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DEVELOPMENT OF MODULAR AUTONOMOUS ROBOT PLATFORM FOR UNDERWATER APPLICATIONS

AROCKIA SELVAKUMAR AROCKIA DOSS*, V. DHANUSH ABHIJIT and L. PAVAN KALYAN
School of Mechanical Engineering, Vellore Institute of Technology,
Chennai, Tamil Nadu, India
*E-mail: *arockia.selvakumar@vit.ac.in*

Abstract- Autonomous underwater vehicle (AUV) requires autonomous guidance and control systems to perform underwater tasks. The navigation and guidance system of the AUV is still undergoing research to adapt to various conditions in the underwater tasks in oceans. Due to high cost of equipment, AUVs are not widely used for water sources like rivers, lakes etc. The present research involves developing a low cost modular AUV platform for underwater navigation in low depth water sources. The AUV body was designed and developed using standard PVC components as they are easily available and to keep the cost to a bare minimum. The submerging and resurfacing of AUV is based on a ballast tank. The drag force is calculated using ANSYS Fluent for different velocities for validation of the design. The control system is designed and developed for different trajectories. Further, the performance of AUV is found to be satisfactory under known environment.

Keywords: Autonomous guidance, low cost, propulsive force, modular, ballast system, drag force

1. Introduction

Underwater vehicles are important for underwater exploration and they allow humans to explore the depths of the ocean. The maximum depth a professional scuba diver can dive is about 40m. So for reaching greater depths, an underwater vehicle which can sustain the extreme surrounding conditions of ocean is required. This requirement increased the human interest in the research for underwater vehicles.

Most unmanned underwater vehicle are bound and remote controlled. They are called Remotely Operated Vehicles (ROV) [1]. Most of them are equipped with manipulators and can be used for specific underwater purposes. But the operation cost is high and it is difficult to operate remotely in extreme underwater conditions. Since ROVs remain attached to the host vehicle, the communication between the host and the ROV is easy as well as the power required by ROV is supplied by the host vehicle, but at the cost of limited speed and mobility. Hence the extensive uses of ROVs are restricted. This increased the demand for advanced underwater technology and the solution to this problem is a self-contained and decision making underwater vehicle [2]. This vehicle when dropped into the water fulfills its task and return to the initial position [3]. These unmanned and self-propelled vehicles which can operate independently for a period of time are called the Autonomous Underwater vehicle [4].

The AUV development began in the 1960s at the University of Washington and by early 1990s; the research has made large leaps. AUVs can move through low depth areas enabling them gather data with better resolution [5]. AUVs are becoming increasingly popular in scientific [6] as well as military applications.

But due to the high cost of design and development of an AUV, the AUVs are used whenever higher resolution of data is required. Once designed, the maintenance and modification of an AUV is not easy, due to various factors. Most of the navigation systems working on surface, tend to fail underwater. Various researches has been conducted and this issue was cleared by using various new technologies like GPS [7].

In this research, it was found that the most of the low cost AUVs developed utilizes vertical thrusters [8] for submerging underwater. This is done to reduce the size of the vehicle there by reducing the drag force. But the power required for vertical thrusters depends on the buoyancy of the vehicle and the depth of operation [9] is limited. It was also found that the most common method turning of AUV is by controlling the fins, with which controlling the turning of AUV is much difficult as continuous usage of propulsion system is required. This reduces the agility of the vehicle.

In this paper, the development of AUV is classified under different sections. The second section consists of the hull designed to incorporate the ballast chamber and to keep the drag force to a minimum. The third section explains the ballast chamber and factors regarding its design. The fourth section comprises of drag force estimation of the AUV under various velocities. The fifth section is about the working of propulsion system and the sixth is the open loop control system of the AUV.

2. Hull Design

The hull of the AUV consists of ballast system, propulsion system, navigation system, power source etc. The hull should be designed to hold all these systems [10].

The shape of the hull is chosen to be cylindrical so as to reduce the drag forces. To keep the cost to a minimum, PVC pipes were chosen, since they are easily available. Figure 1 shows the hull of the design proposed in this work consisting of 4 pipes. One pipe is the ballast chamber, another is the ballast control chamber and rest of the two is for incorporating the control and navigation systems of the AUV.

