Lab 1: Introduction to MATLAB and Simulink

I. Objective

The goal of this lab is:

- **a.** To help students become familiar with the MATLAB and Simulink environment.
- **b.** Understand some of the basic concepts behind control theory: equilibrium points, stability, feedback and steady state response.

II. Software and equipment

1. Computer with MATLAB and Simulink installed.
2. ee128 student account

III. Theory

MATLAB (MATrix LABoratory) is an industry standard for control systems design. Simulink is the graphical front end to MATLAB.

Please note that lab 1 assumes you are familiar with chapters 1 through 4 in [1] (your textbook). For this lab, the theory section is just a reference for MATLAB commands and Simulink blocks. You could directly go to the Lab Policies section, but this section should be very helpful when you do the actual lab.

1. MATLAB commands

You will be mainly using the MATLAB Control System Toolbox. A great way to get started with the toolbox is to run the demo. This is done by typing "demo('toolbox','control')" at the MATLAB prompt. Aside from the basic MATLAB plotting commands, you should become familiar with:

a. tf - This command is used to enter transfer functions. For example to enter the transfer function $H(s) = \frac{s+2}{s^2+5}$, you would type "H = tf([1,2],[1 0 5])". The first parameter is a row vector of the numerator coefficients. Similarly, the second parameter is a row vector of the denominator coefficients.

b. conv - This command is used to convolve two polynomials. It is particularly useful for determining the expanded coefficients for factored polynomials. For example, this command can be used to enter the transfer function $H(s) = \frac{s+2}{(s+1)(s-3)}$ by typing "H = tf([1 2],conv([1 1],[1 -3]))".

c. series or * - This command is used to combine two transfer functions that are in series. For example, if $H(s)$ and $G(s)$ are in series, they could be combined with the command "T = G*H" or "T = series(G,H)".

d. feedback - This command is used to combine two transfer functions that are in feedback. For example, if $G(s)$ is in the forward path and $H(s)$ is in the feedback path, they could be combined with the command "T = feedback(G,H)".

e. step - This command is used to plot the step response of a system. For example, "step(T)" would plot the step response of the system $T(s)$.

f. bode - This command is used to plot the frequency response. For example, "bode(H)" would plot the frequency response (both magnitude and phase) for the system $H(s)$.

g. rlocus - This command is used to plot the root locus. For example, "bode(G*H)" would plot the frequency response of the system $G(s)*H(s)$. **Keep in mind that this command is used on the loop gain of the system** as opposed to the closed-loop transfer function. For example, consider the standard negative feedback system with forward path G and feedback path H. The loop gain would be $G(s)*H(s)$ whereas the closed-loop transfer function would be $\frac{G(s)}{1+G(s)H(s)}$.

2. Simulink components

For most of the systems we will encounter, we only need to be concerned with a small fraction of Simulink's component library. In particular, the components you should be familiar with are:

a. ”Continuous” library
Integrator – integrates a signal
State-Space – used to add a system block in state-space form
Transfer Fcn – used to add a system block in transfer function form

b. ”Math Operations” library
Gain – a constant gain
Sum – used to add two or more signals. To add more input nodes or change the sign of an input node, double-click on the "Sum" component and modify the text in the "List of Signs" parameter. To make the sum have a "+" and a "-" node, change the "List of Signs" parameter to "|+-". To add a third summing input node, change the text to "I+++".
Trigonometric Function – used to place non-linear trigonometric elements

c. ”Signal Routing” library
Mux – used to multiplex signals together in order to plot several on one graph

d. ”Sinks” library
Scope – used for viewing system output
To workspace – used to transfer a signal to MATLAB where you can plot it or process it as you wish. To set this up, double-click on the component and change the 'Save format'

parameter to 'Array'. Also, set the 'Variable name' parameter to something descriptive, such as 'yout'. Simulink also automatically exports the time in the MATLAB variable 'tout'. This allows you to plot the output in MATLAB using the standard 'plot' command, and also allows you to nicely label the plots.

e. ”Sources” library

Ramp – generates a ramp signal
Sine Wave – generates a sinusoid
Step – generates a unit step signal

IV. Lab Policies

Since this is the first lab, the lab policies for the course will be clarified. The labs are a significant part of this course, both in terms of effort and grading. There are certain guidelines and rules to let you know what is expected from you in the lab and in your lab write-ups. Labs will typically be worth between about 30 and 70 points total. The style and write-up considerations mentioned below will be worth ten points of your lab write-up grade. Other penalties (e.g., illegible writing, late lab write-up, etc.) will receive an additional point deduction outside of the ten points for style and write-up. Also, these policies are subject to change, though a reasonable effort will be made to notify you of any changes.

