General Lab Information & Policies

"People know what they do; frequently they know why they do what they do; but what they don't know is what what they do does." – Michel Foucault

This class's labs are designed to give you an opportunity to apply the theoretical concepts you learn in class and reinforce them in the homeworks. During the labs you will design feedback controllers for two different dynamical systems: an inverted pendulum mounted to a cart running on a linear stage and a magnetic levitation system.

The labs are a significant part of this course, both in terms of effort and grading. How well you do in the labs will determine 30% of your grade. Each group will have to write a lab report for each lab. Presented here are guidelines and rules to let you know what is expected from you in the lab and in your lab reports. Labs will typically be worth between about 30 and 80 points total, depending on the amount of work needed for the lab activities. The style and report considerations mentioned below will be worth ten points of your lab report grade. Other penalties (e.g. illegible writing, lateness, etc.) will receive an additional point deduction outside of the ten points for style and report.

1 Lab Logistics

Labs logistics and clarifications:

- Pre-labs are due the same week of the lab, each Monday at 10 am Berkeley time zone (PST). Submissions must be done individually via Gradescope.
- Final lab reports are due on Saturday at 6 pm Berkeley time. Submissions must be done via Gradescope (one submission per group). Lab reports turned in after these time will be considered late. Late labs will receive a 20% point deduction off of your lab report grade per working day. Lab reports will not be accepted beyond five days after your due date and your group will receive zero credit for the lab report.
- There is no lab checkoff for Labs 1-4 and 6. Just submit your individual pre-lab and your lab report with your group via Gradescope.
- Lab Office Hours are optional OHs to provide help on pre-lab and labs. Starting from lab 2, the entire group must attend to lab OH if you want to ask for help.
- Copying, fabricating data, and any other forms of cheating will be referred to the professor for disciplinary action.

2 Instructions for writing lab reports

- At the top of each lab report, you should include: the name of your group members, the date, and your assigned lab section.
- The lab reports must be typed and plots must be computer generated. Equations, block diagrams, schematics, and other figures may be done by hand and scanned; 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, generate them on a computer.

- If you use MATLAB or Simulink for plots or calculations, you must include all accompanying system diagrams and code. The code and system diagrams should be labeled. It is good practice to put your MATLAB code into separate m-files for record-keeping and to include your name in a comment section in the first few lines of your code.
- 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.
- Lab reports should be self-contained, i.e., the lab report should make sense without having to reference the experiment report. This includes things such as:
  - Answers to questions from the lab assignment should include the question itself; you do not need to copy the question, but you should incorporate the question into the answer itself.
  - Figures (schematics, block diagrams, graphs) of the system being analyzed should be included in the lab report.
  - All analysis and derivations should be shown.
  - Explain your answers; your line-of-reasoning should be included.
- The lab report should generally contain the following sections:
  - **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.
  - **Pre-lab:** Include all the Pre-lab analysis and questions in your formal lab report. You should confer with the other members after submitting your individual Pre-labs to make a finalized version to include here. Your graded Pre-labs will be returned before the final report is due. This section will be graded the same as your individual Pre-labs.
  - **Lab:** This section should include what you did in the lab, problems you experienced during 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. It should also include any analysis of the system or data from the lab. Be sure to answer **ALL** questions asked in the lab in the proper order for grading.

Additional information and examples on how to write a good lab report can be found in the *Lab Writing Guide* handout.

A Lab descriptions

Lab 1: Modeling and Simulation in MATLAB / Simulink

Theory: MATLAB and Simulink IDE, dynamical systems, transfer functions, state space representation, block diagrams. *Tasks:* Construct state space, transfer function and block diagram models of dynamical systems and to simulate these models in MATLAB / Simulink.

Lab 2: Basic Concepts in Control System Design

Theory: Equilibrium points, transfer functions, stability, feedback, steady-state response, linearization. *Tasks:* Design proportional feedback control in MATLAB / Simulink, compare nonlinear model with linearized model.

Lab 3: Quanser Hardware and Proportional Control

Theory: Modeling, step response (incl. steady-state value and error, overshoot, delay time, rise time and settling time), state-space model, SS to TF. *Tasks:* Derive equations of motions of a cart (including DC motor dynamics), interface cart of inverted pendulum setup using Quanser QuaRC software in Simulink, Implement proportional controller on the actual hardware.

Lab 4: Model-based Position Control of a Cart

Theory: Second-order dynamics, relation between location of poles and properties of step response, P and PD controller. Pure zeros? Closed-loop TF, root locus *Tasks:* Implement P and PD controller for position control of the cart on the actual hardware. Analyze performance for different input signals.

Lab 5: tbd (two weeks)

Lab 6a: Pole Placement for the Inverted Pendulum

Theory: Modeling of inverted pendulum system. Linearization around (unstable) equilibrium point. SS model of linearized system. Eigenvalues, stability (internally, BIBO) controllability, observability. Local vs. global properties NL vs. linearized system. State-feedback controller using pole-placement. *Tasks:* Implement state-feedback controller for inverted pendulum on actual hardware, balance pendulum upright.

Lab 6b: Luenberger Observer Design for Inverted Pendulum

Theory: Full state Luenberger Observer. Choice of observer gain matrix. *Tasks:* Observer design for inverted pendulum (linearized), outputs: position and angle. Implement state-feedback controller using the observer on actual hardware. Compare performance of full state-feedback vs. state estimates.

Lab 6c: LQR Controller Design for Inverted Pendulum

Theory: LQR. Effect of the cost matrices on closed-loop pole locations and gain matrix. *Tasks:* Implement LQR for nominal weights on actual hardware (both state-feedback and output-feedback case). Investigate effect of changing weights on control performance.

miniProject tbd