WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

ME 601 Advanced Robotics: Modern Motion Planning, Estimation, and Control

Xiaobin Xiong, UW Madison, Fall 2024

1. Core Information

Canvas: https://canvas.wisc.edu/courses/419400 (Managed by the Instructor)
Piazza: https://piazza.com/wisc/fall2024/me601 (Managed by the TA)
Time: Monday & Wednesday, 4-5:15pm.
Location: ME 2121.

2. Instructor

Name: Xiaobin Xiong, Assistant Professor.
Office hours: By appointment.
Location: ME 2031.
Email: xiaobin.xiong@wisc.edu

3. TA (10%)

Name: Jiarong Kang, PhD student in ME.
Office Hour: Wednesday 1-2pm.
Location: ECB 1025.
Email: kang248@wisc.edu

4. Course Description

Rigid body models of robots, constraints and contact, motion planning methods including sampling based, trajectory optimizations, state estimation algorithms including linear observers and filters, Kalman filters, optimization-based filters, feedback control methods including PD, Impedance Control, optimization-based controllers, Differential Dynamic Programming, Lyapunov Analysis and Design, and Underactuation.

5. Requisites

Enroll Info: Knowledge of robotic systems [such as ME439, ME441] is encouraged, however not required. Knowledge of Basics of Undergrad-level Rigid Body Kinematics and Dynamics, and Dynamical System (such as ME340) is necessary.

6. Learning Outcomes

Upon successful completion of this course, you will be able to

- Understand the mathematical models of general robotic systems.
- Plan motion that realizes certain desired tasks.
- Estimate robot states from available sensors.
- Control robot motion using appropriate controller designs.

7. Relevant Materials

There is no required textbook for this course. The following materials are available for reference:

1. Choset H, Lynch K M, Hutchinson S, et al. Principles of robot motion: theory, algorithms, and implementations[M]. MIT press, 2005.
2. Tedrake R. Underactuated robotics: Learning, planning, and control for efficient and agile machines course notes for MIT 6.832[J]. Working draft edition, 2009, 3(4): 2.
3. Lynch K M, Park F C. Modern robotics[M]. Cambridge University Press, 2017.
4. Optimized Robotics - Advanced Robotics: www.nathanratliff.com

8. Grading

In-class Participation - 10%
Homework - 40%
Midterm Exam - 20%
Final Project - 30%

Midterm (20%) There will be one written midterm exam conducted in class. Further policies will be posted on the canvas course page.

Final Project and Presentation: A project will be used to evaluate your understanding of the course material. The work for the project will start midway through the semester with a project proposal due after the midterm. Students can form a team of size 1-4. The goal of the project will be to implement the various planning, estimation, and control learned in the course on a robotic system (either in simulation or hardware). Examples of the robotic system are quadrotors, segways, robot arms, and legged robots. There will be a final presentation scheduled for all teams. Grading will be based on reviews from the peers, TA, and the instructor.

Homework Assignments: There will be 4 graded homework assignments throughout the semester. You will have more than one week to complete each assignment. The rules are:

- It is your responsibility to ensure that what you turn in fully documents and explains your solution
- Submit your homework as a short report through Canvas; MATLAB scripts should be attached.
- Explain your work: write in words how you solved the problem.
- You are encouraged to discuss homework problems. However, the work you turn in must be your own. If you use any external sources, be sure to cite your sources. You must be able to demonstrate that you understand your solution.

In-class Participation: Attending to the lectures is important to ensure the learning outcome. For some lectures, I may select students to type the notes from the lecture, document in LaTeX Format (template will be provided) and submit them to TA directly through email. The notes will be due one week after the corresponding lecture. The purpose is to provide you with targeted feedback on the understanding of the course material, and everyone will have a document for future reference after completion of the course. The notes and explanation will be graded (out of 5 points).

9. Course Schedule (subject to changes):

Chapter	Week	Date	Day	Lecture Topics	Logistics
How to **Model** Robot Motion	1	9/4/2024	W	Intro to Robotic Systems, Kinematics and Dynamics	
	2	9/9/2024	M	Dynamics Model, ODE	
		9/11/2024	W	Integrators and Difference Equation (Discrete Mechanics)	
	3	9/16/2024	M	Contact and Constraints: Collision and Friction	
		9/18/2024	W	Hybrid Dynamics Models (LCP formulation)	
	4	9/23/2024	M	Equilibriums, Stability & Linearization (Periodic Orbits)	HW1 out
		9/25/2024	W	Lyapunov Analysis (Poincare Map)	
How to **Control** Robot Motion	5	9/30/2024	M	Control Basics: Feedback & Linear Control	
		10/2/2024	W	State/Output Feedback	
	6	10/7/2024	M	Feedback Linearization: Full-State/Input-Output	
		10/9/2024	W	Underactuation: Zero Dynamics, Differential Flat System	
	7	10/14/2024	M	Control Lyapunov Function	HW1 Due, HW2 out
		10/16/2024	W	QP Formulations, Lyapunov Backstepping	
	8	10/21/2024	M	Optimization-based: Task-Space Control, LQR (MPC)	
		10/23/2024	W	**Mid-term**	
How to **Plan** Robot Motion	9	10/28/2024	M	Motion Planning: Grid Search	Project Proposal Due
		10/30/2024	W	Probabilistic RoadMap	
	10	11/4/2024	M	Rapidly-exploring Random Trees	HW2 Due, HW3 out
		11/6/2024	W	Nonholonomic Planning (Kino-Dynamic Planning)	
	11	11/11/2024	M	Trajectory Optimization	
		11/13/2024	W	Solution Methods, DDP (Contact-implicit Optimization)	
How to **Estimate** Robot Motion	12	11/18/2024	M	State Estimation: Observability & Observers	
		11/20/2024	W	Probability Basics	
	13	11/25/2024	M	Kalman Filter	HW3 Due, HW4 out
		11/27/2024	W	Nonlinear Filters: EKF, UKF, Particle.	Thanksgiving week
	14	12/2/2024	M	Optimization-based: MHE (Factor Graph)	
		12/4/2024	W	Summary	
Do it all together if you can	15	12/9/2024	M	**Final Presentation**	
		12/11/2024	W		HW4 Due

(--) are advanced topics that we may or may not cover in the lecture.