LAB REPORT

Lab 3: Familiarization with Equipment and Basic Cruise Control Design

Lab Date: March 19 2024

Submission Date: March 19 2024

Prelab: 1 marks

Lab Report: 4 marks

Lab Work: 5 marks

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$\boxed{\text{356 Lab 3 Pre-Lab}}$ Group 3

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3 Preparation

Consider the block diagram in Figure 2 and assume that the road is flat, i.e., $\theta = 0$ and hence $D(s) = 0$. Suppose that a step voltage $v_m(t) = V_0 \cdot \mathbf{1}(t)$ $(V_0 > 0)$ is applied to the DC motor and that at time $t = 0$ the cart is still (i.e., $v(0) = 0$). Using the final value theorem determine $v(+\infty) = \lim_{t\to\infty} v(t)$ in terms of V_0, a, and b.

Submit the preparation report to your lab TA at the beginning of the lab. Read thoroughly he next section before attending the lab.

$$V_m(t) = V_0 \mathbb{1}(t)$$

$$\downarrow \mathcal{L}$$

$$V_m(s) = \frac{V_0}{s}$$

$$V_m(s) \longrightarrow \boxed{\frac{a}{s+b}} \longrightarrow V(s)$$

$$V(s) = \left(\frac{a}{s+b}\right) V_m(s) \quad \frac{V_0 a}{s(s+b)}$$

Since $V(s)$ is rational and proper, and has one pole at $s=0$ and another pole at $s=-b$, we can apply FVT to $V(s)$.

$$v(\infty) = \lim_{t\to\infty} v(t) = \lim_{s\to 0} sV(s) = \lim_{s\to 0} \cancel{s} \cdot \frac{V_0 a}{\cancel{s}(s+b)} = \boxed{\frac{V_0 a}{b}}$$

signal that approximates the desired control value (D/A). (see the Appendix section for further information about the experimental setup)

3 Preparation

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4 Experiment

4.1 Introduction to the Arduino

4.1.1 Apply sinusoidal voltage to the DC motor

In this section you will learn how to configure and setup your system. The objective is to have the cart on the rails swing back and forth following a sinusoidal pattern. Note that the various files on the computer that you will use have the label "**Lab2**" attached. This is because this experiment used to be Lab 2. Rather than renaming the files and directories, we choose to alert you to this label mismatch.
First, open the Arduino code file named "*Lab2_4_1.ino*" located in the *Lab*2 > *Lab*2_4_1 directory and then press the `upload` button in the Arduino software to upload the code on the micro-controller. As the code is uploaded the cart will start moving for 15 seconds. Pay attention to the amplitude and frequency you will impose on the sinusoid, as it will affect the swing of the cart on the rails.

Have your TA sign here before proceeding to the next step. SM

4.1.2 Collecting data from the cart

To plot the position of the cart on the rails, open the Matlab m-file located in the same directory as the Arduino code named as "*real_time_data_plot_Lab2_4_1.m*" . Then launch the m-file as it will run the uploaded code on Arduino. The data received from Arduino is recorded and plotted automatically.

4.2 Identification of model parameters a and b

Recall that in the introduction we modelled the car as a transfer function $V(s)/V_m(s) = a/(s+b)$, where $V_m(s)$ is the Laplace transform of the input voltage signal and $V(s)$ is the Laplace transform of the cart speed signal. Before controlling the system, we need to experimentally determine the

Figure 4: Arduino software user interface

parameters a and b. This is the objective of this section.

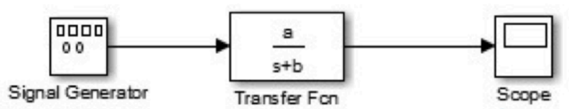


Figure 5: Schematic representation of the Matlab Simulink model

1. Create a Simulink model as in Fig. 5. The detailed steps to construct it are listed below.

   - Open a blank Simulink model and the Library browser.
   - Using the `Continuous/Transfer Function` block, create a system with transfer function $\frac{a}{s+b}$. This block represents the mathematical model of the plant assuming that the disturbance is zero, that is, assuming that the cart track is horizontal. The objective here is to experimentally determine the values a and b.
   - Using the `Sources/Signal Generator` block in Simulink, create a block that generates a square wave for $v_m(t)$ with amplitude 1.5 V and frequency 0.5Hz.
   - Connect the output of the transfer function block to a Scope (found in the `Sinks` library).

