PRAIRIE VIEW A&M UNIVESITY

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SENIOR DESIGN & PROFESSIONALISM

"DESIGN OF AN AUTONOMOUS UNDERWATER VEHICLE"

Submitted by

Vireak Long

Stephen Ivory

Victor Rocha

Jason Glass

David Gibson

On

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To

AUVSI COMMITY

Letter of Transmittal

RoboSub Senior Design Team
Prairie View, Texas 77446
June 10, 2014

To Whom It May Concern

The attached report contains the details of the "Autonomous Underwater Vehicle" project. For any questions, the team leaders can be contacted at vireaklong87@yahoo.com

Regards,
Senior Design

Vireak Long
Stephen Ivory
Victor Rocha
Jason Glass
David Gibson

ACKNOWLEDGEMENT

The members of the mechanical engineering RoboSub Senior Design team created this report. Members include Vireak Long, Karim Amaya, William Sorto, Prentiss McGary, Creed Henry, Chanston Morrison, and Victor Rocha. The electrical engineering team in charge of the electrical components include: Robert Gomez, Kevin Cole, Josh James, Melanie Young, Myesha Rice, Paige Jackson, T'Ron Gooch, Stephen Ivory, Jason Glass, and David Gibson.

ABSTRACT

An autonomous underwater vehicle (AUV) is designed to operate underwater without human input. AUV's are needed in order to carry out tasks where either a typical submarine cannot enter or allowed to be at. In this project an AUV is designed taking into consideration previous models from different schools as well as Prairie View's previous model. The main areas encountered for design are hydrodynamics, propulsion, optical and audio sensing, mechanical systems, power systems, and systems engineering. By following the design process starting with identifying the problem to finally testing and debugging, the AUV will be ready for competition during July 2014. Regardless of how much testing and debugging is done, there is always an understanding that things can go wrong and the team is ready to act with solutions at hand.

The project team aims to build a fully functional AUV that will be used in the ASVI competition in the summer of 2014. The AUV will be evaluated on its ability to complete various task in a simulated environment. Some of the task include going through an underwater gate, shooting an underwater target and being able to parallel park the AUV. The project team has done extensive research on current AUV models to ensure that the new design is completely optimized. During the literature review period, the project team focused on the following parameters. Frame design, Diving methods, Thruster selection and positioning, and waterproofing.

Once the literature review was completed, each member of the project team submitted a concept design that would be considered to be the final design. The key factors that were focused on for the concept design were the allowable degrees of freedom, size, weight, and design flexibility.

After extensive evaluation of the concept designs the project team finalized on a design. The current design consists of a railing system that will be used to modularize the AUV for easy assembly and adaptability. The use of 6 thrusters was used to ensure movement in 6 directions.

The project team ended the fall semester by ordering all necessary materials that are required to manufacture the AUV. Currently, the project team is working on manufacturing the frame of the AUV while also designing the electrical housing. Initially, the project team planned on using aluminum "1/16 thick to manufacture the fame in the university's manufacturing lab. However, due to the overall strength of the "1/16" aluminum sheet the project team had to use a overall thicker material to ensure that deflection in the frame would be minimized as much as possible. In addition, the complete manufacture process were done professionally in house.

BASE CONCEPT DESIGN

Three Dimensional Model of Concept Design

This section will provide the CAD drawings for the concept design. In addition, an explanation of the system and supporting information will be provided.

