

Thrusters

There are six SeaBotix BTD 150 thrusters on the AUV, 4 mounted vertically and 2 mounted horizontally providing backward/forward thrust as well as yaw control. These are controlled by three different motor controllers hooked up to an Arduino Mega. The connections between all these devices can be seen below.

Operation Instructions

Lab Testing

The Zotac can be powered by either the universal laptop battery or the wall adaptor. It is recommended to plug it into the wall in the lab when ding out of water testing. The Zotac's power button is on the front. You should see a blue ring of light on the computer when it comes on.

Torpedo/ Gripper Test

Open the Arduino IDE and open the file known as actuator_2013_04_18.ino. This file should be located in a folder known as “Torpedo” which is located inside of the desktop folder labeled “RoboSub 20152016”. The code is well commented and the instructions are inside telling how to activate each air valve. This program uses the serial input of the Arduino to output pins to high.

Marker Dropper Test

Open the Arduino IDE and open the file known as marker_dropper.ino. This file should be located in a folder known as “Marker Dropper” which is located inside of the desktop folder labeled “RoboSub 20152016”. The code is straightforward to use. There are two inputs to this code. One of the input tells the servo to rotate 45 degrees to the right and then return center while the other input tells the servo to rotate 45 degrees to the left and then return center This program uses the serial input of the Arduino to send the signal to the servo motor.

Control Test

Open the Arduino IDE and open the file known as final_sub_control.ino. This file should be located in a folder known as “final_sub_control” which is located inside of the desktop folder labeled “RoboSub 2015-2016”. The code is well commented with a diagram and the instructions are inside telling what inputs control what thrusters. This program uses the serial input of the Arduino to output PWM signals to the motor controllers.

Water Testing

Sealing The AUV

Sealing the AUV is now a very simple task. All that is needed is the acrylic lid and metal top that contains the hook the latches attach to. Put the lid on the top of the AUV and then the metal top on top of this. Hook the latches to the designated areas and adjust them by screwing them either left or right so that they are not sitting loose when attached to the lid. Finally, push all six of the latches down. There should be a lot of resistance and this is how you know it is a solid seal. If the latches close too easily then they probably have not created a tight enough seal.

Wireless Control

In order for the sub to function it first needs to be set up using a computer. Since the Zotac does not contain a screen, it has to be wirelessly shared in order to control it. To do this all that is needed is a common network connection between the Zotac and a laptop. Then on the laptop the user can search for devices and the Zotac should appear and be labeled "robosub1314". Once the user hits share screen, the desktop on the Zotac should appear in a new window on the laptop and the user can control it from their own device.

Running Code

There are a few steps for running the code to run the autonomous abilities of the AUV. Currently the ME Team has created subsystem code as well, but this is pending image processing from the ECE team to work autonomously. To activate the navigation code follow the following steps:

1. Open Terminal on the Zotac and open up three windows.

2. The first window is for the object tracking. Type cd Desktop/RoboSub14- 15/RS_C. To execute the program, input the command "./RoboSub_Control_v2". This will turn the thrusters on and they will adjust speed in order to maintain a constant depth and start navigating to the first orange gate.

3. The next tab is for the thruster control. Then enter "./ColorDetection". This should open up two new windows, one for the front facing camera and the other for the bottom facing camera. To test if the code is working hold an orange object, the camera is currently said to identify this color, and see if the camera identifies it.

4. The last tab is for the IMU. Type the command cd Desktop/RoboSub14-15/IMU/C++. This should pull up the IMU program in the terminal. To execute the program the user has to type "./example". The program should now be running and the user should see the different sets of axis updating based off of the current orientation of the IMU.

Troubleshooting

Water Leak

If water leaks into the sealed hull the electronics can be permanently damaged and cause the sub to stop working during competition. To prevent this, proper testing must be performed before placing electronics in the hull. Furthermore absorbent material can be placed on the bottom/sides of the hull to prevent small leaks from puddling up near electronics.