   Have the TA check your model and sign here before proceeding to the next step.

   JM

2. We choose the initial guesses for a and b in the system model as 0.5 and 5 respectively.

3. Run the Simulink model to obtain the corresponding results for the considered a and b. The scope data is stored in the Matlab workspace to be compared with the experimental results.

4. Then open the Arduino code file named as "*Lab2_4_2.ino*", following the same procedure described in the previous section, upload the code and then launch the provided Matlab m-file "*real_time_data_plot_Lab2_4_2.m*" to observe the obtained experimental results. The uploaded code will impose the same square wave form considered in the Matlab Simulink to the DC motor. Both the displacement and the velocity of the cart are recorded and illustrated in the obtained figure. The experimentally obtained velocity can be used to modify and correct the initial guesses for the a and b parameters.

   Have your TA sign here before proceeding to the next step. JM

5. Look at the experimental velocity and determine as accurately as you can its total variation over the half period. We'll denote such variation by $\triangle v$. $\Delta v = 1$

6. Notice that over the half period under consideration, the signal $v_m(t)$ performs a step of amplitude $V_0 = 3V$. We'll make the approximation to consider the signal v_t to be in steady state at the end of the half period. So we deduce that, in response to an input step of amplitude $3V$, the plant output has a total variation of $\triangle v$. Using the formula you found in your lab preparation and the value $\triangle v$ you just found, find a relationship between a and b. Specifically, find an expression of the type $a = f(b)$.

   Have your TA sign here before proceeding to the next step. JM

7. It should be now clear that for any choice of b, setting $a = f(b)$ guarantees that the steady state value of the model output approximately coincides with that of the actual plant output. Now you'll tune b to make sure that the transients coincide as much as possible.

   Keep the value of b you were using earlier, and set $a = f(b)$ in Simulink. Run the simulation and verify that the steady-state values of the model and actual plant outputs coincide.

8. Now try to increase b. Don't forget, every time you modify b, you must also update $a = f(b)$ in Simulink. Run the simulation to see if the new value of b yields better results. Keep tuning b until you minimize the discrepancy between the actual plant and model outputs.

   You'll use the values of a and b you just found in Lab 4.

   Ask the TA to check that your estimates of a and b are reasonable, and have the TA sign here before proceeding to the next step. JM

   $$\boxed{\begin{array}{l} a = 2.5 \\ b = 7.5 \end{array}}$$

4.3 Proportional Control

Now you'll implement a proportional controller to regulate the speed of the cart. A proportional controller is a controller of the form

$$v_m(t) = Ke(t), \tag{6}$$

where $e(t) := r(t) - v(t)$ is called the tracking error. This is the difference between the reference signal $r(t)$ and the actual plant output $v(t)$. In the cart experiment, $r(t)$ represents a desired velocity profile for the car, while $v(t)$ represents the actual cart speed. Do the following steps for this section.

- Open the Arduino code file named as "*Lab2_4_3.ino*", The velocity reference is set to a square wave form with the amplitude of 0.2 m/s and frequency of 0.5 Hz.
- Set $K = 5$, then compile and upload the code.
- Following the same procedure described in the previous sections, launch the provided Matlab m-file "*real_time_data_plot_Lab2_4_3.m*" to observe the obtained experimental results. Both the displacement and the velocity of the cart are recorded and represented in the obtained plot.

  Have your TA sign here before proceeding to the next step. JM

- You'll notice that the controller does not succeed in regulating the speed to the desired value. Increase the controller gain, and run the system again. Repeat this operation a few times. Do not increase K beyond 20. increasing K increases velocity. (closer to reference)

  Record your observations: does the P controller successfully regulate the speed to the desired value? What's the effect of increasing the gain K on the output response?

- Save the plot of the output response obtained when $K = 20$.

  Have your TA sign here before proceeding to the next step. JM

4.4 Proportional-Integral Control

You'll now implement a proportional-integral controller. A PI controller is an enhancement of a P controller and has the form

$$v_m(t) = Ke(t) + \frac{K}{T_I}\int_0^t e(\tau)d\tau, \tag{7}$$

where K and T_I are two positive design constants. Your TA will explain to you the rationale for using the controller. Taking the Laplace transform, we find that a PI controller has a transfer function (from e to v_m),

$$K + \frac{K}{T_I s} = K(\frac{T_I s + 1}{T_I s}) \tag{8}$$

Do the following steps for this section.

