Mech 401-04
Mechanical Engineering Design

Unmanned Submarine Drone Midterm Report

Report Submitted to Dr. Saboori and Dr. Walker

May 7, 2018

Group: Dream Team Submarine Machine

Kathia Coronado
Damiano Falanga
Alexandra Santelli
Veronica Valerio
Edbin Gonzalez-Calderon

Department of Mechanical Engineering
Manhattan College

Table of Contents

Abstract

The aim of this project was to create and design a prototype for a submarine drone or Unmanned Underwater Vehicle (UUV) . A submarine has the ability to control its buoyancy in order to dive and resurface at will. While floating on the surface, a submarine fills its ballast tanks with air to maintain an overall density that is less than that of the surrounding water, thus creating positive buoyancy. To dive beneath the surface, the submarine fills the ballasts with water and the air is released. By doing this,the overall density of the vessel increases and creates negative buoyancy. For a submarine to resurface, the ballast tanks must be filled with compressed air in order to expel the water from the tanks.

For this project, a very similar design will be implemented. The size constraints of the design makes it difficult to use compressed air to allow the submarine to resurface. Due to the amount of compressed air needed, a large tank must be used but would overwhelm the small design. Instead, a piston cylinder driven by an actuator will be utilized to allow the removal of water from the tanks and would draw the water out rather than forcing it out of the water tank.

Background

Aerial drones have seen an increase in popularity throughout these past few years. Underwater drones have just as many uses as aerial drones. These autonomous underwater vehicles (AUV) have also seen an increase in popularity for industrial uses, largely due to the fact that AUVs can go places that human divers cannot. For example, AUVs are often used in surveying infrastructure. Underwater drones allow for an easy and safe way to inspect the underwater components of bridges quickly and effectively. Additionally, AUVs have many applications in undersea mining for valuable materials such as gold, silver, and cooper, and in deep sea drilling for oil. In fact, submarine drones were employed during cleanup of the Deepwater Horizon oil spill in the Gulf of Mexico in 2010 to obtain important information about the water, such as its salinity, temperature, and even the composition of the oil droplets.

The Department of Defense has taken interest in implementing AUV technology for the United States Navy. In early 2016, the Secretary of Defense stated that over $600 million dollars would be invested over the next five years in UUVs for use by the Navy. Proposed applications of these devices include simple tasks such as base support and ocean mapping, as well more complex tasks like mine countermeasures and anti-submarine warfare.

There exists a variety of Unmanned Underwater Vehicles (UUV) in the market as well. However, they are mostly for professional use and thus are typically more expensive than other hobbyist toys or gadgets. The following figures provide existing examples of submarine drones, including important specifications such as price, depth, speed, and payload.

The drone shown in Figure 1 is the Aquabotix HydroView Sport RC Underwater Vehicle, which sells for $5800. Its maximum depth is 150 feet and has a maximum range of 75 feet, due to its tethered cable. This drone features a 2-lb payload and has a full forward speed of 4.6 km/hr.

Figure 1: Aquabotix HydroView Sport RC

The drone in Figure 2 is the HydroView Pro 7M Mini ROV, which retails for nearly $17,000. This particular model has a maximum depth of 250 feet and a maximum range of 250 feet as well. Similar to the previous drone, the HydroView Pro also has a full forward speed of 4.6 km/hr.

Figure 2: HydroView 7M Mini ROV

The Endura 100 Mini ROV Underwater Vehicle, shown below, sells for $29,000. This vehicle has a maximum 328 foot depth and a 328 foot range. It has a 4-lb payload and a full forward speed of 5.6 km/hr.

Figure 3: Endura 100 Mini ROV Underware Vehicle

By taking features of existing models of UUVs, the group was better able to establish a feasible and competitive design for this project.

Objectives

The goal of this project is to design an unmanned underwater vehicle, UUV, that is remotely and wirelessly controlled or untethered. To optimize the performance, it is essential to minimize cost and create a unique operating envelope with a distinctive communication system. Constructing a successful design will entail knowledge of fluid dynamics, statics, dynamics, solid mechanics, and Computer Aided Engineering (CAE). A design that does not overlap with existing drones allows for a less competitive market. To accomplish this, the design for typical UUVs will be simplified and will utilize appropriate and more economical materials. Unmanned Underwater Vehicles currently in the market are expensive, tethered and difficult to control. The cost of submarine drones can range from $1,000 to $25,000. Inexpensive UUVs are usually tethered and of low quality. The main focus behind the design of the prospective submarine drone or UUV are cost and design. The prototype being built should reach a maximum depth of ten feet. The maximum range of the prototype should be 32.8 feet untethered traveling at a maximum speed of five feet per second. The diameter of the prototype is planned to be six inches with a length of one foot. The design should also be able to hold a 2.2 pound mass payload while also costing less than our maximum budget of $500.

This project is estimated to be completed by May 2018. This timeline includes creating and simulating a design, building prototype and conducting tests on the prototype.

Research

Prior to beginning the design process for this project, it was important to first understand how a submarine operates. Submarines control their buoyancy to dive and resurface at will, utilizing the principles of positive and negative buoyancy. Positive buoyancy means that the submarine has an overall density that is less than that of the surrounding water. Conversely, negative buoyancy means that the submarine's densitty is greater than the density of the surrounding water. In order to create positive buoyancy, the submarine must fill its ballast tanks with air. To produce negative buoyancy, its ballast tanks must take in water. When the submarine is ready to resurface, compressed air enters the ballast tanks in order to expel water. Neutral buoyancy is when the density of the submarine is that of the liquid it is submersed in, thus the submarine neither rises or sinks.

One of the major differences between submarines and unmanned underwater vehicles has to do with the fact that submarine must consider diving modes, while UUVs are primarily concerned with their communication systems.

The diving modes of a submarine describe the essential operations to submerge and resurface the vessel. The diving systems of a submarine can be split into two general groups: static diving and dynamic diving. In a static diving model, the submarine submerges itself by changing its buoyancy through the use of ballast tanks. It can then resurface at any time, even while stationary, simply by adjusting its buoyancy. Additionally, a static diving system allows a submarine to operate below the surface at any speed.