Overheating

Because the hull is small and air tight conduction of heat produced by electrical components can cause the electrical components to overheat and fail. To prevent this fans are placed in the hull to aid in convective heat transfer. Furthermore a heat sink can be added to use the outside water to facilitate heat transfer.

Connection Issues

Due to the amount of subsystems on the hull there are many electrical connections both outside and inside the hull. These electrical connections can be broken or malfunction through normal movement or user error and cause the AUV to stop working. To prevent these electrical disconnections more secure connections can be made by soldering and using clamps on the wires. Also connections could be tested using a multimeter to ensure proper connections.

Regular Maintenance

Mechanical Maintenance

The moving components in the mechanical system require some form of lubrication, this includes the solenoid valves, gripping mechanism, and latches. All seals on the hull that separate the hull internals from the water must be checked prior to and immediately following any aquatic operation. If leakage is noticed extra sealant should be applied to the problem area and retested. The Hull lid should be inspected for cracks and the waterproof rubber spacer between the lid and the hull edge should be inspected for tears prior to any pool testing.

Electrical Maintenance

The electrical components for the most part should last for many years to come. The major components, such as the Zotac and Arduinos, should not need to be replaced unless during testing one of them gets shorted. The same goes for the four relays as well as the voltage regulators. The only maintenance that should need to be done should be checking to make sure all the connections are still solid and all of the solder joints are still intact. The batteries to power the AUV will also need to be charged.

Spare Parts

Table 2: Parts List

Part	Cost	Quantity	Distributor	Part Number
Stainless steel			McMaster-Carr	
Rubber Seal	$20.00	1	Steelerubber	70-1192-52
Acrylic Lid	$16.83	1	McMaster-Carr	8574K28
Toggle Latches	$20.93	6	J.W. Winco INC	110ENGL
Latch Catch Plate	$2.98	6	Protex	03-1692SS
Cable Penetrators	$4.00	12	BlueRobotics	PENETRATOR-10-25-A-R2
34” Aluminum Bar	$9.77	2	8020.net	1010
8” Aluminum Bar	$3.79	12	8020.net	1010
5 hole 90° bracket	$6.30	4	8020.net	4151
2 hole 90° bracket	$2.90	20	8020.net	4119
¼-20 x .500" Button Head	$0.30	62	8020.net	3690
¼ - 20 T-Nut	$0.61	62	8020.net	3675
2 Hole T-Nut	$0.95	4	8020.net	3356
3 Hole T-Nut	$1.55	4	8020.net	3358
Kill Switch	$22.88	1	Oznium	

Recommended Approach/Conclusion

Thruster Modifications

Currently the sub has 5 degrees of freedom and is only missing translation in the sideways direction. By placing and additional thruster pointing sideways the sub can navigate easier and allow it to complete tasks more efficiently. Furthermore the thrusters on the sub are several years old and are in need of replacement in the near future. The thrusters are about $700 therefore new thrusters should be investigated such as the blureobotics thrusters which are recommended by competition officials.

Camera Modifications

Much like the thrusters the cameras are beginning to age and will eventually need to be replaced. The current camera housing is fairly large and could accommodate several different types of cameras. If a more compact camera is chosen a new camera housing could be made that is smaller and produces less buoyancy force.

Waterproofing Air Tank

The air tank that it currently being used is not made for underwater use and will eventually rust. A waterproof casing could easily be made to prevent this rusting and corrosion. Another solution would be to find a small enough tank that is waterproof. Finally the more complex option would be to place the tank inside the hull and drill a hole that a pipe could fit to. This may not work due to the little available space in the hull.