- Open the Arduino code file named as ”*Lab2_4_4.ino*”, The velocity reference is set to a square wave form with the amplitude of 0.2m/s and frequency of 0.5Hz.

- Set $T_i = 0.07$ and $K = 2$. Compile and upload the model and run it.

- Following the same procedure described in the previous sections, launch the provided Matlab m-file ”*real_time_data_plot_Lab2_4_4.m*” to observe the obtained experimental results. Both the displacement and the velocity of the cart are recorded and represented in the obtained plot.

- Save the plot for $T_i = 0.07$ and $K = 2$.

  Have your TA sign here before proceeding to the next step. JM

- Next, keep T_i constant and start increasing K. **Do not increase K beyond 20.**

  Record your observations: what's the effect of increasing K? How does the performance of the P and PI controllers compare?

- Save a plot of the output response when $T_i = 0.07$ and $K = 20$.

  Have your TA sign here before proceeding to the next step. JM

5 Report

Please submit your final report before the assigned deadline to your laboratory TA.

4.2 Identification of model parameters

(0.25 mark) Find the relationship between the parameters *a* and *b*:
(Provide a derivation of this relationship based on your experimental observations)

a = b/Vo where Vo = 3 V

(0.25 mark) The values of *a* and *b* found experimentally are: *a = 2.5* *b =7.5*

4.3 Proportional Control

(0.25 mark) Does the P controller successfully regulate the speed to the desired value?

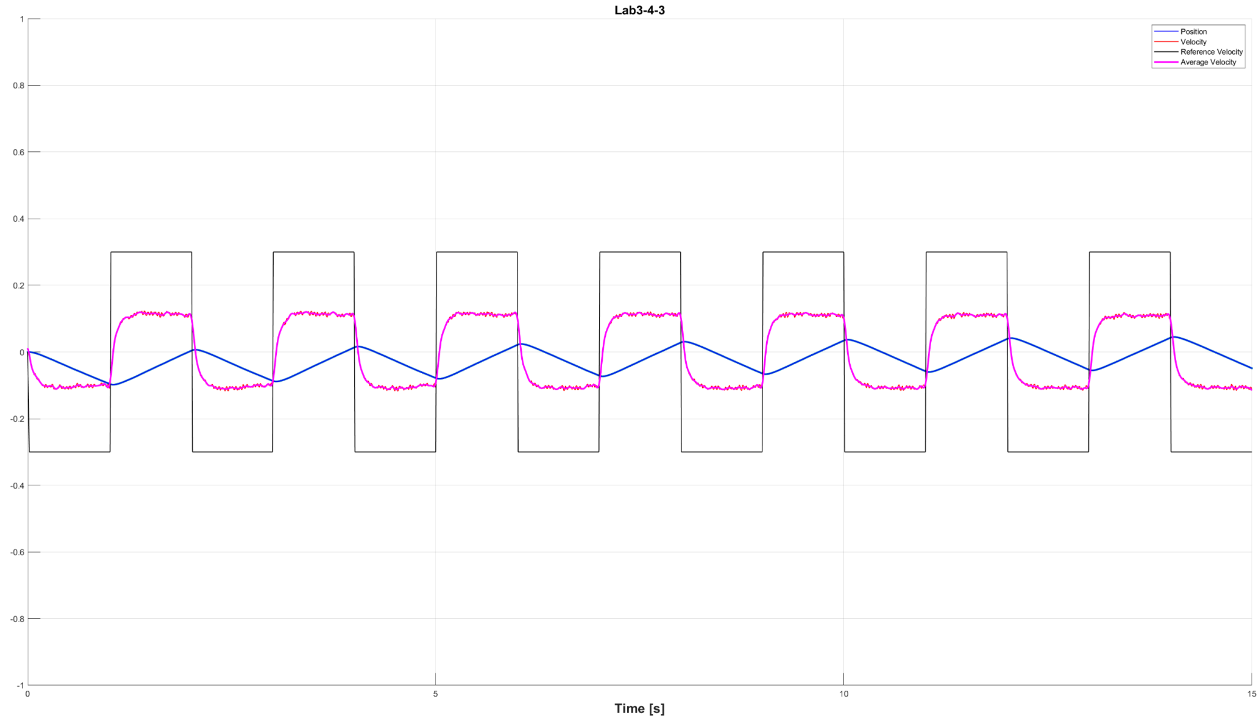
Sort of. It got better with higher Ks, but was not really good. It never matched amplitudes.

