Mech 401-04
Mechanical Engineering Design

Unmanned Submarine Drone Midterm Report

Report Submitted to Dr. Saboori and Dr. Walker

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Group :Dream Team Submarine Machine
(nightmare) (Sub-adub-dub)

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Abstract

The aim of this project to create a design and 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 make 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.

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 well, 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 density 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.

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.

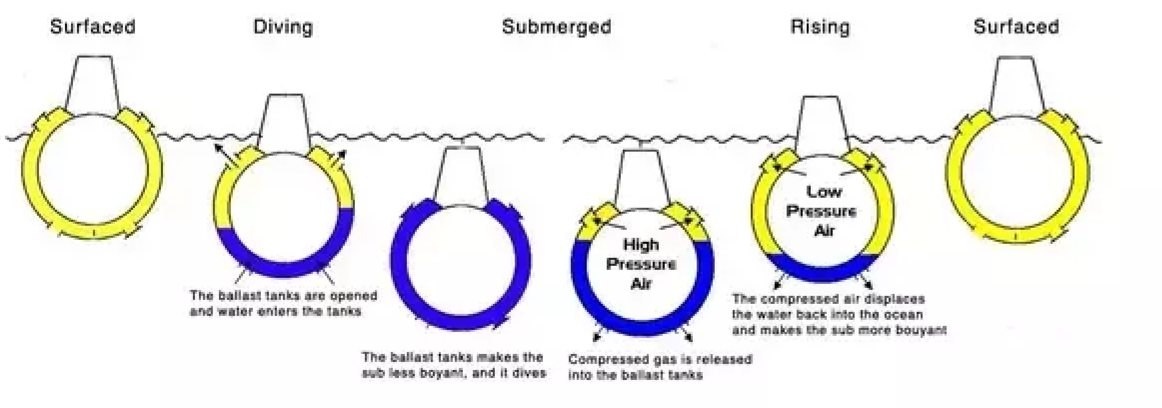

Figure 4: Static Diving Submarine

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.

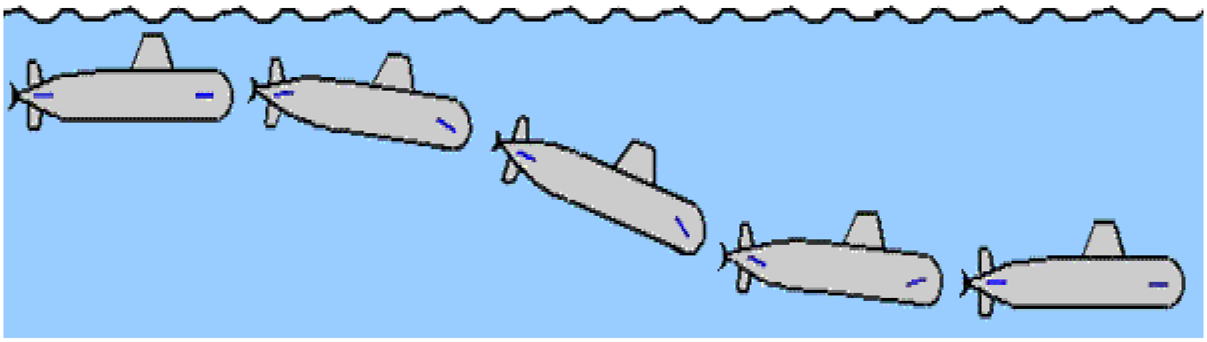

Figure 5: Dynamic Diving Submarine

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. 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. The Figure 6, below, displays a 3-dimensional model of the initial design.