The type of design chosen is of the modular nature. In case of further development of the vehicle, the components can be easily removed or replaced. The sealing and unsealing of PVC pipes are easy because of their smooth surface. This helps in changing the circuit or recharging the power source.

Table 1. Design Specifications

Specifications	Dimensions
Length	74
Breadth	33
Height	28

The dimensions of the AUV is mentioned in table 1. The PVC pipes are cut and attached for the development of the vehicle body. Since the ballast chamber is also PVC pipe, the stresses are to be calculated. Ultimate tensile strength of PVC pipe is 52 MPa.

The stresses acting on the cylinder was calculated and it was found that the hoop stress and longitudinal stress calculated are much lower than the ultimate tensile strength of the PVC pipe. So it is safe to use PVC for ballast tank.

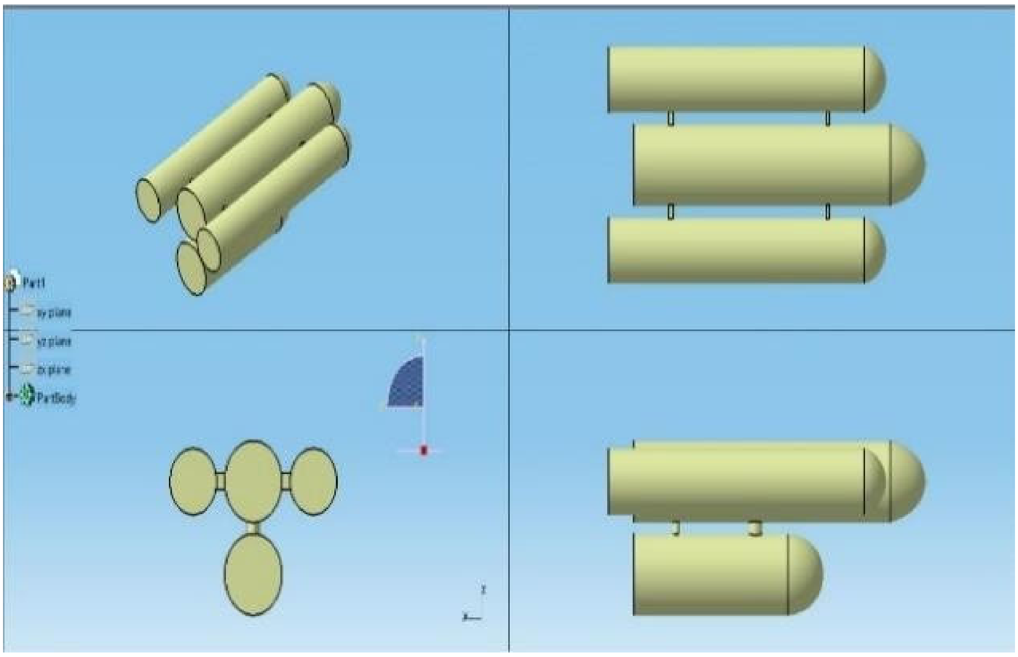

Figure 1. The Conceptual Hull of the AUV.

3. Hull Design

The ballast tank is responsible for the submerging and resurfacing of the robot. The mass of the vessel is set such that the AUV is just afloat. The volume of tank is related to the buoyancy and is determined by calculations below.

$$\text{Buoyancy}, = m \times g = \rho \times g \times V \quad (1)$$

For 0.5% buoyancy of the mass,

$$1.005 \times m \times g = \rho \times g \times V$$

$$1.005 \times m = \rho \times V$$

{As ρ = 1 g/cc for water}

$$V = 1005 \times m$$

For every 1 kg, 1005 cc of volume is needed for the ballast tank.

