ECE 380 Analog Control Systems Winter 2023

Lectures: Tuesdays/Thursdays, 0830-0950, E7–4053.
Laboratory: E2-3341
Tutorials: Wednesdays, 0830-0950, E7–4053.

Website: http://learn.uwaterloo.ca/
This course will follow the University of Waterloo current face coverings mandate, available at https://uwaterloo.ca/coronavirus/health-and-safety/face-coverings.

Calendar Description

This course provides an introduction to feedback control systems, viewed through the continuous-time, or analog, lens. The course focuses on developing mathematical system models, developing basic feedback controllers, and analyzing their performance and stability. This also involves understanding block diagrams and signal flow graphs, frequency response analysis techniques, root-locus analysis and control design in both time and frequency domains. The laboratory component focuses on hands-on application of these methods.

Prerequisites: ECE 207.

Instructors

Lectures: Dr. Yash Vardhan Pant (yash.pant@uwaterloo.ca).
Office hours: Thursdays, 1400-1600, E5–5114.
Lab instructor: Carmen Caradima (cmcaradima@uwaterloo.ca).

Teaching Assistant: Alex Lovi (alovi@uwaterloo.ca).

Teaching Assistant: Mahsa Parsapour (mahsa.parsapour@uwaterloo.ca).

Teaching Assistant: Kaixiang Zheng (k56zheng@uwaterloo.ca).

TA Office Hours: TBD. Will be announced via LEARN.
Important: Please start your email's subject with "ECE 380:"; do not expect a reply to your email otherwise. The teaching staff will aim to get back to you within 24 hours, but it may not always be possible to do so.

Note: This term we will be using Piazza for class discussion. The system is highly catered to getting you help fast and efficiently from classmates, the TAs, and the instructors. Rather than

emailing questions to the teaching staff, I encourage you to post your questions on Piazza. If you have any problems or feedback for the developers, email team@piazza.com.
Find our class signup link at: https://piazza.com/uwaterloo.ca/winter2023/ece380

Intended learning outcomes

At the end of the course it is hoped that you have learned:

- What feedback control is and why it is useful.
- Mathematical (time and frequency domain) modeling of dynamical systems.
- The value of block diagram representations.
- How to use a graphical tool (Simulink) for simulations.
- Why we use transfer functions to model systems and controllers, as well as frequency domain analysis of closed-loop systems.
- The meaning of stability in the context of feedback control systems, and methods to determine if a system is stable.
- To apply the modelling, analysis, design and implementation techniques of the course to a lab experiment.

Text

Course notes (courtesy of Professor Chris Nielsen) will be made available on the course website and will serve as the primary reference. The optional suggested textbook is: Modern Control Systems, 14^{th} edition, Richard C. Dorf and Robert H. Bishop. Pearson.

Additional references:

- ECE 380 (Winter 2014) notes by Prof. Shreyas Sundaram. See `https://engineering.purdue.edu/~sundara2/teaching.html`
- Linear systems and signals. B.P. Lathi.
- Signals and systems: A fresh look. C.T. Chen.

Evaluation

- 20% Laboratory ($\{1, 2, 3, 4, 5\} = \{2\%, 4\%, 4\%, 5\%, 5\%\}$).
- 5% Assignments (8 total, each weighed equally, electronic submission by midnight on Fridays). Note, late submissions will not be graded. Assignment grade is calculated as:
  Assignment = Sum of best 5 scores, normalized to create a total score out of 5.

- 5% Project on controller design (teams of 2, same team as in the lab). The grade will be partially based on performance of the designed controller. More details will be released after the midterm week, and the final project is due in the last week of classes.

- 70% Combination of final exam and midterm scores. Grade calculated as:
  Exams = max$\{20\%$ Midterm + 50% Final, 70% Final$\}$.

The midterm and final are in-person. If you miss the midterm for *any* reason, then the score for the midterm is zero but you will get the opportunity to make up in the final exam (see scoring above). Both exams will be open-book subject to the limitations that you are only allowed to refer to: a) your class notes, b) the course notes, c) the textbook.

Midterm and final dates and locations:

Midterm: Monday, February 27, 1400-1515[1]. E7 4043, E7 4053, E7 5343.
Final: TBD.

Tentative Topics List

1. **Introduction** (1 lecture)
   Course details, motivating examples, open-loop versus closed-loop control.

2. **Mathematical models of systems** (3 lectures)
   Non-linear and linear State-space models, linearization, Linear-time invariant (LTI) systems, transfer functions, block-diagrams.

3. **Linear system theory** (4 lectures)
   Asymptotic stability, bounded input bounded output stability, frequency response, graphical representations of the frequency response.

