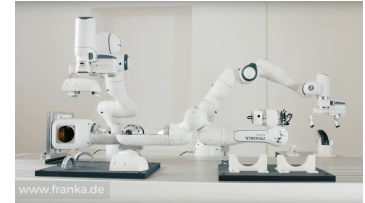
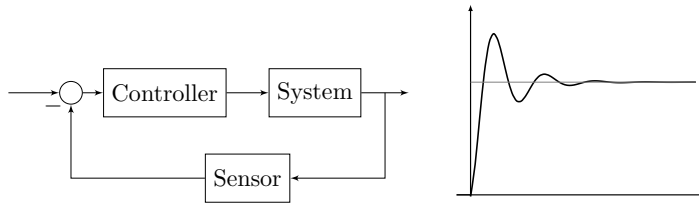
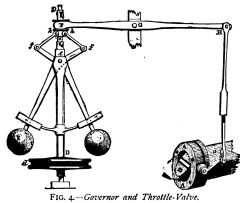


SE 380 Introduction to Feedback Control

Fall 2022



Without control systems there could be no manufacturing, no vehicles, no computers, no regulated environment—in short, no technology.

J. Doyle, B. Francis, A. Tannenbaum
Feedback Control Theory (1990)

All modern control algorithms for engineering systems are implemented in software.

K. J. Åström, R. Murray
Feedback Systems (2020)

| | | |
|----------------------------|---------------------------------------|--|
| Instructor | Dr. Gennaro Notomista | |
| | Email: gennaro.notomista@uwaterloo.ca | |
| | Office: E5 4006 | |
| Lab instructor | Carmen Caradima | |
| | Email: cmcaradima@uwaterloo.ca | |
| | Office: E2 3337 | |
| Teaching assistants | Alex Lovi | alovi@uwaterloo.ca |
| | Karanjot Singh | k259sing@uwaterloo.ca |
| Time and place | Lectures | Monday, Wednesday, Friday 9:30-10:20, STC 0040 |
| | Tutorials | Monday 16:30-17:20, RCH 103 |
| | Laboratory | E2 3341 |
| | Office hours | TBD |

Website <http://learn.uwaterloo.ca/>, <https://www.gnotomista.com/teaching/se380.html>

Description

This course will introduce students to the mathematical modeling of physical systems and to the analysis and design of feedback control systems. The course will be divided into four modules, corresponding to the following topics:

- Mathematical models of systems
- Linear system theory
- Analysis of feedback control systems
- Controller synthesis

Each topic will be presented during lectures and reinforced with assignments containing both theoretical and programming exercises (using MATLAB). The course will also include a project which will allow students to apply the concepts learned during the course to control a real robotic manipulator.

Prerequisites MATH 213

Reading

The course textbook is:

(DB) Richard C. Dorf, Robert H. Bishop, *Modern Control Systems*, 13th edition, Pearson, 2016

Other useful resources are:

(N) Norman S. Nise, *Control Systems Engineering*, 8th edition, John Wiley & Sons, 2019

(AM) K. J. Åström, R. Murray, *Feedback Systems. An Introduction for Scientists and Engineers*, 2nd edition, Princeton University Press, 2021 https://fbswiki.org/wiki/index.php/Main_Page

Grading

- Assignments: 10% (5 assignments, each worth 2%)
- Laboratory: 15% (Lab $i = i\%$, $i \in \{1, 2, 3, 4, 5\}$)
- Project: 20%
- Midterm exam: 25%
- Final exam: 30%

Project details

The project consists of designing a controller for a robotic manipulator. The deliverable will be two:

- A controller block, designed using Simulink, which will be tested on a real robotic manipulator in the RoboHub (<https://uwaterloo.ca/robohub/>)
- A written report, in the form of a PDF document of maximum 4 pages using the IEEE conference template (<https://www.ieee.org/conferences/publishing/templates.html>), structured as follows:
 - Control design methodologies
 - Simulation results
 - Discussion

The work may be carried out individually or in a group of maximum 3 people. In the latter case, the report should be accompanied by the detailed description of the work carried out by each member of the group, including what sections of the report were written by whom.

A complete and detailed description of the project will be posted on LEARN.

Lab details

- The lab work is done in groups of two students enrolled in the same lab section. Groups of one are permitted, if an odd number of students are enrolled, groups of three are not. Lab groups are formed on LEARN at the beginning of the term.
- All lab submissions, one per lab group, uploaded to Crowdmark, are due at 11:59pm on the dates shown in the Course Outline.
- Both lab partners are responsible for verifying that the group submission was complete at the time of uploading it.

- Students will submit their In-Lab Data at the end of their lab session (one submission per group). This submission should contain all their experimental measurements and the required screen-shots.
- Revised submissions prior to the deadline are accepted.
- Late submissions will incur a penalty of 2% per hour (or part thereof) that the submission is late up to a limit of 13 hours, and 100% thereafter. If prior arrangements are made or a valid reason presented within one week from the missed deadline, the late penalty is waived. In no case will a lab report be accepted more than one week past the deadline. If a valid reason exists for being unable to hand in the lab report within a week following the deadline, then a solution tailored to each particular situation will be offered.
- Lab attendance is mandatory for each student.