1. Lab Instructions

a. If you are unable to attend a lab session because of a legitimate conflict, please contact the GSI in advance to arrange an alternative time to make up the missed lab.

b. Lab write-ups for lab "n" are due at the start of lab "n+1" (n is a natural number). That is, the lab write-up for lab 1 is due at the start of lab 2. You will receive a 10 minute grace period (in addition to Berkeley-time) in which to turn in your lab. Labs turned in after this grace period will be considered late. Late labs will receive a twenty-percent point deduction off of your lab write-up grade, and you will have to make arrangements with the GSI for late submission. Lab write-ups will not be accepted beyond two days after your due date and you will receive zero credit for the lab write-up.

c. Pre-labs should be done before getting to lab, but the pre-lab does not have to be formally written up. However, if your pre-lab is not complete within the 10 minute grace period, you will receive a five-percent deduction off of your lab write-up grade. **Prelabs are to be done individually.**

d. At the top of each lab write-up include: the name of your group members, the date, and your lab section.

e. Experiments should be done in groups of three. Groups of four might be needed if there are an odd number of people in the lab or if a particular lab does not have enough lab setups.

f. The lab write-ups are to be done as a group. You will submit one lab write-up per group.

g. Copying, fabricating data, and any other forms of cheating will be referred to the professor for disciplinary action.

2. Lab write-up Style

a. The lab write-ups must be typed and plots must be computer generated. Equations, block diagrams, schematics, and other figures may be done by hand; however, hand-drawn figures must be legible, neat, and done in black or blue pen. If hand-drawn figures do not follow these guidelines, points will be deducted. If you are in doubt about the quality of your figures or drawing ability, make them on a computer.

b. If you use MATLAB or SIMULINK for plots or calculations, you must include all accompanying code and system diagrams. The code and system diagrams should also be labeled. It is good practice to put your MATLAB code into separate M-files for record-keeping and to include your name in the comments of your code.

c. All figures, plots, and code must be labeled, including hand-drawn figures. The labels should describe what a figure is, without having to reference any other information. The labels can be done by hand if appropriate and reasonable, while following the guidelines on hand-drawn figures.

d. Lab write-ups should be self-contained. What this means is that the lab write-up should make sense without having to reference the experiment write-up. This includes things such as:

   i. Answers to questions from experiment write-up should include the question itself; you do not have to copy the question, but you should incorporate the question into the answer itself.

   ii. Figures (e.g., schematics, block diagrams) of the system being analyzed should be included in the lab write-up.

   iii. All analysis and derivations should be shown.

   iv. Explain your answers; your line-of-reasoning should be included.

e. The lab write-up should generally contain the following sections:

   i. **Purpose** - This should be a short, introductory paragraph on the objectives or goals of the lab and what general tasks you did in the lab.

   ii. **Pre-lab** - If the lab has an associated pre-lab, include all the pre-lab analysis and questions in your formal lab report.

iii. **Procedure** - This section should include what you did in the lab, problems you had in the lab and how you dealt with those problems, and measurements you made; also, include anything that is different, unique, or novel about your procedure.

iv. **Analysis** - This section should include the analysis of the system as well as the analysis of the data from the lab.

v. **Conclusion** - This should include several parts including a section comparing theory to the experiment and another section on what you learned in the lab. Make sure to discuss the reasons for any disagreement between theoretical predictions and experimental results and make suggestions on how to reduce this disagreement, if possible.

f. You are free to split the procedure (and analysis) section into smaller sections, if you feel the need to do so. The only set constraints are the purpose, pre-lab, and conclusion sections. You can organize the other sections however you want as long as you include the above, general ideas.

V. Prelab

1. Simple feedback system

Consider the system shown in figure 1 below.

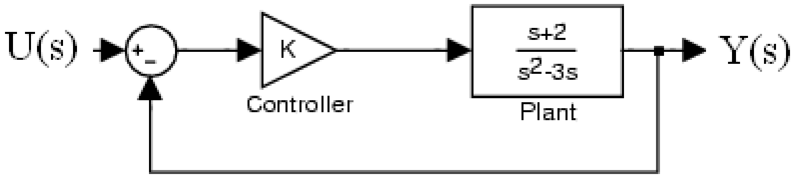

Figure 1. Simple proportional control system

Suppose the control goal is to track a step input.

a. What are the poles and zeroes of the open loop system? Is the open loop system stable? Can the open loop system track a step input?
b. Suppose you use proportional feedback control as shown in figure 1. Explain *why* the scheme above is called proportional feedback. Explain *how* this scheme can be used to stabilize the system (hint: try and explain the *how* part mathematically).
c. Can you make the system stable for all values of K? Explain.
d. For what values of K is the system completely oscillatory?
e. For what values of K is the system stable?