Presentation of AUV

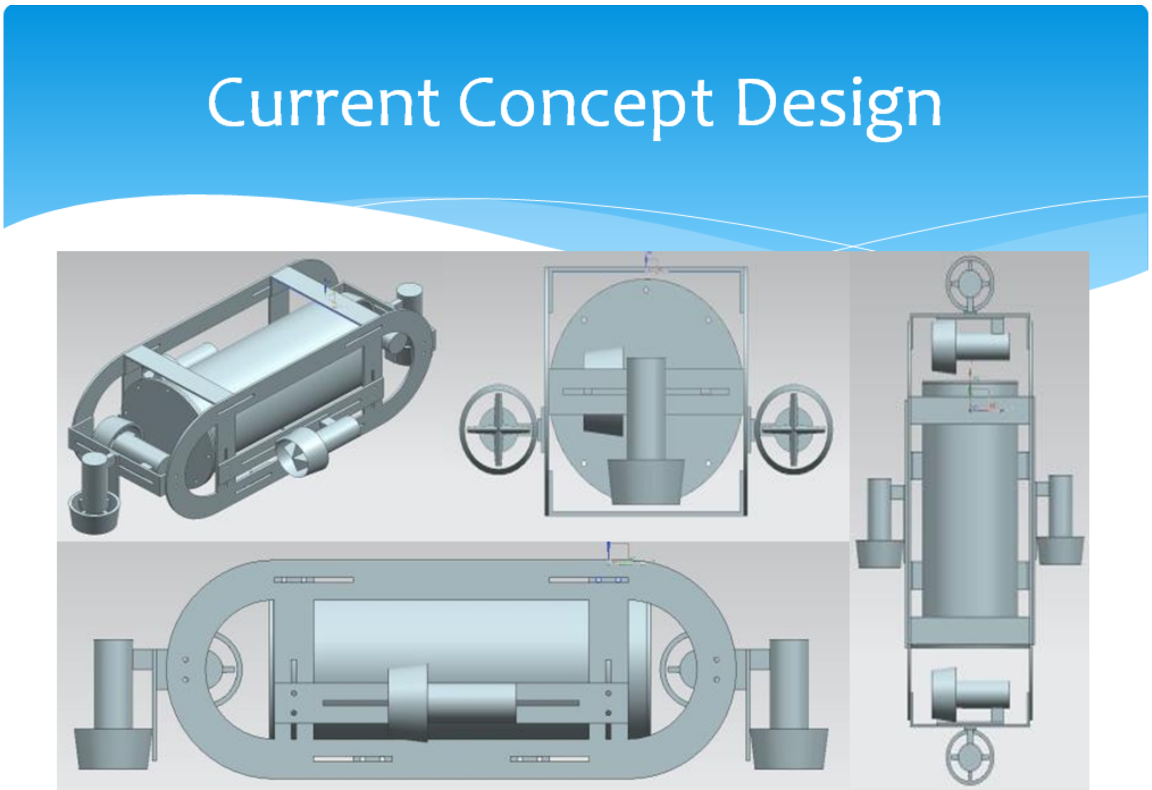

Figure 1: CAD drawing of AUV

The BCM in Figure 5.1 has all the major physical aspects learned about from other AUV designs. It has a thin cross sectional frame for easy movement in the forward and backward directions. It has 6 thrusters which will provide 5 degrees of freedom. This year’s model may not actually use 6 thrusters but the placement of them will allow for next year’s team to make further improvements and attempt more tasks underwater. The thruster mounts are created in a way to allow individual movement up, down, left and right according to its placement axis’. The small holes on the side frame and the thruster mounts will allow this free range movement if needed. This will come to great benefit if any buoyant or weight calculations are off and thruster placement needs to be altered to account for a different centers of mass and buoyancy. The housing element for all the electronic components in Figure 5.1 is a basic representation of the actual model. Section 5.2 will go into further detail about the electronics housing.

Electrical Housing

The electrical housing is very important when it comes to the design of the autonomous underwater vehicle (AUV). As the vehicle is submerged, all of the electronic units must be safeguarded from any types of fluids. The enclosed housing must be waterproof, aerodynamic, able to eliminate moisture, able to reduce heat produced by electrical units, and must have easy access to all the electrical units inside. This is a challenge that the Mechanical Team will have. The concept design that the project team will proceed with can be seen below in Figure 3.25.

The housing will be made from aluminum because of the higher thermal conductivity. 6061-T6 aluminum will be used. This aluminum also offers other advantages such as weight, durability, strength & stress, and high coefficient of heat transfer. Also, the manufacturing cost is relatively cheaper. Aluminum is lighter then steel, yet very solid for its weight, and has a high resistance to corrosion. The aluminum enclosure will work as a heat sink to reduce the operating temperature of all the electrical units, this will also cause the moisture content to reduce as the temperature reduces. The housing will be a cylindrical shell with a diameter of 8 inches and length of 19 inches. The inner housing will be separated into two parts, the upper part will be a removable tray design which will allow the engineer to remove the electrical components for routine maintenance, checkup, and modify or replace the units. The tray will rest on four welded on supports in order to restrict loose movement and provide stability. In addition to the weld supports, the upper tray unit will lock in place by the back of the housing and sealing plate. All the electrical units will be placed on to the upper tray with a thermal insulator in-between to prevent cross current. The lower plate will be welded on all sides to the housing in order to create the heat sink effect effectively creating two types of heat transfer convection and conduction. This is a more effective design since the batteries produce a large amount of heat during operation. This means the lower plate will be part of the housing. This non-removable plate is where the six batteries will be placed. The electrical housing will have a circular flat plate type enclosure that allow access to all electronic units, but this application can cause a leak, and the fluid may enter the housing and will lead to damaging all the electrical units. So the design of the flat plate will require a gasket to prevent any types of fluids to enter the housing. Figure 5.2 shows what the housing will look like.

