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# Study of control system and flow analysis of an autonomous underwater vehicle

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**Abstract**
An underwater vehicle is used for various purposes like ocean exploration, data collection, military applications, environment monitoring etc. Underwater vehicles are mainly sub classed into manned and unmanned vehicles. Remotely operated vehicle and Autonomous underwater vehicle are two types of unmanned vehicles. An autonomous underwater vehicle is one that travels underwater without any input. It needs to be preprogramed and main advantage is that degree of human intervention will be less. Various types of controllers like P-Type, PI-Type, PID-Type, Sliding mode controller etc. are being used for altering the dynamics of a system. In this study sliding mode controller is selected because of its various advantages over other controllers. The motion along diving plane (vertical) is considered and along heading plane (horizontal) is not taken into account. The motions considered in this study are heave velocity and pitch movement along with heave forces. Simulation is done using MATLAB by modifying an existing code replacing the various factors like hydrodynamic coefficients, weight, buoyancy, geometric centres etc. of a new AUV. The design of an existing AUV is made using Catia and is used for flow analysis using Ansys (fluent). The results obtained such as heave rate, pitch rate, pitch angle, depth and plane angles as a function of time are reported. The response of the controller to the commanded depth is also analysed and reported in this paper.

**Keywords:** control system, autonomous underwater vehicle

## 1. Introduction

An autonomous underwater vehicle is a vehicle that travels under water without any input from the operator. It is a part of unmanned underwater vehicle, that consist of non-autonomous underwater vehicle which is operated with a remote, ROV (Remotely Operated Underwater vehicles) that are controlled and powered from the surface with the help of an operator using remote control. The autonomy level of an AUV is mainly determined by its performance in the below mentioned areas. They include:

- Energy autonomy – it include efficient power source and low power consumption for long mission.
- b) Navigation autonomy – precise navigation and positioning with little or no position estimate error growth for given periods of time.
- c) Decision autonomy – it is the ability to sense, interpret and act accordingly with changes.

In recent times, AUV development is more focused on improving the range and endurance in order to achieve long term data collection in the field of coastal management and oceanography. As said earlier AUV has significant role in purpose like ocean exploration, military and industrial applications, air crash investigation, commercial uses etc.

## 2. Literature review

AUVs are found in a range of man portable light weight AUV to large diameter AUVs with 10 metres length. It is found that the large vehicle took advantages from its endurance and sensor payload capacities whereas the smaller AUVs are mainly benefits from its lower logistics (for example: support vessel footprint; launch and recovery systems) The vehicle is to be propelled mainly by rear propeller. Yaw and pitch movements will be achieved through the use of four bilge pumps. It should have enough space to carry controller unit, batteries, and sensors, payloads (clash-free arrangement). It should have a velocity range, specific dimensions according to the application and requires on-board energy for proper working.

The majority utilize the same design and operate in a cruise mode. They collect the required data while following a pre planed route with a speed of 1-4 knots.

### 2.1 Layout

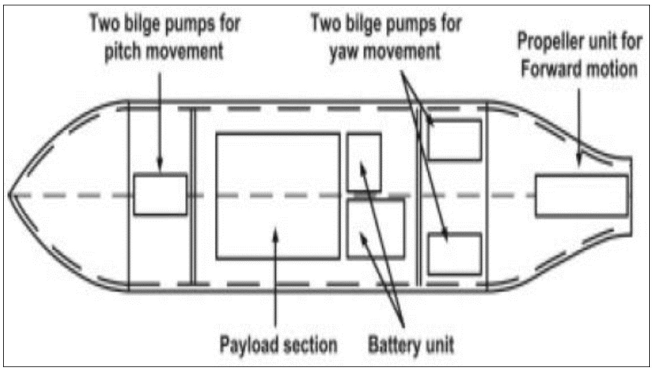



**Fig 2.1.1:** General layout of an AUV

The front section is called the nose. There are bilge pumps for yaw and pitch movement. Frontal cone may include mission specific sensors. Payload section include operational devices. Space is given to battery units. The end section is called tail cone which include propellers.

Total autonomy does not provide the user with any feedback on the vehicle's progress or health, nor does it provide a means of controlling or redirecting the vehicle during a mission. The main advantage is that it makes the user free to perform other tasks as a result of which operational cost is reduced drastically.

### 2.2 Generalized equations of motion

This section describes the equations of motion for an AUV. It is from these Equations of motion that a model can be developed simulation of model and construction of model based on controller.

