Mechanical Engineering 190L
Practical Control System Design: A Systematic Loopshaping approach

- Instructor: Andrew Packard, `pack@me.berkeley.edu`, also Hedrick, Horowitz, Kazerooni, Poolla and Tomizuka.
- Course to be offered: once/year
- Units: 1
- Hours per week: 1 hour of lecture.
- Prerequisite: ME 132 or EECS 128 (EECS 20 may suffice) or similar introductory experience regarding feedback control systems. The student should understand basic properties of feedback systems, be comfortable with transfer function and differential equation descriptions of systems, and be familiar with typical feedback objectives such as disturbance rejection, command following, noise insensitivity and closed loop stability.
- Course Elements: 4 homework assignments, 1 midterm quiz, 1-hour Final
- Text: Notes and slides in class, both based on "A Loop Shaping Design Procedure Using H_∞ Synthesis," *IEEE Transactions on Automatic Control*, vol. 37, no. 6, pp. 759-769, June 1992, and *Robust Controller Design Using Normalized Coprime Factor Plant Descriptions*, Springer-Verlag Lecture Notes in Control and Information Sciences, vo. 138, 1990, both authored by by D McFarlane and K. Glover.

Brief Description

After a review of basic loopshaping, we introduce the loopshaping design methodology of McFarlane and Glover, and learn how to use it effectively. The remainder of the course studies the mathematics underlying the new method (one of the most prevalent advanced techniques used in industry) justifying its validity.

Expanded course description

Traditionally, loopshaping is a standard, informal technique to design single-loop and multi-loop feedback systems. Using approximate relations on how the open-loop gain affects the closed-loop behavior, the designer shapes the open-loop gain, by adding dynamics to the controller, using several 1st and 2nd order filter stages. The process is relatively straightforward for benign plant models, but involves additional trial-and-error for plants with unstable poles, or non-minimum phase zeros, or lightly-damped poles.

Recently, McFarlane and Glover developed theory to automate the process further, and proved that for a desired loopshape, there is a computable necessary and sufficient condition to establish the existence of a control law which achieves this loopshape, and has adequate robustness margins in the crossover region. This theorem, along with numerical tools in Matlab, combine to form a very powerful design technique.

In this 1-unit course, students will learn the theory and gain practical experience in using the technique.

Contribution of the course to meeting the professional component

The loopshaping technique taught in this course is the most prevalent advanced technique used in industry. Undergraduates who complete this course will be well suited to design single-input, single-output control laws for a variety of processes, including aerospace, electromechanical, hydraulic, pneumatic and chemical manufacturing. Moreover, the use of sophisticated numerical tools to enable advanced design is prevalent in industry, and this class reinforces this notion.

Relationship of the course to ABET program objectives

The course addresses objective 1 in an obvious manner. The course addresses the life-long learning aspect of objective 3, as the students will fully learn a design technique that is not covered in any undergraduate textbook (and not properly covered in any graduate textbook either). This will be (likely) the first exposure to the *IEEE Transactions on Automatic Control*, and they will learn that the current literature is often dense and challenging to read, but may offer significant insight into the problems being addressed.

Contents

1. review of SISO loopshaping, how main design objectives are captured the open-loop loopshape, Bode phase formula;
2. The McFarlane/Glover loopshaping methodology; claims, examples, comparisons to other designs;
3. Limitations and conservation laws in feedback systems;
4. Small gain theorem;
5. Coprime factor plant description and coprime factor robustness tests;
6. H_∞ design problem: statement, solution, available software;
7. The McFarlane/Glover loopshaping theorem for single-input, single-output systems; statement and derivation.

Relationship of course to undergraduate degree program objectives

Optional Elective. Counts as an ME Technical elective.

Assessment of student progress toward course objectives

- 4 graded homework assignments (70%)
- 1 midterm quiz (15%)
- 1 final exam (15%)