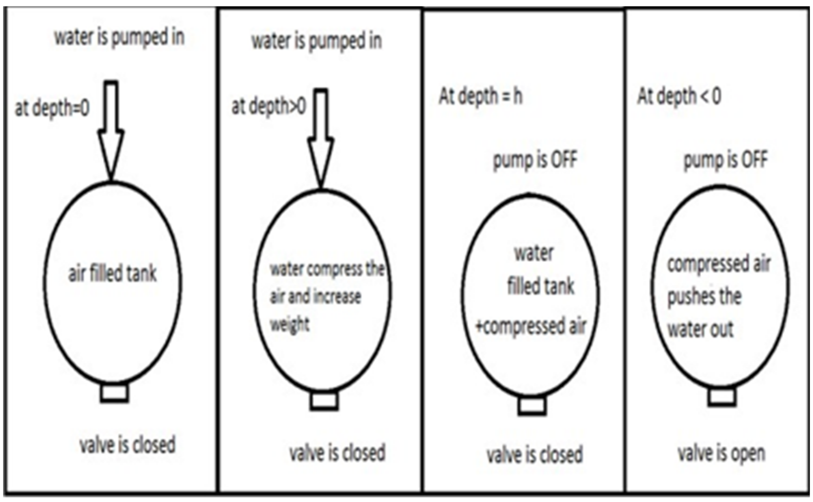

Figure 2. Working of Ballast Chamber.

The ballast system can be worked using a positive displacement pump and a solenoid valve, instead of using two positive displacement pumps. Figure 2 shows the steps in working of the ballast system.

The ballast chamber should be designed such that the whole body should be naturally buoyant as well as it doesn't require large amount of water to submerge. Dead weights are required in this case as PVC pipes are used. The dead weights are used to vary natural buoyancy so that the space for other systems can be improved.

4. Drag Force Estimation

The drag force is the force produced during the movement of body through a viscous fluid. The drag force [11] is calculated by CFD analysis using ANSYS FLUENT. The velocity of water is chosen to be 1 m/s.

The hull is designed in CATIA and imported in ANSYS Workbench. As in Figure 3, an enclosure is drawn around the hull body for appropriate boundary conditions.

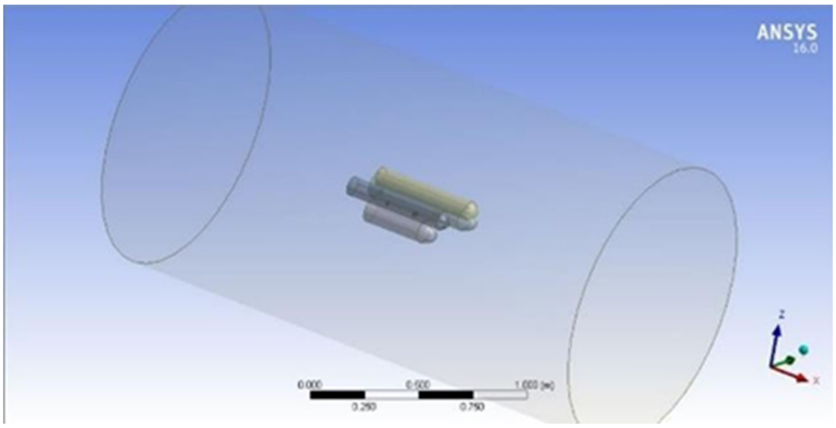

Figure 3. Flow Domain of AUV.

The hull is imported and an enclosure is made according to the size of the hull body to act as a medium of flow. The Boolean operation is used to subtract the enclosure with the AUV.

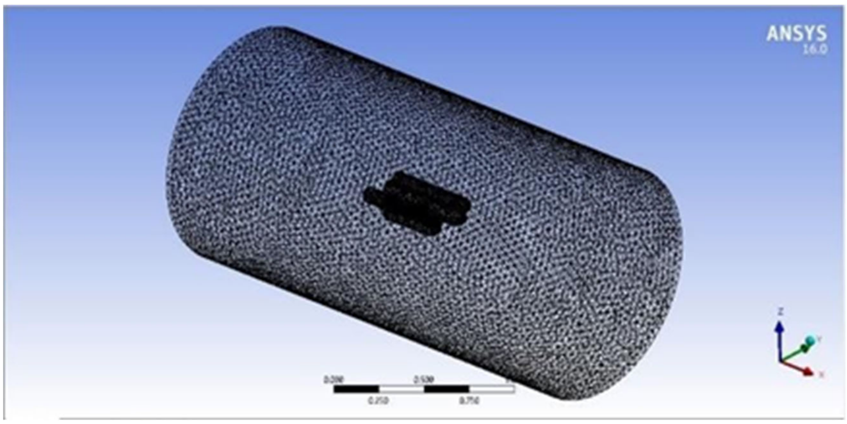

Figure 4. Generated Mesh of AUV.

