ECE-521 Control Systems II
Laboratory 1

In this lab we will practice making second order models in a couple of different ways, and then comparing the models with the real system. In future labs we will have to make models of the systems before we can do any controls, so you need to be able to do this quickly. First a few notes:

- Each of the systems is quite expensive, **BE CAREFUL!**
- There is a hardware shut off button on the box. One member of the group must be ready to push this button whenever the device is being used.
- Do not touch the system when it is operating.
- We will only be using the first cart for this lab. The other two masses should remain locked in position with a nut between the stop tabs.

The last page of this lab indicates the types of things that need to be collected. Be sure the nuts and tools are put away before you leave the lab!

Pre-Lab: Log Decrement For Determining System Parameters

We will assume our mass/spring/damper system is an ideal second order system. If the system is at rest and we provide the mass with an initial displacement away from equilibrium, the response due to this displacement is

$$x(t) \quad = Ae^{-\zeta\omega_n t}\cos(\omega_d t + \theta)$$

where

$$\begin{aligned} x(t) &= \text{the displacement of the mass as a function of time} \\ \zeta &= \text{the damping ratio} \\ \omega_n &= \text{the natural frequency} \\ \omega_d &= \text{the damped frequency} = \omega_n\sqrt{1-\zeta^2} \end{aligned}$$

After the mass is released, the mass will oscillate back and forth with period given by $T_d = 2\pi/\omega_d$, so if we measure the period of the oscillation (T_d) we can determine ω_d.

Let's assume t_0 is the time of one peak of the cosine. Subsequent peaks will occur at times given by $t_n = t_0 + nT_d$.

a) Now examine the ratio of the response of the two times, and show that

$$\frac{x(t_0)}{x(t_n)} \quad = \quad e^{\zeta\omega_n T_d n}$$

b) Define the log decrement as $\delta = \ln\left[\frac{x(t_0)}{x(t_n)}\right]$ and show that

$$\zeta \quad = \quad \frac{\delta}{\sqrt{4\pi^2 n^2 + \delta^2}}$$

From our estimate of ζ and ω_d we can estimate ω_n. We will be using a Matlab program which uses the log decrement method for computing these parameters.

In general, we will be doing the same things over and over (to be explained in more detail below)

1. set up a system (adjusting masses/springs/dampers) (*record the system configuration*)
2. reset the zero position of the system
3. with the (open loop) step input set at zero volts, displace the mass and hold it (*record the displacement*)
4. release the mass while running the system
5. look at the data on the screen
6. if the data is good, export the data to a file
7. set the input (open loop) step response to a voltage between 0.5 and 2 volts. (*record the voltage*)
8. determine the step response of the system
9. look at the data on the screen
10. if the data is good, export it
11. edit both file so Matlab can read them
12. using the log-decrement program, determine a second order system representation (*record this model*)
13. compare the step response of the estimated system with the true step response
14. using the second Matlab file, estimate the second order system based only on the step response. (*record this model and the gain*)

In what follows, I think I've listed all of the commands you will need to complete this Lab, in the order you will need to use them. It looks bad, but it will be easy after a few tries.

If your system starts to sound funny or oscillate wildly, either shut it off or click on the ABORT button!!

Running The ECP Systems

0. Starting the software

From Windows, go to **Programs** → **ECP** → **ECP32**

1. Setting up the system

With the control system turned off (push the button on the white and black box, the green **pwr** light should be off), set up the device for you group. You may change the number of masses, add/subtract/change springs, and add/subtract the damper. Be sure all masses/springs are tightened down. If you use the dashpot, be sure the screw on the dashpot (damper) is at least two full turns away from its closed position. If the dashpot exerts too much damping your system will not oscillate.

2. Setting the mechanical zero position

By turning the thumbscrews, set the mechanical zero position indicator. This will help you determine the size of the initial displacement.

3. Turn on the system

Push the button on the white and black box to enable the control system.

4. Set the electrical zero position

Select **Utility** → **Zero Position** to set the current position to zero. You may have to click on this a few times. Look at the **Following Error** readouts, if they are zero or near it you can continue..

