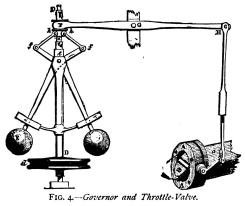
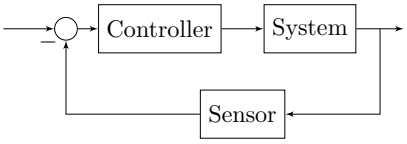
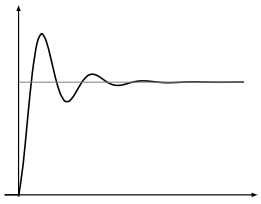
SE 380 Introduction to Feedback Control
Fall 2022








> 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
	Rollen D'Souza	rs2dsouz@uwaterloo.ca

Time and place	Lectures	Monday, Wednesday, Friday 9:30-10:20, STC 0040
	Tutorials	Monday 16:30-17:20, RCH 103
	Office hours	Tuesday 15:00-17:00, E5 4006
		Thursday 15:00-17:00, E7 5318

Website	`learn.uwaterloo.ca/`
	`piazza.com/uwaterloo.ca/fall2022/se380`
	`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: 10% (Lab $i = i\%$, $i \in \{1, 2, 3, 4\}$)
- Project: 10%
- Midterm exam: 30%
- Final exam: 40%

Lab details

- The lab work is carried out in groups of 2 students. 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.
- 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.

Rules about group work in labs:

- Students work in groups of two. Both partners must do all of the lab work.
- 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 four lab modules has a manual and other related files, available under the course account on LEARN.

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 1-page PDF document using the IEEE conference template (`https://www.ieee.org/conferences/publishing/templates.html`), structured as follows:
  - Control design process
  - Simulation results
  - Discussion

The project work is carried out in groups of 2 people (same groups as the labs). 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.

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