4. **First and second order systems** (2 lectures)
   First order systems, second order systems, time domain effect of pole locations, characteristics of step responses, settling time, overshoot, time-to-peak, rise time, effects of adding poles and zeros, reduced order models.

5. **Feedback control theory** (3 lectures)
   Stability of feedback systems, Routh-Hurwitz criterion, steady-state performance.

6. **Root-locus method** (2 lectures)
   Basic root locus, non-standard problems.

7. **Feedback controller design** (2 lectures)
   Classical PID controller, pole placement.

[1]The actual time to solve the midterm will be 1 hour. The total time is how long we have the room for, and for the invigilators to finish their duties.

8. **Frequency domain methods for stability analysis** (2 lectures)
   Nyquist stability criterion, stability margins.

9. **Introduction to control design in the frequency domain** (3 lectures)
   Loop shaping, performance specifications, lag compensation, lead compensation.

10. **Beyond classical analog control** (1 lecture)
    Quick introduction to the power of modern non-linear, optimal, and data-driven control methods and their applications in autonomous driving (and racing), aerial robots etc.

Laboratory

- This laboratory will follow the University of Waterloo current face coverings mandate, available at https://uwaterloo.ca/coronavirus/health-and-safety/face-coverings.

- All lab-related postings (files or news notifications), the lab manual, the lab calendar, lab group formation, lab station assignments will be carried out on LEARN.

- All lab submissions are to be done electronically on LEARN and/or Crowdmark.

- Laboratory work is done in groups of two students from the same lab section, unless there is an odd number of students in a lab section, in which case there will be (at least) one group of one. Both lab partners are responsible for verifying that the group submission was uploaded to LEARN and/or Crowdmark.

- Due dates for submissions can be found in the Lab Calendar, available on LEARN.

- At the end of their lab session, each group must submit their raw data to LEARN. Raw data consists of lab measurements, typically captured in a spreadsheet, and all relevant plots/screen captures.

- Prelab 5 will be graded and the grade makes up a part of the overall grade for Lab 5. Late submissions are not accepted for Prelab 5, since prelab answers are available once the lab sessions start.

- Late lab reports will incur a penalty of 1% per hour in the first 24 hours, and 100% thereafter, unless prior arrangements are made or a valid reason is presented within a week from the missed deadline. Under no circumstances will a lab report be accepted more than a week past the deadline.

- Lab attendance is mandatory for each student. 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 for group work in the lab project:

- Students work in groups of two. Both partners must do all of the lab work, and attend all lab sessions (see above). All ECE 380 lab submissions are group submissions.
- 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/SE 380 lab reports or answers or results from previous terms. Such access will be treated as an academic offence under Policy 71. The use of "homework services" such as chegg.com and course- hero.com is prohibited.
- 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.

Other information

Fair Contingencies for Emergency Remote Teaching: We are facing unusual and challenging times. The course outline presents the instructor's intentions for course assessments, their weights, and due dates. As best as possible, we will keep to the specified assessments, weights, and dates. To provide contingency for unforeseen circumstances, the instructor reserves the right to modify course topics and/or assessments and/or weight and/or deadlines with due and fair notice to students. In the event of such challenges, the instructor will work with the Department/Faculty to find reasonable and fair solutions that respect rights and workloads of students, staff, and faculty.

In case of either: 1) a short-term cancellation of in-person meetings, whether for this particular course or University-wide, or b) a longer-term cancellation of in-person meetings, whether for this particular course or University-wide; the lectures will be held online via zoom.

Academic integrity, grievance, discipline, appeals and note for students with disabilities:

Academic integrity: See www.uwaterloo.ca/academicintegrity/ for more information.

Grievance: Read Policy 70, Student Petitions and Grievances, Section 4, https://uwaterloo.ca/secretariat/policies-procedures-guidelines/policy-70. When in doubt please be certain to contact the department's administrative assistant who will provide further assistance.

Discipline: A student is expected to know what constitutes academic integrity https://www.uwaterloo.ca/academicintegrity/ to avoid committing an academic offence, and to take responsibility for his/her actions. See https://uwaterloo.ca/secretariat/pol

icies-procedures-guidelines/policy-71 for offenses and types of penalties. For typical penalty guidelines, see https://uwaterloo.ca/secretariat/guidelines/guidelines-assessment-penalties.

Note for students with disabilities: AccessAbility Services, located in Needles Hall, Room 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.

Acknowledgement

The course instructor would like to thank Professor Chris Nielsen and Professor Stephen L. Smith for sharing their course material.