Lab 1: System Identification

Overview

In this lab, you will put your system identification skills to the test by using two different experiments to identify the transfer function of a simulated spring mass damper system. The parameters of this system are unique to every student.

Note: The system could be overdamped or underdamped, which might lead to responses that resemble those of a first-order system, in which case, you may wish to propose a reduced-order model. It might not be possible to estimate the locations of both poles, or find the spring and damping coefficients of the system using these rudimentary tests. **You will be marked primarily on your approach, not the accuracy and detail of your eventual model.**

Preparation

To complete this activity, you should be familiar with the time and frequency domain responses of first- and second-order LTI systems, and able to extract the transfer function of such a system from either its step response or Bode plot. If you can confidently answer the tutorial questions on this topic (Tutorials 2 and 3), the only preparation you need to do is going over the lab setup and instructions so you know what to expect when you get to your bench. Otherwise, please revise this topic and try working through the questions with the assistance of a tutor.

Lab Setup

You will use the suspension simulator program in the Control Lab to perform your experiments. You will find a manual for this program attached to this document.

Instructions

Test System

The simulated spring mass damper system is represented by the differential equation,

$$m\ddot{x}(t) = -b\dot{x}(t) - kx(t) + F(t)$$

where $x(t)$ is the displacement of the mass, and $F(t)$ is an applied force that is directly proportional to the voltage input to the system. The goal of your experiments is to apply appropriate input signals so you can estimate the damping and spring coefficients based on the system's responses. You can assume that the system starts from rest (zero initial conditions) and that all parameters are scaled to the mass of the system (effectively, $m = 1$).

A system with unique, randomized parameters will be generated each time you do the test. This system could have any of the damping conditions that have been discussed in class.

Stage 1 – Step Test

Apply a step input to the system and record its response over a reasonable time interval.
Hint: In the suspension simulator, selecting 'Start Step Test' will step the height of the plane, not the suspension. To get results in the format you are used to seeing, you should select 'Laboratory Testing' and use the offset input to apply a unit step.

Use the step response to answer the following questions. Your answers will help you in the next stage.

1. What is the gain of the system?
2. Does the system have real or complex poles?
3. Where do you estimate the dominant pole or complex pole pair to be?
4. From 3, what would you expect the corner frequency of this system to be?

Stage 2 – Frequency Response Test

Apply sinusoidal inputs over a sensible range of frequencies (based on your results in the previous test) to obtain the frequency response of your system.

Use features of the frequency response to confirm your answers to the four questions in the previous stage. Depending on the damping of your system, it may be possible to expand on your answer to question 3 by identifying the location of a non-dominant pole that would not have been visible from the step response alone.

Hints: The simulator does not perform a full frequency sweep. You will be applying individual sinusoids to the system, and noting the change in magnitude and phase between input and output. This will enable you to sketch a coarse Bode plot for the system. This is why it is important to have some idea of which frequencies are worth testing *upfront.* You will probably need at least five frequencies to get a complete enough frequency response to work with. You may want to choose more frequencies close to important features such as the estimated corner frequency. It is a good idea to plot your points as you go, so you can identify regions where you might want more information.

Report

Use the provided template to write a brief report on your findings.

We have included a rough template to give you an idea of what you should include in your report.

EEE3094S Lab 1 Report

About this template: The purpose of this template is to show you the minimum information that we expect you to include in your report, and a rough idea of how you might want to lay it out. It is not a 'fill in the blocks' exercise – to get a good mark, you will need to support your figures and calculations with clear explanations of your thought process **in words.**

How to do well in your lab report:

The aim of these labs is not only to give you a chance to apply your control knowledge practically, but also to teach you how to document experiments effectively. This is a really important skill that you will use many times in the remainder of your degree (e.g. in your fourth year design course, and your final year project), and more so if you decide to continue into postgraduate studies.

In this course and others, it's always important to remind yourself: your markers see your report, not your actual work. **So you're not getting marked on how well you do the thing, but how well you communicate about it.**

General Advice

With academic writing, the most important thing to keep in mind is that your document must be **useful** for the reader. Always imagine somebody trying to understand what you did in your experiment and why, and then try with every decision to make their life easy. Just think: *Would I want to read this?*

Academic papers can give you an idea of good practices, since they would have had to do all of these things right to pass peer review. If you haven't read a paper before, here is one by A/Prof. Patel about his cheetah-inspired robot, Dima: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6697154

(If that link doesn't work, search: Rapid turning at high-speed: Inspirations from the cheetah's tail, Patel, Braae)

Calculations

Wherever we ask for calculations, we don't just want you to dump a bunch of illegible mathematics at us. Think about the worst worked solutions lecturers or textbooks might have thrown at you before, the ones that make you ask:

Wtf is happening here? Where did that number come from? What formula is this? What does that symbol mean? How did we even get from there to here? Why are these equations scattered across the page with no obvious order or structure? What can I do with my life if I just drop out right now instead of dealing with this unintelligible wall of numbers and letters?