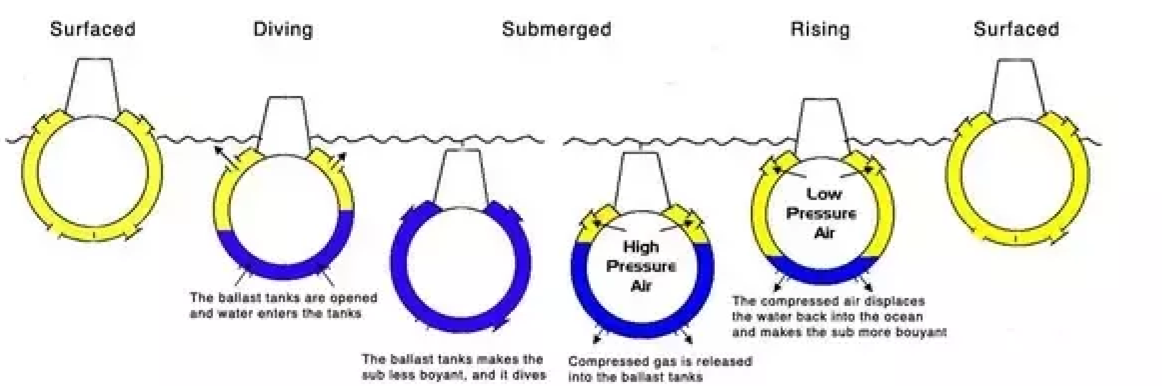

Figure 4: Static Diving Submarine

In a dynamic diving model, dynamic forces are used to overcome a submarine's buoyancy typically through the use of hydroplanes. As the submarine moves through the water with sufficient forward speed, the hydroplanes create the force that pushes the vessel underwater. The submarine will remain submerged so long as the force is enough to overcome its buoyancy.

As soon as the forward motion of the vessel stops, it will begin to resurface. Because the vessel must operate at a considerable speed, it limits its ability to operate at slower speeds underwater.

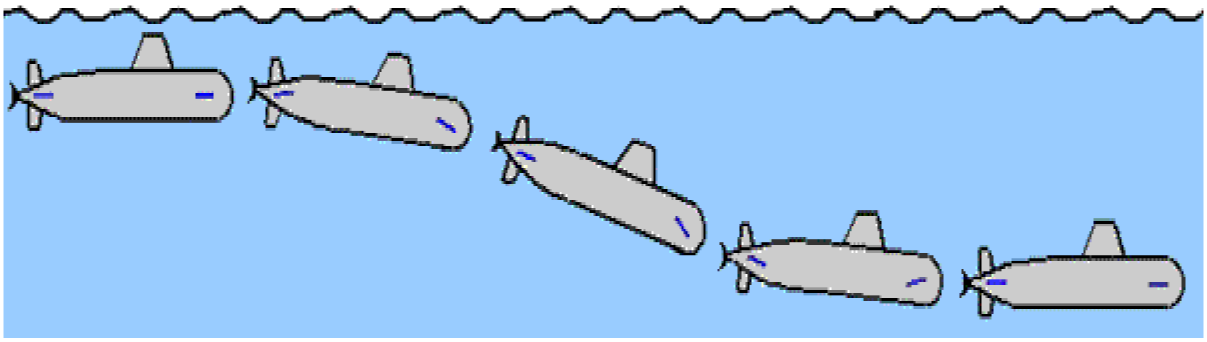

Figure 5: Dynamic Diving Submarine

Because submarines are manned, they do not require a communication system to control the vehicle. However, UUVs must feature an onboard communication system in order to operate. There are two modes of communication for unmanned vehicles: tethered and untethered, or wireless. A tethered system communicates with the vessel through a wire, which ultimately places a constraint on the range of the vehicle as it may only travel as far as the tether allows. An untethered communication system does not feature a wired connection, but rather receives signals transmitted from the surface. These signals can be transmitted via radio waves, visible light communication (VLC), or Sound Navigation & Ranging (SONAR). As with a tethered communication, there also limitations to untethered communication due to the fact that signals must be transmitted through both air and water.

Initial Design

At the beginning of the design process, the first thing to be created was the body of the submarine. It took a cylindrical shape with hemispherical ends which acted as ballasts. These ballasts would hold blocks, which would act as dead weight in order for the submarine to submerge and rise evenly as well as prevent the submarine from rotating while submerged. In addition, the material chosen for the submarine was the plastic known as polyvinyl chloride (PVC). With the known densities PVC and air, and the volume of the proposed submarine, the allowable mass in order for the submarine to remain floating on water, was calculated. It was assumed that the design density of the vessel must be at or below 1029 kg/m^3 as this is the density of seawater. Figure 6, below, displays a 3-dimensional model of the initial design. The hull was designed to be four inches in diameter and ten inches in length. The ballast tanks were designed to have a four inch diameter as well.

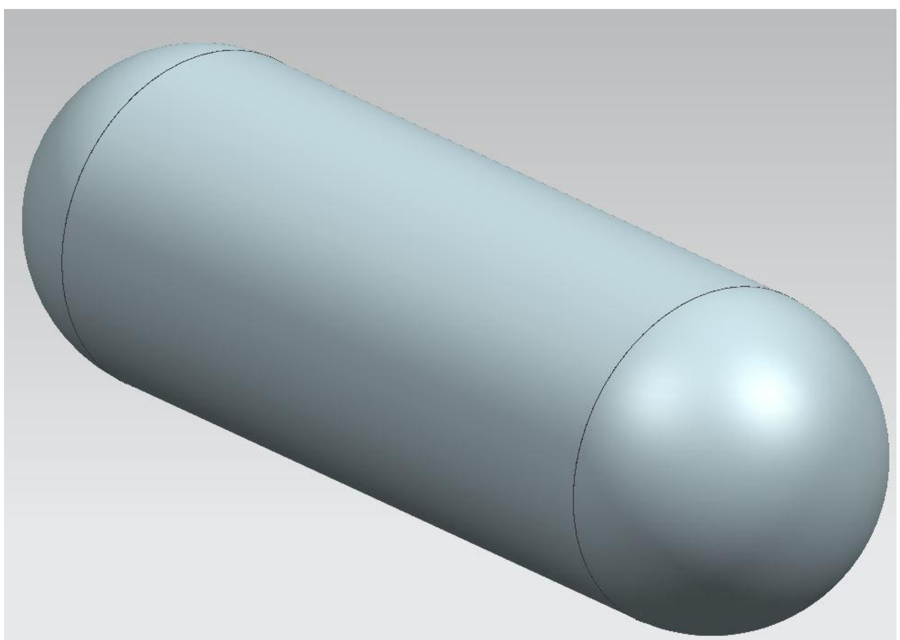

Figure 6: Initial design of submarine

The interior of the submarine contained a water ejection system that was powered by two pumps. In order for the vessel to submerge, the vessel created negative buoyancy by allowing water to enter through hoses, in the bottom of the vessel, into a water sealed tank at the center. In order to control the amount of water entering the system, a solenoid valve could be utilized to obstruct the water's path. In order for the vessel to rise, the pumps would create positive buoyancy by expelling water, from the water tank, via tubing to the surrounding environment of the vessel. Figure 7 shows the schematic of the initial water ejection system.