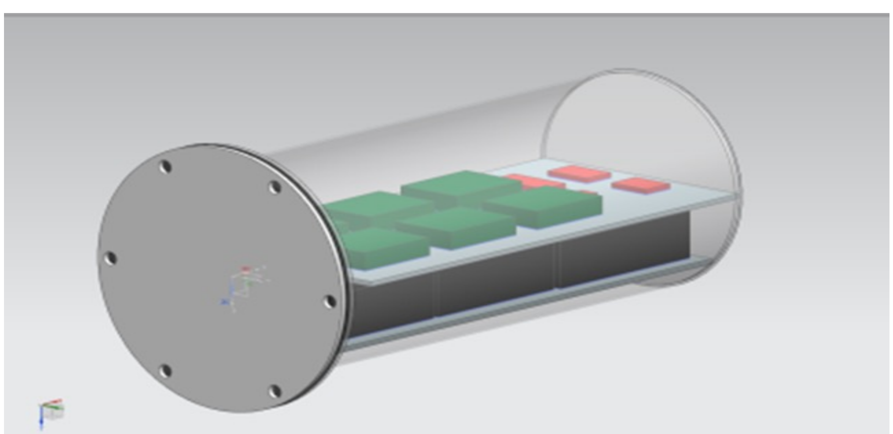

Figure 2: CAD drawing of Housing

Engineering Analysis and Calculations

This section will present all of the analysis that the project team has completed for the AUV. Analysis will include things such as hand calculations and engineering software analysis. The engineering analysis is very important because it provides the team with the correct direction to continue on in the selection of materials and the manufacturing of the submarine.

Buoyancy Calculations

$$Buoyancy\ Force = F_B = \rho_{(H20)} * g * V$$

Where:

ρ is the density of water (assuming water temperature at 70 F)
g is the gravitational acceleration 32.2 (ft/sec^2)
V is the volume of the displaced liquid (water in this case)

The volume of the housing is determined from the volume equation of a cylinder.

$$V\ cylinder = \pi * r^{\wedge 2} * L_{\text{housing}}$$

The housing has a length of 19 in, diameter of 8 in, and wall thickness of 3/16 in.
The volume of the frame, V frame, was generated using NX7.5 Modeling software. The calculated buoyancy force is:

$$F_B = 55.03 lbf$$

Weight Force Calculations

$$Available\ Weight = F_B * 99\% = 54.48\ lbf$$

The total weight of the AUV can be a maximum of 36.9lbf to achieve the desired 1% positive buoyancy. This value is very important and from here the next step is to calculate the location of the center of mass for the BCD. This is needed to determine the proper position of each thruster in order to have proper balance in all directions.

Drag Force Calculations

$$Drag\ Force = F_D = C_{Drag} * \rho_{(H20)} * V^{\wedge 2} * (A/2)$$

$$F_D = .250\ lbf$$

Where:

C_{Drag} is the drag coefficient
V is the velocity of the AUV
A is the surface area of the AUV

ANSYS Analysis of Frame

The stress analysis on the frame was done as an approximation. An exact analysis is not needed because from Figure 1, the maximum stress occurring on the frame is about 170 psi. The yield strength for 6061- T6 aluminum is 40000 psi. Therefore the approximate factor of safety is 235. The stress analysis was only done on a single side of the frame. Once the AUV is moving at constant maximum velocity, a steady state frame of reference is reached. The AUV will not be moving or accelerating relative to it, the force from the thrusters will still be acting therefore creating stresses within the frame. The principle is the same as a cantilever beam with a force at the edge, the beam is static (steady state) relative to itself and wall, while the force creates stresses within the beam. There are 4 rectangles at the top of the Figure 3 and 4 located at the bottom.