Appendix

Table 3: Spec Sheets

Component	Spec Sheet
Zotac-ZBOX CI321 nano PC	https://www.zotac.com/us/product/mini_pcs/ci321-nano
Arduino Uno	https://www.arduino.cc/en/Main/ArduinoBoardUno
Mega	https://www.arduino.cc/en/Main/ArduinoBoardMega2560
IMU	https://www.sparkfun.com/products/10736 and https://www.sparkfun.com/products/9873
Motor Controllers	https://www.sparkfun.com/products/9670
Seabotics motor	
Gripper	https://trimantec.com/wp-content/uploads/2015/06/catalog-for-HFY.pdf
Marker Dropper Servo	

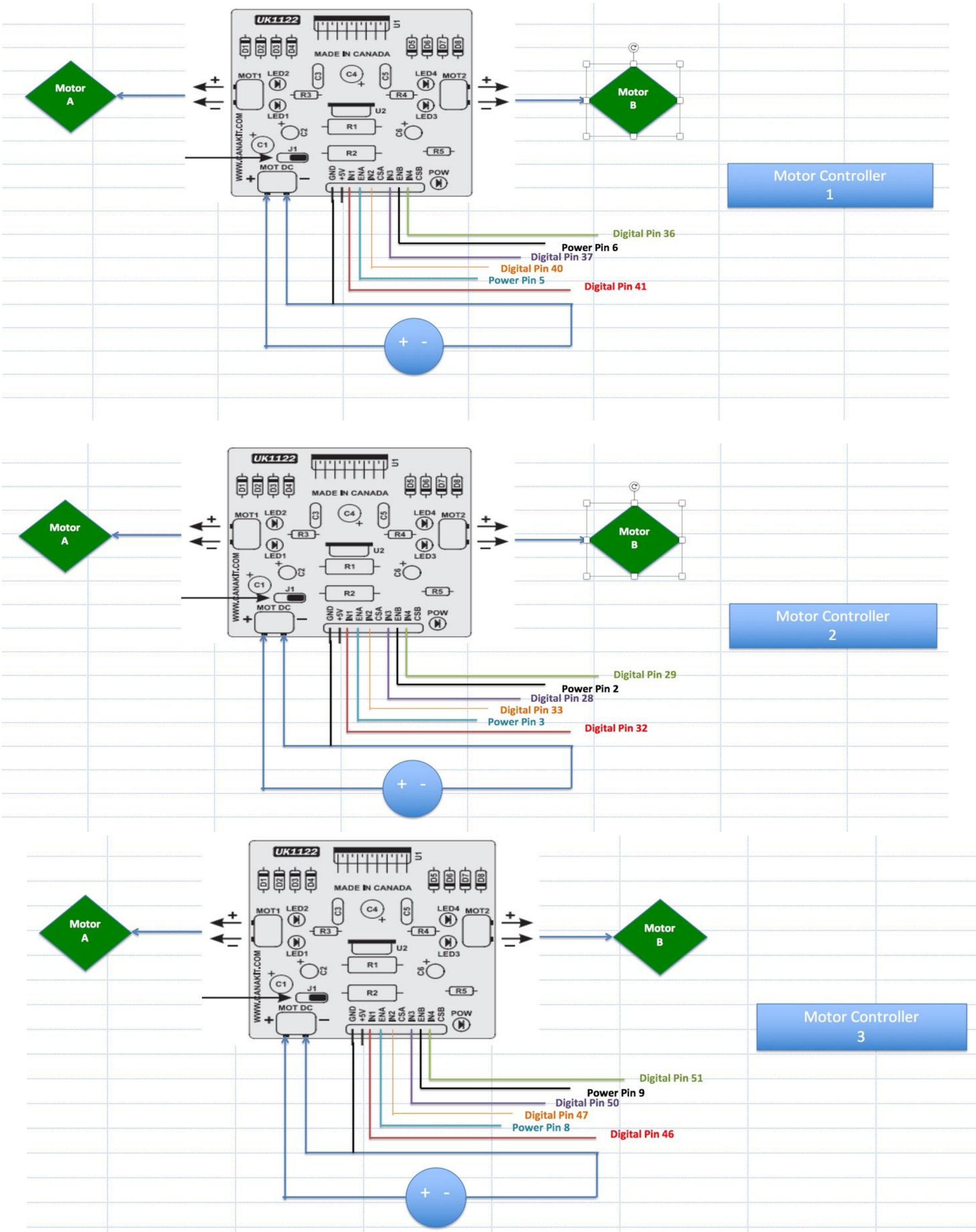

Figure 12: Motor Controller Wiring

Appendix D- Design Report for manufacturing, reliability and economics

Design for Manufacturing, Reliability, and Economics

Design and Development of an Autonomous Underwater Vehicle

Team 23

AUVSI Robosub

Members:

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Table of Contents

Table of Figures

Table of Tables

No table of figures entries found.