Surge Equation

$$m\left[\dot{u}_r - v_r r + w_r q - x_G\left(q^2 + r^2\right) + y_G\left(pq - \dot{r}\right) + z_G\left(pr + \dot{q}\right)\right] + \left(W - B\right)\sin\theta = X_f$$

Sway Equation

$$m\left[\dot{v}_r + u_r r - w_r p + x_G\left(pq + \dot{r}\right) - y_G\left(p^2 + r^2\right) + z_G\left(qr - \dot{p}\right)\right] - \left(W - B\right)\cos\theta\sin\phi = Y_f$$

Heave Equation

$$m\left[\dot{w}_r - u_r q + v_r p + x_G\left(pr - \dot{q}\right) + y_G\left(qr + \dot{p}\right) - z_G\left(p^2 + q^2\right)\right] + \left(W - B\right)\cos\theta\cos\phi = Z_f$$

Roll Equation

$$I_x\dot{p} + \left(I_z - I_y\right)qr + I_{xy}\left(pr - \dot{q}\right) - I_{yz}\left(q^2 - r^2\right) - I_{xz}\left(pq + \dot{r}\right) + m\left[y_G\left(\dot{w} - u_r q + v_r p\right)\right.$$
$$\left. - z_G\left(\dot{v}_r + u_r r - w_r p\right)\right] - \left(y_G W - y_B B\right)\cos\theta\cos\phi + \left(z_G W - z_B B\right)\cos\theta\sin\phi = K_f$$

Pitch Equation

$$I_y\dot{q} + \left(I_z - I_z\right)pr - I_{xy}\left(qr + \dot{p}\right) + I_{yz}\left(pq - \dot{r}\right) + I_{xz}\left(p^2 - r^2\right) - m\left[x_G\left(\dot{w} - u_r q + v_r p\right)\right.$$
$$\left. - z_G\left(\dot{u}_r - v_r r + w_r q\right)\right] + \left(x_G W - x_B B\right)\cos\theta\cos\phi + \left(z_G W - z_B B\right)\sin\theta = M_f$$

Yaw Equation

$$I_z\dot{r} + \left(I_y - I_x\right)pq - I_{xy}\left(p^2 - q^2\right) - I_{yz}\left(pr + \dot{q}\right) + I_{xz}\left(qr - \dot{p}\right) + m\left[x_G\left(\dot{v}_r + u_r r - w_r p\right)\right.$$
$$\left. - y_G\left(\dot{u}_r - v_r r + w_r q\right)\right] - \left(x_G W - x_B B\right)\cos\theta\sin\phi - \left(y_G W - y_B B\right)\sin\theta = N_f$$

Where:

ur, vr, wr= component velocities for a body fixed system with respect to the water

p, q, r = component angular velocities for a body fixed system

W = weight

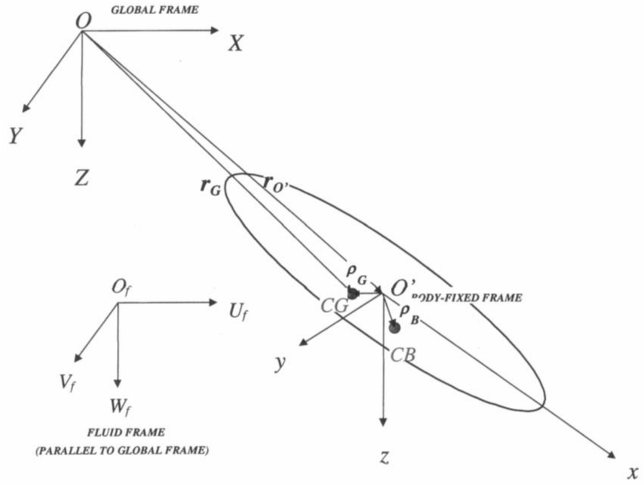
B = buoyancy

I = mass moment of inertia terms

xB, yB, zB= position difference between geometric centre of the AUV and centre of buoyancy

xG, yG, zG= position difference between geometric centre of AUV and centre of gravity

Xf, Yf, Zf, KF, Mf, Nf= sums of all external forces and moments acting on an AUV in the particular body fixed direction




### 2.3 Sliding mode controller

Sliding mode control is a controlling technique of nonlinear mode with important properties of accuracy, robustness and easy implementation. It is designed to drive the system state onto a sliding surface. It keeps the state on close of neighbourhood of the surface when the surface is once reached. It has a two part controller design. The first part involve in the designing section of sliding surface and the second part deals with the selection of control law as per requirement to attract the switching surface to the system state.

The main advantages of sliding mode control are as below:

The dynamic behaviour of a given system is tailored based on particular choice of sliding function.

For certain uncertainties, the closed loop response became totally insensitive.

### 3. Simulation and Result

The depth controllers are primarily designed to act as a depth regulator where once a command for depth is received, its job is to approach the commanded depth with desired characteristics.

