24-774: Special Topics in ACSI
Laboratory 2: System Identification, ILC, and Input Shaping

<u>Background</u>: The goal of this lab is to experimentally measure system response and use that model to develop a learning controller and input shaper. Once again, you will be provided with pre-made Quanser labs for your reference along with sample code for the Arduino – if you are having trouble, I would recommend going through some of the Quanser labs for guidance. Before performing the tasks here, please read the user manual for the Qube Servo 2 system to understand the encoder / motor parameters and limitations.

Figure 1: Quanser Qube Servo System. This is a class single input, dual output control problem.

It is expected that you will work through this lab with some degree of parallelization, i.e., not everyone needs to be involved in every task. However, you must ensure that the work load is balanced, and that every team member understands the content that was generated by others. The report should also be written in parallel, but each team member is responsible for proof reading the final report.

Please use the following to schedule your time in the lab: https://docs.google.com/spreadsheets/d/1-HBBI4rfZ4E6kNXw2ItmmTEfcK_-X65dsGPQlqiEGzw/edit?usp=sharing. To ensure fair access, each team will have a maximum of 4 hours / day in the lab; as a courtesy to others, please do not reserve times until you know you will use them. Your success will critically depend on starting early and putting in a consistent effort, rather than waiting until the last days before the due date.

Procedure

System Identification

In this section you will use your knowledge of system identification techniques to develop a working plant model. For system identification we will only be using Simulink – it is tedious but straightforward to do this with the Arduino.

1. With the pendulum hanging down, perform frequency domain system identification on the system. Present the result as a 2×1 matrix of Bode plots. Fit a parametric model to your data (e.g. with *fitfrd*).
2. Perform least squares system identification on the system and convert the result into a transfer function matrix.

   ***Discussion*:**

   a. Compare the performance of the two system identification methods. How well do the models match? Which do you think is more accurate and why?
   b. Repeat the frequency domain experiment to test the sensitivity to input magnitude. Show the resulting Bode plots for at least three different input magnitudes and comment on the system's linearity.
3. Design a controller to keep the pendulum stabilized in the upright position. Using the method of your choice, experimentally identify the plant model when the pendulum is upright.

   ***Discussion*:**

   a. How did the measured model compare to what you could infer from the stable plant model?
   b. Other than unstable situations, can you think of other situations in which it is better to extract the plant model from a closed loop experiment?

Iterative Learning Control

Now we will develop prototypes of learning controllers using Simulink. For each of the exercises, please capture a short video that demonstrates performance and post to YouTube.

1. With the pendulum hanging down, design a simple SISO controller for the motor angle – the pendulum dynamics can be considered as a disturbance. Now design an iterative learning controller to follow a 1 Hz sine wave in position.

   ***Discussion*:**

   a. Plot the standard deviation of the tracking error vs. iteration number. How many iterations are needed to converge?
   b. Change the learning gain. Plot the convergence, and discuss how gain changes affect convergence.
2. Repeat the exercise with the pendulum in the upright position, i.e. design an iterative learning controller that works with your stabilizing controller from system identification to follow sine waves in motor angle with minimal pendulum disturbance.

   ***Discussion*:**

   a. Plot the standard deviation of the tracking error vs. iteration number. Is the convergence similar to the stable case?

b. Change the learning gain and plot the convergence. Is the unstable design more sensitive or less sensitive to learning gain variations?

Input Shaping

Now we will develop prototypes of input shaping controllers using Simulink. For each of the exercises, please capture a short video that demonstrates performance and post to YouTube.

1. With the pendulum in the stable (down) position, use input shaping techniques to design a controller that tracks a square wave in motor angle while keeping the pendulum stationary when the motor reaches its final position. This should be open-loop, i.e. without the use of a feedback controller.
   ***Discussion*:**
   a. Plot the error in both pendulum angle and motor angle. Discuss the effectiveness of your controller.
   b. Change your design, perturbing the natural frequency and damping ratio from the measured values. Plot the results for several perturbations and comment on the sensitivity of your design to errors in natural frequency and damping ratio.
2. Repeat the design but with a feedback controller that controls the motor position. The input shaper will now shape the reference to the controller rather than the input voltage.
   ***Discussion*:**
   a. Plot the error in both pendulum angle and motor angle and compare the effectiveness to the open loop input shaper.
   b. Repeat the sensitivity analysis in 1.b for the reference input shaper.

Embedded Control

Now we will develop prototypes of previous controllers using Arduino. For each of the exercises, please capture a short video that demonstrates performance and post to YouTube.

1. Repeat both the pendulum-down and pendulum-up ILC designs on the Arduino.
   Discussion:
      a. As in the Simulink case, plot the error convergences.
      b. Repeat the pendulum-down design for different sampling rates and discuss the effect of sampling rate on ILC performance.
2. Implement both open and closed loop input shaping controllers on the Arduino.
   Discussion:
      a. Compare the implementation difficulty in Simulink vs. the Arduino. What did you find to be the hardest part of embedded input shaping?

Reporting

Compile a single PDF lab report for your team following the provided format. Place the PDF file and all associated files (including all Simulink models, Matlab scripts, and Arduino code that you developed) in a .zip file and upload to Canvas.

MEMORANDUM

TO: Dr. Bedillion
FROM: 24-771 Student Names
DATE: September 21, 2018
RE: Laboratory No. X: Laboratory Name

A paragraph or two here should transmit the laboratory report. You should think of this as the report abstract.

This report has been proofread by all members of the group:

Print Name	Signature and Date
Print Name	Signature and Date
Print Name	Signature and Date
Print Name	Signature and Date

Your "Informal Laboratory Report" should start here. It should be organized in terms of numbered items in the lab procedure. For each numbered item in the lab procedure you must address the following items at a minimum:

1.) A brief description of the goals of the lab exercise, and the equipment and procedure used to achieve those goals. The equipment can be specified once per subsection, i.e. describe the Aero system only once, not *n* times.
2.) The details of all calculations involved in generating your results. Be sure to highlight the main results.
3.) Presentation of your results in the form of plots and tables. This should include all relevant plots and Simulink models. Do not present plots that use the black background that is the Simulink scope default. Place in-line links to your Youtube videos for video results.
4.) General discussion. What sense do you make of the results? What can you conclude?
5.) Answers to all of the discussion questions in the lab procedure.

After completing these tasks for all numbered items in the lab procedure, complete the following sections to finish your report:

- Conclusions: What were the main results? What did you learn (if anything) by completing the lab? What suggestions do you have to make the lab better or more interesting?
- Work Distribution: To what specific tasks did each team member contribute? Address this for both the laboratory exercises and the report writing.
- References: Compile all of your references into a single section at the end of the document. I highly recommend the use of a reference manager, e.g. Bibtex, EndNote, etc.
- Appendix: Attach scans of any hand calculations and copy and paste any Matlab / Arduino code. This is simply for ease of grading; you will also be posting the code files in your .zip file.