Once the geometry is defined, it is necessary to divide the flow domain into finer elements for the purpose of analysis. By decomposing the flow domain to finer elements improve the accuracy of result. Automatic mesh generation in ANSYS FLUENT was used to create tetrahedral and hexahedral elements as shown in figure 4.

The simulation of flow of water is applied by using the k-epsilon turbulence model. This model is said to be robust and reliable for a numerous range of turbulent flows. Velocity component is applied at the inlet as the boundary condition.

5. Propulsion System

The propulsion system [7] of the AUV consist of twin DC motors which is also responsible for turning the AUV. The primary objective of DC motors is to act as Thrusters [12], [13].In order to determine the Torque required, the drag force is to be calculated.

For forward thrust, both motors start working simultaneously to rotate in the clockwise direction. To turn the AUV to one side, the rpm of motor on opposite side can be increased or the rpm of the motor on that side can be reduced. The AUV can be stopped by rotating the motor in counter clockwise direction.

The propulsion system does not depend upon the lift or angle of attack of the AUV, because the propulsion system is designed to move in X and Y direction alone.

6. Control System

The control system mainly consists of propulsion system and ballast system [14], [15]. An Arduino board is chosen as the controller because of the components compatible to the Arduino board are easy to obtain. The ballast control system is used to control the pump and valve using a 5V 2-channel relay as in figure 5.

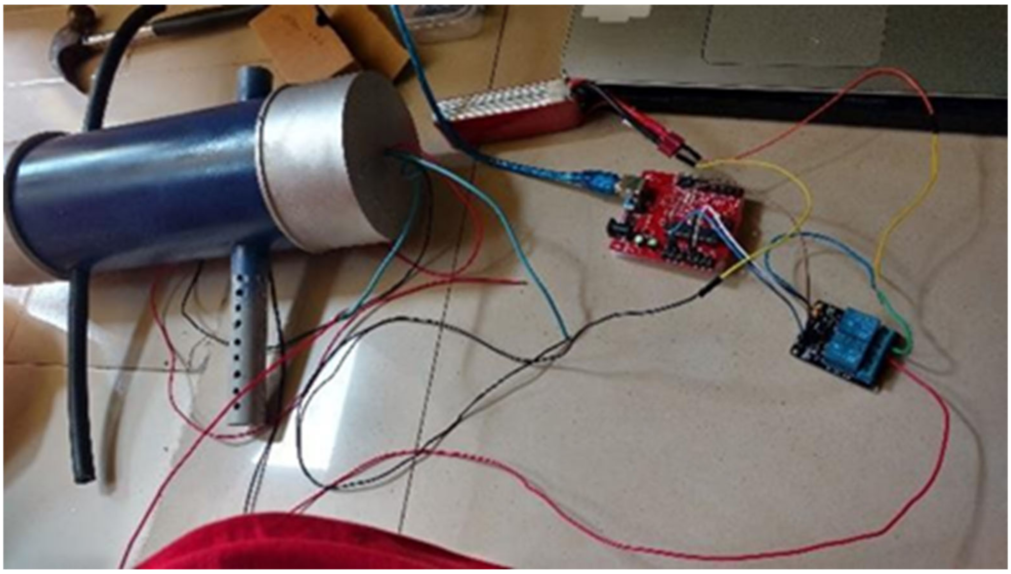

Figure 5. Ballast control using relay.

Initially the solenoid valve is closed and the pump is used to pump water into the tank, thus increasing air pressure inside the tank. The weight of the AUV increases resulting in submerging of the vehicle. A time required to fill the tank can be calculated and can be used to limit the pumping time.

The AUV on reaching a particular height stops the pump and initiate the propulsion system. On reaching its destination, it resurfaces.

To resurface the vessel, the solenoid valve is opened and the pressure inside the tank is higher compared to underwater pressure, up to a certain height. Hence the water from the tank is forced out and the vehicle resurfaces. The propulsion system is controlled using Arduino and L298 motor driver as in figure 6.

