ECE 780 T03 Robot Dynamics & Control
Spring 2022

Instructor
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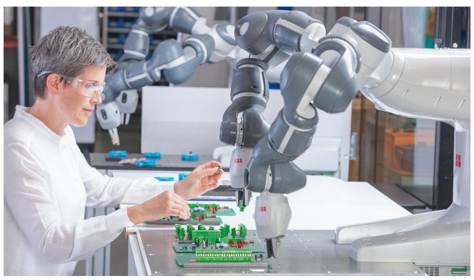
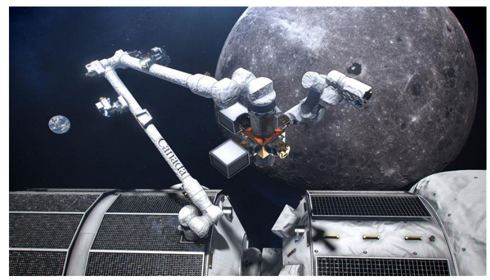
Time and place Wednesday, Friday 11:30-12:50, E7 4437

Office hours Wednesday 13:30-15:30

Website `https://www.gnotomista.com/teaching.html#ece780t03`





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 six modules, corresponding to the following topics:

1. Robot dynamics
2. Motion control of manipulators
3. Force control of manipulators
4. Mobile robots
5. Motion control of mobile robots
6. Optimization-based control of robotic systems

Each module will be presented during lectures and reinforced with homeworks containing both theoretical exercises and programming assignments (MATLAB or Python). The course will also include a project which will allow students to explore a specific area of robot dynamics and control that interests them in more depth.

Prerequisites There are no formal prerequisites for the course. Some knowledge of linear algebra, mathematical optimization, control systems, and robot kinematics can make life a bit easier.

Reading
There is no required textbook. The following texts will be used for parts of the course.

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

[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.

Grading

- Homeworks: 60%
- Project: 40%

Project details

The project may consist of:

- Solution to a problem in the student's research area using the techniques covered during the course
- Independent study of a topic not covered in class

In both cases, a critical review of the research literature as well as computer modeling and simulations have to be carried out.
The deliverables will be two:

- A short proposal, in the form of a 1-page PDF document, containing:
  - Problem description
  - Novelty and/or impact
  - How robot dynamics and control techniques play a key role
  - Technical challenges
  - Metric for success
  - Timeline
- A final report, in the form of a PDF document of maximum 8 pages in the IEEE conference template (`https://www.ieee.org/conferences/publishing/templates.html`), structured as follows:
  - Introduction
  - Literature review
  - Materials and methods
  - Results
  - Discussion

Additionally, a short video (maximum 1 minute) to supplement the results may also be attached.
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.

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`.

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`.

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

Schedule

Date	**Subject**	**Optional reading**	**HW/project due**
	ROBOT DYNAMICS		
May 4	Direct and inverse kinematics	3 [1], 2 [2]	
May 6	Differential kinematics	4 [1], 3 [2]	
May 11	Inverse kinematics algorithms	5 [1], 3 [2]	
May 13	Lagrange formulation	6 [1], 7 [2]	
May 18	Dynamics of common manipulators	6 [1], 7 [2]	
May 20	Dynamic parameter identification	7 [2]	HW1 (Dynamics)
	MOTION CONTROL OF MANIPULATORS		
May 25	Recap of nonlinear control	C [1], C [2], 4 [4]	
May 27	Centralized control	9 [1], 8 [2]	
Jun 1	Robust and adaptive control	9 [1], 8 [2]	
Jun 3	Operational space control	9 [1], 8 [2]	Project proposal
Jun 8	Passivity-based control	13 [1]	
	FORCE CONTROL OF MANIPULATORS		
Jun 10	Impedance and admittance control	10 [1], 9 [2]	
Jun 15	Force control	10 [1], 9 [2]	
	MOBILE ROBOTS		
Jun 17	Kinematic constraints	14 [1], 11 [2]	HW2 (Control of manipulators)
Jun 22	Controllability	14 [1], 11 [2]	
Jun 24	Differential flatness	14 [1], 11 [2]	
	MOTION CONTROL OF MOBILE ROBOTS		
Jun 29	Control of unicycles	14 [1], 11 [2]	HW3 (Mobile robots)
Jul 1	**Canada day — No class**		
Jul 6	Control of autovehicles		
Jul 8	Control of quadrotors		
	OPTIMIZATION-BASED CONTROL OF ROBOTIC SYSTEMS		
Jul 13	Recap of mathematical optimization	1 [3]	
Jul 15	Constrained convex optimization	4, 5 [3]	HW4 (Control of mobile robots)
Jul 20	Min-norm control laws	4 [4]	
Jul 22	Research challenges and opportunities		Final project report