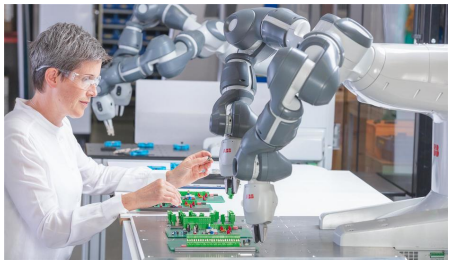
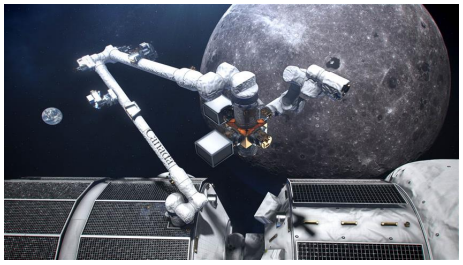
ECE 486 / 687 Robot Dynamics & Control
Spring 2025





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Teaching assistants	Sheikh Tahmid Email: sheikh.abrar.tahmid@uwaterloo.ca

Time and place	Lectures	Tuesday, Thursday	13:00–14:20	E2 1732
	Tutorials	Thursday	10:30–11:20	E7 4433
	Office hours	Wednesday	10:00–12:00	E5 4006

Website	`learn.uwaterloo.ca/`
	`https://piazza.com/uwaterloo.ca/spring2025/ece486ece780t03`
	`https://www.gnotomista.com/teaching/ece486_ece687_spring2025.html`

Description
This course will introduce students to dynamic modeling and control techniques for robotic systems, and expose them to some cutting-edge research. The course will be divided into five modules, corresponding to the following topics:

1. Dynamics of manipulators
2. Control of manipulators
3. Kinematics of mobile robots
4. Control of mobile robots
5. Optimization-based robot control

Each module will be presented during lectures supported by interactive demonstrations with the Franka Emika manipulator robot (`https://www.franka.de/research`) in the RoboHub. The concepts will be reinforced through homeworks containing both theoretical exercises and programming assignments (Python or MATLAB). The course will also include a lab section (for undergraduate students only) and a project which will allow students to implement robot control algorithms on a table-top robotic arm and the mobile manipulator DJI RoboMaster EP (`https://www.dji.com/ca/robomaster-ep`), respectively.

Prerequisites

- ECE 380 for ECE 486

- No formal prerequisites for ECE 687

Prior knowledge of linear algebra, rigid body dynamics, feedback control systems, and mathematical optimization can make life a bit easier.

Reading
The course textbook is:

[1] Mark Spong, Seth Hutchinson, and Mathukumalli Vidyasagar, *Robot modeling and control*, John Wiley & Sons, 2020

The following texts will be used for parts of the course:

[2] Bruno Siciliano, Lorenzo Sciavicco, Luigi Villani, and Giuseppe Oriolo, *Robotics. Modelling, planning and control*, Springer, 2009

[3] Stephen Boyd and Lieven Vandenberghe, *Convex optimization*, Cambridge University Press, 2004

[4] Magnus Egerstedt, *Robot Ecology: Constraint-Based Design for Long-Duration Autonomy*, Princeton University Press, 2021

Additional reading material will be provided as appropriate.

Deliverables and grading

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- Homeworks (20%)
  - 2 homeworks
  - 10% each
- Midterm (30%)
- Lab (25%)
  - Labs 1, 2, 3, 4, 5 are worth 2%, 4%, 5%, 6%, 8%, respectively
- Project (25%)
  - Final project report: 20%
  - Project code: 5%

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- Homeworks (50%)
  - 2 homeworks
  - 25% each
- Project (50%)
  - Final project report: 40%
  - Project code: 10%

Extra project points will be assigned to the groups participating in the *1st edition of the Robotics Quidditch tournaments* together with ECE481 / ECE780 T01 students!

Lab details
The lab will consist of the visual servoing of a robotic arm. The work will be carried out in groups of at most 2 people (same as the project groups). More details in the lab manual on the course website.

Project details
The project will consist of the control of a mobile manipulator. The work will be carried out in groups of at most 2 people (same as lab groups). More details in the project description on the course website.

Project details: Alternative for MASc and PhD students
The project will consist of the solution to a problem in the student's research area using the techniques covered during the course.

Audit policy
Either the homeworks or the project must be completed to audit the course.

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

Date	Subject	Reading	Deliverable due
	DYNAMICS OF MANIPULATORS		
May 6	Introduction to robot dynamics and control		
May 8	Rigid body transformations	2 [1], 2 [2]	
May 13	Rigid body transformations	2 [1], 2 [2]	
May 15	Direct kinematics	4 [1], 3 [2]	
May 20	Differential kinematics	3 [1], 2 [2]	
May 22	Inverse kinematics	5 [1], 3 [2]	
	CONTROL OF MANIPULATORS		
May 27	Dynamic model of manipulators	6 [1], 7 [2]	
May 29	Decentralized and centralized control	8, 9 [1], 8 [2]	
May 30			Lab 1
Jun 1			Project proposal
Jun 3	Operational space control	9 [1], 8 [2]	
Jun 5	Impedance control	9 [1], 8 [2]	
Jun 8			HW 1
	KINEMATICS OF MOBILE ROBOTS		
Jun 10	Kinematic constraints	14 [1], 11 [2]	
Jun 12	Kinematic model	14 [1], 11 [2]	
Jun 13			Lab 2
Jun 16-20	**Midterm week — no class**		
Jun 16	Robohub session, 8:30–11:30		
Jun 19	**Midterm exam, 14:30–16:00, E7 5353**		
	CONTROL OF MOBILE ROBOTS		
Jun 24	Controllability	14 [1], 11 [2]	
Jun 26	Control of driftless systems	14 [1], 11 [2]	

Jun 27			Lab 3
Jun 30	Robohub session, 8:30–11:30		
Jul 1	**Canada day — No class**		
Jul 3	Control of differentially flat systems	14 [1], 11 [2]	
Jul 6			HW 2
	OPTIMIZATION-BASED ROBOT CONTROL		
Jul 7	Robohub session, 8:30–11:30		
Jul 8	Recap of mathematical optimization	1 [3], lecture notes	
Jul 10	Constrained convex optimization	4, 5 [3], lecture notes	
Jul 14	Robohub session, 8:30–11:30		
Jul 15	Stability and control Lyapunov functions	4 [4], lecture notes	
Jul 17	Invariance and control barrier functions	4 [4], lecture notes	
Jul 18			Lab 4
Jul 21	Robohub session, 8:30–11:30		
Jul 22	Combining stability and invariance tasks	4 [4], lecture notes	
Jul 24	Research challenges and opportunities		
Jul 28	Robohub session, 8:30–11:30		
Jul 30	Extra class		
Aug 1			Lab 5
Aug 4			Project final report