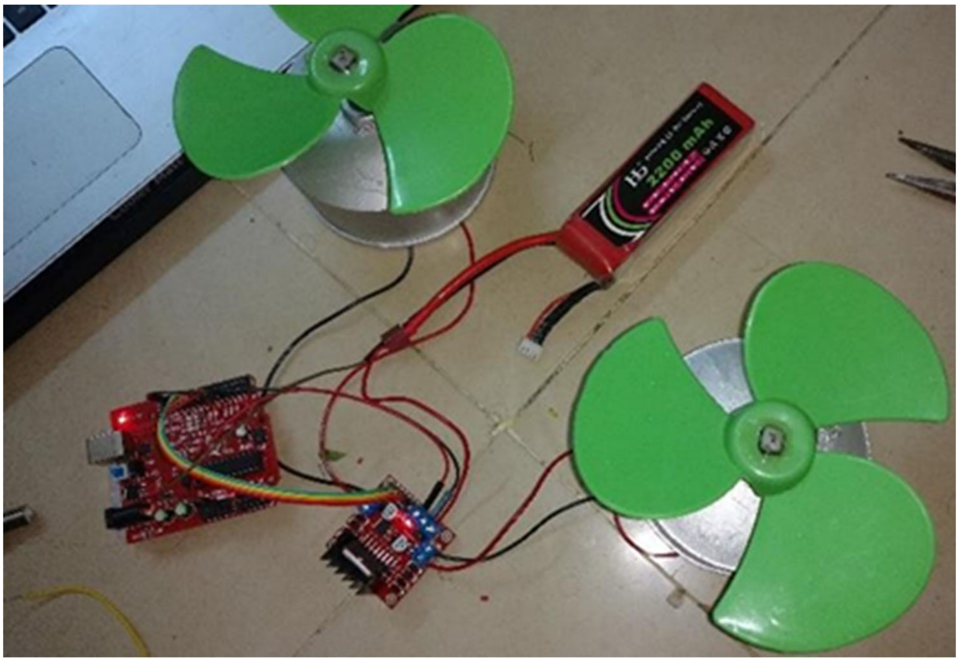

Figure 6. Motor control.

The power source used is a 12V Li-Po (Lithium polymer) battery because of its low weight and it can be recharged many times.

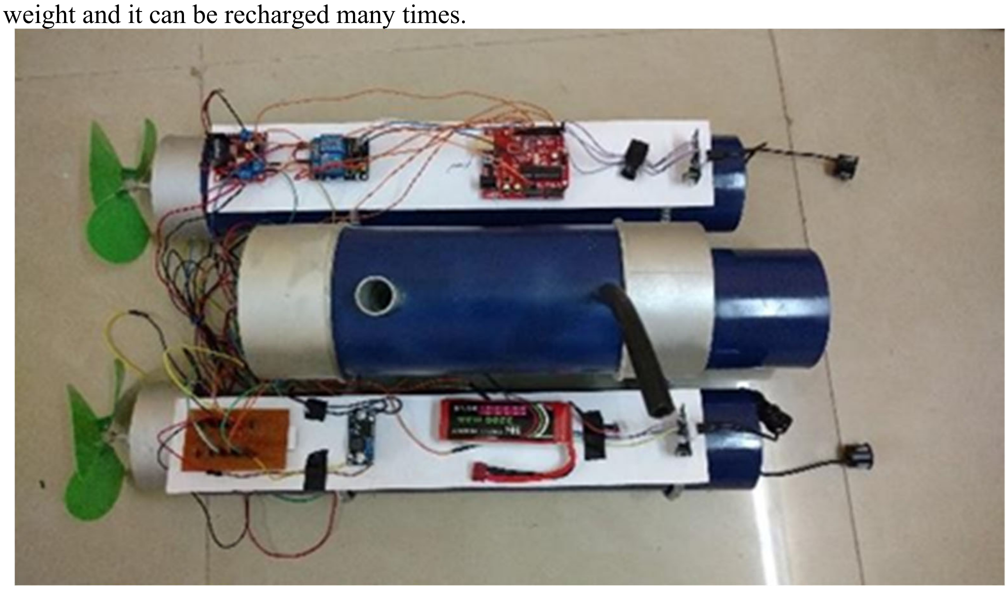

Figure 7. Control Setup for the AUV.

Figure 7 shows the complete control system connected on foam board in order to slide the circuit easily into the pipes.

7. Results and Discussion

The modular AUV body is designed for low depth water bodies. This design was done considering the cost of each component such that the total cost of the vehicle body remains low. The AUV body can incorporate the electronic systems for navigation as well as specific purposes. In case of major design change, only part of the body needs to be changed. The cost will still remain low.