Here are some tips to make your calculations not look like that:

- Be neat. Use the equation editor in Word or LaTex to **type** your calculations out.
- Keep your steps clearly separated (e.g. on different lines)
- Give short descriptions of each step **in words** before showing the mathematical description.
- State which formulas, assumptions and general transforms you are using.
- Check that every symbol you use has a clearly-communicated meaning somewhere in the text, even if you think the meaning is obvious or already established in class.
- Avoid "magic numbers" i.e. numerical values dropped in with no explanation. Your descriptions should make it clear where the values come from (e.g. your plots).

- Try to write so your mathematics and text descriptions flow together into readable sentences, for example:

> Based on the oscillations observed in the step response of the system (Figure 2), we consider the behaviour to be consistent with a second-order underdamped system. We will therefore model the transfer function $G(s)$ using the form
>
> $$G(s) = \frac{A\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$
>
> where A is the gain of the system, ω_n is the natural frequency and ζ is the damping ratio.
>
> To obtain A, we used the final value of the step response, which was shown in Figure 2 to be...

Figures

Figures should be high-quality and professional. This means:

- Clear, high-resolution images
- Figures that are properly exported from the software you choose to use. If you absolutely must use a screenshot, please crop it appropriately.
- Labelled axes, with fonts that are clear and large enough to read.
- Sensible plot parameters: your choices of colours, line widths, markers, gridlines, etc. should work to make your data as readable as possible.
- Descriptive captions briefly explaining the image and its most important features.
- Thoughtful annotations drawing attention to key features.

Figures must always be referenced in the text (in this case, the description of your calculations). If you have no reason to reference a figure, it's irrelevant and shouldn't even be included. Something important in one of your plots should be pointed out in **at least three places:**

1) The figure itself (preferably annotated)
2) The caption of the figure
3) In the text, where that feature is used as evidence to support something.

This might seem redundant, but it will help your report be readable to two levels of reader: (1) people who are just scanning through to get a general feeling of what you did and what happened, and (2) people reading it in-depth.

Bad example:

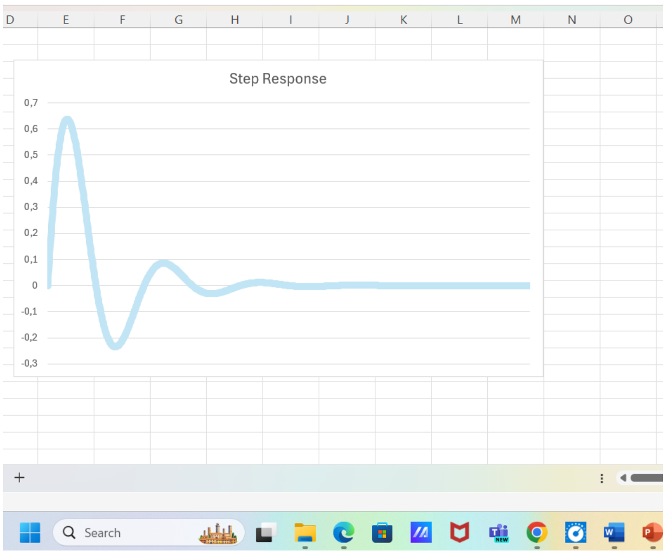

Figure 1: Step Response

Good example:

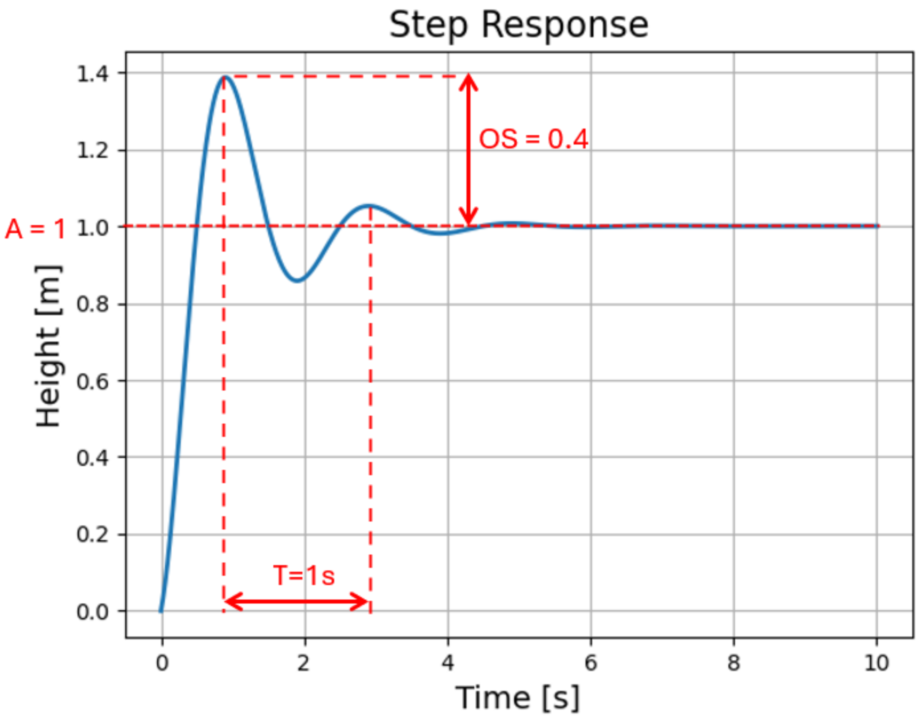

Figure 2: Step Response. The response is oscillatory, with an overshoot (OS) of 0.4 m. The final value (A) is 1 m and the period (T) is 1 s.