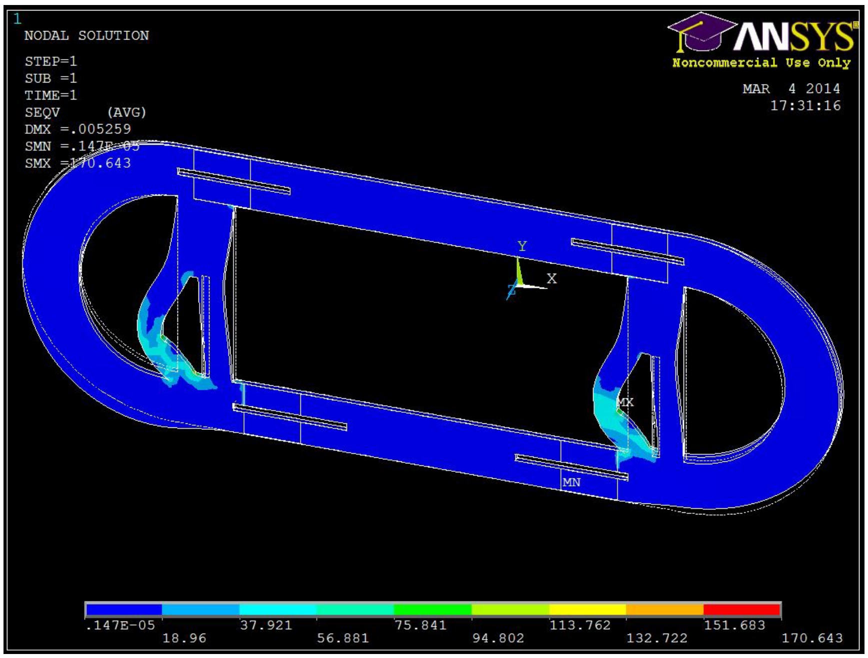

Figure 3: Initial Stress Analysis on Frame

These are the locations where the housing mounts will be placed then connected to the other side frame. At these 8 locations a displacement constraint of 0 was placed to simulate the housing mounts holding on to the frame. The application of the force by the thrusters is placed on 2 small areas located by where Figure 1 marks "MX" and the other on the other vertical column, which is displaced. The locations where the displacement is visually large are the 2 pressure areas. The size of the area is determines by the cross sectional area of the bolt which comes in contact with the frame. Each thruster parts out about 64 psi acting on each location. This is not the exact way in which the load of the thrusters acts on the frame, however this is a good approximation considering the maximum stress is 170 psi. Figure 4 is the displacement vector sum of the side frame. Visually Figure 4 depicts a large displacement at the two locations where the force was placed.

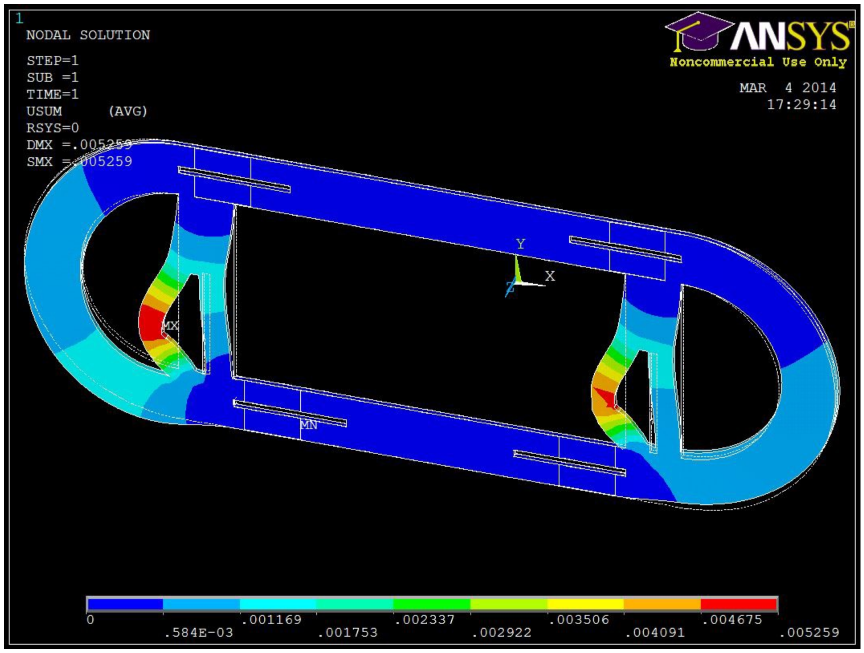

Figure 4: Stress Analysis of Frame

The maximum defection according to Figure 4 is 0.005 in. This is a very small deflection, which leads to the conclusion that thinner aluminum could have been used for this current AUV design. A thicker frame however will allow for future AUV teams to place additional mechanisms without the hassle of strengthening the frame. For this AUV, some parts will be welded meaning the thinner the metal the more it will warp during the process, therefore the thicker aluminum will resist the wrap.

