ECE 380: Analog Control Systems

Spring 2017 – Class 2

Department of Electrical and Computer Engineering
University of Waterloo

Calendar Description and Intended Learning Outcomes

Introduction to control systems. Advantages of closed-loop feedback systems. The role of the system mathematical model. Block diagrams and signal flow graphs. The basic control system design problem, stability in control systems. Frequency response analysis techniques. Root-locus analysis. Elementary lead-lag compensation.

Upon successful completion of the course, students should be able to

(i) explain the advantages and disadvantages feedback control,

(ii) describe common control objectives, specs, and control strategies

(iii) assess stability of continuous-time feedback systems, and

(iv) apply root-locus, PID, and lead/lag design techniques to single-input single-output control systems.

Instructor

John W. Simpson-Porco
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(*Please place "ECE 380" in the subject header of all e-mail correspondence.*)

Lab Instructor

Carmen Caradima
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Teaching Assistants

Laboratory TAs:

- Ahmad Bilal Asghar (abasghar@uwaterloo.ca)
- Tanushree Banerjee (tbanerje@uwaterloo.ca)
- Ali Saheb Pasand (asahebpa@uwaterloo.ca)

Tutorial TA

- Phillip McCarthy (philip.mccarthy@uwaterloo.ca)

Course Website and Credit

Units: 0.5

Website: Hosted via UW Learn. For access issues please contact learnhelp@uwaterloo.ca.

(*Note: Course website will be available from the first day of class until the final exam is given.*)

Prerequisites

ECE 207 *or* MATH 213

Antirequisites: ME 360, MTE 360, SE 380, SYDE 352

Lecture, Tutorial, and Lab Schedule

Lectures:

- Tuesday: 1:30–2:50, RCH 211
- Wednesday: 12:30–1:20, RCH 211 (every other week, beginning on May 10th)
- Thursday: 1:30–2:50, RCH 211

Note: The lecture on Thursday, May 4th will be cancelled.

Tutorials:

- Wednesday: 1:30–2:50, RCH 211

Laboratory:

- (Group 204) Thursday 8:30–11:20, E2 3341 (every other week, beginning on May 25th)
- (Group 205) Tuesday 8:30–11:20, E2 3341 (every other week, beginning on May 23rd)
- (Group 206) Wednesday 8:30–11:20, E2 3341 (every other week, beginning on May 24th)

More detailed laboratory information — including all due dates for labs and prelabs — will be posted on UW Learn.

Note: The lab for Group 205 on Tuesday May 23rd will be held from 7:00pm–9:50pm.

Course Materials

The courseware for lectures is available for purchase at Campus Copy in Davis, and is downloadable through the course page on UW Learn.

Additional useful reference books (on 3 hour reserve at Davis Library) are

- G. Franklin, J. Powell, and A. Emami-Naeini, *Feedback Control of Dynamic Systems*, 7th edition, Pearson, 2014.

- K. J. Astrom and R. M. Murray, *Feedback Systems: An Introduction for Scientists and Engineers*, 2nd edition, Princeton, 2016.

- N. S. Nise, *Control System Engineering*, 6th edition, Wiley, 2010.

Other specific reference material may be posted or linked to on LEARN as the course progresses.

Homework

There will be roughly 9 homework assignments, which will be posted on the UW Learn course website as the course progresses. Solutions posted one week later. Homework will not be graded.

Evaluation

Lab completion is mandatory; you must perform and submit all five labs or you will receive a grade of INC. Exceptions will be granted only in exceptional circumstances, at the discretion of the course and lab instructors. If you complete all five labs, then your grade is given by the formula

$$\mathbf{Grade} = 0.2 \times \mathbf{Lab} + \max\{0.25 \times \mathbf{Midterm} + 0.55 \times \mathbf{Final}, 0.8 \times \mathbf{Final}\}.$$

The midterm will be held on Friday June 16th from 8:30am–10:00am in STC 1012. Midterm conflicts will not be accommodated. If you miss the midterm for any reason, your midterm mark is zero; your exam will therefore be worth 80%.

Final examination time and location to be determined. If you have a conflict, please complete the final exam conflict form.

Please familiarize yourself with University of Waterloo's Assignment and Exam Regulations.

Laboratory Information

Lab Room: E2-3341

Lab Webpage: UW Learn

Each of the five lab modules has a manual, found under the course account on LEARN. More detail about labs can be found on the webpage.

