Depth Control Model of an Underwater Vehicle

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Introduction and Objectives

Underwater Autonomous Vehicle

The main objective of this research project was to develop a depth control model for an underwater autonomous vehicle that accurately models the dynamics of the vehicle from a given set of conditions. This project is a subset of a larger project with the goal to create a low-cost alternative to the current expensive underwater autonomous vehicle design. This depth control model provides the team of researchers with a way to test designs using computer simulations that can be used as a preliminary to real-world tests. The current prototype of the vehicle can be seen in *Figure 1*, along with the CAD design seen in *Figure 2.*

Figure 1: Photo of current vehicle assembly

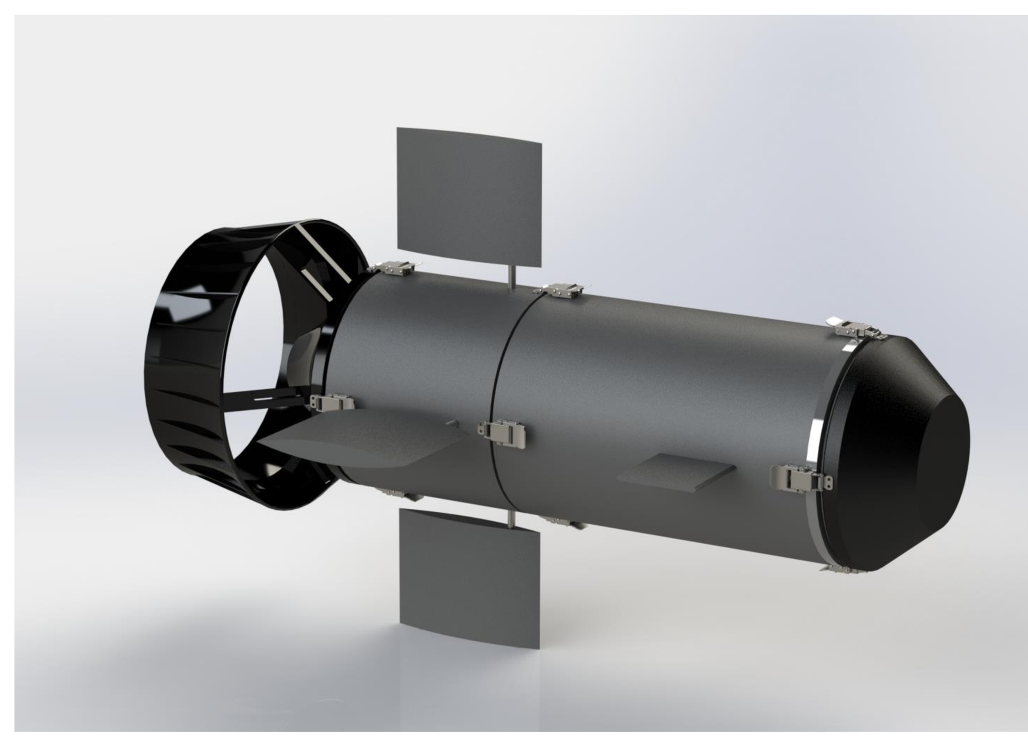

Figure 2: *CAD design of vehicle made by Gillian Besko*

Research Process

Modeling of Marine Vehicles

This project required background knowledge of the physics of the vehicle, starting the project I researched the physical modeling of underwater vehicles from the book "Guidance and Control of Ocean Vehicles". From this research, I developed an understanding of coordinate systems and equations that describe the motion of an underwater vehicle. From this, I was able to determine forces and moments acting on the vehicle using the approximation of the vehicle to be an ellipsoid seen in *Figure 3.*