Abstract

The goal of Team 23 is to represent the FAMU/FSU College of Engineering in the 19th annual AUVSI robosub competition, which occurs from July 25th to July 31st of 2016. This will be accomplished through the design, development, and extensive testing of a modular sub which meets all of the competition requirements provided by the AUVSI Robosub competition. The particular aspects of design that the mechanical team will endeavor are a redesign of the hull to make it less buoyant, torpedoes design and actuation, and finally the gripper mechanism, which are all normally tasks required of the AUV in the robosub competition.

Team 23 is also not the only team to be working on the robosub this year, team 4 of the ECE teams will also be working to reach the goal of reaching the competition this year. While the two teams will be assisting each other in the development of various subsystems required for the AUV, team 4 will be more focused on the navigation and vision systems for the sub while team 23 focuses more on the mechanical subsystems for the sub. This collaboration of work will give the teams the best chance at sending a sub to compete in competition.

Acknowledgements

We would like to thank the people who have helped us thus far and the ones who plan to help us in the future. This includes Kim Hinckley at the Morcom pool for letting us use FSU's dive pool for testing. Dr. Gupta and Dr. Shih for guidance and constructive criticism throughout the project and the course. Dr. Clark for pushing us to set high goals and achieve them. Dr. Harvey and Dr. Hooker for their support and suggestions and the ME and ECE department for funding our senior design project.

1 Introduction

This report conveys the importance of taking into consideration manufacturability, reliability, and cost analysis when designing a product. However, the Robosub team's project was to produce a single product for competition means; not something meant for large scale manufacturing. Reliability and cost analysis however, is very important in any engineering project because being able to afford the components and ensuring that the product actually works is key.

2 Design for Manufacturing

2.1 Hull/Frame fabrication

The new hull is constructed from ¼ inch stainless steel welded to form a box measuring 12" x 18" x 5". Six panels where cut using a cnc waterjet machine. 15 holes were drilled for electrical penetrations and 18 holes were tapped for bolting on hardware. Six stainless steel adjustable toggle latches are bolted to the side of the hull to clamp the lid down to form a watertight seal. The toggle latches grab stainless steel hooks which are bolted to an aluminum lid which provides even compression across the acrylic lid. A rubber seal is fit over the rim of the hull and joined together using glue to form the rectangular shape of the hull.

