ME 406 ADVENTURE 9

State Feedback Control

Course Value: 100 points

Deadline: COB 10 / 12 Nov 2004

INTRODUCTION

We can design better controllers if we have more measurements of the system behavior. In the case where we can measure all of the system states, we can place the closed-loop poles anywhere we choose within the constraint of actuator saturation. In this lab, we should be able to demonstrate drastically better performance than lab 8 by using full-state feedback to place the poles somewhere to our liking

OBJECTIVE

The objective of this adventure is to:

+ Design a State feedback compensator.
+ Implement the controller on the ECP hardware.
+ Compare the hardware performance with that of a Matlab simulation.
+ Confirm the location of the closed-loop poles in from system response data.

A. PRE-LAB

For this lab, we will use the same setup as Lab 8. You should have the first cart configured with two 500g brass masses and the second one with four. A lumped parameter schematic is shown in the figure below.

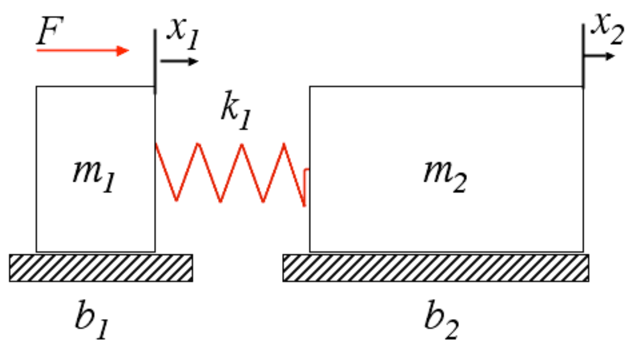

Figure 1: Plant Schematic

The state space description of the system above is shown below. The ECP software uses the state vector: $\mathbf{x} = \begin{bmatrix} x_1 & \dot{x}_1 & x_2 & \dot{x}_2 \end{bmatrix}^T$. Thus, we have transformed the state description accordingly. We will use the state space method of pole placement to design feedback gains.

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}u$$

where

$$\mathbf{A} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{k_1}{m_1} & -\frac{b_1}{m_1} & \frac{k_1}{m_1} & 0 \\ 0 & 0 & 0 & 1 \\ \frac{k_1}{m_2} & 0 & -\frac{k_1}{m_2} & -\frac{b_2}{m_2} \end{bmatrix}, \quad \mathbf{B} = \begin{bmatrix} 0 \\ \frac{K}{m_1} \\ 0 \\ 0 \end{bmatrix}$$

With the output equation

$$\mathbf{y} = \mathbf{C}\mathbf{x} + Du$$

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad \mathbf{D} = [0]$$

This time, we will use state feedback. Recall that using the feedback law The ECP software takes the encoder measurements and electronically differentiates them. It then applies the user specified gains to each state. The block diagram is shown below.

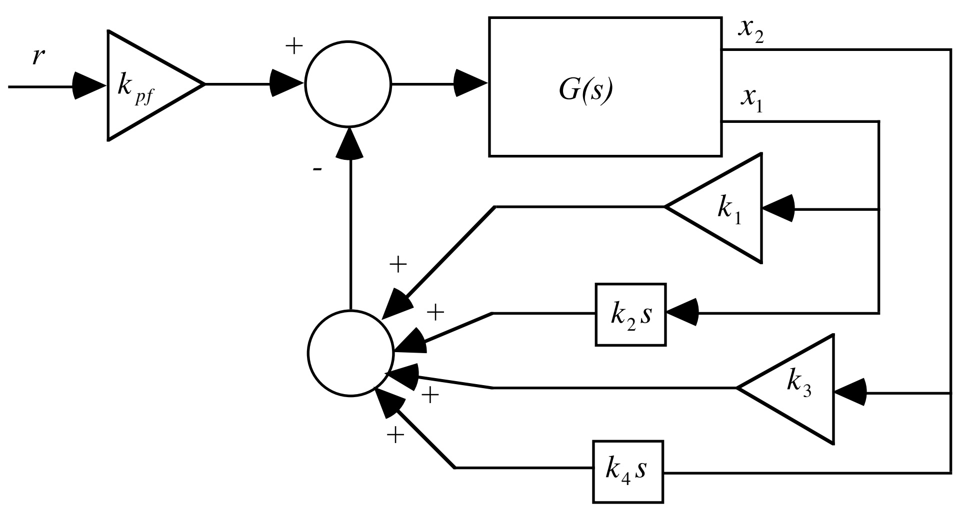

Figure 2: Closed-loop Block Diagram

Construct the state space using the system paramters that you identified in Lab 2. Your model should be in units of 'counts'. If you have parameters valid for cm, simply multiply the system static gain K by 2196. Use Ackermann's formula (Eqn 7.80 on p. 521 of the text) to determine the feedback gains $\mathbf{K} = [k_1 \quad k_2 \quad k_3 \quad k_4]$ for each of the following sets of poles