The student must inform the lab instructor by email of any anticipated absence. 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.
- The instructor or lab instructor has the authority to split up 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.
- Students are allowed to talk with other students currently enrolled in the course about the lab content at a high level, but each group must write up their lab reports completely independently. Of course, students can also talk to the lab TA, the lab instructor, or the course professor for help.

Each of the five lab modules has a manual and other related files, available under the course account on LEARN.

Policy on academic integrity

Academic integrity To maintain a culture of academic integrity, members of the University of Waterloo are expected to promote honesty, trust, fairness, respect and responsibility. A student is expected to know what constitutes academic integrity, to avoid committing academic offences, and to take responsibility for their 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 course instructor, academic advisor, or Graduate Associate Dean. When misconduct has been found to have occurred, disciplinary penalties will be imposed under Policy 71 - Student Discipline. For information on categories of offenses and types of penalties, students should refer to Policy 71 - Student Discipline, <https://uwaterloo.ca/secretariat/policies-procedures-guidelines/policy-71>.

Grievance A student who believes that a decision affecting some aspect of their University life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70 - Student Petitions and Grievances, Section 4, <https://uwaterloo.ca/secretariat/policies-procedures-guidelines/policy-70>.

Discipline A student is expected to know what constitutes academic integrity (<https://uwaterloo.ca/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.

Appeals A student may appeal the finding and/or penalty in a decision made under Policy 70 - Student Petitions and Grievances (other than regarding a petition) or Policy 71 - Student Discipline if a ground for an appeal can be established. Read Policy 72 - Student Appeals, <https://uwaterloo.ca/secretariat/policies-procedures-guidelines/policy-72>.

Note for students with disabilities The Office for persons with Disabilities (OPD), located in Needles Hall, Room 1132, 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 the OPD at the beginning of each academic term.

Academic Integrity Office (UW) <https://uwaterloo.ca/academic-integrity/>.

Schedule

| Week | Date | Subject | Reading | Deliverables |
|--------------------------------------|--------------|--|-----------|---------------------|
| MATHEMATICAL MODELS OF SYSTEMS | | | | |
| 1 | W, Sep 7 | Introduction to control systems | 1 (DB) | Assignment 1 |
| | F, Sep 9 | Examples of control systems | 1 (DB) | |
| 2 | M, Sep 12 | From differential equations to state space | 2, 3 (DB) | |
| | W, Sep 14 | Linearization | 2 (DB) | |
| 3 | F, Sep 16 | Laplace transform | 2 (DB) | |
| | M, Sep 19 | Transfer function | 2 (DB) | |
| | W, Sep 21 | Examples of transfer functions | 2 (DB) | |
| LINEAR SYSTEM THEORY | | | | |
| 4 | F, Sep 23 | System stability | 3, 6 (DB) | Assignment 2 |
| | M, Sep 26 | Types of stability | 6 (DB) | |
| | W, Sep 28 | Performance | 5 (DB) | Lab 1 |
| | Th, Sep 29 | - | | |
| 5 | F, Sep 30 | First order systems | 5 (DB) | Assignment 3 |
| | M, Oct 3 | Second order systems | 5 (DB) | |
| | W, Oct 5 | Lower-order approximations | 5 (DB) | |
| | F, Oct 6 | System identification | | |
| 6 | Oct 10-14 | Reading week — no class | | |
| | M, Oct 17 | Midterm review | | |
| | W, Oct 19 | Midterm exam | | |
| ANALYSIS OF FEEDBACK CONTROL SYSTEMS | | | | |
| 7 | F, Oct 21 | Block diagrams | 2 (DB) | Lab 2 |
| | M, Oct 24 | Stability of interconnected systems | 4 (DB) | |
| | W, Oct 26 | Closed-loop stability: Routh-Hurwitz criterion | 6 (DB) | |
| | Th, Oct 27 | - | | |
| 8 | F, Oct 28 | Frequency response | 8 (DB) | Assignment 4 |
| | M, Oct 31 | Bode plots | 8 (DB) | |
| | W, Nov 2 | Examples of bode plots | | |
| | F, Nov 4 | Closed-loop stability: Nyquist plot | 9 (DB) | |
| 9 | M, Nov 7 | Closed-loop stability: Bode plot | 9 (DB) | |
| CONTROLLER SYNTHESIS | | | | |
| 10 | W, Nov 9 | Loop shaping | 10 (DB) | Lab 3 |
| | F, Nov 11 | Integral control | 7 (DB) | |
| | M, Nov 14 | Lead compensators | 10 (DB) | Assignment 5 |
| | W, Nov 16 | Lag compensators | 10 (DB) | |
| 11 | F, Nov 18 | PID controller | 7 (DB) | Lab 4 |
| | M, Nov 21 | Root locus | 7 (DB) | |
| | W, Nov 23 | Controller design with root locus | 7 (DB) | |
| 12 | F, Nov 25 | Back to state space | 11 (DB) | Prelab 5 Project |
| | M, Nov 28 | Pole placement | 11 (DB) | |
| | W, Nov 30 | Writing software for control systems | | |
| 13 | F, Dec 2 | Robot control | | Lab 5 |
| | M, Dec 5 | Final review | | |
| | TBD Dec 9-23 | Final exam | | |