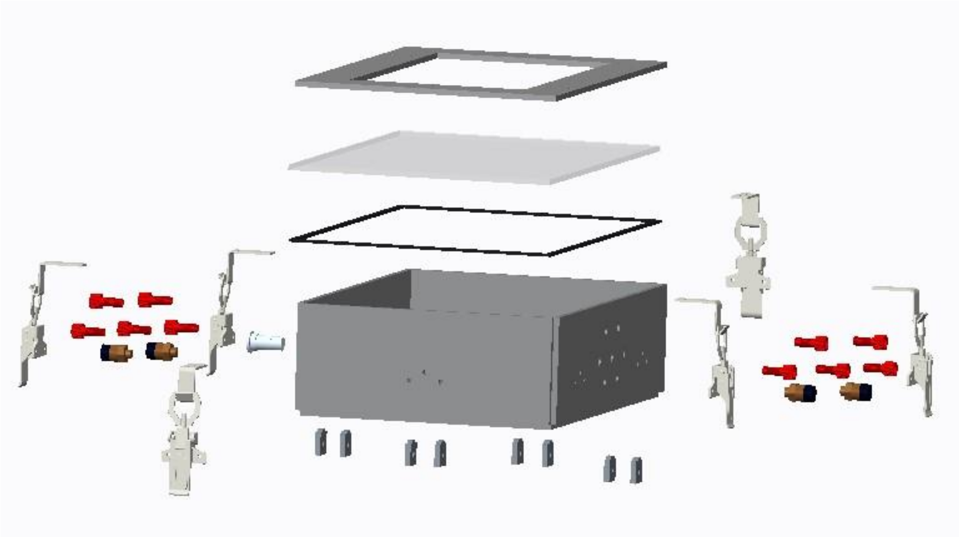

Figure 1: Exploded View

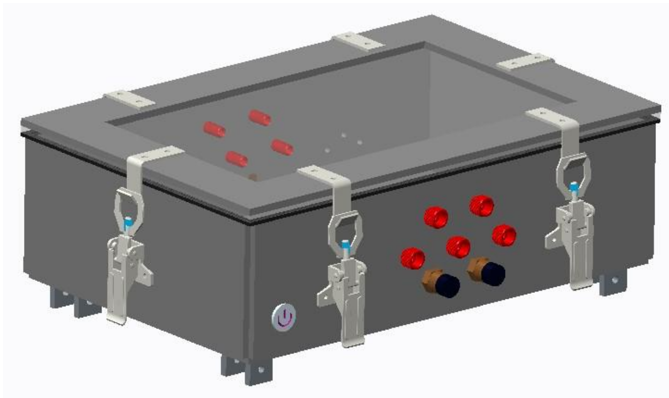

Figure 2: CAD of hull

The frame is composed of 8020 extruded aluminum which was cut to size by the distributor. The frame uses two 34 inch 10 series bars in the long direction and several 8 inch 10 series bars for support and hardware. The frame is assembled using a variety of t-slot fasteners. The entire frame can be assembled and attached to the hull with an Allen wrench.

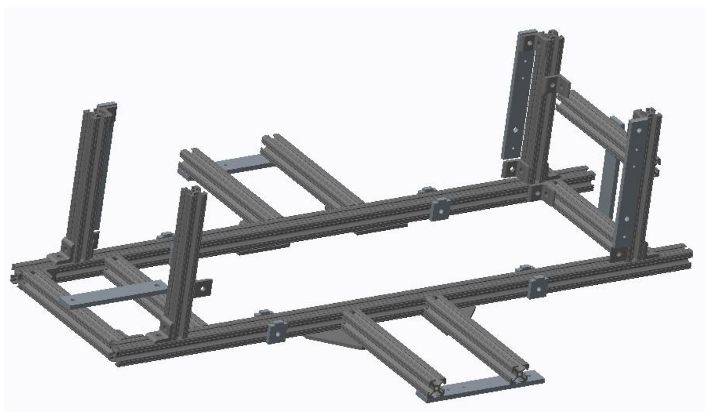

Figure 3: Framing for hull

2.2 Marker dropper fabrication

The marker dropper is made out of two aluminum 6061 parallel plates that contain a curved guide track. Both the curved boundaries of the guide track and the containing plates can be cut and drilled using a waterjet cnc machine. Spacers are located between the bars of the guides and plates held in place by the screws and lock nuts that hold the frame together. The spacing is adjusted by the addition of washers along these same shafts. This is mounted to the frame by an 80-20 piece of aluminum. A waterproof servo is held in the window of the aluminum plate with a standard servo arm and held in place with the servo mounting screws that came with the servo.

This subsystem has a very simple design that can be manufactured and assembled easily within a few hours. One of the best qualities of this design is its open air set up, which allows for easy testing and does not require any external water sealing. If this system were to be redesigned it may be beneficial to replace the curved guide rails with individual tubes to contain the markers. This would ensure that the markers stay in place during transit which may be an issue that arises that we are as of now unaware of due to the lack of extensive testing. This change would likely not affect the manufacturing or assembly time.

