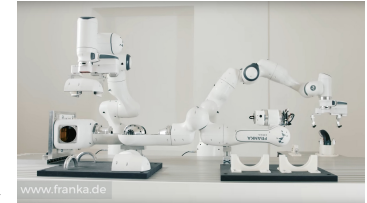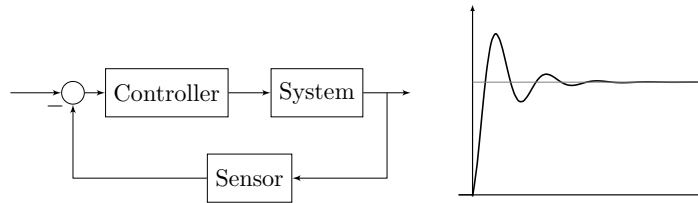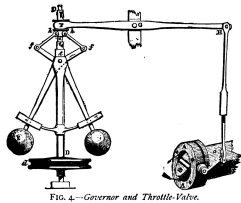# SE 380 Introduction to Feedback Control
Fall 2024

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)

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Lab instructor	Manisha Shah Email: manisha@uwaterloo.ca Office: E2 3343
Teaching assistants	Prajwal Thakur prajwal.thakur@uwaterloo.ca Andrew Nasif andrew.nasif@uwaterloo.ca
Time and place	Lectures Monday, Wednesday, Friday 11:30-12:20, E7 5343 Tutorials Thursday 11:30-12:20, STC 0040 Office hours Wednesday 13:00-15:00, E5 4006

Website	`learn.uwaterloo.ca/`
	`https://www.gnotomista.com/teaching/se380_fall2024.html`
	`https://piazza.com/uwaterloo.ca/fall2024/se380`

Description

This course will introduce students to the mathematical modeling of 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 via homeworks. Moreover, throughout the term, a project will walk the students through the implementation of a controller for an autonomous mobile robot, which will be demonstrated on a real robotic platform in the UWaterloo Robohub.

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:

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

Deliverables and grading

- Homeworks (`10%`)
  - 5 homeworks (referred to as HW1, ..., HW5, in the following)
  - Each homework is worth `2%`
  - Handled via Crowdmark

- Project (`10%`)
  - 3 tasks (referred to as PT1, PT2, PT3, in the following)
  - PT1, PT2, PT3 are worth `2%,3%,5%`, respectively
  - Handled via LEARN
  - Carried out in groups
  - Project description on the course website

- Labs (`10%`)
  - 4 labs (referred to as Lab1, ..., Lab4, in the following)
  - Lab1, ..., Lab4 are worth `1%,2%,3%,4%`, respectively
  - Handled via Crowdmark
  - Carried out in groups (same as project)
  - Lab description on the course website

- Exams (`70%`)
  - 1 midterm, 1 final
  - Total worth `max{30% midterm + 40% final, 70% final}`

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	HW/PT due
		MATHEMATICAL MODELS OF SYSTEMS		
1	W, Sep 4	Introduction to control systems	1 (DB)	
	F, Sep 6	Examples of control systems	1 (DB)	
2	M, Sep 9	From differential equations to state space	2, 3 (DB)	
	W, Sep 11	Linearization	2 (DB)	
	F, Sep 13	Laplace transform	2 (DB)	HW1
3	M, Sep 16	Transfer function	2 (DB)	
	W, Sep 18	Examples of transfer functions	2 (DB)	
	F, Sep 20	Frequency response	8 (DB)	
4	M, Sep 23	Bode plots	8 (DB)	
	W, Sep 25	Examples of bode plots	8 (DB)	
		LINEAR SYSTEM THEORY		
	F, Sep 27	Stability	3, 6 (DB)	HW2
5	M, Sep 30	Stability	3, 6 (DB)	
	W, Oct 2	Performance	5 (DB)	
	F, Oct 4	First order systems	5 (DB)	PT1
6	M, Oct 7	Second order systems	5 (DB)	
	W, Oct 9	Lower-order approximations	5 (DB)	
	F, Oct 11	System identification		HW3
	Oct 14-18	**Reading week — no class**		
7	M, Oct 21	Midterm review		
	Tu, Oct 22	**Midterm exam, 19:00–20:20, DC 1351**		
		ANALYSIS OF FEEDBACK CONTROL SYSTEMS		
	W, Oct 23	Block diagrams	2 (DB)	
	F, Oct 25	Stability of interconnected systems	4 (DB)	
8	M, Oct 28	Routh-Hurwitz criterion	6 (DB)	PT2
	W, Oct 30	Nyquist criterion	9 (DB)	
	F, Nov 1	Bode criterion	9 (DB)	HW4
		CONTROLLER SYNTHESIS		
9	M, Nov 4	Loop shaping	10 (DB)	
	W, Nov 6	Integral control	7 (DB)	
	F, Nov 8	Lead-lag compensators	10 (DB)	
10	M, Nov 11	PID controller	7 (DB)	
	W, Nov 13	Root locus	7 (DB)	
	F, Nov 15	Root locus	7 (DB)	HW5
11	M, Nov 18	Back to state space	11 (DB)	
	W, Nov 20	Pole placement	11 (DB)	
	F, Nov 22	Pole placement	11 (DB)	PT3
12	M, Nov 25	Control for software & software for control		
	W, Nov 27	Robohub sessions		
	F, Nov 29	Robohub sessions		
13	M, Dec 2	Final review		
	Th, Dec 12	**Final exam, 12:30–14:30, Room TBA**		