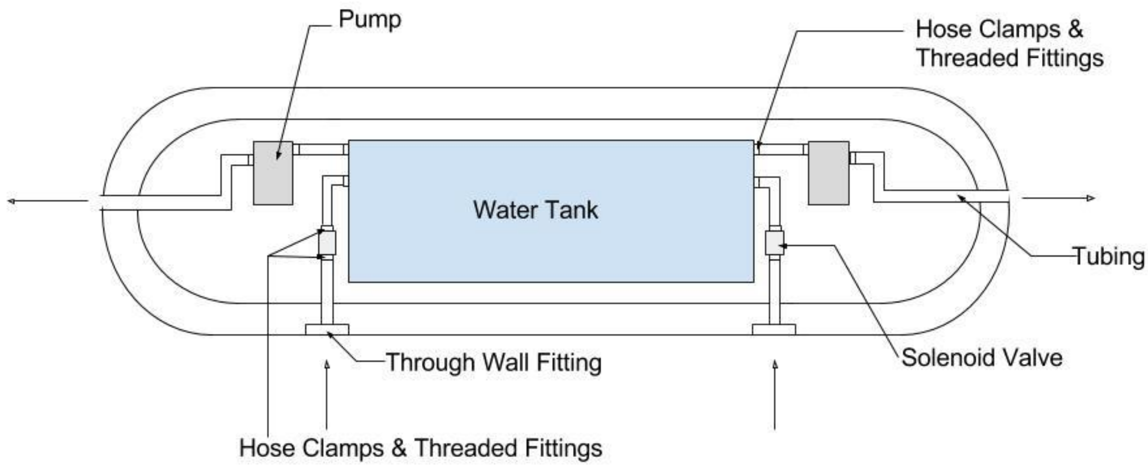

Figure 7: Schematic of Initial Water Ejection System

With all initial designs come challenges and room for improvement. One of many challenges included finding components which were compatible with each other, for example finding the right size tubing for the solenoid valves. Another challenge involved the water ejection system. The advantage of utilizing a pump was its accessibility in the market. Despite this advantage, it was decided that the pump was not suitable for the design of our proposed submarine. This is because the pumps available in the market were too large to meet the submarine's design requirements. In addition, the pump was found to not be strong enough to expel the water at target depths; this was found to be a problem even when implementing two pumps in the design. Because the pumps had to eject the water to resurface, the pumps would have to be strong enough to essentially produce a vacuum within the tank

Design challenges were also faced while designing the communication system of the submarine drone. The goal of the proposed communication system was to wirelessly communicate the the submarine drone, submerged in the water, with a human operator. While designing the communication system, it was decided that a customized form of a Sound Navigation and Ranging (SONAR) system was the most appropriate for this project. Figure 11 displays the layout for the communication system. While designing this system it was found that receiver, or sound sensor, that the team using was not sensitive enough to be able to pick up sound between small to medium distances. The sound sensor was also unidirectional, meaning that it only had the ability to detect sounds along one fixed direction. Also, the pinger, or piezo buzzer, used for the communication system circuit was not loud or sharp enough to be picked up by the microphone sensor. Therefore, for the current design it was deemed necessary to obtain a sensitive and omnidirectional sound sensor, as well as a louder and sharper pinger.

Second Design

After a reevaluation of the initial design, several changes were made. Although the body of the submarine remained cylindrical, the ends went from being semi-spherical to having flat cylindrical caps. The hull length remained the same as well as the diameter. In addition, in order to ensure that unwanted water did not enter the system, causing damage to any electronics, grooves were made and O-Rings were placed between the caps and the body of the submarine. In order to implement O-Rings into our new design, grooves were made into the submarine's hull to place the O-Rings. First, the inner and outer diameters of the O-Ring were decided. The outer diameter of an O-Ring should be approximately equal to the outer diameter of where it will be placed. Once the O-Ring was chosen, the groove was then designed. The group consulted a handbook to design the groove necessary for the O-Ring. Our O-Ring has a diameter of 4.693 inches and a width of 0.103 inches, which is close to the outer diameter of the four inch PVC pipe of 4.5 inches. Because of this width, Parker O-Ring Handbook suggests a groove depth between 0.081 to 0.083 inches and a groove width of 0.140 to 0.145 inches in order to provide an ample amount of compression on the O-Ring, providing the sealing. These alterations are displayed Figure 8.

Figure 8: Current Design of the Hull of Submarine

A new water ejection system using a piston and cylinder was designed to replace the original design that utilized two pumps. The piston and cylinder system would be driven by a linear actuator, purchased from Actuonix with a voltage of 12V and a maximum speed of 1 in/s, attached to the piston. The cylinder would be created with a threaded cap and a pipe, both made of stainless steel with a maximum pressure of 150 psi. The cap would have a diameter of 3 in and a length of 1.77 in, while the pipe would have an outer diameter of 2.38 in and a length of 3 in. The piston would be 3-D modeled, using CAE software, and printed with a diameter of 2 in, a length of 1 in, and two grooves and O-rings to ensure that the cylinder remains watertight throughout the strokes of the piston. Protruding from the cap of the system would be a hose which would lead to the outside of the submarine. The hose would need to be attached to a solenoid valve, which acts as a precaution to water leakage into the submarine. The new system resolves the size problem that was experienced with the pumps. The piston and cylinder system is also stronger and more capable of expelling water from the drone than the pump.. A schematic of the current designed water ejection system inside the submarine is shown in Figure 9.