(1 mark) What's the effect of increasing the gain K on the output response? Explain what is, in your opinion, the reason for the effect you have observed.

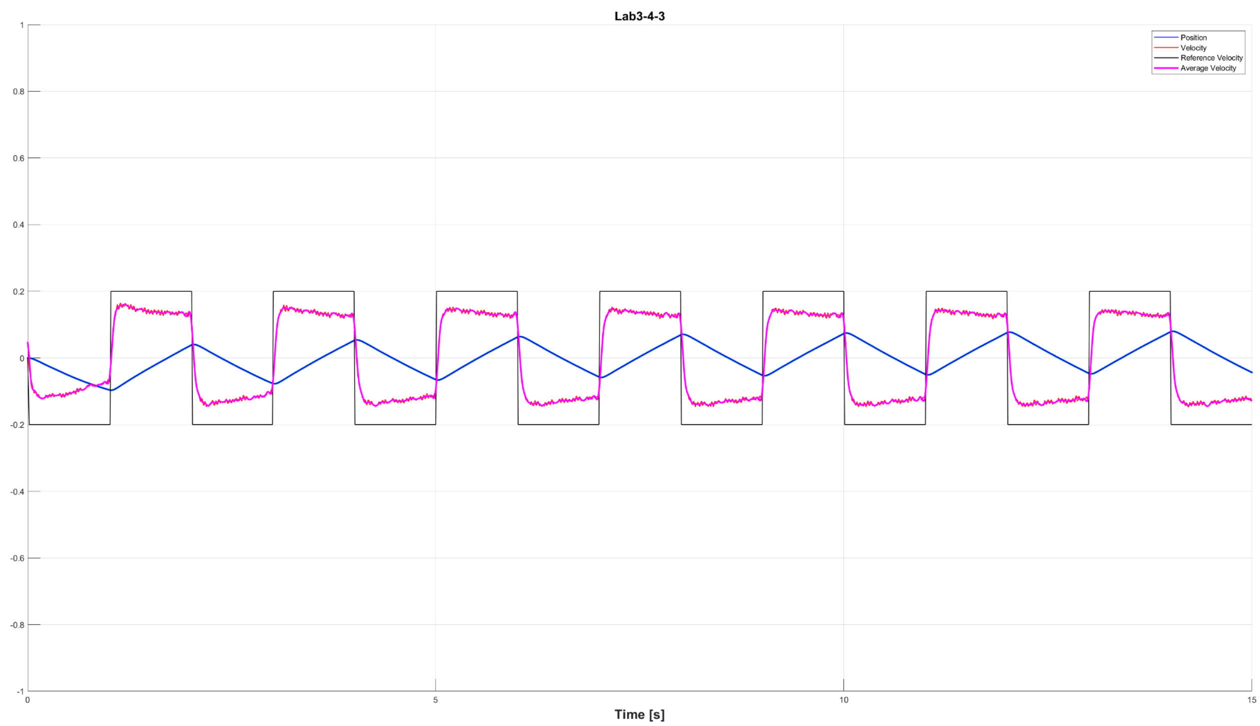
Increases the velocity amplitude by increasing the gain on the voltage. This means that the feedback signal it receives is given more weight and thus the velocity matches the reference velocity with higher K values.

(0.75 mark) Plot the "P controller" experimental results; containing the measured velocity and the reference signal (with proper labels).

K =5:


Lab3-4-3
Position
Velocity
Reference Velocity
Average Velocity
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
5
10
15
Time [s]

K = 20:


Lab3-4-3
Position
Velocity
Reference Velocity
Average Velocity
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
5
10
15
Time [s]

4.4 Proportional-Integral Control

(1.25 mark) How does the performance of the P and PI controllers compare? Explain the differences you observe and explain what is the reason for such differences?

PI is better than P because it accounts for cumulative errors while the P controller only accounts for the present error. This means that its able to follow the reference signall better and more closely than the P controller.

(0.5 mark) What's the effect of increasing the gain K?

Increases the velocity amplitude by increasing the gain on the voltage. This means that the feedback signal it receives is given more weight and thus the velocity matches the reference velocity with higher K values. Since K is also used in the Integral part of the PI controller, the K value also affects the amount of influence the cumulative error has on the present voltage.

(0.75 mark) Plot the "PI controller" experimental results; containing the measured velocity and the reference signal (with proper labels).

K =20: