ECE147C/ME106A Project #1: Two-cart with spring

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Abstract

The first project aims at illustrating the concepts covered in the identification lectures. This document provides a general description of what you are expected to do before and during the corresponding lab sessions. It also serves as a "template" both for the first and final project reports.

[**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.

Sidebar 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 lab project is to acquire experience in system identification, both parametric and non-parametric. The first part of the project is focused on parametric identification of a two-cart system, whereas the second part of the project is about nonparametric identification of a Rijke tube.

The portion of the project devoted to the two-cart system 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.

The portion of the project devoted to the Rijke tube will allow you to understand the issues involved in identifying unstable systems and system identification validation. This document *does not* provide you detailed information about the Rijke tube experiment. This will be provided later.

You will have significant autonomy in choosing the experiments that you will perform in the lab but your report will have to demonstrate that you understand the topics covered in the lectures. You are expected to turn in the following:

1. Solutions to the problems in the lecture notes (on a weekly basis).
2. A lab report that summarizes your results both for the two-cart system and the Rijke tube. *Keep the report short!* Your grade will reflect your ability to provide all the information needed in a concise format.

Sidebar 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 **before and during the lab sessions** and it also serves as a template for the **lab report** that you will need to turn in the middle of the quarter. The final project report (due at the end of the quarter) should also follow this basic template.

The remaining of this document is organized as follows: Section 2 is devoted to parametric identification. Subsection 2.1 describes the system to be controlled and Subsection 2.2

addresses the experimental identification of this process. 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 is devoted to the topic of nonparametric identification. More details regarding this section will be provided later. Section 4 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.

Plan ahead: Before coming to the first lab you should *read all the hints in this document* (including the ones for subsequent sessions), plan which inputs you want to try, and have all the MATLAB scripts ready to analyze the data.

2 Parametric 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 parametric identification of the system to be controlled, the controller design procedure, and it also documents the closed-loop performance that was achieved.

2.1 Process to be controlled

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

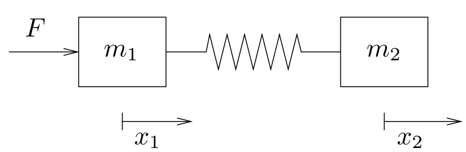

Figure 1: Two-mass with spring

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

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

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:

$$G(s) = \frac{Y(s)}{U(s)} = \frac{2.97 \times 61.2}{s^4 + 13.24s^3 + 127.15s^2 + 810.37s}, \tag{1}$$

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

[Before the lab (session 1)] Read carefully the System Identification Lecture Notes, in particular Lectures #2–#4. The topics in Sections 3.2, 3.3, 4.1, 4.2, 4.3, and 4.4 are especially crucial for the identification procedure to work.

Sidebar 3. The lab session numbers provided do not need to be followed exactly. It is quite possible that you may need to repeat sessions to re-collect data that has problems.

In addition, solve the following (previously assigned) exercises: 6 (input magnitude), 7 (model order), and 8 (sampling frequency) for least-square identification.

Important: Keep all the MATLAB scripts that you wrote for the exercises because you will need them for the system identification of the two-cart system and for your final project.

Hint: To get good models you should use the knowledge that the system has an integrator (i.e., a discrete-time pole at $z = 1$). See Section 3.3 and Exercises 4, 5 of the System Identification Lecture Notes.

Sidebar 4. This is very important otherwise some experiments will lead to an unstable stable system and others to a stable one, making stabilization of the process very difficult.

[In the lab (session 1)] Identify an ARX model for the two-cart system using least-squares. You should try several types on inputs: at least a few square waves of low frequency and chirp signals.

You should carry out experiments along the lines of the lecture notes exercises to address the following issues:

1. Selection of the input magnitude (Exercise 6).

   Hint: Make sure that you validate the data obtained (at least testing visually for linearity across differently scaled inputs, see discussion in Section 4.2). This is crucial because the system easily gets into saturation. Also, very small inputs lead to bad results because of dry friction.

   Be careful! Since the experiments are open-loop it is easy to crash the cart if your input is too large. Make sure your inputs will not make the cart go in one direction too fast and for too long.

2. Selection of the sampling frequency (Exercise 8)

   Hint: It will be crucial to downsample and do some filtering to remove quantization noise. The lecture notes have a discussion of this.

3. Selection of the model order (Exercise 7)

Stop and double check: Before leaving the lab you should convince yourself that the data collected is indeed good. *Look carefully at the transfer functions that you are getting and make sure that they look reasonable.* In doubt, collect more (and hopefully better) data. The better the identified transfer function the more likely it is that you will be able to design a good controller.

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

1. Brief description of the different identification methods used, with a justification of all the choices made (e.g., model order, type and magnitude of input, validation procedure, sampling rate, etc.).

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

2.3 Controller design

[**Before the lab (session 2)**] Design a feedback controller for the process that you identified in Section 2.2. You may use any 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.
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. Briefly describe the control design procedure that you used. Provide (and briefly justify) your design choices.
2. 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

[**In the lab (session 2)**] Implement your controller and refine the control design if needed. Run experiments 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.

Sidebar 5. Also here you need to be careful in collecting data to make sure that it is valid–linear regimen, etc. All comments and hints of the Identification Session apply.

[**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 theoretical and measured responses.

3 Nonparametric identification

This section is devoted to the identification of a Rijke tube. More details on the content of this section and the related lab experiments will be provided later.

4 Conclusions and future work

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

(i) A brief summary of the main project achievements.

(ii) A paragraph outlining what else could be done if more time were available.

References

[Report] Any references should appear here.