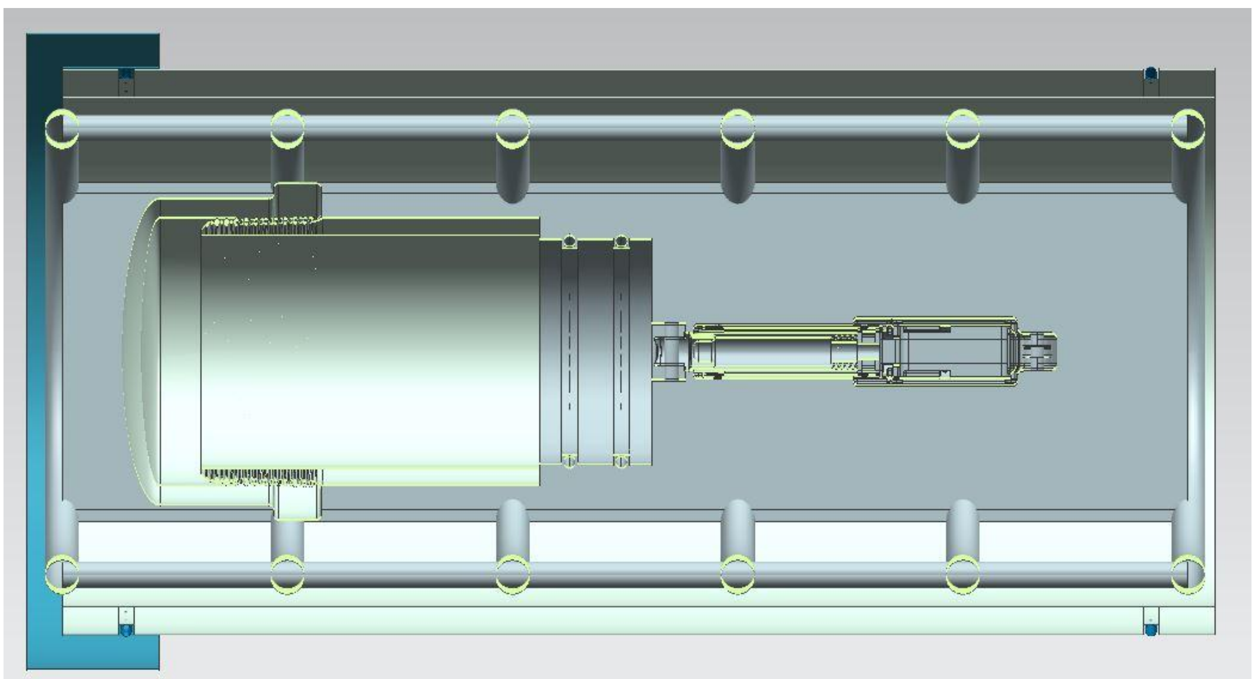

Figure 9: Schematic of Current Water Ejection System

Another modification made to the initial design was the addition of an equipment frame. As previously mentioned, this submarine gives a size constraint; this makes it difficult to work on different sections within the vessel. The equipment frame would allow for both the water ejection system and the communication system to be placed within the frame and be easily positioned into the body of the submarine. This enables the frame to be easily removed and accessed if anything were to malfunction or require alteration.The frame was designed for the purpose of keeping the components of the submarine accessible and compartmentalized. It was designed to have an outer diameter of 4 inches with two compartments; one for the communication system and one for the pump and cylinder system. This frame would also be custom made with CAE software and 3D printed. The frame with the water ejection system inside is displayed in Figure 10.

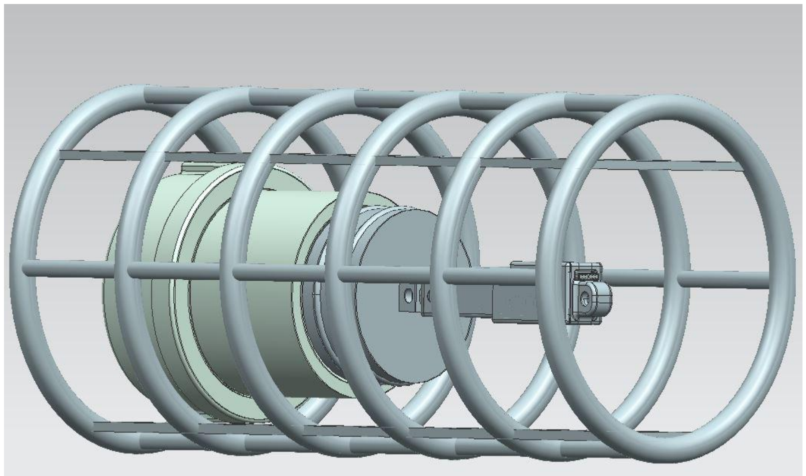

Figure 10: Equipment Frame with the Water Ejection System Inside

As previously mentioned it was decided that the best communication system for the needs and requirements of this project was a custom SONAR system. Initially, radio frequency and light communication were considered as possible candidates for the system. However it was quickly discovered that radio frequencies are not suitable for underwater due to the fact that electromagnetic signals, which have high frequencies and large band widths at short distances, are attenuated in water. Light communication was also deemed inadequate for the communication design of this experiment because light does not require a medium to travel; therefore, when light passes through water it slows down and is not seen or detected past certain depths underwater. The large density of water, which is about 800 times more than that of air, absorbs the light. SONAR communication, on the other hand, is ideal for underwater because, unlike light, sound does need a medium to travel or propagate. In fact, sound travels faster in air than in water and is suitable for communication across long distances. The NAVY uses SONAR communication for their submarines and underwater drones.The only downside about using the SONAR communication technology available in the market, is that it is too expensive, such as marine grade technology, or not suitable for water. Thus, designing a custom SONAR system was the best option, given the budget and size constraints of the proposed submarine.

The custom communication system design for the our submarine drone is displayed in Figure 11. The design includes a transmitter or transponder, a receiver and an Arduino UNO microcontroller. The way that the system functions is having a human operator five navigation instructions to the transmitter, which is submerged in the water towards the water surface. There are only four types of instructions that can be given: up, down, left and right. Once the transmitter receives these instructions it emits pings into the water, using a pinger or buzzer. The pings are then detected by the receiver, or microphone sensor, and are translated into navigational instructions by the Arduino UNO. Based on the received instructions the Arduino would either engage the actuator connected to the piston cylinder in order to intake or expel water from the cylinder to allow the submarine to dive or resurface or it would activate propellers which allows the submarine to make lateral movements.