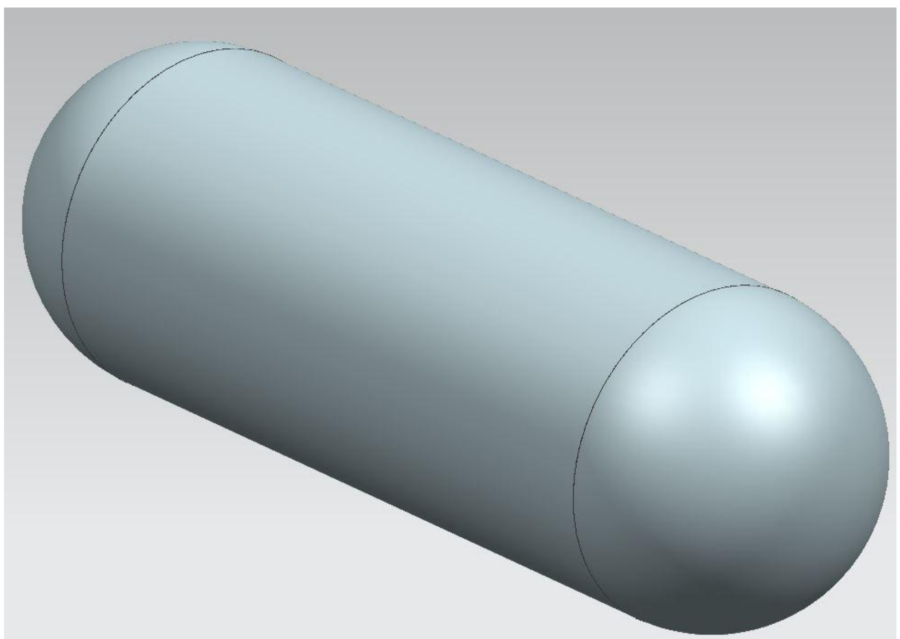

Figure 6: Initial design of submarine

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.

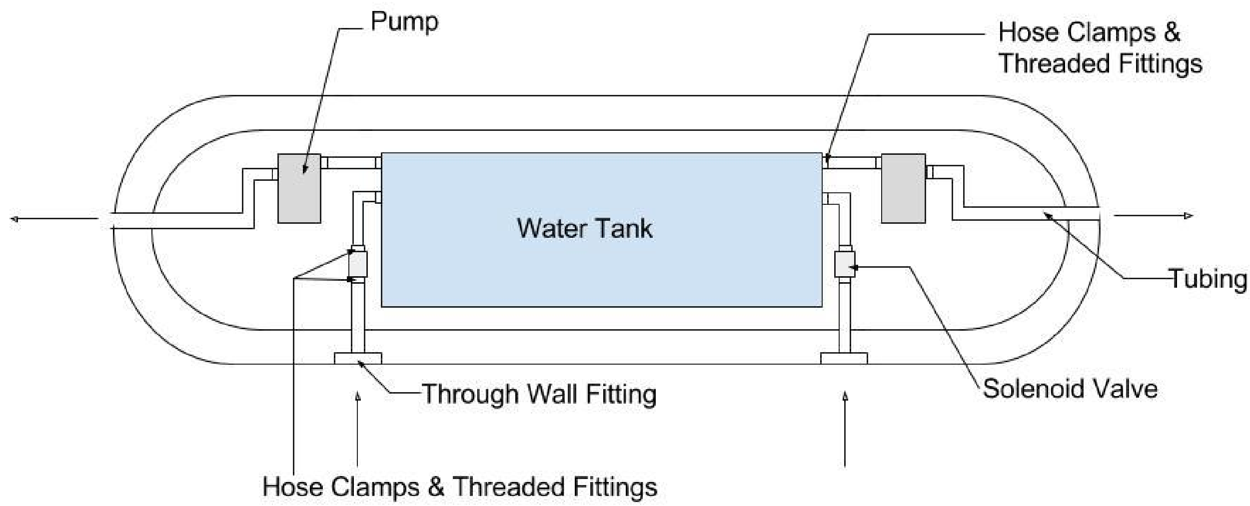

Figure 7: Schematic of Initial Water Ejection System

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 mee 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.

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.

Current 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. In addition, in order to ensure that unwanted water did not enter the system, causing damage 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 depth of 4.693 inches and a width of 0.103 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. 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.

