ECE 481 Digital Control Systems Spring 2022

Lectures: Tuesdays/Thursdays, 0830-0950, E7-4433.
Laboratory: E2-3342
Tutorials: Mondays, 2100-2150, Via zoom (starting from May 9^{th}). See Teaching Assistant (TA) information below for link.

Calendar Description

This course covers the fundamentals required to design, implement and analyze sampled-data and discrete-time control systems. Topics covered include modeling of dynamical systems: transfer functions and state-space, both continuous and discrete-time; introductory non-linear system analysis; digital control system design: via emulation methods, in both the z-domain and frequency domain, and via pole placement. Implementation of digital controllers. The laboratory component involves projects on computer control of mechatronic and other systems.

Prerequisites: ECE 380/MTE 360/SYDE 352 or equivalent.

Instructors

Lectures: Dr. Yash Vardhan Pant (yash.pant@uwaterloo.ca)
Office hours will be held on Thursdays from 10-11am Eastern time via Zoom, https://uwaterloo.zoom.us/j/93297994319?pwd=YU5OdnYxZU9jeEpuRE9uNkpxTDFlQT09
Lab instructor: Carmen Caradima (cmcaradima@uwaterloo.ca).
Teaching Assistant, tutorials: Yifan Cai (y242cai@uwaterloo.ca).
TA Office Hours: Yifan Cai, Monday from 5 - 6pm Eastern time online via Zoom. https://uwaterloo.zoom.us/j/5440297035?pwd=Y0h3R2xGRzRySjFpYVBvRGV1bVUydz09
(same link for tutorials.)

Intended learning outcomes

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

- Design controllers to deal with basic nonlinear effects.
- Explain how sampling rates affect the performance of a digital control system and how to account for the sampling rate when you design feedback controllers.

- Discretize a plant in order to do control design directly in the discrete-time domain and discretize a continuous control law to implement it in a computer program.
- Test stability of discrete-time systems and quantify dynamic performance of these systems.
- Design digital control laws by emulation, in both the z-domain and the frequency domain. Design techniques include deadbeat control and pole placement.
- Apply the modelling, analysis, design and implementation techniques of the course to a lab experiment.

Text

Course notes (courtesy of Professor Chris Nielsen) are available on the course website. The optional suggested textbook is: Digital Control System Analysis and Design, 4th edition, C.L. Phillips, H.T. Nagle, A. Chakrabortty.

Additional references:

- Digital control engineering: Analysis and design, 2nd edition. M. Sami Fadali, A. Visioli.
- Digital Control of Dynamic Systems, 3rd edition. G.F. Franklin, J.D. Powell, M. Workman.
- Linear systems and signals. B.P. Lathi.
- Signals and systems: A fresh look. C.T. Chen.

Evaluation

- 25% Laboratory. See breakdown below.
  - Lab 1: 4%
  - Lab 2: 6%
  - Lab 3: 7%
  - Controller demo and project Q&A: 8%
- 20% Mid-term exam (16th June 2022, 830am, in-class).
- 10% Assignment 1 (released: 05/31/22, due: 06/09/22)[1].
- 10% Assignment 2 (released: 07/12/22, due: 07/21/22)
- 35% Final exam (1.5 hrs, TBD).

[1] Submissions that are n days late will be graded out of a maximum of $100 - 20 * n$ points. Last late-day to submit is the Sunday after the due day (i.e., $0 \leq n \leq 3$).

Tentative Topics List

1. **Introduction** (1 lecture)
   Motivating examples, introduction to discrete-time control systems and sampled-data control systems.

2. **Review of signals, systems and analog control** (2 lectures)
   Bounded-input bounded-output stability, feedback stability, time-domain specifications, steady-state performance, frequency domain analysis.

3. **Pole placement** (3 lectures)
   Pole placement controller design for continuous-time systems in the s-domain, incorporating tracking specifications.

4. **Discretization of continuous-time controllers** (2 lectures)
   Numerical integration, step-invariant transform, design based on discretizing continuous-time controllers.

5. **Nonlinear systems** (3 lectures)
   State-space models, linearization, inverting static non-linearities, static friction.

6. **Linear discrete-time systems** (4 lectures)
   Difference equations, z-transforms, bounded-input bounded-output stability, asymptotic stability, feedback stability, frequency response.

7. **Control design in discrete-time** (7 lectures)
   Discretize the plant and design the controller in the discrete-time domain, stability tests, design in the frequency domain, design in the time-domain.

8. **Optimization-based control of constrained systems** (1 lecture)
   Introduction to optimal control, effect of constraints, Model Predictive Control.

Laboratory

- 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 submission are to be done electronically on LEARN and/or Crowdmark. Lab reports, excluding source code, must be in pdf format.

- Revised submissions prior to the deadline are accepted; in such cases, the most recent file of will be marked.

- Students work in groups of two unless there is an odd number of students in the class, 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.

- Any lab report (including any associated project code) submitted late will lose marks, at the discretion of the lab instructor, at a rate of 1% per hour, unless prior arrangements are made or a valid reason presented within a week from the missed deadline. Under no circumstances will a lab report be accepted more than a week past the deadline.
- Completion of all three labs and the lab demo is mandatory.

Rules for group work in the lab project:

- Students work in groups of two. Both partners must do all of the lab work. Each group submits one report per lab plus associated source code.
- 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, ECE484/ECE481 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 in Spring 2022. 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/policies-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 Dan Davison for sharing their course material.