2.3 Torpedo fabrication

The torpedo was built in four steps. The initial step is the development of the CAD model. Taking designs of real world torpedoes and rubber torpedo pool toys an initial design is made. Upon completion of the CAD model the file is saved as a stereolithograph at relatively high constraints. The stereolithograph is moved to a slicing software such as makerware to prepare it for the 3D printer. In the software it is important to take into account build tray limits and part orientation, it should be oriented vertically to reduce potential model errors during printing. The model is printed out of ABS plastic and with any infill density. The finished 3D printed part once finished is post processed using increasingly fine grits of sandpaper to produce a smooth surface finish to ensure the part will be better streamlined. The third step in the fabrication is development of a two-part plaster mold. In setting up this mold it is important to consider the shape of the part and the orientation of the pour spouts, the mold material will not completely fill the mold if airways are not located at the highest parts of the designed piece. In order to cast this mold a basin to hold the wet plaster is required. In general cardboard is used with hot glue sealing cracks to prevent leaks. Additionally, a stand may be used to suspend the part within the basis to ensure a consistent height, this can be done with a piece of hot glue. Before pouring the plaster both the mold and the torpedo must be coated in wax or some other seal releasing agent to ensure separation of the piece from the mold, this must be done every time the mold is used and between each mold half during fabrication. After pouring the first half of the plaster into the mold, when the plaster begins to thicken, notches are made in the piece to create places for the two mold halves to lock together. At any point the plaster mold edited through the use of a scalpel to carve away any problem areas. The final step in the manufacture of the torpedo is to pour the mold material into the mold. The material used is Simpact 85A urethane rubber purchased from Smooth-on, it used an 1:0.85 mixing ratio by mass which therefore requires a scale to measure properly. Though not required, it should be handled with nitrile gloves to minimize skin contact. This material has a very short pot life of only about 4 minutes, and as such requires rapid mixing and pouring. Once poured the material is given forty eight hours to cure fully before releasing the mold to ensure the part does not tear. Final touches to clean the part are made using a scalpel and sandpaper.

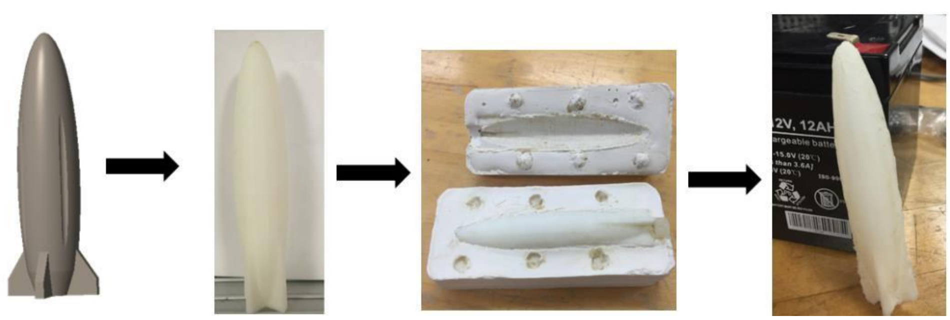

Figure 4: Torpedo Process

This process in its entirety takes a minimum of three days. Though it seems highly involved it was made to mimic the injection mold process used by most companies which work with polymers as well as sculpting techniques. If this was every required to be mass produced an assembly line could easily complete many of these in a short time frame. One possible way for this process to be improved is to rather than designing a torpedo first and creating a plaster mold a direct mold design can 3D printed and used to fabricate the torpedo. This would slow prototype editing and active model adjustment but could improve mold durability and accuracy of a well established design.

3 Design for Reliability

To ensure the Robosub is successful for multiple performances, the design and modifications have been implemented to allow for long lasting, consistently successful performances. The design choice of making the hull out of stainless steel to prevent corrosion from occurring from continued usage within the water. The major concerns for this project that needed to be addressed are the overheating of the electronics and ensuring the watertight nature of the submersible.