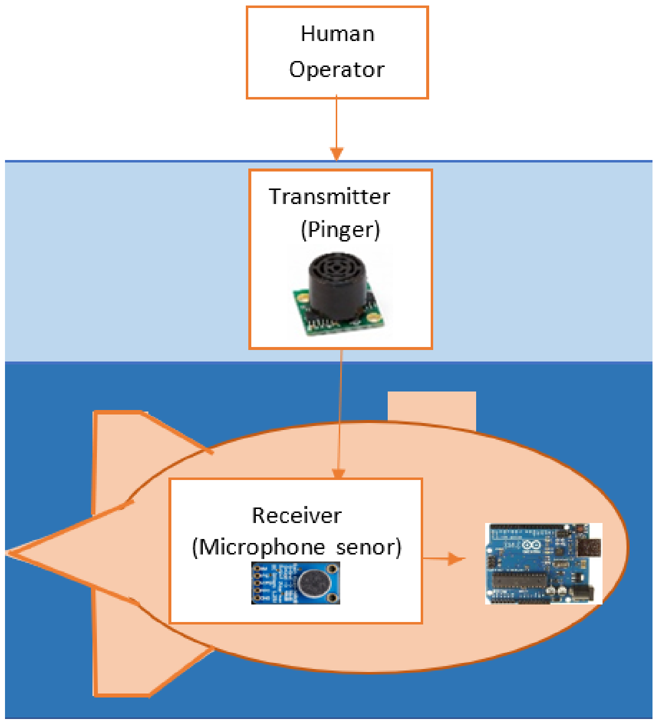

Figure 11: Communication system layout

A test was designed and conducted to see if a sound input could produce a desired output. The circuit of the test circuit is displayed in Figure 12. It utilized ten LED lights, one sound sensor, one Arduino UNO, ten resistors and a sound input. The way that the circuit functioned was that as the microphone or sound sensor detected a sound this would cause the light LED to light up. The code for the circuit is displayed in Figure 13. The code uses analog input for the sound sensor because it allows the sound sensor to be more sensitive to sound.The test was successful; whenever a sound was produced the the light would turn on. However, one of the goals for improving the current design of the circuit and the communication system is to purchase a more sensitive microphone sensor and pinger, such as the ones displayed in Figure 11. The layout of the submarine drone's internal design can be seen in Figure 14.

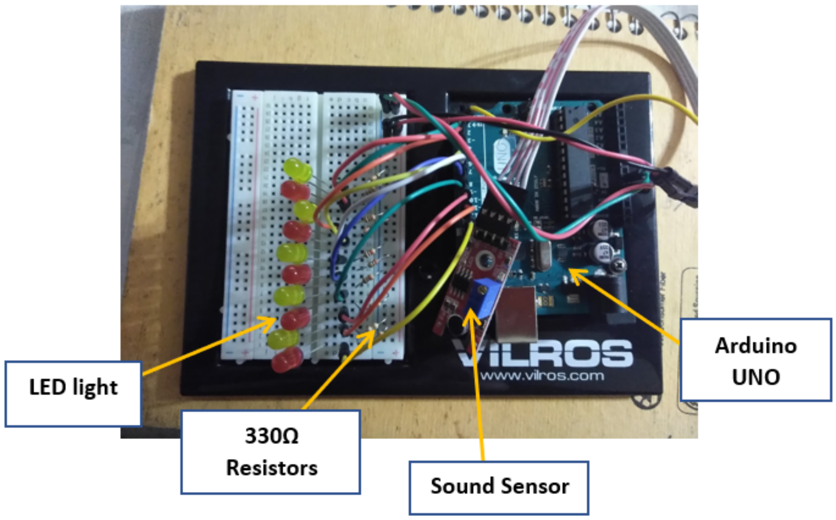

Figure 12: Sound input, light output test circuit

MANY_LED

```
int soundSensor = 2;
int LED1 = 3;  int LED2 = 4;  int LED3 = 5;  int LED4 = 6;
int LED5 = 7;  int LED6 = 8;  int LED7 = 9;  int LED8 = 10;
int LED9 = 11; int LED10 = 12;

void setup() {
  pinMode (soundSensor, INPUT);
  pinMode (LED1, OUTPUT); pinMode (LED2, OUTPUT);
  pinMode (LED3, OUTPUT); pinMode (LED4, OUTPUT);
  pinMode (LED5, OUTPUT); pinMode (LED6, OUTPUT);
  pinMode (LED7, OUTPUT); pinMode (LED8, OUTPUT);
  pinMode (LED9, OUTPUT); pinMode (LED10, OUTPUT);
           }

void loop(){
  int statusSensor = digitalRead (soundSensor);

  if (statusSensor == 1)
  {
    digitalWrite(LED1, HIGH); digitalWrite(LED2, HIGH);
    digitalWrite(LED3, HIGH); digitalWrite(LED4, HIGH);
    digitalWrite(LED5, HIGH); digitalWrite(LED6, HIGH);
    digitalWrite(LED7, HIGH); digitalWrite(LED8, HIGH);
    digitalWrite(LED9, HIGH); digitalWrite(LED10, HIGH);
  }
  else
  {
    digitalWrite(LED1, LOW); digitalWrite(LED2, LOW);
    digitalWrite(LED3, LOW); digitalWrite(LED4, LOW);
    digitalWrite(LED5, LOW); digitalWrite(LED6, LOW);
    digitalWrite(LED7, LOW); digitalWrite(LED8, LOW);
    digitalWrite(LED9, LOW); digitalWrite(LED10, LOW);
  }
         }
```

Done Saving.

Figure 13: Code for test circuit

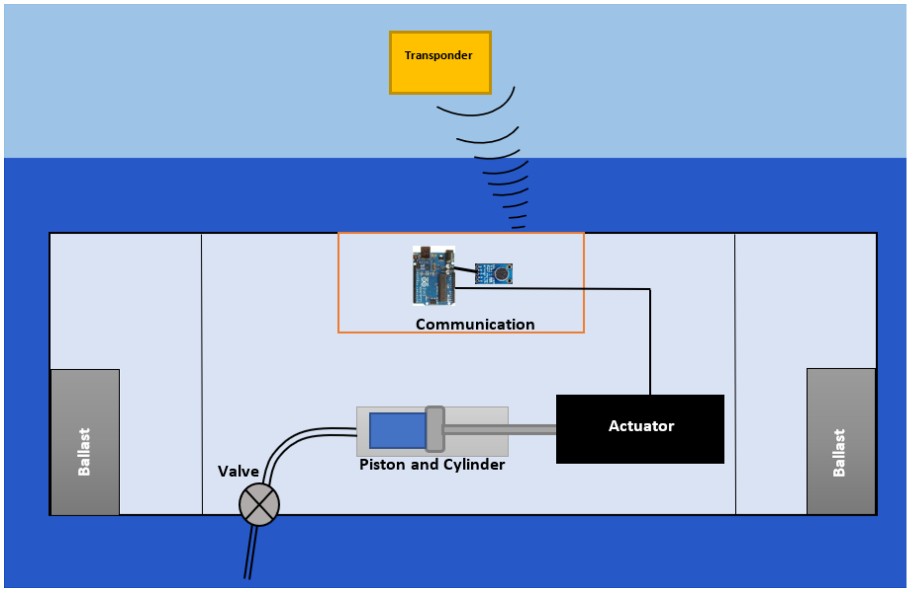

Figure 14: Second design layout

Current Design

Due to further design challenges, further changes were made to the design of the submarine. The diameter of the PVC hull was increased to six inch nominal size with corresponding non threaded PVC caps in order to create further room within the submarine for both the electronic components as well as the equipment frame. Instead of using O-Rings to seal the hull of the submarine, caulking was used for its ease of use and applying. The caulking would require approximately 36 hours to cure and settle. The current design of the hull can be seen in figure 15.

