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Design of an Autonomous Submarine Model with Simplified Architechture

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Abstract—*Underwater vehicles like submarines have been a regular topic of research for decades. Primary focus has been on development of such vehicles in terms of enhanced security, simplified architectures and cost effective designs. The present work proposes a state of the art design of an autonomous underwater vehicle where innovative placement of ballast tanks allows achievement of roll and pitch movements as well as elevation control of the vehicle. This in turn results in reduction in the requirement of number of control surfaces. Analysis of all these movements in relation to the water flow rates in and out of the ballast tanks have also been studied and presented in the paper.*

1. INTRODUCTION

Submarines are topics for industrial and defence research for quite a long time. Starting from rescue operation and exploration of underwater world to missile carrying underwater vehicles, submarines have a wide range of applications. Till date, submarines, being bulky in design due to constructional difficulties, have limited commercial use. Many researchers[1][2][3] have started working on miniature designs of some state of art submarines beneficial for being used in smaller water bodies like rivers and lakes. The present idea is to develop a small submarine model to move inside a water channel available in the laboratory and to control its movement in a predetermined pathway by vision control techniques.

Real-time remote-control system for the submarine model movement is also required to be developed in order to control the motion of the same in a pre-determined pathway. In order to ensure minimum chance of damage of the model during real-time testing, a feed forward control system [4] is of utmost necessity that requires identification of various factors affecting the movement. With a corresponding simulation model development, both the simulation and the real-time model can be tested for motion generation under same input signal. The error between the real-time and the simulation motion tracking data is required to be minimized using suitable bio-inspired optimization algorithm[5], that in turn will allow to identify the near exact values of the affecting factors in case of the real model. The feed forward controller can be developed with the help of these values. In order to achieve automation however, the submarine model is required to follow a pre-demanded pathway in its motion. The end control of the same requires a remote control system that is proposed to be of a vision control type. A suitable DAQ comprising of a high-speed camera is proposed to be used for real-time motion tracking under water. This will ultimately make the total control a feed forward-feedback type, where correcting action will be developed by the controller in case any deviation from the predetermined pathway is observed by the vision control system.

These experimental observations and control analysis of different factors affecting the submarine model movement will lead to design opportunities of a real-life unmanned underwater vehicle. Such a vehicle will be most useful for defence purpose especially in case of carrying torpedoes as it will be totally autonomous thus requiring no man power, thereby nullifying any chance of casualties of human lives.

The present work comprises of designing a model of an autonomous submarine with new idea of eliminating some of the control surfaces, which have till date been considered mandatory to achieve the roll, pitch and yaw movements. Here two of those movements, roll and pitch are proposed to be achieved using innovative placement of ballast tanks. So this will eliminate the requirements of some control surfaces. The mathematical relationship between the water flow rate in and out of the ballast tanks with the roll and pitch movements of the vehicle are also in the scope of the present work. Along with the elevation control is also to be done by proper control of ballast tanks' flow rates. The formulation is also provided in the studies.

2. DESIGN IDEA

The submarine is designed to have a semi-circular front, a cylindrical body and a conical end. The dimensions are calculated after taking the electronics in consideration, as well as the keeping the strength of the body. There are four ballast tanks placed in the four bottom corners of the main cylindrical part of the submarine. These four ballast tanks store water to increase the density of the submarine and make it submerge. Innovative placement of the ballast tanks would reduce the number of control surfaces on the submarine.

The aim is to analyse the movement and predict the linear displacement, the velocity and the acceleration along the Z axis of the submarine. Certain assumptions were taken purely to simplify the governing equation, and a mathematical force equation was formulated to get the values of the properties.

The analysis of movement, or rather rotation along X and Y axis was also done to determine the angle of rotation, the angular velocity, and the angular acceleration. The mathematical equations thus formulated would be able to predict the movement of the pitch and roll of the submarine.

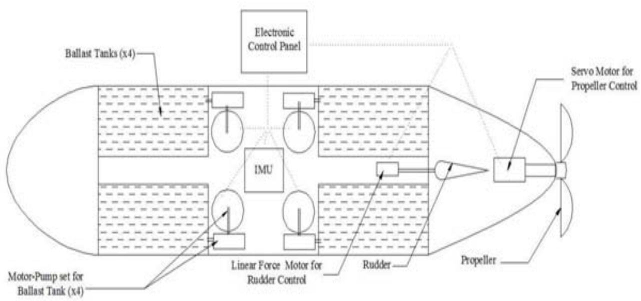

Fig. 1: Schematic diagram of the submarine model

3. MATHEMATICAL FORMULATION

For analysis of movement in Z-direction, it has been assumed that the volume flow rates for all four ballast tanks are constant. It is easily backed by the fact that the opening area for the ballast tanks are equal, and hence equal volume of water would enter at an equal time. Here, *t* has been taken as the time taken for ballast tanks to fill up completely. Also, the volume of each ballast tank is given by,

$$V(t)=Q\times t, \quad (1)$$

while *m* has been taken as the mass of the submarine with empty ballast tanks.