The current electronic systems in the AUV can be easily replaced. Figure 8 to Figure 12 shows the pressure contours of AUV at different velocities of flowing water. Figure 13 shows the relation between flow velocity of water and the drag force created on AUV at different velocities. Drag force for various velocities were calculated with CFD. The torque of motor was calculated taking in the velocity to be 1 m/s. According to the CFD results, the propulsion system will work perfectly up to 1 m/s velocity of AUV.

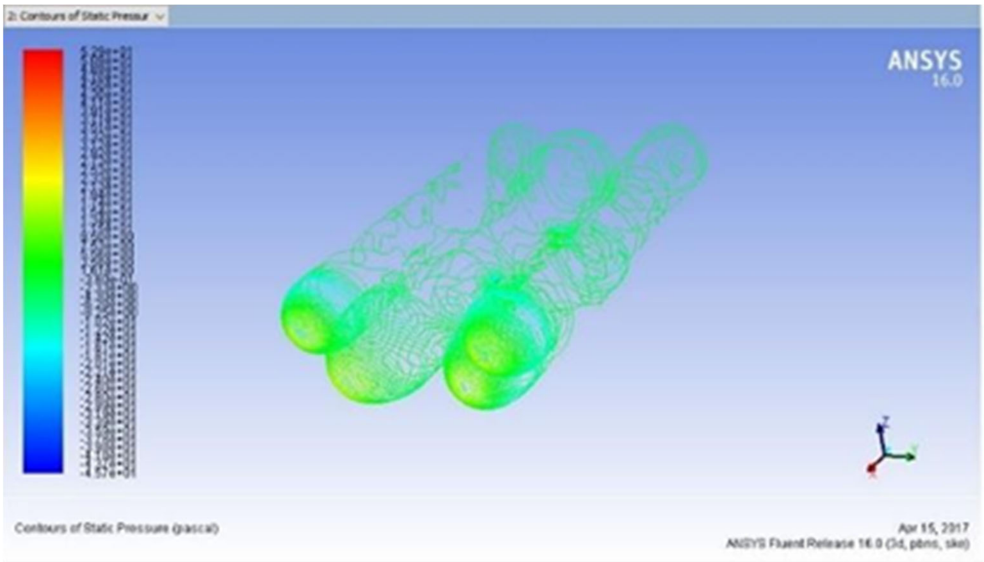

Figure 8. Pressure contour for 0.2m/s.

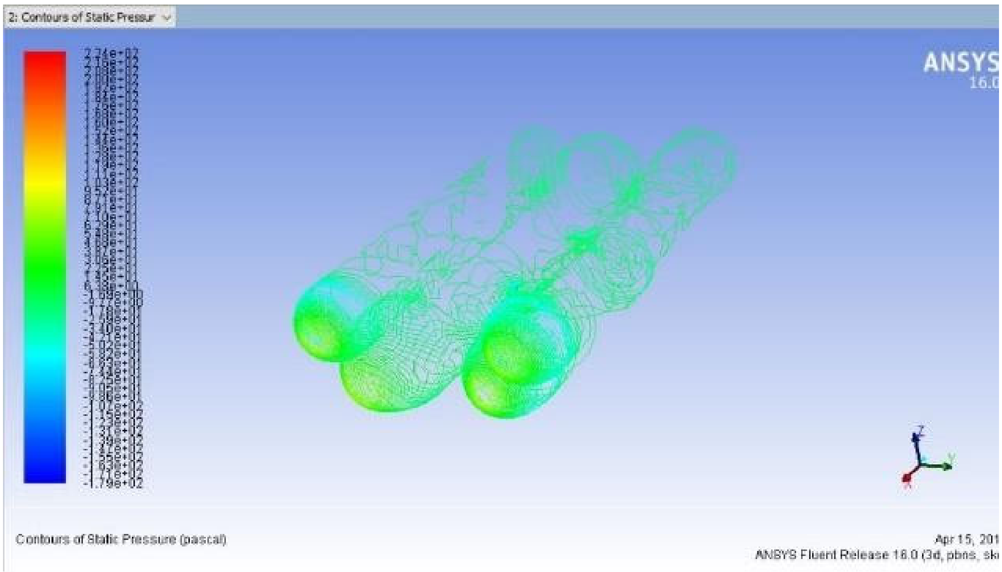

Figure 9. Pressure contour for 0.4m/s.