5. Set the units

Select **Setup** → **User Units** and set the units to **counts**.

6. Set the trajectory for an initial condition response

Select **Command** → **Trajectory**. Select **Step** and click on **Setup**. Select **Open Loop Step** and set **Step Size** to **0 (zero)** volts. This is important, we do not want the system trying to move the cart! Set the **Dwell Time** to something like 2000 ms, this is the time the system will be recording data. Finally click **OK**, then **OK** and you should be back to the main menu.

7. Prepare to collect data

Select **Data** → **Setup Data Aquisition**. Set the **Sample Period** to every 1 servo cycle. Be sure you are recording from all of the encoders (if you need to change this, see me). Click **OK** to get back to the main menu.

8. Prepare to plot the data

Select **Plotting** → **Setup Plot** You'll want to remove **Encoder 3 Position** and add **Encoder 1 Position**. The click **OK** and get back to the main menu.

9. Collecting initial condition data for log-decrement analysis

Select **Command Execute**. A menu box will come up with a number of options, and a big green **Run** button. At this point one person should displace the first cart and try and hold it still (so there is no initial velocity, only an initial position). One partner should then click on the **Run** button, and a short time later the person holding the cart should release it. You want to record the initial position and the subsequent motion of the cart. **If the motor is on, release the mass at once!** When the system has finished collecting data, a box will appear indicating the how many sample points of data have been collected. (If you have hit a stop, the system stops recording data.) Click on **OK** to get back to the main menu.

10. Plotting the data

Select **Plotting** → **Setup Plot**,then **Plot Data**. You should look at the data before you export it.

11. Exporting the data

Select **Data** → **Export Raw Data**. When asked where to put the data, put it into the **ECE 521** folder or any folder you want to in the **ECE 521** folder.

12. Set the trajectory for a step response

Select **Command** → **Trajectory**. Select **Step** and click on **Setup**. Select **Open Loop Step** and set **Step Size** to a voltage level below 3 volts. You may want to try various voltages. Be sure to record this voltage! Set the **Dwell Time** to something like 2000 ms, this is the time the system will be recording data. Finally click **OK**, then **OK** and you should be back to the main menu.

13. Collecting step response data

Select **Command Execute**. A menu box will come up with a number of options, and a big green **Run** button. Click on the **Run** button. When the system has finished collecting data, a box will appear indicating the how many sample points of data have been collected. (If you have hit a stop, the system stops recording data. This usually means you're input amplitude in step 12 was too large. Got back to step 12 and choose a smaller voltage.) Click on **OK** to get back to the main menu.

14. Plotting the data

Select **Plotting** → **Setup Plot**, or just **Plotting Data** → **Plot Data**. You should look at the data before you export it.

15. Exporting the data

Select **Data** → **Export Raw Data**. When asked where to put the data, put it into the **ECE 521** folder or any folder you want to in the **ECE 521** folder. You should give this file a name similar to the name you gave to the corresponding initial condition response so you will remember they go together.

16. Preparing the data for analysis

At this point you need to locate the files you have exported, and edit out the first line and the '[' at the beginning of the second line. Save the files as type '.dat'. If you screw up you'll still have the original files, and the GUI's expect files to have the suffix '.dat'.

17. Log-Decrement Analysis

Start Matlab and set the default folder to the **ECE 521** folder. Type log_dec to start the log-decrement analysis. You will need to compare the estimated transfer function with the measured step response. Be sure to print out a figure of your final estimate of the step response.(See subsequent page for a description of this program)

18. Step Response Analysis

From Matlab, type **fit**, which starts a routine to help you find a second order estimate of a transfer function using the settling time and the damping ratio directly. Be sure to print out a figure of your final estimate of the step response.
(See subsequent page for a description of this program)

NOTE The *log-decrement* and *fit* programs are to be use *independently*. Do not just take the estimates from the *log-decrement program* and type them into the *fit* program. You may want to have one partner operate one program and the other operate the other program and then compare the answers.

log_dec Program

You should generally go through the following steps in the following order:

1. Load IC Response Click here to load the file with the initial condition response.

2. Encoder In this lab we will be looking at the displacement of the first mass, so enter **1** for the first encoder.

3. Plot IC Response This will plot the initial condition response from the file you chose. If you don't get anything you may have entered the filename wrong or chose the wrong encoder. Other possibilities are that you did not record all of the encoders in the default order, or that you did not edit the data file properly.

