16-745: Optimal Control and Reinforcement Learning

Spring 2021

Course Description

This is a course about how to make robots move through and interact with their environment with speed, efficiency, and robustness. We will survey a broad range of topics from nonlinear dynamics, linear systems theory, classical optimal control, numerical optimization, state estimation, system identification, and reinforcement learning. The goal is to provide students with hands-on experience applying each of these ideas to a variety of robotic systems so that they can use them in their own research.

Prerequisites: Strong linear algebra skills, experience with a high-level programming language like Python, MATLAB, or Julia, and basic familiarity with ordinary differential equations.

Instructors

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TA: Tanmay Shankar	**Email:** tshankar@andrew.cmu.edu

Logistics

- Lectures will be held Tuesdays and Thursdays 6:00–7:20 PM Eastern time on Zoom.
- Office hours will be TODO: based on survey.
- Homework assignments will be due by 11:59 PM Eastern time on Wednesdays. Two weeks will be given to complete each assignment.
- GitHub will be used to distribute and collect assignments.
- Slack will be used for general discussion and Q&A outside of class and office hours.
- There will be no exams. Instead, each student will complete a project on a topic of their choice.

Learning Objectives

By the end of this course, students should be able to do the following:

1. Analyze the stability of dynamical systems
2. Design LQR controllers that stabilize equilibria and trajectories

3. Use offline trajectory optimization to design trajectories for nonlinear systems
4. Use online convex optimization to implement model-predictive control
5. Understand the effects of stochasticity and model uncertainty
6. Directly optimize feedback policies when good models are unavailable

Learning Resources

There is no textbook required for this course. Video recordings of lectures and lecture notes will be posted online. Additional references for further reading will be provided with each lecture.

Homework

Homework will be posted every 2 weeks and students will be given at least one full week to complete assignments. All homework will be distributed and collected using GitHub. Solutions and grades will be returned within one week of homework due dates.

Project Guidelines

Students should work in groups of 1–4 to complete a substantial final project. The goal is for students to apply the coarse content to their own research. Project proposals will be solicited in March and topics will be selected in consultation with the instructors.

Project grades will be based on a short presentation given during the last week of class and a final report submitted by May 14. Reports should be written in the form of a 6–8 page conference paper using the standard two-column IEEE format.

Grading

Grading will be based on:

- 60% Project
- 30% Homeworks
- 10% Participation

Attendance during lectures is not required to earn a full participation grade. Students can also participate through any combination of office hours, Slack discussions, project presentations, and by offering constructive feedback about the course to the instructors.

Course Policies

Late Homework: Students are allowed a budget of 2 late days for turning in homework with no penalty throughout the semester. They may be used together on one assignment, or separately on two assignments. Beyond these two days, no other late homework will be accepted.

Accommodations for Students with Disabilities: If you have a disability and are registered with the Office of Disability Resources, I encourage you to use their online system to notify me of your accommodations and discuss your needs with me as early in the semester as possible. I will work with you to ensure that accommodations are provided as appropriate. If you suspect that you may have a disability and would benefit from accommodations but are not yet registered with the Office of Disability Resources, I encourage you to contact them at access@andrew.cmu.edu.

Statement of Support for Students' Health & Well-Being: Take care of yourself. Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep, and taking some time to relax. This will help you achieve your goals and cope with stress.

If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit http://www.cmu.edu/counseling. Consider reaching out to a friend, faculty, or family member you trust for help getting connected to the support that can help.

If you or someone you know is feeling suicidal or in danger of self-harm, call someone immediately, day or night:

CaPS: 412-268-2922
Re:solve Crisis Network: 888-796-8226

If the situation is life threatening, call the police:

On campus: CMU Police: 412-268-2323
Off campus: 911

If you have questions about this or your coursework, please let me know. Thank you, and have a great semester.

Tentative Schedule

Week	Dates	Topics	Assignments
1	Feb 2	Course Overview, Dynamics Intro	Survey
	Feb 4	Discrete-Time Dynamics	
2	Feb 9	Optimization Intro	HW 1 Out
	Feb 11	Unconstrained Numerical Optimization	
3	Feb 16	Constrained Numerical Optimization	
	Feb 18	Linear Systems & LQR	
4	Feb 23	No Class	HW 1 Due
	Feb 25	LQR as a QP and the Riccati Equation	HW 2 Out
5	Mar 2	Dynamic Programming	
	Mar 4	Convex MPC	
6	Mar 9	Nonlinear Trajectory Optimization & DDP	HW2 Due
	Mar 11	DDP with Constraints	HW3 Out
7	Mar 16	Direct Collocation & SQP	
	Mar 18	Floating Base Systems & Attitude	
8	Mar 23	Optimization with Quaternions	
	Mar 25	Contact Intro	
9	Mar 30	Hybrid Trajectory Optimization for Legged Systems	HW3 Due
	Apr 1	No Class	
10	Apr 6	Model Uncertainty: Iterative Learning Control	HW4 Out
	Apr 8	Stochastic Optimal Control & LQG	
11	Apr 13	Robust Control & Minimax DDP	
	Apr 15	No Class	
12	Apr 20	Practical Tips and Tricks & Control History	HW4 Due
	Apr 22	Optimal Control in the Wild: SpaceX & JPL	
13	Apr 27	Optimal Control in the Wild: Autonomous Driving	
	Apr 29	Optimal Control in the Wild: Legged Robots	
14	May 4	Project Presentations	
	May 6	Project Presentations	