

ECE 445

Introduction to Control Systems

Overview

Course Catalog Description: Credits (3)

Introduction to the feedback control problem. Plant modeling, transfer function and state-space descriptions. Stability criteria. Nyquist and root-locus design. Introduction to analytical design. Z-transforms and digital control. Laboratory design project.

Prerequisites: ECE 314

Textbook: Norman S. Nise. *Control Systems Engineering*, Wiley, 5th edition, 2008. ISBN: 978-0471-79475-2.

Class Goals: The main goal of this course is to gain a solid foundation in feedback control systems analysis. This course is a required class for all electrical engineering majors. More specifically, the class goals are:

1. Understanding the transfer function and state-space modeling of electrical, mechanical, electromechanical, thermal, and hydraulic systems.
2. Understanding the concept of “state”.
3. Understanding of system analogies.
4. Understanding of fundamental theoretical results associated with feedback control systems e.g., Routh-Hurwitz stability criterion, Nyquist stability criterion, root-locus analysis, and frequency response techniques.
5. Basic understanding of robustness, stability, and performance of control systems.
6. Knowledge and use of software available for simulation and control design (Matlab/Simulink).
7. Applying modeling, analysis, and design techniques to a real-world control system.

Course Coordinator: Prof. Rafael Fierro

Table I: Objectives, Implementation, and Assessment

| Objectives | | Implementation | Assessment | A | B | C | D | E | F | G | H | I | J | K |
|----------------|--|---------------------------------|-----------------------------|---|---|---|---|---|---|---|---|---|---|---|
| O ₁ | Understanding the transfer function and state-space modeling of electrical, mechanical, electromechanical, thermal, and hydraulic systems. | 10 hrs. lecture in weeks 1-4 | HW 1-2, Exam I | X | | X | | X | | | | | | X |
| O ₂ | Understanding of system analogies. | 2.5 hrs. lecture in week 5 | HW 3, Exam I | X | | | | X | | | | X | | X |
| O ₃ | Understanding of dynamic behavior and stability e.g., Routh-Hurwitz stability criterion. | 7.5 hrs. lecture in weeks 6-8 | HW 4-5 Exam I | X | | | | X | | | | | | X |
| O ₄ | Understanding root-locus analysis and design. | 5 hrs. lecture in weeks 9-10 | HW 6, Exam II | X | | X | | X | | | | | | X |
| O ₅ | Understanding frequency response techniques and Nyquist stability criterion. | 7.5 hrs. lecture in weeks 11-13 | HW 7-8 Exam II | X | | X | | X | | | | | | X |
| O ₆ | Basic understanding of robustness and performance of feedback control systems. | 7.5 hrs. lecture in weeks 14-16 | HW 9-10 Exam II, Final Exam | X | | X | | X | | | | | | X |
| O ₇ | Applying modeling, analysis, and design techniques to a real-world control system. | | Report | X | X | X | X | X | | X | | | X | X |

**Table II: Expectation and Assessment Outcome
Fall 2008, Dr. R. Fierro**

General expectations:

Homework: Homework problems are assigned on a weekly basis. Most assignments have a simulation/Matlab component. It is expected that students will be able to answer at least 75% of the problems assigned.

Lab Experiment: This is a team project. Students design and verify a control system.

Exams: Expect 75% of the students to score 70% or better on all exams.

| | Objectives | Outcome Assessment | Evaluation |
|----------------|--|---|--|
| O ₁ | Understanding the transfer function and state-space modeling of electrical, mechanical, electromechanical, thermal, and hydraulic systems. | 80 % of students completed HW 1 & 2 satisfactorily. Avg. on Exam I was 65%, with 50% scoring 70% or better. | Some students lacked some prerequisite knowledge: Laplace transforms, ordinary differential equations, and linear algebra. |
| O ₂ | Understanding of system analogies. | 85% of the students completed HW 3 satisfactorily. | Some students lacked some prerequisite knowledge Linear circuits |
| O ₃ | Understanding of dynamic behavior and stability e.g., Routh-Hurwitz stability criterion. | 88% of the students completed HW 4-5 satisfactorily. | |
| O ₄ | Understanding root-locus analysis and design. | 90% of the students completed HW 6 satisfactorily. Avg. on Exam II was 76%, with 75% scoring 70% or better. | Some students lacked some prerequisite knowledge Complex numbers. |
| O ₅ | Understanding frequency response techniques and Nyquist stability criterion. | 87% of the students completed HW 7-8 satisfactorily. | Some students lacked some prerequisite knowledge Complex numbers. |
| O ₆ | Basic understanding of robustness and performance of feedback control systems. | 85% of the students completed HW 9-10 satisfactorily. Avg. on Final exam 70%, with 60% scoring 70% or better. | |
| O ₇ | Applying modeling, analysis, and design techniques to a real-world control system. | 100% of the students completed this assignment. | |

Course Schedule

| Week | Date | Lect. | Topic | Assignment |
|------|--------|-------|---|------------|
| 1 | 26 Aug | 1 | Introduction, Motivation & Course Administration | Ch. 1 |
| | 28 Aug | 2 | Modeling in the Frequency Domain - Laplace | Ch. 2 |
| 2 | 02 Sep | 3 | Electrical Networks | Ch. 2 |
| | 04 Sep | 4 | Mechanical Systems | Ch. 2 |
| 3 | 09 Sep | 5 | Electromechanical Systems | Ch. 2 |
| | 11 Sep | 6 | Thermal Systems | |
| 4 | 16 Sep | 7 | Hydraulic Systems | |
| | 18 Sep | 8 | System Analogies | Ch. 2 |
| 5 | 23 Sep | 9 | State-space Representation (State concept) | Ch. 3 |
| | 25 Sep | 10 | Transfer Function to State-space | Ch. 3 |
| 6 | 30 Sep | 11 | Transfer Function to State-space | Ch. 3 |
| | 02 Oct | 12 | Linearization | Ch. 3 |
| 7 | 07 Oct | 13 | Time Response: Poles and Zeros, 1 st Order Systems | Ch. 4 |
| | 09 Oct | – | Exam I | |
| 8 | 14 Oct | 14 | Block Diagrams Reduction | Ch. 5 |
| | 16 Oct | – | <i>Fall Break</i> | |
| 9 | 21 Oct | 15 | Signal-flow Graphs and Mason's Rule | Ch. 5 |
| | 23 Oct | 16 | Stability | Ch. 6 |
| 10 | 28 Oct | 17 | Routh-Hurwitz Stability Criterion | Ch. 6 |
| | 30 Oct | 18 | Steady-state Errors | Ch. 7 |
| 11 | 04 Nov | 19 | Sensitivity | Ch. 7 |
| | 06 Nov | 20 | Analysis via Root-Locus; Basic Properties | Ch. 8 |
| 12 | 11 Nov | 21 | Transient Response Design | Ch. 8 |
| | 13 Nov | 22 | Introduction to Design via Root-locus | Ch. 9 |
| 13 | 18 Nov | 23 | Frequency Response Techniques | Ch. 10 |
| | 20 Nov | 24 | Bode Diagrams | Ch. 10 |
| 14 | 25 Nov | – | Exam II | |
| | 27 Nov | – | <i>Thanksgiving Holiday</i> | |
| 15 | 02 Dec | 25 | Nyquist Stability Criterion | Ch. 10 |
| | 04 Dec | 26 | Gain Margins | Ch. 10 |
| 16 | 09 Dec | 27 | Introduction to Design via Frequency Response | Ch. 11 |
| | 11 Dec | 28 | Review for Final Exam | |