4.1 Waterproof Testing and Ports

In order to prevent the sub from having any leaks several measures were taken. To connect the microcontrollers to the mechatronic systems attached to the frame two methods were used, the Seacon ports and the cable penetrators. The Seacon ports were carried over from previous years as a reliable method, but upon further inspection the Robosub team noticed major corrosion and deterioration. The cable penetrators were used instead as both an economic alternative, when properly assembled they do not allow water to pass through them. The cable penetrators feature a paint coated outside and an aluminum structure. The addition of the painted coat will improve corrosion resistance and thereby increase the lifespan of the part.

Pressure washers are attached at the entrance of every exterior hole behind both the ports and screws acting as the front lines of defense against water passage. Teflon tape was used around every screw traveling from outside to inside the sub as an additional leak prevention measure. Liquid Electrical Tape is used at the junction of any electronic connection just as secondary measure in addition to the waterproof components. These considerations were made to ensure reliable usage of the submarine.

4.2 Replacement and Addition of Electronics

Starting with an older design, there were numerous electronic systems that needed to be updated. The submersible consisted of three motor controllers powering six thrusters. After careful inspection, it was discovered that one of the motor controllers was malfunctioning. This led to the implementation of a third motor controller which is identical to the other two and equally reliable. This has resulted in the consistent success and operation of all six thrusters.

Furthermore, electronics were not only replaced, but also added within the Robosub. The fabrication of a relay system allowed functioning torpedo and gripper subsystems. The relay system has been tested successfully numerous times, is compact, and allows reliable operation of multiple subsystems. In addition, a waterproof servo was added to the marker dropper subsystem. This allows for a functional marker dropper that is reliable because it is waterproof.

A new kill switch was purchased and implemented to the submersible to allow an operator to easily shut down the electronics from outside of the hull. This is important so that in case the autonomous submarine does something that may cause damage to itself or the surroundings the robot can be shutdown to prevent any further damage from occurring.

3.1 Organization of Electronics

The organization of electronics allowed for a more reliable and aesthetically pleasing product. Most of the internal electronics were initially in an unorganized state, which made pinpointing errors difficult, and allowed limited flexibility with interior modifications. To fix this, two black boxes were implemented to house separate subsystems. Instead of the motor controllers being connected to the Arduino MEGA with unorganized jumper cables and a breadboard medium, the motor controllers and Arduino MEGA are connected directly to the main CPU. Because the Arduino, internal jumper cables, and motor controllers are housed within a black box, this allows for flexibility with interior modifications and a more reliable product. The second black box consists of the relay system for the torpedo and gripper subsystems and allows for increased internal efficiency and reliability.

4 Design for Economics

The Robosub senior design project was allotted $2000 dollars total over the course of two semesters as a budget. In order to meet these budget contraints the team realized the budget had to be properly managed in order to insure the proper funding throughout the project. For example some of the components that are on the sub which have been used over the years like the BTD150 thrusters and Seacon ports could use some replacement, but given they're high expense that was not a priority. The project is comprised of many different subsystems, so for simplicity categories have been broken down into the main areas seen in the pie chart below.

