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 20% 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 Organization

1.1 Location, scheduled lab times and lab access

The labs will take place in 125 Cory, a room shared with other classes. Assigned to this class are the two rows (six stations) in the left corner of the room when entering form the double door. Scheduled lab times are listed on the syllabus. Each section accommodates 18 students. We have 6 hardware setups for each lab, so students will need to work in groups of 3 per station.

You will also get key card access to the lab, to allow work on lab assignments outside scheduled times. This is out of courtesy and for your benefit; please be responsible in what you do.

Important: You are allowed to work on the hardware only after your group has received an introduction to the setup by the GSI during your lab section.

Very Important: If you break the hardware, this will negatively impact not only you, but all the other groups as well (not to mention the instructor and GSIs...). Do not break the hardware!

Extremely Important: If you are unsure about anything, ask! If you are still unsure, stop right then. Do not break the hardware!!

Most important of all: **Do not break the hardware!!!**

1.2 Group assignment

The labs are designed to accommodate 18 students in each section. You will work in groups of 3 students. We expect everyone to have found a group within her or his section by the start of Lab 2. Anyone who has not been reported as a member of a group by then will be randomly assigned to a group. Each group will work together on the physical lab and submit a single lab report.

1.3 Computer accounts

Each student will receive an instructional account for the machines in 125 Cory. A handout with all relevant information has been distributed in class. If you have not already received one, you can pick one up during one of the GSI's office hours.

2 Lab instructions

- Being constrained on the number of hardware setups, we will generally not be able to accommodate additional students in other sections. **You have to go to the lab section that you are registered for.** In *exceptional* cases (such as personal hardship), please contact your section's GSI as soon as possible. You will not be able to switch sections because your favorite sports team is playing. If you are unable to attend a particular lab because of a *legitimate* conflict, please contact the GSI as early as possible to arrange an alternative time to make up the missed lab.
- Lab reports are to be done as a group. You will submit one lab report per group. Lab reports are due one week after your lab, at the time your lab begins. **If lab is in session, print and submit the lab report to the GSI at the start of lab. If lab is not held (ie. holiday), submit a .pdf of the lab report to your GSI**. Lab reports turned in after these times will be considered late. Late labs will receive a 25% point deduction off of your lab report grade up to 12 hours and 50% off for 12-24 hours late. Lab reports will not be accepted beyond one day after your due date and your group will receive zero credit for the lab report.
- In order to prepare you for the experiments you will perform on the hardware, each lab will require you to do some Pre-lab work. **Pre-lab work is done individually, and is due at the beginning of your assigned lab section**. Your group will also provide a single (correct) solution to the Pre-lab work as part of the lab report.
- **Copying, fabricating data, and any other forms of cheating will be referred to the professor for disciplinary action**.

3 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: Magnetic Levitation (two weeks)

Theory: Linearizing NL plant around operating point. TF of linearized system. Rudimentary System ID, getting linear model from measurements. Root locus, frequency response. Lead/lag compensators. Analog Controller - Realizing TFs using OpAmps and passive elements.

Tasks: System ID on Maglev system. Design lead/lag compensator. Implement analog controller on circuit board using OpAmps and passive elements. Levitation of a steel ball.

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.

Lab 6d: Self-Erecting Inverted Pendulum (SEIP)

Theory: Gain scheduling: swing-up and balancing controller.

Tasks: Implement swing-up controller for inverted pendulum, catch pendulum in upright position and balance. Students have a lot of freedom here, this is an actual design project.