ECE147C/ME155C Project: Two-cart with spring

Spring 2020 **Due: June 12, 2020**

Note: Since the campus is currently closed due to Covid 19, the data that you would have normally collected in the lab is now collected and given to you. You will then proceed with the rest of the parts.

Abstract
The project aims at illustrating the concepts covered in the identification lectures. This document provides a general description of what you are expected to do. It also serves as a "template" for the project report.
[**Report**] The abstract of a report should consist of one or two paragraphs summarizing the content of the whole document. It should focus on the key project achievements.

Note 1. Throughout this document you will find information about what the report should include in the paragraphs labeled [**Report**] .

1 Introduction

The goal of this project is to acquire experience in system identification and controller design. It will allow you to carry out the entire control design process, which consists of:

1. experimental identification,
2. controller design
3. closed-loop testing (and redesign if needed),
4. documentation of the project.

Your report will have to demonstrate that you understand the topics covered in the lectures. You are expected to turn in the following:

1. Answers to the questions posed in this document.
2. A report that summarizes your results. Keep the report short! Your grade will reflect your ability to provide all the information needed in a concise format.

Note 2. E.g., do not give "ten" Bode plots one for each identification experiment, but instead provide one plot with "ten" curves (properly labeled). You will be graded on the quality of the report as a document **not just on its content.**

This document serves a dual purpose: it provides a general description of what you are expected to do and it also serves as a template for the report that you will need to turn in. The final project report should follow this as a template (abstract, introduction and so on).

The remaining of this document is organized as follows: Section 2 is devoted to system identification. Subsection 2.1 describes the system to be controlled and Subsection 2.2 addresses the experimental identification of this process for both parametric and non-parametric identification. The controller design is discussed in Subsection 2.3 and the performance of the closed-loop system is described in Subsection 2.4. Section 3 provides final conclusions and suggests directions for further improvement.

[**Report**] The introduction of a report generally covers, at least, the following three topics:

1. A brief self-contained description of the basic problem addressed in the report.
2. A summary and references to previous related work.
3. A short paragraph outlining how the remaining of the report is organized.

2 System Identification

This section is devoted to the identification and control of a two-cart mechanical system. It describes the entire control design process starting from the identification of the system to be controlled, the controller design procedure, and it also documents the closed-loop performance that will be achieved.

2.1 Process to be controlled

The process to be controlled is the two-carts with spring apparatus shown in Figure 1.

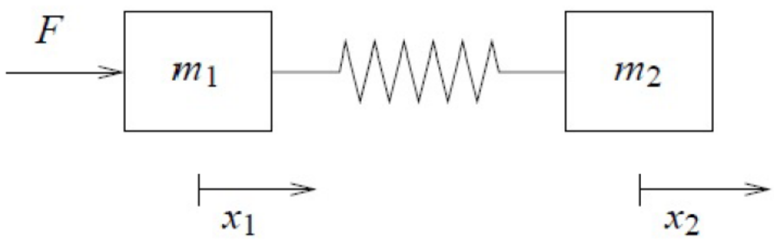

Figure 1: Two-mass with spring

From Newton's law one concludes that

$$m_1\ddot{x}_1 = k(x_2 - x_1) + F, \qquad m_2\ddot{x}_2 = k(x_1 - x_2)$$

where x_1 and x_2 are the positions of both carts, m_1 and m_2 the masses of the carts, and k the spring constant. The force F is produced by an electrical motor driven by an applied voltage V according to

$$F = \frac{K_m K_g}{R_m r}(V - \frac{K_m K_g}{r}\dot{x}_1)$$

where K_m, K_g, R_m, and r are the motor parameters. The control input is a applied voltage $u := V$ and the goal is to control the position $y := x_2$ of the second cart.
The following continuous-time transfer function was provided for this system in ECE147A&B:

$$G(s) = \frac{Y(s)}{U(s)} = \frac{2.97x61.2}{s^4 + 13.24s^3 + 127.15s^2 + 810.37s}, \tag{1}$$

for an input in volts and an output in meters. However, this is *not* the true transfer function of the system.
[Report] This section of the report should briefly describe the model of the process that you are going to control. Make sure that you explain the meaning of all the variables, their units of measure, and specify which ones correspond to the control input(s) and measured output(s).