Figure 15: Current Hull Design

Another change made was to the ballast tank as well as the equipment frame. Due to the weight of the metal ballast tanks, the second design had to be changed in order to ensure that the density of the submarine would remain below the density of water to ensure it will float. The new ballast tanks were designed to be two inch nominal PVC pipe with its corresponding cap. Caulking would also be used between the cap and pipe to prevent any water from leaking out. The final design change made was to the equipment frame. Originally, the equipment frame was designed to be printed as one piece. This however would require a large amount of support material during printing. The equipment frame was then broken into multiple pieces that would fit together. This would allow for less support material to be used. Also, should a piece break the piece can be 3-D printed again without having to print the entire frame once more. An additional piece was also added to the equipment frame. Connected to the top and bottom platform of the frame is a piece that the actuator will be fixed to, this will prevent the actuator from moving. The ballast tank will also be held down using zip ties. A CAD drawing of the equipment frame can be seen in figure 16. Figure 17 also shows a cross section of the entire assembly including the hull of the submarine

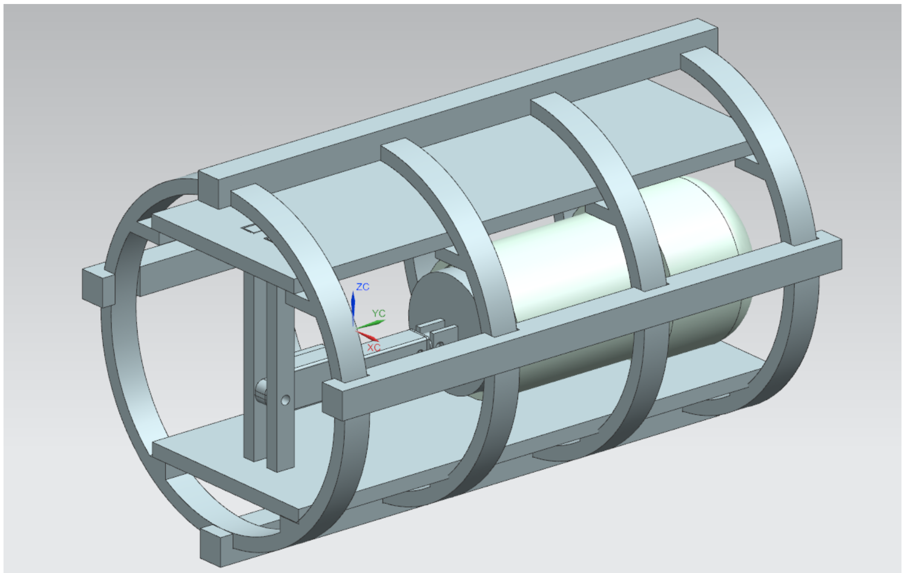

Figure 16: Equipment Frame with Ballast Tank

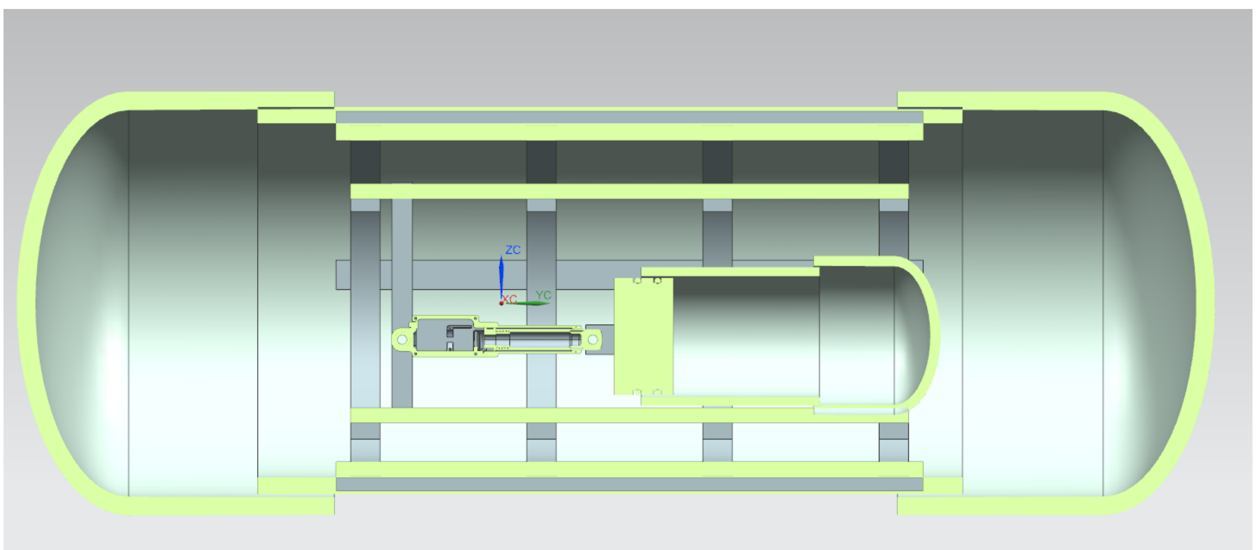

Figure 17: Cross section of submarine assembly

To improve the communication system of the submarine drone the microphone sensor and pinger of the previous design were replaced. The new microphone sensor, the MAX9814, was purchased from Adafruit Industries. It is more sensitive than the previous sensor and had adjustable gain. The adjustable gain allows for nearby loud sounds, that are not the input signal, to be quieted down so that sounds coming from fa-wat can be amplified. The new pinger was also purchased from Adafruit Industries and is louder than the precious pinger utilized.

The current design's circuit integrates the actuator that drives the piston, as shown in Figure 18. The circuit utilizes two Arduino UNO, one linear actuator, one linear actuator controller, one microphone sensor, one piezo buzzer and one external battery. The way that the circuit would work is that the Arduino UNO and the piezo buzzer wired to it would be placed in the transponder, that sits on the surface of the water. The user would interact with the transponder to send pingers through the water to the submarine drone. The other portion of the circuit would be located inside of the submarine drone. The microphone sensor would detect the sound waves coming from the transponder, this would then activate the linear actuator. Depending the the type of ping received, the linear actuator would either contract or extend to either take in or expel water. In this way the drone would because to submerge and resurface wirelessly.