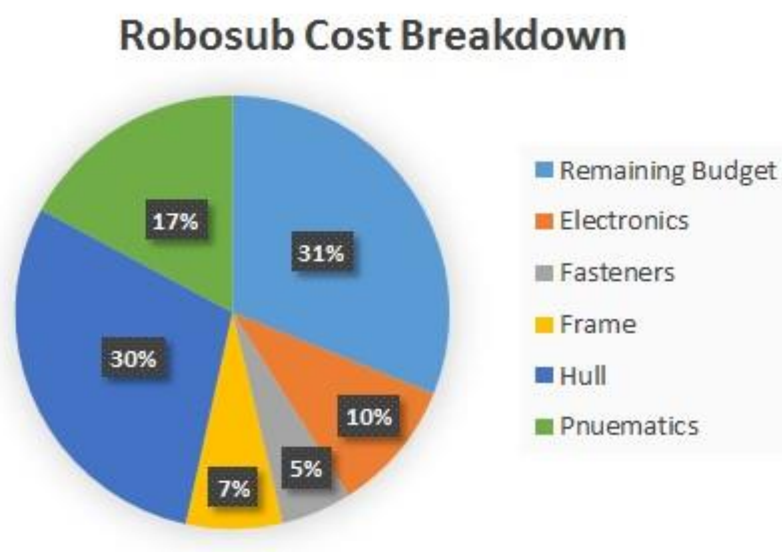

Figure 5: Budget Breakdown

In general, up to now the majority of the budget has been spent on the fabrication of the new hull equating to 30% of the total budget which comes out to $590. These cost when mainly to the purchases of raw materials, including the stainless steel for the hull, aluminum for the lid, and also the stainless steel toggle latches for enclosing. These were some of the more expensive items necessary to improve the design of the Robosub. The pneumatic system has made a lot of progress and was a large focus while the new hull has been under construction. Many items were required to get the pneumatics up and running which include the torpedoes firing and gripper actuation. Some of the items that have been purchased for these systems were the compressed air tank, pneumatic actuator, solenoid valves, and of course the hose and waterproof connections to tie it all together. Seen in the pie chart this has contributed to 17% of the total budget coming down to roughly $350. The three remaining categories including the electronics, fasteners, and frame go hand in hand with the major components of the submersible. The frame can be elaborated upon to include more subsystems if needed which require additional electronics and fasteners for integration. These categories grow together with progression of the project each contributing between 5 and 10% of the budget which is about $150 each.

The market for underwater vehicles is rather limited in scope, as most people do not have a need or desire for them. Although there is a lack of demand for these kinds of products they still do exist, for instance the company Blue Robotics sells their own ROV at $1290 and is an unassembled kit which contains a frame, electronics housing and thrusters with speed controllers, but nothing else. The robosub team, with components grandfathered from previous years, was able to design and manufacture a similar product but also was able to include additional subsystems for about the same amount of money spent.

5 Conclusion

In general, the design was significantly improved over the previous years mechanical design. The new hull has a more complex fabrication method than previous years however due to the user friendly access and the addition of modular components it solves the problems of the old design. The cable penetrators and the kill switch change will improve the lifespan and safety of the submersible body. The alteration of the marker dropper enabled new functionality and can be replicated and altered easily. The Torpedo fabrication was an extensive process but can be done entirely in house in four steps. The process is easily repeatable and can be used to quickly produce multiple parts from a single design. Electronics being shift into modular boxes and electrically insulated provide an easy access and safe work space for the user. It also makes the transfer of new electrical components easier for the user. The remaining budget after several purchases is 31% of our total budget after replacing most of the physical systems. When compared with previous year's expenditures there is a significant improvement in total system cost.

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11. Biography

Max Austin:

A Mechanical Engineering senior working in STRIDE Lab, TA's for Dynamics System's 2, planning on going to Graduate School after graduation.

Corey Cavalli:

A Mechanical Engineering senior interned with United Launch Alliance as a strength analyst during summer of 2015. After graduation he will return to United Launch Alliance in Cape Canaveral as a test engineer.

John Nicholson:

A Mechanical Engineering senior worked in the STRIDE Lab under Dr. Clark as an undergraduate research assistant during the summer of 2015. Also has been a teaching assistant for Mechatronic 1 since spring 2015.

Ross Richardson:

A Mechanical Engineering senior who work as an undergraduate research assistant at the Applied Superconductivity Center under Dr. Hellstrom since summer 2014. Interested in going to graduate school upon graduation.

Erik Olson:

An Electrical Engineering senior who's participating in an REU over the summer and is interested in working in the power systems industry after graduation.

Jordan Clein:

An Electrical Engineering senior who interned at Nextera Energy summer 2015 and will be returning to Nextera for a job after graduation.