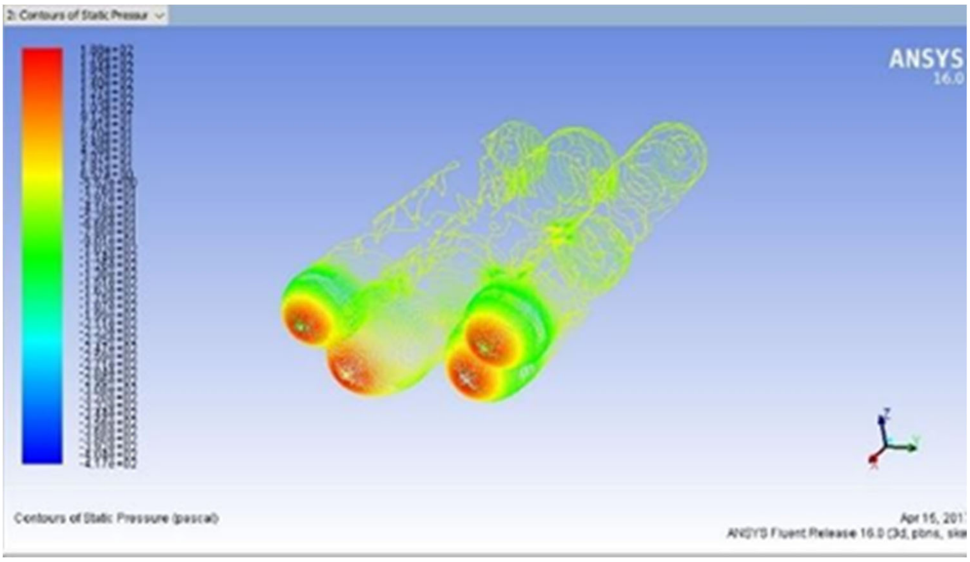

Figure 10. Pressure contour for 0.6m/s.

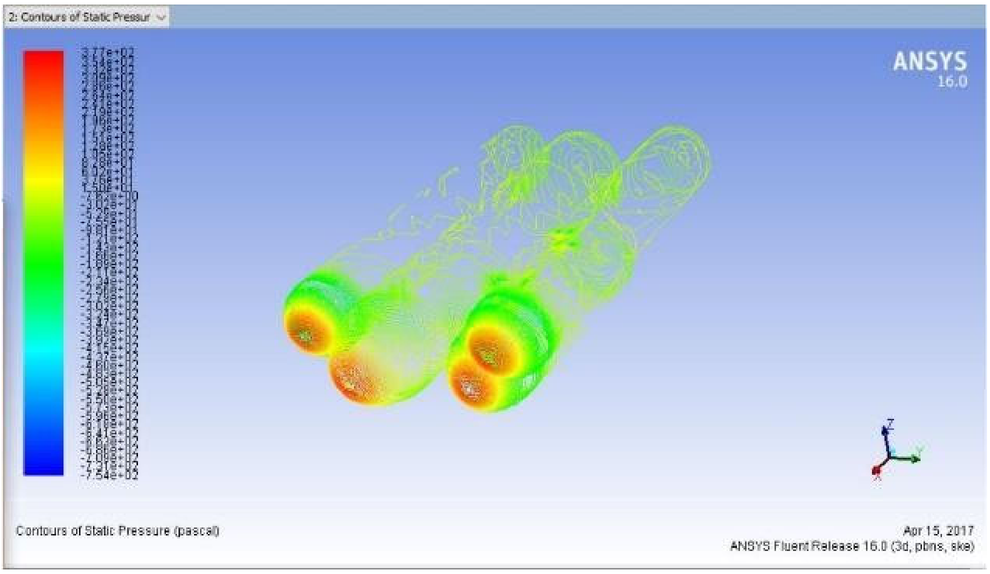

Figure 11. Pressure contour for 0.8m/s.

