The Control of a Gantry

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1 – Introduction

1.1 – Objectives, Goals, and Purposes

The main objective of the lab was to use a controller to control a gantry while keeping the angle of a pendulum within specifications and prevent it from swinging. This is done by getting the physical characteristics of the pendulum, using pole placement to compute gains of the controller, and an integral controller. This is done such that when small perturbations to the angle of the pendulum will be fixed by the movement of cart which is only able to move back and forth in one direction.

1.2 – Intended Methods

The intended methods include inputting certain poles that will make the system stable while also performing fast enough to keep the pendulum in the desired angle. The outputs that will be measured are the angle of the pendulum and the position of the cart on the track.

2 – Procedure

2.2 – Definition of Variables

Variable	Description	Units
xc	Position of the cart	M, cm, or mm
Alpha	Angle of the pendulum	
Fc	Cart force	kg/s
K	Controller gains	
ωn	Natural frequency	m
G	gravity	kg/s
B_{eq}	Damping of cart due to friction	kg/s
V	Voltage	V

2.2 – Schematic and Description of Apparatus

Figure 1- Experimental Apparatus

Similar to the previous lab, a cart is on a toothed track which interfaces with the gear on the cart to induce movement with a motor. Again, the cart data is connected to the computer which can be interacted with using MATLAB and Simulink. The new part of the apparatus is the pendulum that is connected to the gantry. A 12 inch pendulum is left to hang in the downwards position and is able to freely rotate on its connection point to the cart.

2.3 – Procedure of Experiments

Part (i): The Natural Frequency of the Pendulum

a) Move the pendulum to roughly 15 degrees from the downward position
b) Let the pendulum swing for 10 revolutions and stop collecting data

Part (iii): Pole Placement

a) Enter gain values that were calculated in the pre-lab
b) Run the experiment with the calculated gains and tap the pendulum and record the data of the movement
c) Repeat until best results are achieved, record new K values (if necessary)

Part (iv): Integral Control of the Gantry

a) Enter gain values that were calculated in the pre-lab
b) Run the experiment with the calculated gains
c) Set step and/or pulse generator to the correct values and record angle and position data

3 – Results

3.1 – The Natural Frequency of the Pendulum

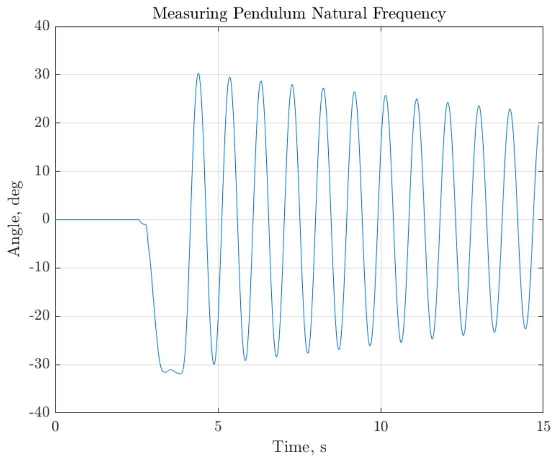

Figure 2 – Angle vs Time, Natural Frequency Measurement

Looking at the plot given in figure 2, we can take the time of where the peaks of the motion occur, count ten revolutions then dividing by ten to get the natural frequency in Hz. To get it to radians per second, multiply the frequency by 2pi. Doing this gives a natural frequency for the pendulum a value of 0.954 Hz or 5.994 rad/sec.

3.3 – Pole Placement

a) Prelab K gains and Settling Time
   K = [2.9304, -5.6420, -3.6179, -1.9520,]
   Settling Time: ts = 2.44 seconds
b) Experimental K gains and Settling Time
   K = [128, -175, 65, 6]
   Settling Time: ts = 2.531 seconds
c) Angle vs. Time

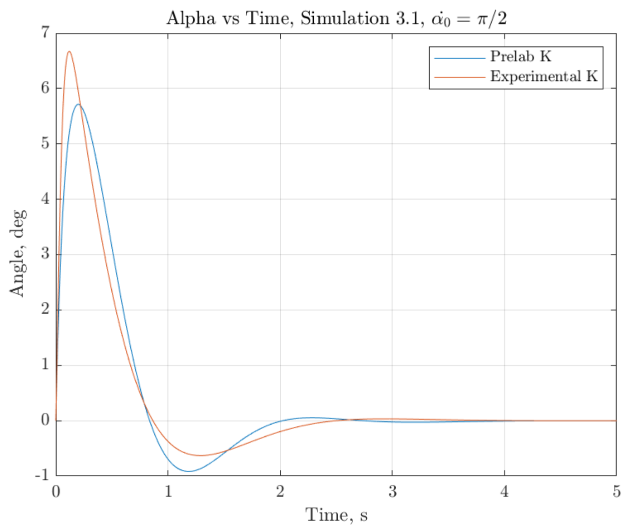

Figure 3 - Experimental Pendulum Angle, Experimental Gains

The estimated value for the initial angular velocity (alpha0_dot) is 4.602 rad/s. This is calculated by taking the derivative (diff(signal)/dt) in MATLAB and taking the value where the angular velocity is applied.