Results

Figure 3: Step input

Figure 2: Step response

Figure 3: Frequency response.

Calculations

The gain of the system is (value).
(Describe evidence from the step and frequency responses that support your findings. Clearly mark and label the features you refer to on each plot. Briefly show and describe any necessary calculations.)

The poles of the system are at (values).
(Describe evidence from the step and frequency responses that support your findings. Clearly mark and label the features you refer to on each plot. Briefly show and describe any necessary calculations.)

Note: you may only be able to clearly identify one pole, depending on the damping characteristics of your system.

System Model

Damping coefficient: $b =$

Spring coefficient: $k =$

Transfer function: $G(s) = \frac{X(s)}{Y(s)}$

Calculations:
Briefly show any necessary working to determine the above using the information you have gathered about your system. Ensure that you describe your process clearly.

Note: You might not be able to estimate both the spring and damping coefficients, or find a complete second-order model for your system. You should state the limitations of your data and what information you expect to be able to extract. Your goal is ultimately just finding a workable model.

Validation:

(Use MATLAB or other software of your choice to simulate your system's step response and frequency response. Compare the simulated results to those observed in the lab. Ensure that you describe what you're seeing, and why you consider it to be a successful or unsuccessful result.)

Figure 4: Simulated vs. observed step response.

Figure 5: Simulated vs. observed frequency response.

Lab 1 Marking Guide

Category	Fail [0-10]	Passable [10-12]	Good [12-15]	Great [15-20]
Step test	Step test was not done or conducted in a way that was flawed to the point of being useless. Results are not displayed, or displayed in a way that is difficult to interpret.	Step test was done mostly correctly, but there may be some errors (e.g. cutting the response off too early to obtain a true final value.) OR there are major problems with how the results are displayed (e.g. unlabeled graphs, marker or colour choices that are hard to read, ugly screenshots.)	Step test was done correctly but there are some minor problems with how the results are displayed (e.g. no gridlines, poor tick spacing.)	Step test was done correctly and the results are displayed clearly. Points of interest are annotated on the graphs for additional clarity.
Frequency test	Frequency test was not done or conducted in a way that was flawed to the point of being useless. Results are not displayed, or displayed in a way that is difficult to interpret.	Frequency test was done mostly correctly but the frequencies selected are arbitrary or miss some features of interest. OR there are major problems with how the results are displayed (e.g. unlabeled graphs, marker or colour choices that are hard to read, ugly screenshots.)	Frequency test was done correctly using sensible choices of frequencies to find important features, there are some minor problems with how the results are displayed (e.g. no gridlines, poor tick spacing.)	Frequency test was done correctly using sensible choices of frequencies to find important features, maybe adding additional frequencies around points of interest to give a more detailed picture. Results are displayed clearly, and points of interest are annotated on the graphs for additional clarity.
Analysis (i.e. calculations)	Analysis of the results is totally incorrect, not based on anything learned in class or absent/ impossible to follow in the report.	The analysis applies some concepts learned in class but they are not well-understood, and there are fundamental mistakes in the approach. There is little to no link drawn between the time and frequency responses, or analysis largely neglects one of the responses	The analysis is logical and well-grounded in the theory of the course. There may be some minor errors e.g. calculation mistakes, or small misunderstandings. Analysis is supported by both the time and frequency responses.	The analysis is logical and well-grounded in the theory of the course, demonstrating a strong understanding, and calculations are accurately done. Analysis is supported by both the time and frequency responses.
Validation	No attempt to validate model, or there was an attempt but it was fundamentally flawed.	A reasonable attempt to validate the model was made, but it is incomplete (e.g. only comparing either the time or frequency response, but not both) or incoherent (conclusions drawn are vague/ incorrect).	A reasonable attempt to validate both responses was made, but there are some minor problems with the approach or conclusions drawn.	The model is tested against both responses and clear, correct conclusions about its validity are obtained. The student has a strong understanding of how to improve the model, and may even have attempted to do so.
Report	Report is unintelligible, very unprofessional or has a lot of missing information.	Report has all the basic information but there are some spelling, grammar or formatting issues.	Report presents all the basic information clearly and professionally. The key steps of the method are described, but some details may have been left out.	Report is clear and professional. Methods are described in sufficient detail to be fully repeatable. Decisions are well-motivated, with clear links drawn between text and figures.