4. Final Time This lets you choose a different final time to display the IC response. You may want to change this and then plot the IC response again since you are interested in only the first few cycles.

5. Peak Separation This is a parameter that determines the minimum number of samples between peaks. It is important that peaks be numbered consecutively (at least the peaks after the initial displacement).

6. Compute + Peaks/ Compute - Peaks The log-decrement looks at what happens from one set of peaks to another. You have the choice of looking at positive peaks or negative peaks. In some instances, where there is alot of damping, you may not get much oscillation. Then you may want to use the negative peaks to do the log-decrement.

7. Make + Figure/ Make - Figure This will print out a figure with the peaks numbered. This is useful for your lab reports.

8. Low and High Once the peaks have been identified, you need to choose the peaks to use for the log-decrement analysis. Here you enter the lowest number (for the starting peak) and the highest number (for the ending peak). Note that it is not necessary to use all of the peaks, and that, in fact, you are usually better off using the first few peaks and ignoring the others.

9. Estimate TF Click on this box to estimate the transfer function parameters (ζ and ω_n) based on the log-decrement analysis and your chosen peaks.

10. Load Step Response Click here to load the step response file into the program.

11. Encoder Enter the encoder for the mass we are looking at (enter 1 for encoder 1)

12. Plot Step Response Plot the step response.

13. Final Time Determine the final time for the step response plot. Note that since the system step response is both “on” then “off” you usually choose a final time where the step is still “on”.

14. Gain Here you guess at the system gain. At this point we have a model of the system but we don’t know the system gain. It won’t take long to iterate and get it pretty close.

15. Compute Fit Click on this to see the step response of the true system and the step response of your model. Note that these may not be very close since we didn’t model the motor/rack/pinion very well. To get the system gain iterate between 14 and 15 a few times.

16. Make Figure This will produce a figure of the step response of the real system and your model. The important system parameters will be printed out. This is a good figure to have in your report.

fit Program

1. Encoder In this lab we will be looking at the displacement of the first mass, so enter **1** for the first encoder.

2. Load Step Response Click here to load the step response file into the program.

3. Plot Step Response Plot the step response of the system.

4. Final Time Determine the final time for the step response plot. Note that since the system step response is both "on" then "off" you usually choose a final time where the step is still "on".

5. Settling Time Enter your estimate of the settling time. We want to match the early part of the step response, so your estimate of the settling time will probably end up being smaller than you think it should be based on the step response.

6. Damping Ratio Enter the damping ratio. Again, we want to match the early part of the step response.

7. Gain Here you guess at the system gain. At this point we have a model of the system but we don't know the system gain. It won't take long to iterate and get it pretty close.

8. Recompute Fit Click on this to see the step response of the true system and the step response of your model. Note that these may not be very close since we didn't model the motor/rack/pinion very well. Try to model the early part of the step response as well as you can. You will probably need to iterate between steps 5 through 8 a few times.

9. Make Figure This will produce a figure of the step response of the real system and your model. The important system parameters will be printed out. This is a good figure to have in your report.

Your memo for this lab should indicate (briefly)

- if the two different methods of estimating the transfer function seemed to match.
- a list any improvements to the lab you might suggest.
- a table showing the estimated gain and the (step) input voltage for each configuration. Is there a constant relationship?

You should have as attachments to your memo (though all in the same document file) plots showing the response of the estimated transfer function using the *log-decrement* program and plots of the estimated transfer function using the *fit* program. Hence there should be two plots for each system analyzed. The captions to these figures should indicate the configuration of the system (weights, springs, damper settings). Your pre-lab does not need to be computer generated.

You should try for seven attempts to identify systems

- with three different spring configurations
- with three different masses
- with and without an active damper