2.2 Identification

- For the nonparametric identification, read carefully Chapters 1,2,3 and 4 and solve the (previously assigned) Exercises 2.1 (step response) and 2.2 (correlation method). In addition, figure out how to use the key ideas presented in those chapters which are important for identification to work.

Hint: Both for nonparametric and parametric identification you should use the knowledge that the system has an integrator (i.e., a discrete-time pole at $z = 1$). This is very important, otherwise some experiments will lead to an unstable system and others to a stable one, making stabilization of the process very difficult.

- Identify the Bode plot of the two-cart system using nonparametric identification and sine-wave testing. The input is already collected for you, in a manner which makes sure the magnitude is large enough that the output is much larger than the measurement noise (quantization) but not too large such that linearization is valid (See Section 5.1). (Input-output data for this part can be found in "Part1.mat")

- Identify an ARX model for the two-cart system using least-squares (you may use MATLAB's arx command and/or my_id function). Several different input types have been given to the system: a few square waves of low frequency and chirp signals. For parametric identification following issues have to be addressed:

  1. Selection of input magnitude (Exercise 5.1)
  2. Selection of sampling frequency (Exercise 5.3)
  3. Selection of the model order (Exercise 5.2)

  Note that some of these are already addressed for you during data collection. (Input-output data for this part can be found in "Part2.mat").

[Report] This section of the report should include the following:

1. Brief description of each identification methods used, with a justification of all the choices made: input magnitude and frequencies (for nonparametric identification) and model order, type and magnitude of input, validation procedure, sampling rate (for parametric identification). If it is already chosen for you, explain how you would have chosen it. In other words, explain the important things you would have checked when choosing these parameters.

2. For nonparametric identification, estimate appropriate locations for the poles, zeros, and the system's gain

$$H(z) = k\frac{(z-\alpha_1)(z-\alpha_2)\dots}{(z-1)(z-\beta_1)(z-\beta_2)\dots}$$

   to get a good match for the Bode plot. You can subsequently use this transfer function for controller design.

3. Bode plots of the models identified by each method.

2.3 Controller Design

Design a feedback controller for the process that you identified in Section 2.2. You may use either the model identified through parametric or nonparametric identification. Pick whichever model seems more reasonable to you. You may use any control design method of your choice. However, make sure that your controller satisfies the following requirements:

1. For a step-response that corresponds to the motion of the cart from one side of the track to the other, the control input does not exceed the maximum one allowed by the hardware (You can assume the track is 1m long).
2. The step response exhibits an overshoot smaller than around 15%.
   Hint: If you would like, you can also do an alternative design with faster response at the expense of a larger overshoot.
3. The step response exhibits the smallest settling time that you are able to achieve.
4. The closed-loop is somewhat robust with respect to measurement noise.

[Report] This section of the report should include the following:

1. State which identified model you have used and justify why.
2. Briefly describe the control design procedure that you used. Provide (and briefly justify) your design choices.
3. Provide a simulated step-response and Bode plot for the closed-loop using the identified model and the one provided in ECE147A&B [cf. equation (1)].

2.4 Closed-loop Performance

Implement your controller and refine the control design if needed. Run simulations to

1. Evaluate the properties of the closed-loop step response (rise-time, overshoot, settling-time, and maximum control magnitude)
2. Identify the closed-loop frequency response using a method of your choice.

Note 3. You may find out that you need to re-design the controller.

[Report] This section of the report should include the following:

1. Description of the closed-loop step response (include a plot and table with relevant parameters).
2. Description of the closed-loop frequency response (include a plot and a brief explanation of the method used to identify the closed-loop response).
3. Discussion of the differences between the ideal and identified responses.

3 Conclusions and Future Work

[Report] The conclusion of a report generally covers, at least, the following two topics:

1. A brief summary of the main project achievements.
2. A paragraph outlining what else could be done if more time were available.

References

[Report] Any references should appear here.