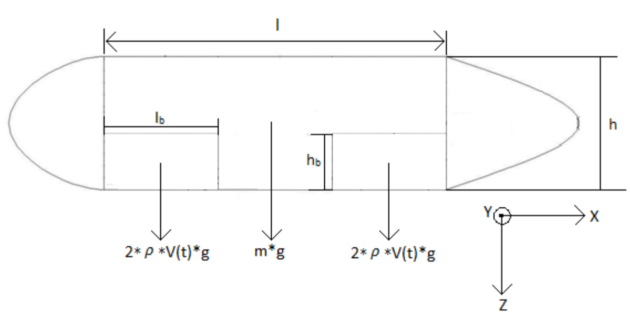

Fig. 2: Free body diagram (side view)

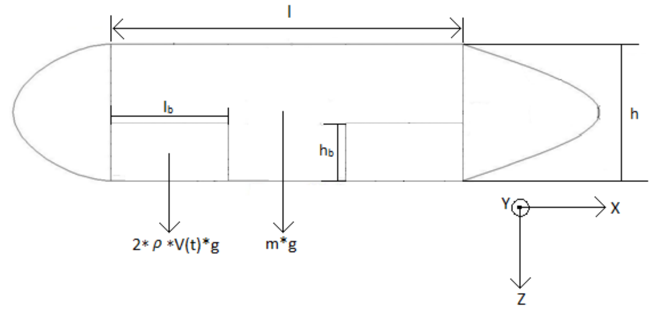

Fig. 3: Free body diagram (side view)

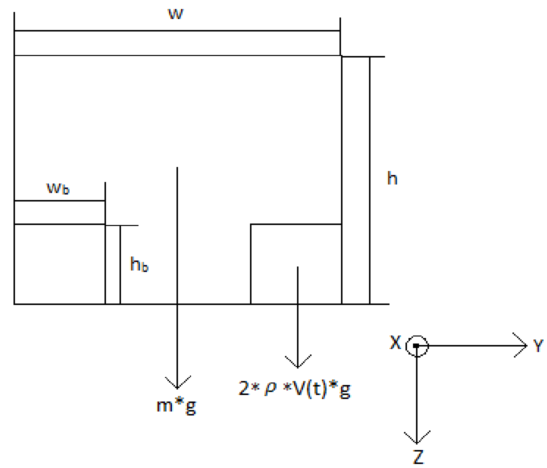

Fig. 4: Free body diagram (front view)

Applying Force equation (as shown in Fig 2), the weight of water in ballast tank is added with the weight of the empty submarine acts opposite to the buoyant force and the skin friction drag, whose net resultant would give us the net force in Z direction.

Formulating mathematically,

$$4\rho V(t)g + mg + \rho wlhg - C_d\dot{z} = (4\rho V(t) + m)\ddot{z} \quad (2)$$

For analysis of rotation in Y-axis, also called pitch, it is assumed that the mass distribution of the submarineremains constant throughout the body of the submarine. It is also assumed that no friction drag is acting while the submarine is rotating about its axis. $\bar{I}_{yy}$ has been taken as the mass moment of inertia about the Y-axis passing through centroid and $\ddot{\theta}$ as the angular acceleration about Y-axis. Here, l is the total length of the submarine and l_b is the total length of the ballast tanks.

Applying moment equation about centroidal Y axis, the weight of the front ballast tanks (as shown in Fig 3) times the distance from the centroidal Y axis will be equal to the centroidal mass moment of inertia along Y axis times the angular acceleration along Y axis.

Formulating mathematically,

$$2\rho V(t)g\left(\frac{l}{2}-\frac{l_b}{2}\right)=I_{yy}\ddot{\theta} \quad (3)$$

For analysis of rotation in X-axis, also calledroll, it is assumed that the mass distribution of the submarine remains constant throughout the body of the submarine. It is also assumed that no friction drag is acting while the submarine is rotating about its axis.$\bar{I}_{xx}$ has been taken as the mass moment of inertia about the X-axis passing through centroid, and $\ddot{\phi}$ as the angular acceleration about X-axis. Here, w is the total width of the submarine, and "w_b" is the width of the ballast tanks.

Applying moment equation about centroidal X axis, the weight of the side ballast tanks (as shown in Fig 4) times the distance from the centroidal X axis will be equal to the centroidal mass moment of inertia along X axis times the angular acceleration along X axis.

Formulating mathematically,

$$2\rho V(t)g\left(\frac{w}{2}-\frac{w_b}{2}\right)=I_{xx}\ddot{\emptyset} \quad (4)$$

Equations (1) to (4) formulate the relation between the movement of the vehicle in different DOFs and the ballast tanks' flow.

4. CONCLUSION AND FUTURE SCOPE OF WORK

An innovative design idea has been proposed for an underwater vehicle with simplified architectures. The analysis done would be immensely valuable for future development of an actual working model of the submarine. It would provide the necessary factors to keep in mind while deciding the dimensions of the submarine, its movement and even the shape.

5. ACKNOWLEDGEMENT

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