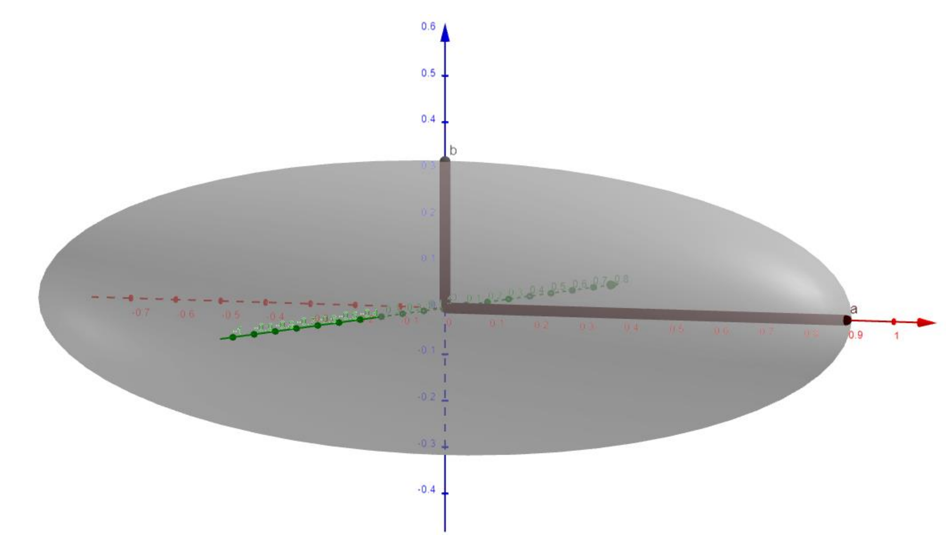

Figure 3: Ellipsoid approximation of vehicle

Dynamic Model

Equations of motion

To simulate the dynamics of the model various equations were used to solve for values such as the depth and pitch angle of the vehicle in motion. in a body-centered coordinate frame ν, and an Earth-fixed reference frame η. These equations were linearized.

- State space equation:

$$\begin{bmatrix} \dot{\Delta\nu} \\ \Delta\eta \end{bmatrix} = \begin{bmatrix} -M^{-1}[C(t)+D(t)] & -M^{-1}[G(t)] \\ J(t) & J^*(t) \end{bmatrix} \begin{bmatrix} \Delta\nu \\ \Delta\eta \end{bmatrix} + \begin{bmatrix} M^{-1} \\ \mathbf{0} \end{bmatrix} \begin{bmatrix} \Delta\tau \\ \mathbf{0} \end{bmatrix}$$

Focusing on the diving motion of the vehicle the state space equation can be simplified to a more specific equation that can be solved as a system of first-order differential equations (ODE).

- Diving equation of motion:

$$\begin{bmatrix} \dot{w} \\ \dot{q} \\ \dot{\theta} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & -u_0 & 0 \end{bmatrix} \begin{bmatrix} w \\ q \\ \theta \\ z \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \\ 0 \\ 0 \end{bmatrix} \delta_s$$

This simplified equation describes the needed dynamic parameters described in the objectives. This equation was solved in Python using an ODE solver to find values for depth (z), pitch angle (θ), and their derivatives (w and q respectively) as a function of time for a given angular deflection of the stern plane (δ_s).

Python Program

To simulate the model a program was created with Dr. Myatt that takes in a series of input values (calculated forces and moments acting on the vehicle) and determines the conditions using the ODE solver to plot the parameters (z, θ, w, and q) against time to provide a visualization of the motion of the vehicle for varying conditions and control inputs.

Results and Conclusions

Simulations

From the Python program, various plots were created with different sets of input conditions:

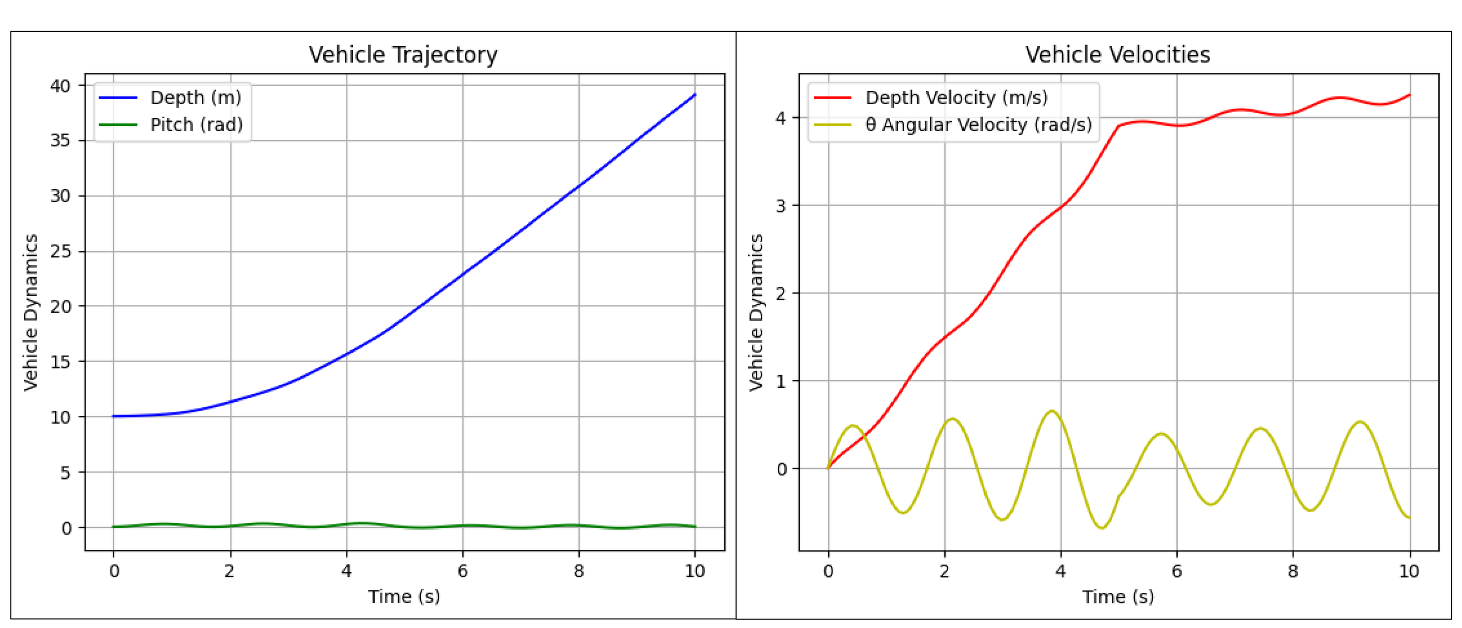

Figure 4: Standard diving Plots (stern plane deflection $\delta_s = 5\ radians$, on for half the duration)