- There are 5 lab modules, which together constitute 20% of your final grade. Each of the labs is weighted as follows:

    - 2% for Lab 1 (Instrumentation and Measurement Techniques)
    - 4% for Lab 2 (Second-Order system Identification and Analysis)
    - 4% for Lab 3 (Motor Velocity and Position Control)
    - 5% for Lab 4 (PID Analysis)
    - 5% for Lab 5 (Lead and Lag Compensator Design)

- All submissions are to be done electronically, through LEARN.

- Prelabs and lab reports are due as specified in the Lab Calendar posted on LEARN. Please verify that you have uploaded your submission on time, the document is complete, and it is under the group account of the correct course number.

- Prelabs will be graded, and the grades make up a part of the overall grade for each lab module. Late prelabs will incur a penalty of 20% in the first 24 hours, and 100% thereafter, unless prior arrangements are made or a valid reason presented. With a valid reason, prelabs can be handed in late, but no later than the date on which the actual lab sessions start.

- Late lab reports will incur a penalty of 20% in the first 24 hours, and 100% thereafter, unless prior arrangements are made or a valid reason presented within a week from the missed deadline. In no case will a lab report be accepted more than a week past the deadline; if a valid reason exists for being unable to hand in the lab within the week following the deadline, then the lab will be assigned a weight of zero and the remaining labs will be reweighted accordingly.

- Lab attendance is mandatory. Missing a significant portion of a lab session without a valid reason will result in a reduction in the lab report grade (for that student only). The grade reduction will be proportional to the fraction of the lab session missed, where missing an entire lab session (without a valid reason) results in a 100% reduction in the lab report grade. In cases where a student misses part of a lab session, the lab instructor is the one who determines the mark reduction.

Rules about group work in labs:

- Students work in groups of two. Both partners must do all of the lab work, and attend all lab sessions (see above). Each group submits one prelab per lab (if applicable), and one report per lab. See LEARN for lab prelab and report expectations.

- The instructor or lab instructor has the authority to split up or re-arrange groups for academic reasons, including the possibility or requiring certain students to work alone.

- Under no circumstances are students allowed to access, in any form, ECE/SE380 lab reports or answers or results from previous terms. Such access will be treated as an academic offence under Policy 71.

- You are allowed to talk with other students currently enrolled in the course about the lab content, but each group must write up their lab reports completely independently. Of course, students can also talk to the lab TAs, the lab instructor, or the course professor for help.

Course Outline

1. Motivation
   Introduction to control engineering, the basic unity feedback structure, feedforward control, feedback control, typical design specifications.

2. Basic Signal and System Concepts
   Complex variables, Laplace transforms, transfer functions, frequency response (Bode plots).

3. System Modeling
   Differential equation models of physical systems, electromechanical examples, block diagram manipulation.

4. Step Responses of Linear Systems
   First order systems, second order systems, standard forms, performance measures, effects of poles and zeros on step response, reduced order models.

5. Stability of Linear Time-Invariant Systems
   BIBO stability, characterization of stability in terms of poles, pole-zero cancellations, stability of unity-feedback loop, tests for stability (sign test, Routh-Hurwitz test).

6. Basic Feedback Control
   Disturbance rejection, sensitivity, tracking of reference signals, PID controller design.

7. Root Locus Design
   Rules for drawing the root-locus, lead and lag dynamic compensator design.

8. Dynamic Compensator Design Using Bode Plots
   Improving phase margin by lead compensation, improving low frequency behaviour by lag compensation, improving phase margin by lag compensation, lead-lag compensation.

9. Nyquist Plots
   Construction of Nyquist plots, Nyquist stability test, quantifying stability robustness, using Nyquist plots for design.

10. Modern Control Theory
    State-space representations of linear systems, nonlinear systems and linearization, linear state feedback.

Academic Integrity, Discipline, Grievances, and Appeals

In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. For an overview of academic integrity policies and sanctions, see here.

A student is expected to know what constitutes academic integrity to avoid committing an academic offence, and to take responsibility for his/her actions. A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about rules for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate Associate Dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline. For typical penalties check Guidelines for the Assessment of Penalties.

A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4. When in doubt please be certain to contact the department's administrative assistant who will provide further assistance.

A decision made or penalty imposed under Policy 70 (Student Petitions and Grievances) (other than a petition) or Policy 71 (Student Discipline) may be appealed if there is a ground. A student who believes he/she has a ground for an appeal should refer to Policy 72 (Student Appeals).

Disability Policy

AccessAbility Services, located in Needles Hall 1401, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with AccessAbility Services at the beginning of each academic term.