ELECTRICAL TEAM

With this being the second year that PVAMU will participate in the 17th annual RoboSub competition, we received working design. Last year’s team was able to design and construct a working model of the Autonomous Underwater Vehicle that is supposed to be used for the competition; however, the AUV did not make it out of the qualifying round. The main focus for this year’s team is to improve on the current AUV through electrical components and software.

After meeting with our technical mentor, Michael Kappus, we were able to find the areas that needed improvement. We found that there was an issue in navigation and the thrusters that were being used for the AUV. Through research and brainstorming, this year’s team decided to add more sensors that would assist with the navigation of the vehicle, as well as cameras, and purchase more reliable thrusters that can be used for the vehicle.

One of our main goals this year is to improve on last year’s model. We will accomplish this by designing the AUV to get through the gate, and then completing the following tasks after that.

Brainstorming/Problem Formulation

The equations formulated so far in this project are the power equations. We have calculated the total power of the components. The reasons we have made these calculations were to make sure our batteries had enough watts to power the Autonomous Underwater Vehicle. Previous to ordering all of the electrical components, we needed to make sure that the components ordered had the correct specs such as voltage and current. Once the calculations were completely, we understood that the total power of the AUV matched the power that the batteries were going to supply to the AUV. The mechanical engineering team needed the total power to utilize an equation that would determine how long the AUV would stay powered in the field at a specific velocity. For the pressure sensor, the voltage recorded was 3.6 volts and $1*10^{-6}$ amps. By multiplying both of these numbers together, we achieved a power at $4*10^{-6}$ watts. The minimum and maximum power for the IMU is $1.8*10^{-5}$ and $8*10^{-50}$ watts respectively. If we had a total of 6 thrusters running at 80 watts, the power would be 480 watts. If we had 4 thrusters running simultaneously, the power would be 320 watts. The power control voltage has a minimum of 5 volts along with 40 amps. This would make the minimum power $2*10^{-2}$ watts. The power control maximum voltage is 16 volts. Power is essential for how efficient our AUV will function. Without knowing the total power, we would not be able to determine significant variables that would determine how efficient our AUV will function.

MCU		Pressure Sensor		IMU
V~4.5[v] – 9[v]		V~3.6[v]		V~3.5[v]- 16[v]
A~ 300[ma]	+	A~ 1x10^-6[A]	+	Standby current
Pt ~ 1.5[v]		P~ 4.0x10^-6[w]		Pmin~1.8x10^-5
				Pmax~ 8x10^-5[w]

Thrusters	Power Control	Total Power

6(thrusters) x 80[w] =480[w] V~5-16[v]

4(thrusters) x 80[w] =320[w] + A~ 40[ma] = **Pt 481.3[w]**

2(thrusters) x 80[w] =160[w] P1~ 6.4x10^-2[w]

P2~ 2x10^-2[w]

Figure 5: Power Calculations

There are many parameters to consider when dealing with any type of submerged vehicle. The first thing that comes to mind is how the AUV will move through the water. Of course, it will need some type of propulsion. As we did research on this competition, we found that most teams use underwater thrusters to move their AUV through the water. We chose SeaBotix as out thruster provider because not only are they the best choice for this competition, SeaBotix will have representatives at the competition to assist us if we have any problems. We'll need something too power these thrusters so we'll need a power source such as batteries or a power core. To ensure that these batteries aren't drained to fast by the thrusters, we need to introduce a power sensor to give the correct amount of power to each thruster. This should allow us to get the maximum life out of our batteries. Now that we have a means of propulsion, we'll need something to measure our movements and depth in water. This is where the IMU (Inertia Measurement Unit) and the pressure sensor come into play. The pressure sensor will read the depth of the AUV to ensure that it is completely submerged when it passes through the gate. The IMU will measure the pitch (x-axis), roll (y-axis), and yaw (z-axis). The IMU will make sure the AUV stays straight and upright will moving through the water. Last but not least, we will need a central processing unit to communicated and regulate all these devices. A microcontroller will be a good choice because it has its own memory, processor, and input/output ports to interface peripheral devices like we presented.