2. Nonlinear damped pendulum

The dynamics of a real plant are nonlinear in nature. There is a plethora of interesting mathematical and physical differences between linear and nonlinear systems. In this part, you study the mathematical differences between a linear and nonlinear version of the pendulum with respect to equilibrium points.

Consider the nonlinear equation of motion for a damped pendulum given by:

$$\ddot{\theta} + \frac{c}{ml}\dot{\theta} + \frac{g}{l}\sin(\theta) = \frac{T_c}{ml^2}$$

Here θ is the angle of the pendulum from the vertical (in radians), c is the velocity dampening term (in 1/s), m is the mass of the pendulum (in kilograms), l is the length (in meters), g is the acceleration due to gravity (in m/s^2) and T_c is the force input (in N.m). For this problem assume that g =9.8, l = 2.5, m = 0.75 and c = 0.15.

a. What is the nonlinear term in the pendulum equation above?
b. Very often, you remove the nonlinearity in the plant by linearizing the plant about an operating point. In our case, we will just do a Taylor series expansion for the nonlinearity and disregard the nonlinear terms in the expansion.

   What are the first three terms in the Taylor series expansion of the nonlinearity? What is the linearized version of the simple pendulum equation?

VI. Lab

0. General Instructions

a. The lab is located in 204 Cory Hall. **TASK 1:** Get a computer account from the TA.

1. Simple feedback system

a. **TASK 2:** Construct a model for the simple feedback system in figure 1 in Simulink. You should plot the step input and the response of the system on a single scope using the MUX block.
b. **TASK 3:** Verify the system is oscillatory for any K value in the corresponding interval by printing the output of the scope block for this value of K.
c. **TASK 4:** Verify the system is stable for any K value in the corresponding interval by printing the output of the scope block for this value of K.
d. **TASK 5:** Suppose we want the final value of our response to be within 0.01% of the final value of our input (step) signal. That is, the *steady state error* is 0.01%. Further, let us assume the final value is achieved for t ≥ 10 seconds. In this case, we say that our tracking goal has been achieved.

USING YOUR SIMULINK BLOCK DIAGRAM, determine for what values of K is the steady state error 0.01% (for t ≥ 10 seconds)? You don't have to analytically solve for the K value (yet).

Notice that in designing a control system we first analyzed the stability of our open loop plant. If our open loop plant is unstable, we use feedback to stabilize the system. Then we pick the values for the parameters in our control law so our control objective (in this case, a constraint on the steady state error) is achieved. Of course, there will be other constraints (transient response for example). Satisfying all the design requirements is the goal of control theory.

2. Nonlinear damped pendulum

a. **TASK 6:** Design the nonlinear damped pendulum in Simulink. To construct this system, you will need to use the "trigonometric function" component which is found in the "Math Operations" library of Simulink. Try and make the model robust, that is, you should parameterize the constants in your model.
b. **TASK 7:** Print the response (theta) of this system to a pulse having amplitude 20 and width 0.1 seconds. There are several ways to generate such a pulse; one easy way is to use a "pulse generator" with period = 100 and the appropriate pulse width. When you print the graph, show the response for 50 seconds of time. To what value is the pendulum angle converging to?
c. **TASK 8:** Print the response (theta) of this system to a pulse having amplitude 200 and width 0.1 seconds. To what value is the pendulum angle converging to now? Using a few sentences, explain why.
d. **TASK 9:** Replace the nonlinear term in your Simulink model with the linear version. Repeat the experiment for the pulse with amplitude 20 and width 0.1 seconds. Do the nonlinear and linear versions agree for the angle response?
e. **TASK 10:** Now try the linear version with the pulse having amplitude 200 and width 0.1 seconds. Do the nonlinear and linear versions agree for the angle response?
f. **TASK 11:** Based on your results from TASKs 9 and 10, is the linear approximation a "good" approximation?

VII. Revision History

Semester and Revision	Author(s)	Comments
Fall 2008 Revision 1.1	Justin Hsia	Changed lab policies regarding group size and write-up
Summer 2008 Revision 1.0	Bharathwaj Muthuswamy	1. Formatted writeup into different sections. 2. Typed up solutions
Fall 2005 Revision 0.0	Ping Hsu	Initial version of the lab writeup

VIII. References

1. Franklin, Gene F., Powell, David J. and Emami-Naeini Abbas. *Feedback Control of Dynamic Systems.* 5th Edition. 2006, Prentice-Hall Inc.
2. EE128 Fall 2007 Lab 1 guide. Online at http://inst.eecs.berkeley.edu/~ee128/fa07