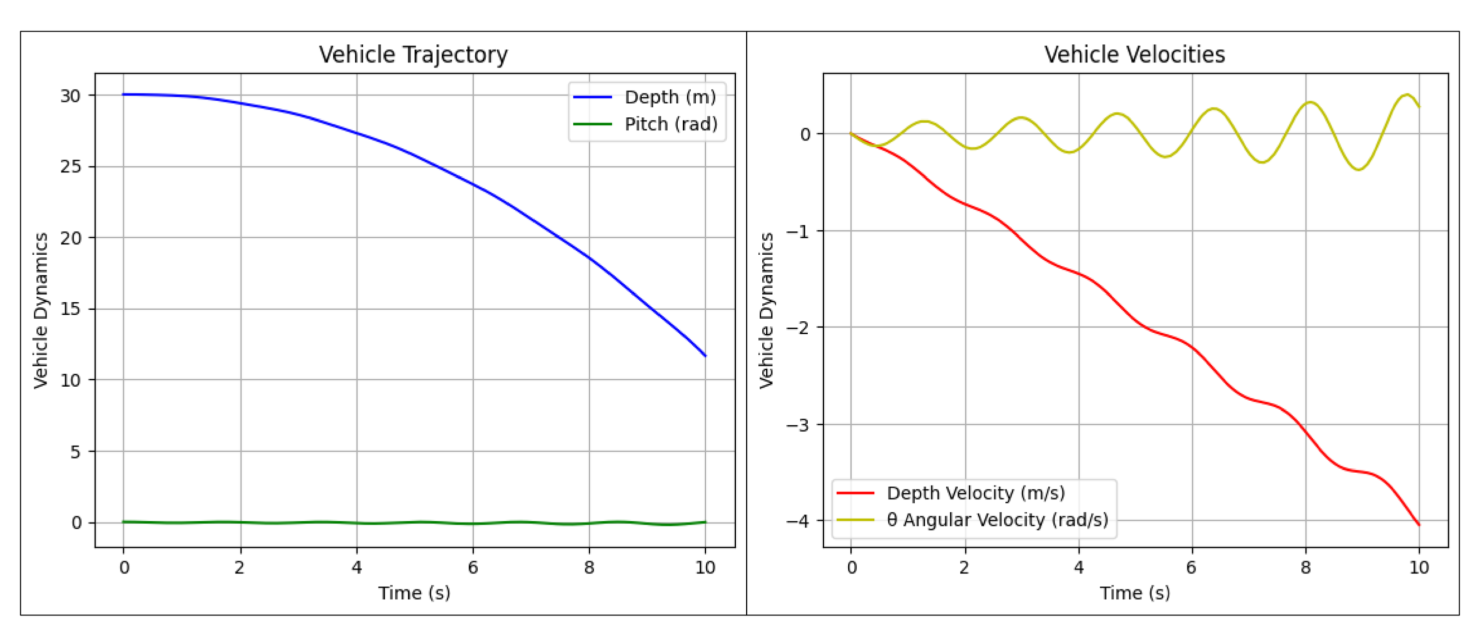

Figure 5: Standard rising plots (stern plane deflection $\delta_s = -5$ radians, on for entire duration)

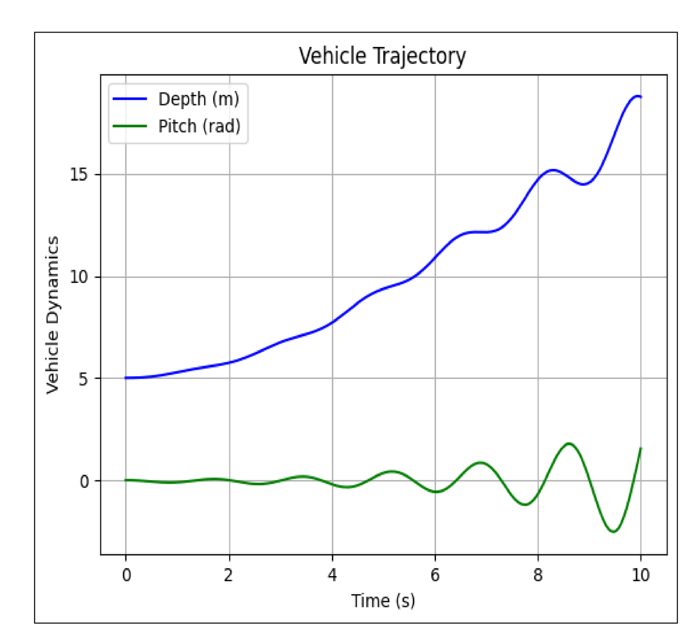

Figure 6: Large moment in pitch plot (control on for half the duration)

Conclusion

The objectives of this project were to develop and implement a simulation model of a underwater autonomous vehicle that can be applied to test the vehicle under a certain set of conditions. These objectives were met by researching the physics of ocean vehicles which led to an approximation of forces and moments to be used as input conditions in the Python program. Through this research, I was able to implement simulations of the vehicle onto plots describing the diving of the vehicle and therefore successfully meeting the objectives of this research project.

References

[1] Thor I. Fossen, *Guidance and Control of Ocean Vehicles*, 1st ed. Chichester, England: John Wiley & Sons, 1994