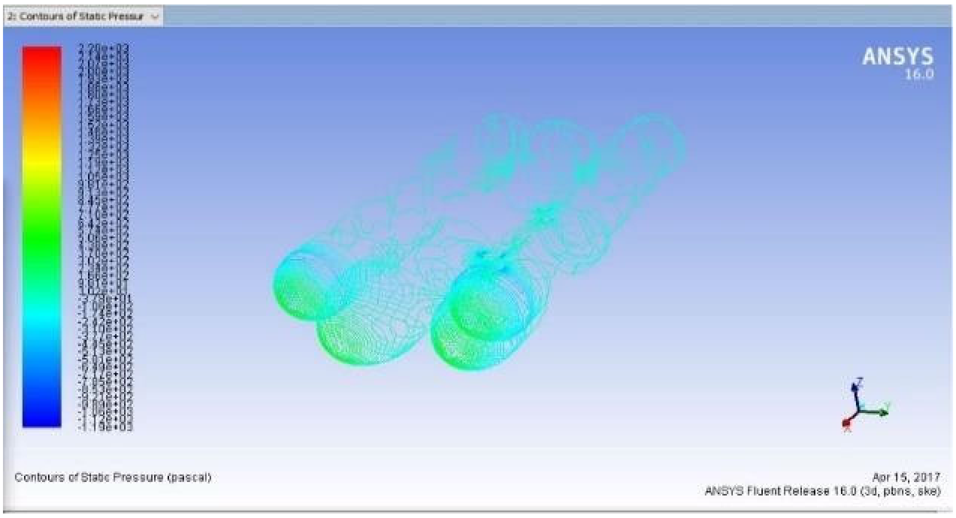

Figure 12. Pressure contour for 1.0m/s.

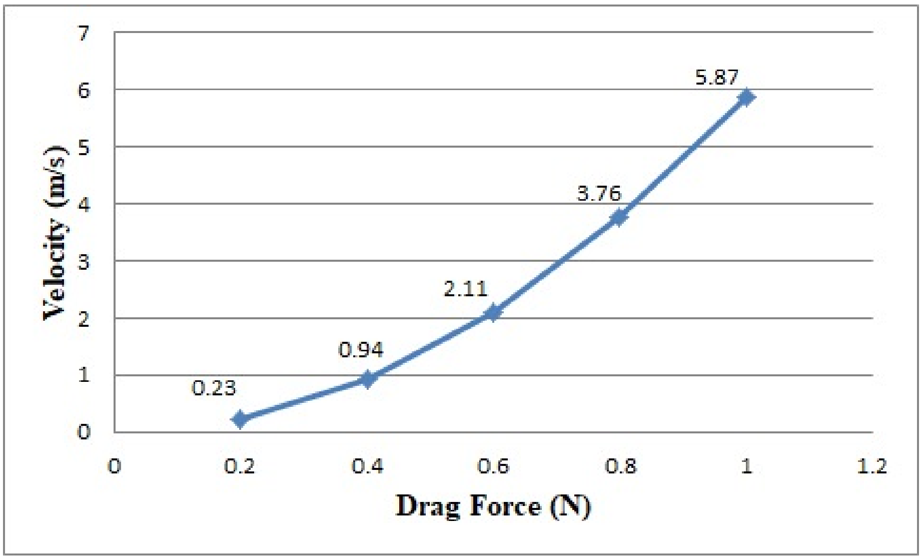

Figure 13. Velocity v/s Drag force.

The chambers were individually tested for leakage and buoyancy. The dead weight required for the AUV was found to be 4.2kg. The ballast chamber was tested and the pump showed satisfactory results in compressing air inside the chamber by pumping in water. The control systems were individually tested above water. They were connected together and tested above water. The control system seems to be working satisfactorily.

8. Summary

The low cost AUV platform for underwater application was designed and developed. The developed AUV is designed and developed to move in a linear path under the water, at a particular height. The depth is controlled by a timer to fill and empty the tank and there by submerging and resurfacing the vehicle.

The drag forces for different velocities were calculated. The torque of motor required for propulsion can be calculated for the required velocity of body from the drag force obtained.

From the graph it was evident that the drag force increases drastically with the increase in the velocity of flow of water.

The control system is found to be working satisfactorily in and out of water. In future, by incorporating a variable depth controller using a high resolution pressure transducer, the performance of the system can be improved. The control system is an open loop control system which can be converted to a closed loop by using an obstacle avoidance system and IMU sensor.

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