Electrical Design

Below is our electrical design for the AUV.

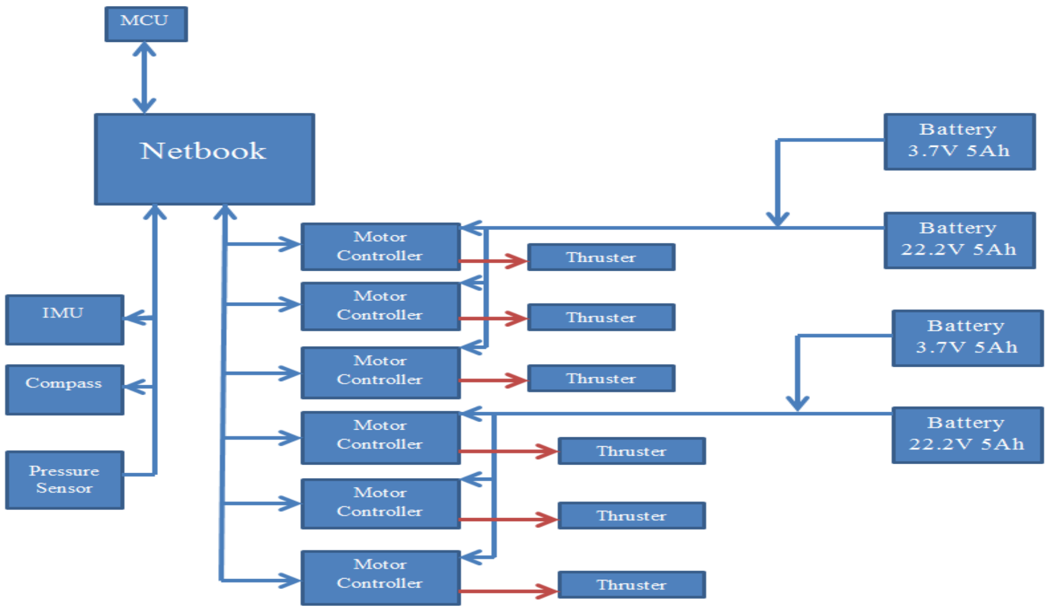

Figure 6: Final Design

In this diagram, the microcontroller (MCU) will be used as the brain of the vehicle. Every component, except for the thrusters, will communicate with the MCU. The inertial measurement unit (IMU) is a sensor that is used to detect the position of the vehicle. The IMU will be constantly communicating with the MCU in order to help determine the position and orientation of the vehicle. The pressure sensor will be constantly communicating with the MCU as well. This sensor will be used to determine both the current pressure and temperature that the vehicle is experiencing. The power control will be an interface between the MCU and thrusters. The purpose behind having power control is to be able to control the power that is delivered to the thrusters. This will assist with the balancing of the load. The thrusters will be communicating with the power control, which receives and sends commands to the MCU. The thrusters will be used to help move the vehicle in a set direction.

Implementing sensors/controllers

As stated about, there are several different components that ultimately make the AUV navigate autonomously in a body of water. We have chosen our components to be an Inertial Measurement Unit known as an IMU, a digital Pressure Sensor, a microcontroller/motor controllers and a set of thrusters. For testing and debugging purposes, there is code implemented that will allow for the real-time values of the sensors to be displayed to a computer.

The sensor we chose to use for our simulation is the Pressure Sensor (BMP085). Its role in the operation of the AUV is a depth sensor. When the diver turns on the AUV, the downward thrusters come on and the Pressure Sensor's values are fed into an algorithm that translates the raw values of the sensor into actual metric depth units. Upon reaching the appropriate depth, the downward thruster will slow down and the forward thrusters will trigger. Throughout the entire course of the AUV, the depth of the AUV is constantly be read and processed with the pressure sensor.

The real-time output is achieved by utilizing a serial terminal communicator, modular Mbed code and one of the sensors. The terminal used is called "Tera Term" and is maintained by Japan's Tera Term Project software developers. After connecting the sensor to the main computer, the Tera Term application can then be launched. The serial port is then selected and lastly the baud rate is set to 9600 bps and 57600 bps.