Set 1	Set 2	Set 3	Set 4
$s = -7.533 \pm 27.28j$	$s = -8.7164 \pm 26.7j$	$s = -9.3632 \pm 26.0j$	$s = -9.6046 \pm 25.516j$
$-18.53 \pm 10.35j$	$-23.59 \pm 9.53j$	-35.1	-60.124
		-26.96	-22.841

Now use the method presented on pp. 525-526 of the text to determine the corresponding prefilter gain k_{pf} for each pole set. The equations are repeated here in standard notation for convenience.

$$\begin{bmatrix} \mathbf{N}_x \\ N_u \end{bmatrix} = \begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{C} & D \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{0} \\ 1 \end{bmatrix}$$

Use only the second row of the original **C** matrix for **C** since we are considering the position of the second mass to be the output.

$$k_{pf} = \left(N_u + \mathbf{K}\mathbf{N}_x\right)$$

Finally, multiply all of these gains (**K** and k_{pf}) by 100/2196 to correct the units for use on the ECP hardware.

B. THE ADVENTURE CONTINUES - IN THE LAB

During the adventure you will set out to accomplish the following:

1. Set up the environment.

a. Use the same station you used for Lab 2. It should be set up in 2 DOF mode with two 500g brass masses on the first carriage, four masses on the second carriage, no damping, and the first two carriages connected by a stiff spring. If you need help configuring your station, ask your instructor.

b. Position the masses at zero on the position ruler. Under Utility, select Zero Position.

c. Check the encoder polarity. This is an important step that should be done each time before implementing a feedback controller. Some systems have 'reverse polarity' meaning that the sensor says the mass is displaced to the left when it is really displaced to the right. I have even seen a system change its polarity overnight! Log on to the computer and start the ECP executive program under Programs/ECP. Select Setup/Control Algorithm... In the dialog box, select the PID radio button, and press 'Setup Algorithm'. Enter a small value for proportional control such as 0.06, and select the Encoder 2 radio button. Set the derivative and integral gains to zero. Press Implement Algorithm. Press OK. Push the black button of the ECP control box. Set up the trajectory for a closed-loop step with an amplitude of 1000 counts, and a dwell time of 3000ms. Select Command/Execute and press Run. Select Plotting/Setup Plot. In the dialog, add Commanded Position and Encoder 2 Position to the Left Axis, the click Plot Data. If the Encoder 2 position moves in the same direction as the Commanded position, your system has normal polarity. If Encoder 2 position moves in the opposite direction, you have reverse polarity. This means you must multiply your contoller gains by -1 throughout the rest of this experiment.

d. Select Setup/Control Algorithm... In the dialog box, select the State Feedback radio button, and press 'Setup Algorithm'. The compensator format is shown in Figure 2 above. Carefully enter the coefficient values for your state feedback controller. Press Implement Algorithm. Press OK. Push the black button of the ECP control box. You might hear the system rattle a bit due to sensor noise in the feedback loop.

2. Recording Step response data:

a. Select Command/Trajectory... In the dialog select the Step radio button and press Setup. Now select Closed Loop Move. The Amplitude should be set to 1500, set the dwell time to 3000 ms. Click OK. Click OK on the Trajectory Configuration dialog.

b. Select Command/Execute and press Run.

d. Watch the response. After the Upload successful dialog completes, click OK.

e. To look at an individual data set, select Plotting/Setup Plot. In the dialog, add Commanded Position and Encoder 2 Position to the Left Axis, add Encoder 1 Position to the Right Axis, then click Plot Data.

f. Export your data. Select Data/Export Raw Data... Browse to a convenient directory, floppy disks are recommended for storing this data. Save as type All files (*.*). Choose a name with meaning, like 'lab9ini.m'.

g. If you are having problems with stability or excessive noise, check that your units agree as shown in the pre-lab near Figure 2.

h. You can use Secure FX to move your data to your afs space. A shortcut is provided on the lab computer desktop.

C. ANALYSIS

1. Plots: Include your experimental step responses, that show Position 1 and Position 2. I have provided a sample response below.

D. REPORTING THE ADVENTURE

Submit one Adventure report per team. Each individual will receive the team grade for the adventure. Be sure your report includes, but is not limited to the following,

+ introduction, results/discussion, conclusion, and appropriate appendices
+ Plots of all closed-loop responses
+ List any suggestions for improving the adventure.