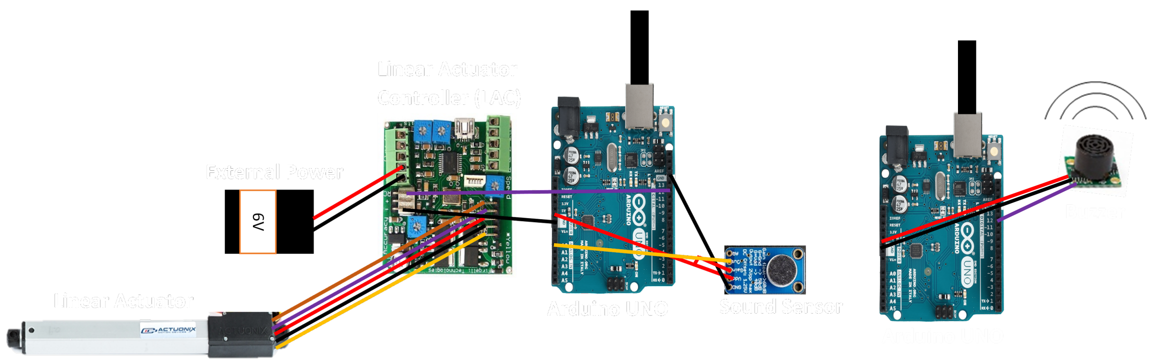

Figure 18: Current Submarine Drone circuit

The circuit was tested in air. The linear actuator was able to successfully drive the piston in and out of the cylinder.

Analysis

With a design finally decided on, a Finite Element Analysis was necessary to ensure that our design would not fail due to the applied loads. Figure 19 shows the model used for the finite element analysis. The hull was cut in half to simplify the analysis done. At the location where the hull was cut, a simple support constraint was made. An internal pressure load of 15 psia was applied to account for atmospheric air within the submarine. An external pressure load of 30 psia was applied on the submarine to account for the water pressure the submarine would experience at maximum depth. All along the outside of the hull a glued surface constraint was applied to connect the cap to the hull. A mesh was then applied on the hull and cap. The mesh type was a tetrahedral mesh, the mesh size was one inch.

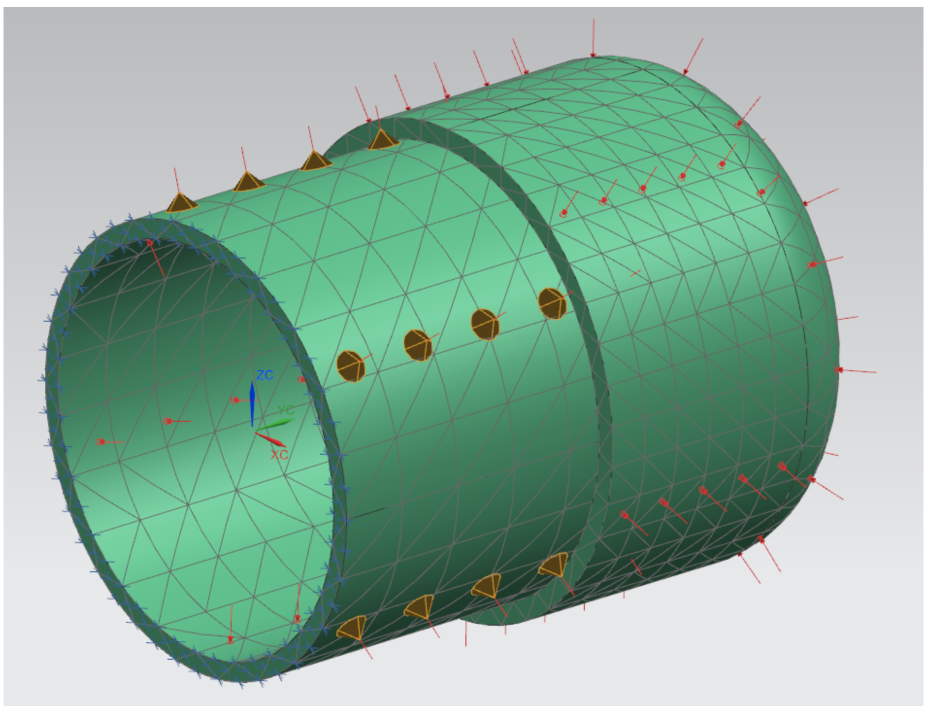

Figure 19: FEA Model of Submarine Hull

With the model completed a buckling analysis as well as a stress analysis was conducted. Figures 20 and 21 show the results of the buckling and stress analysis respectively. The results of the buckling analysis showed a maximum deflection of approximately one inch located along the hull of the submarine. These results are from the first mode shape, which is the most likely failure that would occur. The factor of safety was found to be 49.93, this shows that the load applied is approximately 50 times below the maximum load this assembly can withstand.

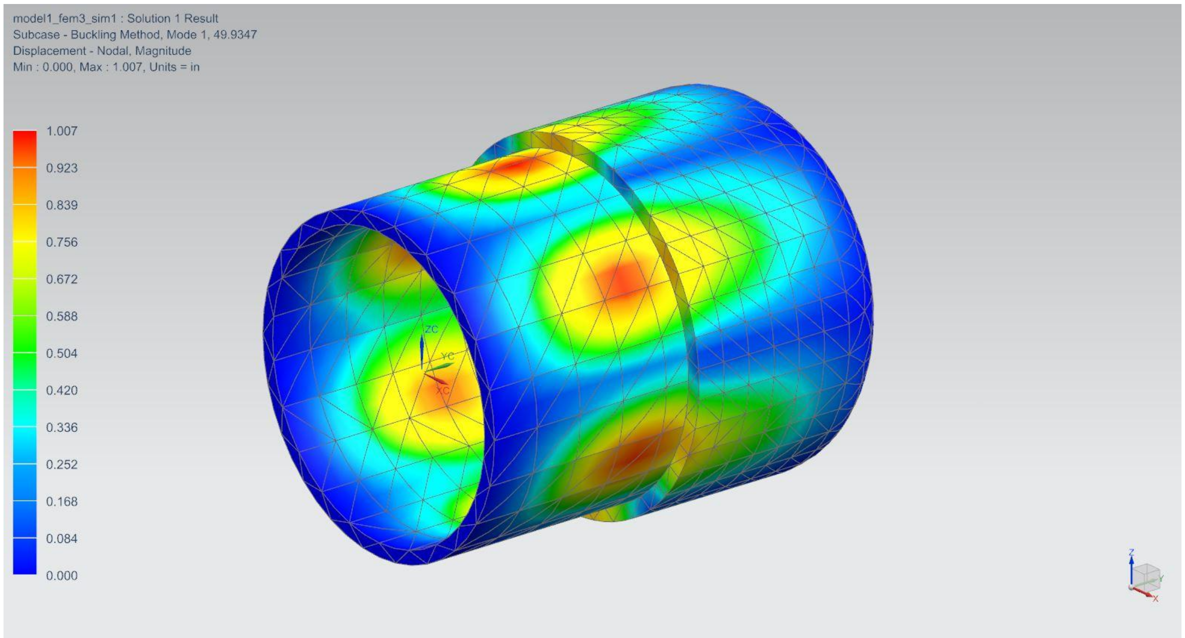

Figure 20: Buckling Analysis on Hull

For the stress analysis done on the same model, the locations where the largest Von Mises stress would occur were found to be at the point where the hull and cap are attached as well as at the center of the cap. These locations experience a maximum stress of approximately 58.15 psi. Compared to the maximum yield strength of PVC, which is 180 psi on the lower end, this stress is not enough to cause failure.