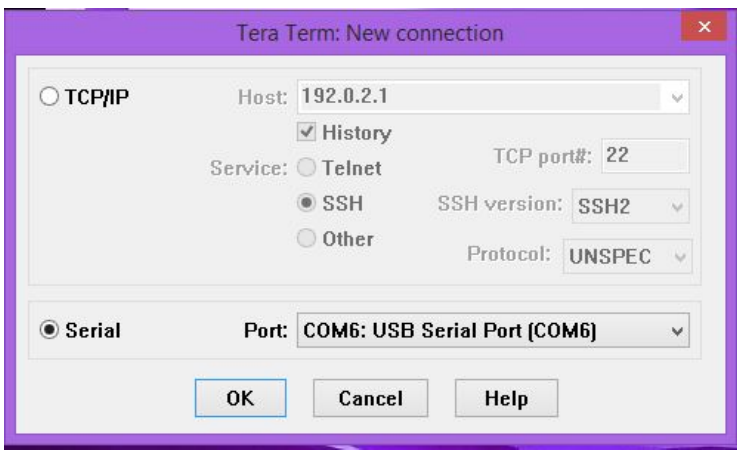

Figure 7: Tera Term used for Serial Communication

The simulation code is devised to read in the values of the sensors every second and output both the Temperature in Celsius and the Pressure in KPA to the screen. The output of the console is designed to be user-friendly and easy to read and interpret. This is achieved by using divider lines and proper linear spacing. As shown below, the values are output to the screen and then interpreted by the microcontroller.

Depending on the value that is read, the downward thruster will either increase or decrease in speed thus raising or lowering the entire AUV. For example, a kpa value of 100 may translate into an actual depth of 2 feet. However, if the desired depth is 3 feet, the downward thruster will continue at that particular speed or faster until the pressure sensor reads a depth of 150, which would correspond be translated to a 3 feet depth by the microcontroller.

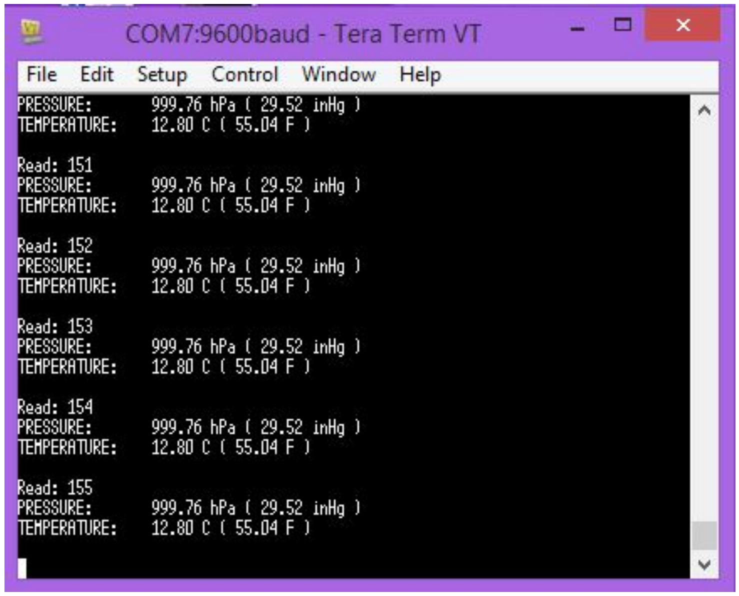

Figure 8: Simulation of Pressure Sensor

Positive Advantages of our design:

- Internal components are exposed; therefore we have easy access if any changes need to be done.
- More cost efficient
- Less preparation in frame design

Negative Advantages of our design:

- Components need to be water-proofed
- Lack in hydrodynamics
- Electromagnetic interference

Solution

Our decision to go with an open frame is impactful as it allows the team to expand on last year's design. The competition is not that of speed or high hydrodynamics, and because of that we went with an open frame as it allows us to focus more on the electrical components in our AUV, allowing for better precision and analytics when compared to last year. The option to troubleshoot without difficulty allows the team to think on their feet in a more efficient basis in case we need to change anything during critical moments of the competition. This design also allows us to save some money, though some of that will go into coding all of the electrical components; we still save a reasonable amount.