Figure 4 – Simulated Pendulum Angle, Experimental Gains, alpha0_dot = 4.602 rad/s

As seen above in figures 3 and 4, the plots are fairly consistent between the experimental data and the simulated data. The maximum angle that is experienced by the pendulum is slightly higher in the experimental data compared to the simulation. This could be due to outside factors such as errors in the calculations or methods of calculating the angular velocity of the experimental data and transferring it to the simulation. Otherwise, the settling time and other specifications of both plots are fairly similar

d) Seen in figure 5, it takes slightly more than 2.5 seconds for the pendulum angle to setting when it is given an initial angular velocity of pi/2. This can be compared to figure 3, where the experimental data gives nearly the same settling time of 2.531 seconds. This means that the simulation is fairly accurate when predicting such values.

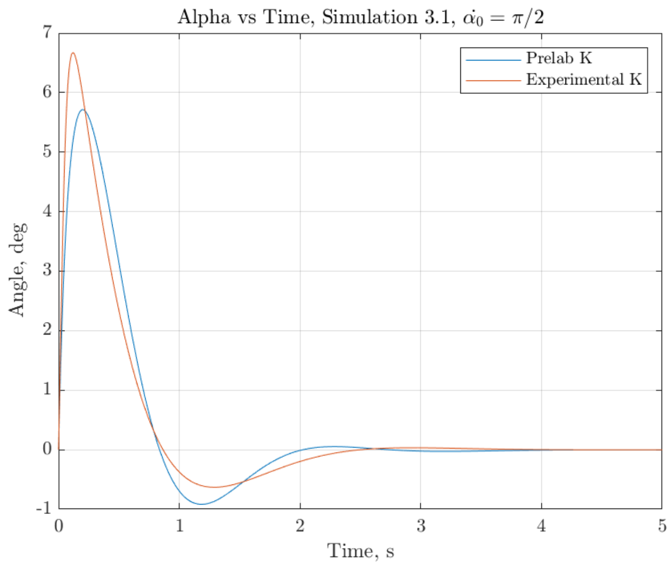

Figure 4 – Simulated Response to Initial Angular Velocity = pi/2

3.4 – Integral Control of the Gantry

a) Prelab K gains and Settling Time
K = [200.5502, -6.5686, 29.9545, 4.0304, -375.0856]
Settling Time: 2.72 seconds

b) Experimental K gains and Settling Time
K = [73.3580, -29.6897, 19.3690, 1.4389, -86.5582]
Setting Time: 3.553 seconds

c)

