ECEN 5458 Project Summary 3

Kyle Harlow

May 18, 2018

1 Introduction

1.1 Model Adjustments

Given the 12DoF model defined in Progress Report 2,

$$
\begin{aligned}
A &= \begin{bmatrix} \mathbf{0} & \boldsymbol{I} \\ -M^{-1} * G & -M^{-1} * D \end{bmatrix} \\
B &= \begin{bmatrix} \mathbf{0} \\ M^{-1} \end{bmatrix}
\end{aligned} \tag{1}
$$

We began looking at controllability and observability of the continuous time system. This system was largely uncontrollable, likely due to inaccuracies in the model whose mass, inertia, and drag properties were estimated based on SolidWorks measurement properties and SolidWorks Flow simulations. In the future, the RoboSub has plans to estimate these parameters, but in order to continue this project it is important for us to find a model that allows us to see controllable results. As such we propose the following changes to the model.

1. The vehicle is positively buoyant.
   - This change allows us to have a greater degree of control over the z and down degrees of freedom, as we will show.
2. The vehicle is symmetrical across the xz-plane.
   - This allows us to diagonalize the M matrix, which allows us to linearly separate our degrees of freedom.

Given these changes to our model we can note the following. If M, G, and D, are all diagonal matrices we can split the 12DoF system into 6 separate 2DoF systems since the states are no longer coupled by any off diagonal terms. Each of these systems will be of the form

$$
\begin{aligned}
A_i &= \begin{bmatrix} 0 & 1 \\ \frac{-g_{i,i}}{m_{i,i}} & \frac{-g_{i,i}}{m_{i,i}} \end{bmatrix} \\
B_i &= \begin{bmatrix} 0 \\ \frac{1}{m_{i,i}} \end{bmatrix}
\end{aligned} \tag{2}
$$

And our states are of the form

$$
\begin{aligned}
\hat{x}_1 &= \begin{bmatrix} \dot{N} \\ \dot{x} \end{bmatrix} \\
\hat{x}_2 &= \begin{bmatrix} \dot{E} \\ \dot{y} \end{bmatrix} \\
&\vdots \\
\hat{x}_6 &= \begin{bmatrix} \dot{\psi} \\ \dot{q} \end{bmatrix}
\end{aligned} \tag{3}
$$

2 Controllability

After forming this new model, we checked the continuous controllability of each new state space model. In the continuous time domain, all models were controllable. From here, we discretized the models using two time samples.

2.1 T = 1/8, DVL Sample Rate

Using c2d we found the discrete equivalent model using a zero order hold of our 6 state space equations. Then we checked the controllability and observability of the systems in the Discrete Domain. Under this arrangement we get the following controllability observations:

$$\begin{aligned} rank(\mathcal{C}_i) &= 2 \quad i \in 1, 2, 3 \\ rank(\mathcal{C}_i) &= 1 \quad i \in 4, 5, 6 \end{aligned} \tag{4}$$

The same ranks hold for the observability matrices.

$$\begin{aligned} rank(\mathcal{O}_i) &= 2 \quad i = 1, 2, 3 \\ rank(\mathcal{O}_i) &= 1 \quad i = 4, 5, 6 \end{aligned} \tag{5}$$

While in class we have largely only discussed controllable and observable models, there are ways to handle unstable and unobservable models, given that they are stabilizeable and detectable. While using the DVL sample rate the roll, pitch, and yaw states are stabilizeable, meaning the unstable pole can be moved as necessary, but they are not detectable. As such this project will focus on the next sample rate, based on our model estimation.

2.2 T = 1/40, Kalman Filter Sample Rate

Since the DVL sample rate leaves three of our state space models, specifically those tied to roll pitch and yaw, uncontrollable and unobservable, we will instead focus on the output from the vehicles Kalman Filter. The state estimator on RoboSub's system publishes a new state every 40Hz estimating values between every DVL ping using faster sensors. Under this system only $rank(\mathcal{C}_4) = 1$, all other controllability and observability matrices are full rank. The one uncontrollable matrix is also stabilizeable. As such we will move forward using this as our primary sample time. Potentially analyzing the effects of other DVL sample time if time permits.