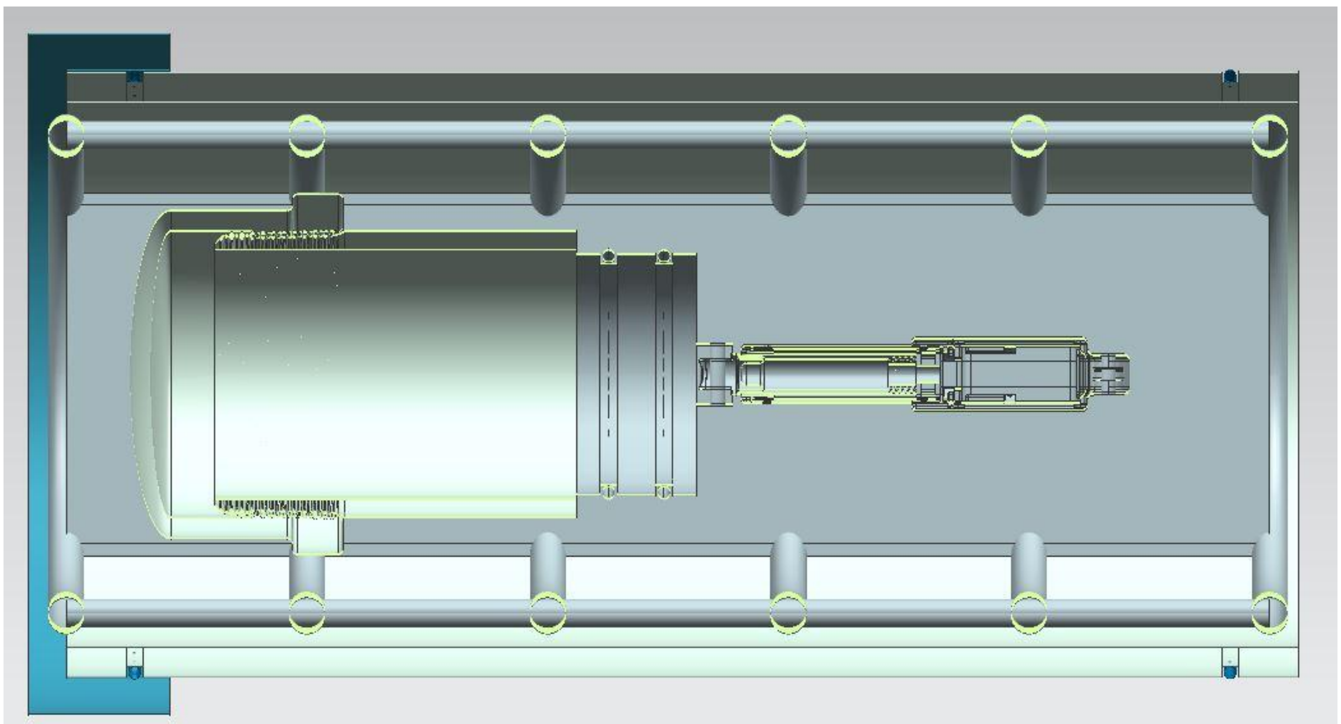

Figure 9: Schematic of Current Water Ejection System

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 in 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.

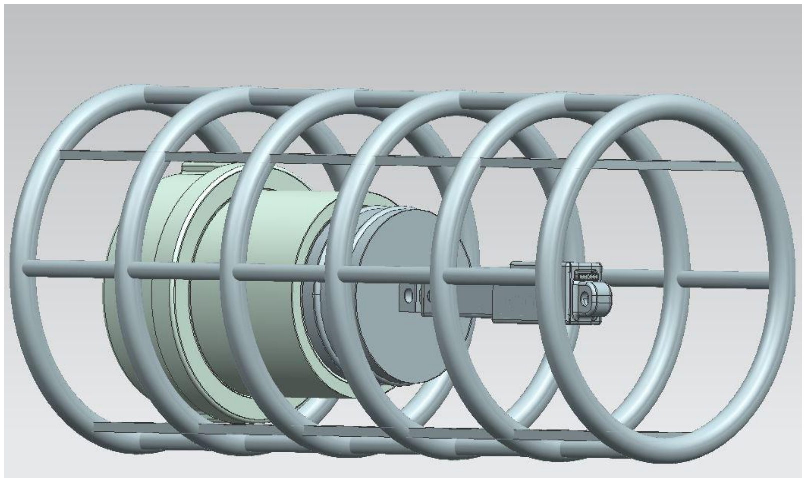

Figure 10: Equipment Frame with the Water Ejection System Inside

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.

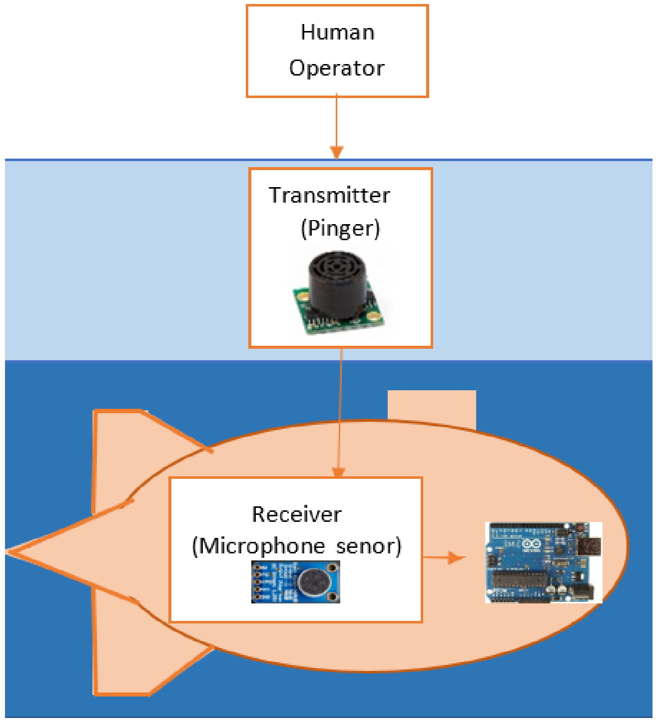

Figure 11: Communication system layout

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 current layout of the submarine drone's internal design can be seen in Figure 13.