Here the below Figure shows the response of WL 2 Depth controller to a sinusoidal commanded depth amplitude ten meter and period of twenty second. It can be observed that there is a significant phase lag in the depth achieved and even an inability to match amplitude of the commanded signal.

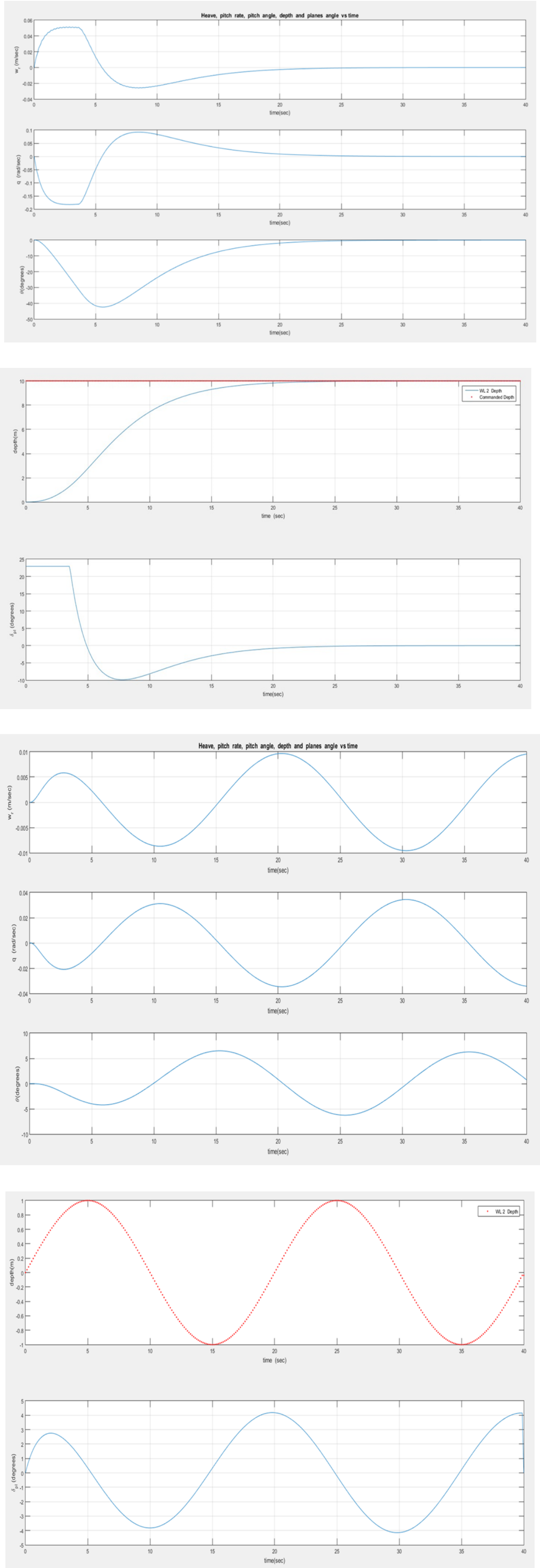



**Fig 3.1:** Simulation result

## 4. Flow analysis

Velocity, Temperature and Pressure are the variables that governs the fluid dynamics laws. By doing Computational Fluid Dynamics analysis (CFD), we were able to solve for pressure, velocity and temperature within the domain.

The model that is used for CFD analysis is as below.

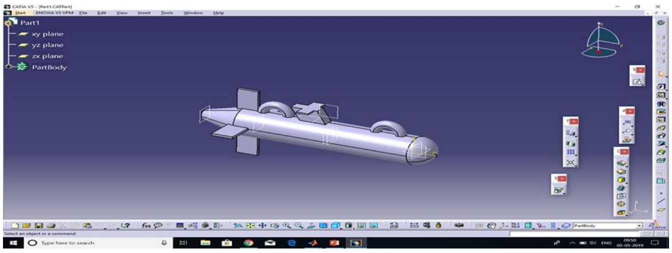


**Fig 4.1:** AUV designed in CATIA

## 5. Conclusion

An AUV is an underwater vehicle which doesn't require an operator to function and has a multitude of opportunities for future. This being the reason is why our work revolved around the study of AUV's and their control systems. It is found that sliding mode depth control is the best and most versatile ones of those available and was selected for this reason. System responses of the WL2 AUV where studied after its hydrodynamic parameters were infused with that of an old AIRES AUV using MATLAB and simulations were done to further validate our results. As an application of Computational Fluid Dynamics, flow analysis was done for a model made in CATIA using ANSYS FLUENT to find lift and drag parameters of the AUV and marks the completion of our work. In this modern day of machines, is with utmost certainty we can believe AUV's would replace all of the underwater survey and reconnaissance work done by humans in the near future.

## 6. Acknowledgement

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