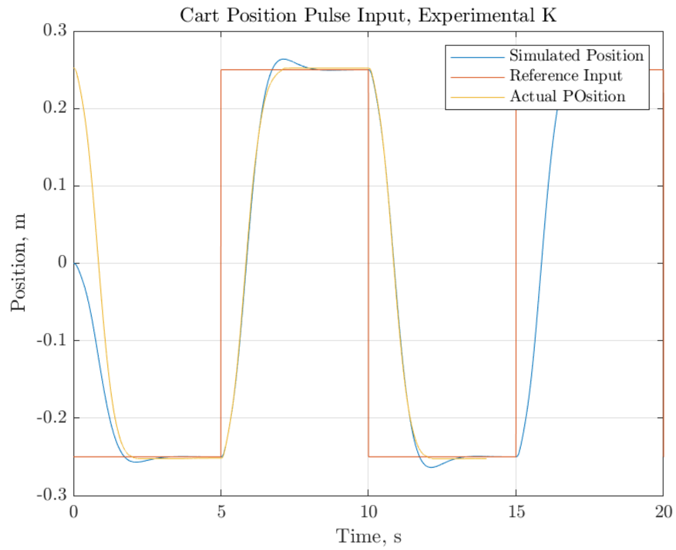

Figure 5 – Pulse Input Cart Position Response

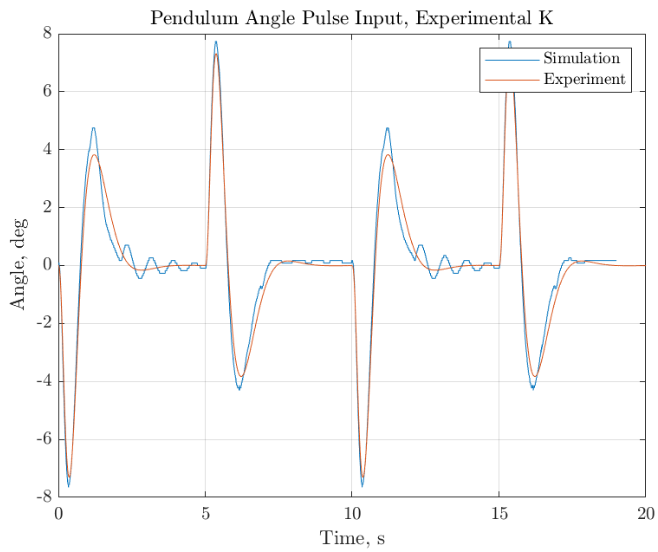

Figure 6 – Pulse Input Pendulum Angle Response

4 – Analysis of Results

4.1 – The Natural Frequency of the Pendulum

The assumptions that were made were that the friction acting at the contact point of the pendulum was negligible, this made simplified the calculations that are needed to compute the natural frequency of the swinging pendulum. To do this, the equations of motion are taken and linearized, this allows the calculation for the natural frequency to be done. From the experimental data, the natural frequency is done by setting the pendulum at and angle and letting it swing freely, taking the recorded data and count the number of 'revolutions' that are made and the time it takes to do that many revolutions, divide the time it takes to do the number of revolutions by the number of revolutions. This give the frequency in Hz, to get radians, divide by 2pi. The plots for this can be seen in figure 2.

4.3 – Pole Placement

The objective of the controller is to stop the cart in a specified amount of time (performance) and the specifications specified in the pre-lab which are a max overshoot of 5% and setting time of 2.2 seconds. The controller was designed by choosing poles locations for the system. This is done using the place command while inputting the A and B matrices for the system then choosing poles that would make the system stable and fit within the performance specifications. This give us the K gains that are multiplied to B to give the new system. The assumptions that had to be made to use a linear controller are that the angles of the pendulum are small since the system is nonlinear because of the angles on the pendulum, the angles must be small for the controller to work. The plots for this section can be seen in figures 3 and 4. As seen in figure 5, the simulation is fairly accurate, the settling time for the simulation is similar to the experiment when the conditions of the experiment were input in the simulation (the angular velocity and K gains). This can be seen in figure 3 which compares the two datasets against each other. The simulation data is very close to the experimental, however, the simulated data did seem to have slightly better performance compared to the experimental data.

4.4 – Integral Control of the Gantry

The objective of the integral controller in this case is to eliminate the steady state error of the position of the cart. Similar to section 3, the controller is designed using the pole placement method. In this case, the input is a pulse input which moves the cart back and forth, the cart must be within the performance metrics and the pendulum must go back to the equilibrium point within the performance metrics as well. Since there is an integral controller, new matrices must be used for A and B which are denoted Ai and Bi, which have an extra row and column at the end for the Ai matrix and an extra element in the Bi matrix to add the integral controller. The pole placement now requires an extra pole to be added to accommodate for the integral controller. Similar assumptions were used when designing this controller as was mentioned in the analysis for section 3. The plot for the position with respect to a reference input can be seen in figure 5 and the resulting angle of the pendulum can be seen in figure 6. The simulations for these plots used the best gains that were computed with the experimental data. Looking at the position plot, it seems that our K gains were not enough to be within the performance metrics.

In this lab, state feedback was used. The gains for this method of control are in the vector K whose elements control a specific state of the system. For example, in section 3, the states that are being controlled are cart position, pendulum angle, cart velocity, and pendulum angular velocity. The poles that were chosen to calculate K were chosen such that the poles result in a stable system and were iterated until the performance specifications were met while being under the maximum gain of 200 for the safety of the equipment.

5 – Conclusion

5.1 – Main Points

This experiment consisted of designing two controllers that were able to control a cart on a track which moved the angle of a pendulum. The data the was obtained shows that the controller design that we reached was not enough to control the system to performance specifications as seen in section 4 (though it was enough in section 3). To remedy this, we could have continued to experiment with the poles that were input to calculate the gains and settle on a set of gains that were fit for the job.

5.2 – Limitations

The assumptions that we had to make for the experiment is that the angles on the pendulum were going to be fairly small. This was necessary to do so that we could linearize the system. A limitation that was apparent for the system is the maximum voltage that the motor could receive, this reduced the maximum speed that the cart could have moved which could have affected the performance of the system, similarly the maximum gain we could have put in was 200. Another limitation was that the time steps that were used for the experiment, this affects the data and the movement of the cart as seen in figure 6, where the data seems to be discretized as the time steps may be too large to capture subtle movements that the cart or pendulum may have. Lastly, there seems to have been a dead zone where the cart would not move until enough voltage was high enough, this could have also caused the data that was seen in figure 6.

5.3 – Recommendations and Lessons Learned

A lesson I learned from this experiment is to continue to experiment with the poles and gains until satisfactory performance is reached. This would have allowed for better data in the end which would result in better analysis. Another lesson I learned from this experiment is to get to know the experiment for deeply by researching the controller types and how they work as I was not sure how they worked until analyzing the data and performing calculations on it. This would have helped in the lab and given me a better intuition on how to adjust the gains and poles to reach a better result.

I have no further recommendations to make this lab better.