3 Characteristic Equations

Given a discrete model, we now wish to control the systems in order to reach some desired parameters. We will begin by assuming that our motors cannot saturate, and attempt to meet the following parameters for our x,y, and z state space models:

$$\begin{aligned} M_p &= 10\% \\ t_r &= 4\text{sec} \end{aligned} \tag{6}$$

In general, we wish for the vehicle to have relatively low overshoot. Since we are controlling the velocity, any significant overshoot can potentially offset our integrated position control later on. In addition, many obstacles require fine movement in order to press levers and manipulate objects underwater. As such large overshoots could cause the vehicle to knock over obstacles.

Our rise time is relatively slow to account for the vehicle needing to move a significant amount of mass, >28kg, through a dense medium. In addition rise time does not significantly affect any competition elements.

This gives us the continuous time desired parameters of

$$\begin{aligned} \zeta &= .5912 \\ \omega_n &= 0.45 \end{aligned} \tag{7}$$

Converting ω_n to its discrete time equivalent with $z = e^{\omega_n * T}$ we get the following discrete time characteristic equation.

ln

$$z^2 + 2(0.5912)(0.9888)z + 0.9888^2 = (z + 0.5846 + 0.7975j)(z + 0.5846 - 0.7975j)) \quad (8)$$

Given this desired characteristic equation we can use place to move the poles of $det(A - BK)$ to the desired locations.

$$\begin{aligned} K_x &= [1.15e^5, 1.50e^3] \\ K_y &= [2.84e^4, 4.44e^2] \\ K_z &= [9.74e^3, 2.00e^2] \end{aligned} \quad (9)$$

These large K's are a cause for some concern.

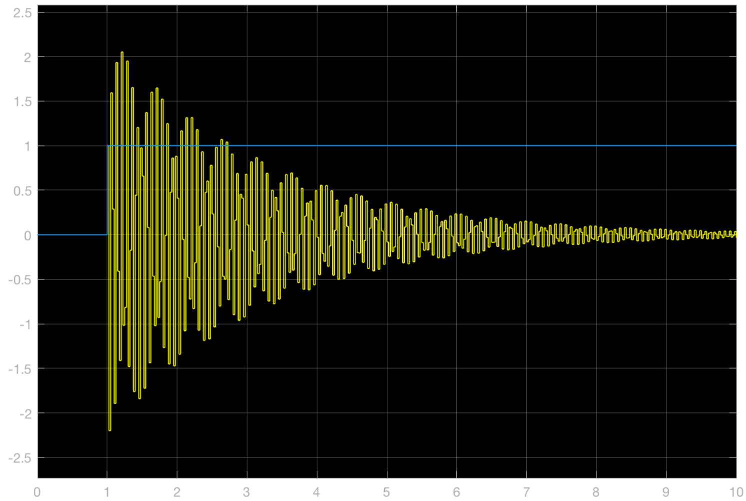

Figure 1: Step input to X, and resulting force output u

The resulting motor output oscillates significantly to a step input for velocity as shown in figure 1. In addition the output states $\dot{N}$ and $\dot{x}$ do not approximate a step response, instead resulting in an oscillation around 0 as shown in 2. Similar graphs result from the other two state equations.

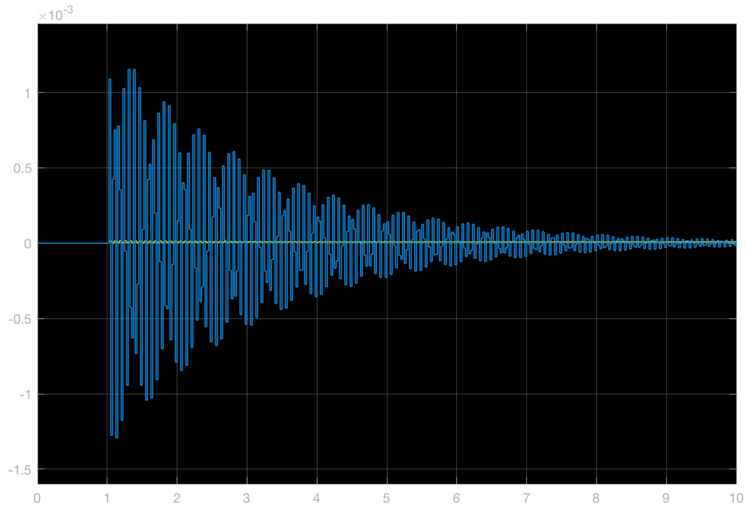

Figure 2: Outputs for a $\dot{N}$ and $\dot{x}$ given a step input

Clearly further iteration is necessary in order to control the vehicles various states. The first step is to relax our constraints, specifically the overshoot, in order decrease the distance we need to move the poles.