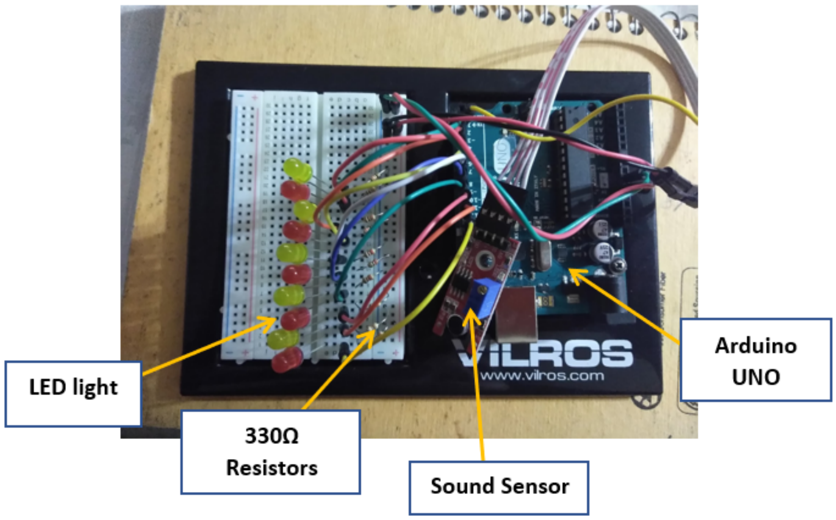

Figure 12: Sound input, light output test circuit

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

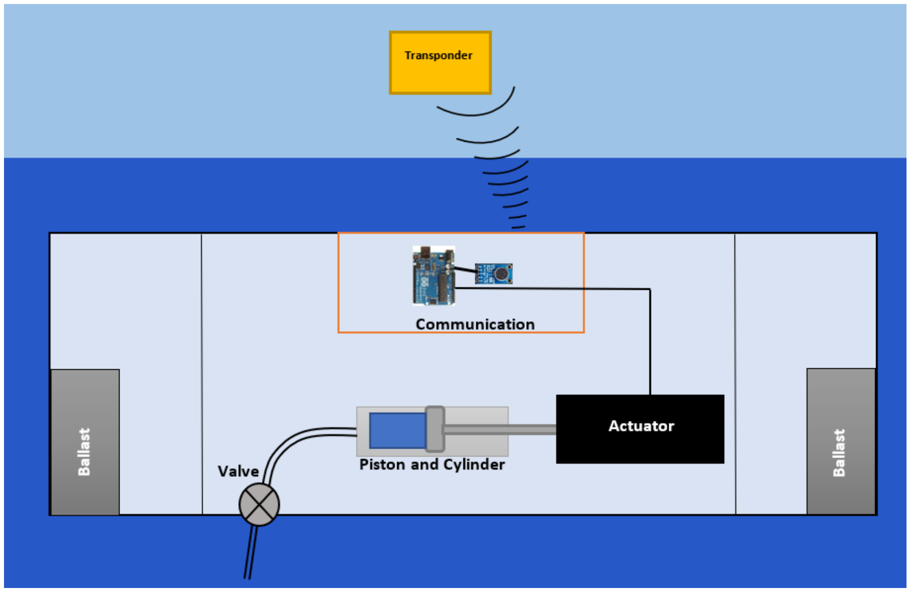

Figure 13: Current design layout

Parts List/ Cost Analysis

Throughout the design of the unmanned submarine drone, a list of the necessary parts as well as their prices were compiled in order to analyse the cost of the current design of the submarine. The current design of the submarine costs approximately $171 to build. This cost is expected to increase as we begin to build the submarine drone. These cost increases will be due to future design changes made as we begin to test the water ejection system as well as how the submarine as a whole fairs when tested underwater.

Other future costs that the group expects to accumulate pertain to the parts necessary to move the submarine while in the water. The submarine will require a propulsion system, the additional components necessary still need to be researched and decided on. These components will further increase the costs for the submarine.

Future Plans/Schedule

Task Week	1	2	3	4	5	6	7	8	9	10	11	12
Print Out Solid Models												
Purchase Tools and Parts												
Test Water Ejection System												
Assemble the Model												
Test Entire System Underwater												
Submarine Redesign												
Final Analysis												

Now that the solid models are completed, the next step is to 3-D print them. The intricate designs of the water system may prolong the print period of the solid models. Once the job is completed, the models must be prepared. Once the tools and parts are purchased and acquired, the team can begin to test the water rejection system, If the water flow system works accordingly, the system can then be assembled into the submarine model. The entire vessel can then be tested as underwater. More time is allowed in case redesign comes about. After any redesign for the water system, solid models, or both take place, a final analysis can be conducted.

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