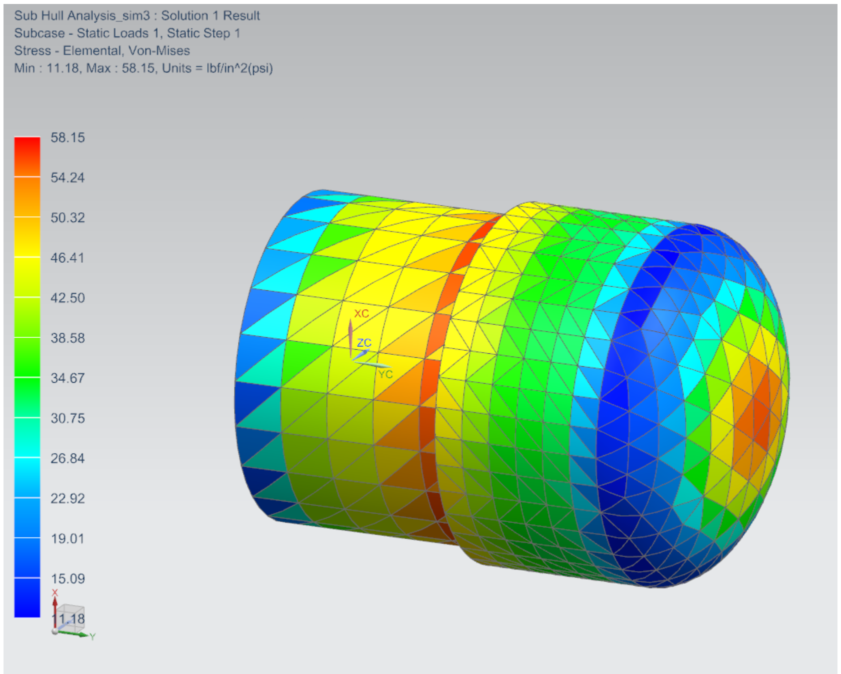

Figure 21: Von Mises Stress Analysis on Hull

Cost Analysis/Parts List

Due to being able to print some parts for free at Manhattan College, the total cost for the submarine prototype is less than tabulated in Table 1. After considering all the parts needed to build the submarine, the total cost of the submarine is approximately $274 if the cost of 3-D printing is included. Some of the big budget items necessary in this design include the actuator which was $70, the Arduino Unos which cost $44. If 3-D printing was taken into account, the average cost of the material used would be $1.33 per cubic inch. The design includes a total of 39.2 cubic inches of material, this would cost approximately $53. Overall, the prototype was built well below the allowable budget making the submarine a competitive model.

Table 1: Cost of Parts

Part	Quantity	Price
6′′ PVC Pipe	1	$10.00
6′′ PVC Pipe Caps	2	$6.00
3′′ PVC Pipe	1	$21.00
3′′ PVC Pipe Caps	2	$7.00
Arduino UNO	2	$44.00
Actuator	1	$70.00
Sound sensor	1	$7.00
Piezo Buzzer (6-16V)	1	$4.00
O-Rings	4	$18.00
Barbed Fitting	2	$17.00
¼-inch Tubing	5 ft	$17.00
3-D Printed Items	39.238 in^3 @ $1.33/$in^3$	$53.00
	TOTAL	**$274.00**

Conclusion

Overall, the prototype was made under budget. However, testing the prototype underwater was not possible due to time constraints. If more time was available, the water ejection system would be tested followed by the entire vessel underwater. The group was able to create an untethered submarine that used a custom SONAR communication system to traverse the water rather than the wiring necessary in a tethered submarine. Although the submarine was not designed to reach large maximum depths and range comparable to other submarines on the market, the prototype designed is well below the current market value of such submarines. With more research and time, future prototypes can include propellers to move about the water as well as a camera on board to display its location. Further design changes to the communication system can include a transmitter on the vessel to allow for the submarine to transmit its location.

References

1. “Aquabotix Endura 300 mini ROV for Deeper Water”. *BhPhotoVideo*. https://www.bhphotovideo.com/bnh/controller/home?A=details&O=&Q=&ap=y&c3api=1876%2C%7Bcreative%7D%2C%7Bkeyword%7D&gclid=Cj0KCQjwxdPNBRDmARIsAAw-TUntO47Exs5hYrpE8CTBmc3ULN5MtWFt83WI_vl3R86Dh8O21r9gK40aAovzEALw_wcB&is=REG&sku=1284364. Accessed 12 December 2017.
2. Gallagher, Kevin. “From Land to Sea: 5 Ways Drones Are Impacting Underwater Operations”. *Simulyze*, 8 December 2016. https://www.simulyze.com/blog/from-land-to-sea-5-ways-drones-are-impacting-underwater-operations
3. Pomerleau, Mark. “DOD plans to invest $600M in unmanned underwater vehicles”. *DefenseSystems*, 4 February 2016. https://defensesystems.com/articles/2016/02/04/dod-navy-uuv-investments.aspx
4. Brain, Marsall. Freudenrich, Craig. “How Submarines Work”. *Science.HowStuffWorks.* https://science.howstuffworks.com/transport/engines-equipment/submarine1.htm
5. “Learn”. *SubmarineSafaris*. http://www.submarinesafaris.com/kids_learn.php. Accessed 12 December 2017.
6. “Submarine Camcorder-Filming underwater with a mini-submarine and an iPad”.*UFUNK*, 18 February 2013. http://www.ufunk.net/en/gadgets/submarine-camcorder/
7. “ Diving Systems: R/C Sub School core curriculum”. *TheSubCommittee*. http://subcommittee.com/rcss-divingsystems.html.Accessed 12 December 2017.
8. “How Do I make a flying submarine?”. *Quora*. https://www.quora.com/How-do-I-make-a-flying-submarine. Accessed 12 December 2017.
9. “Parker O-Ring Handbook” https://www.parker.com/literature/ORD%205700%20Parker_O-Ring_Handbook.pdf