USC Viterbi School of Engineering

AME 599: Robot Dynamics and Control

Units	**4**
Term	**Spring 2021 M Jan 11th – W May 12th**
Section	**28700R**
Location	Lecture M/W 9:00 – 10:50am See the course Blackboard page for updates

Instructor	**Quan Nguyen**
Office	OHE 500G
Office Hours	T 9-10 am, Th 9-10 am.
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Teaching Assistant	TBA
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Course Description

This course will introduce to students the skills and knowledge to analyze kinematics, dynamics of robotic systems and use it for control design. Multiple advanced control techniques will be discussed in the class including Linear Quadratic Regulator (LQR), Model Predictive Control (MPC), Quadratic Program (QP) based nonlinear control, and trajectory optimization. The course will contain a final project on control of quadruped robots. The team with the highest score for the final project will have a chance to implement their controller on a real quadruped robot in the Dynamic Robotics and Control Laboratory.

Course Objectives

The objective of this course is for students to develop the capability of analyzing dynamics and designing advanced controllers for robotic systems. The course will cover the following topics:

- Kinematics and dynamics of robotic systems
- Fundamentals on feedback control systems for robotics
- Advanced control techniques for robotic systems including Linear Quadratic Regulator (LQR), Model Predictive Control (MPC), Quadratic Program (QP) based nonlinear control
- State-of-the-art trajectory optimization
- Fundamentals on control of legged robots

The students will also learn how to use MATLAB to simulate system dynamics, design physical-based simulation and implement a wide variety of advanced controllers and trajectory optimization approaches. The final project on control of quadruped robots will enable the students to become familiar with complex control software based on C++ and ROS and understand the complete architecture of the control system for mobile robots.

Student Learning Outcomes

After completing this course, students should be able to:

- Analyze dynamics and simulate different robotic systems
- Design and implement different control algorithms for robotic manipulation and mobile robots
- Formulate and solve trajectory optimization for robotic systems
- Implement state-of-the-art controllers for legged robots

Prerequisite(s):	N/A
Co-Requisite (s):	N/A
Concurrent Enrollment:	N/A

Recommended Preparation: N/A

Course Content and Discussion Forum

This course will use Piazza for all class discussions. Refrain from emailing questions related to assignments, midterms, etc., and instead **use Piazza**. The TA, myself and even you can answer questions as they arise, thus providing an efficient means for communication. If you have issues accessing the Piazza, contact team@piazza.com directly. Before the semester begins, verify that you have access to these websites; Piazza is accessed from within the Blackboard page. **Recommended download**: Piazza App for phones. It works!

Tentative Course Schedule

Week	Lecture Topics	Reference / Reading	Assignment
1	L1: Overview, math review, basic concepts L2: Configuration space and forward kinematics	[1] Chapter 1, [2] Lecture 2-4 [1] Chapter 2, 4, 6	HW1 (Math and MATLAB)
2	Rigid body motion	[1] Chapter 3, 5, 7	
3	Rigid body dynamics	[1] Chapter 3, 8	HW2 (Kinematics)
4	L1: Dynamics of mobile robots L2: Modeling contacts	[1] Chapter 13 [4] Lecture 6, 7	
5	Feedback control systems and linear control	[1] Chapter 11 [2] Chapter 8	HW3 (Dynamics)
6	LQR controller	[4] Lecture 8, 9	
7	L1: Midterm 1 L2: Force control, Impedance control	[2] Chapter 9	HW4 (Linear control)
8	Model predictive control	[4] Lecture 23	
9	Nonlinear control part 1 (Stability Analysis) Nonlinear control part 2 (Feedback Linearization)	[5] Chapter 1, 3 [5] Chapter 9	HW5 (MPC + Nonlinear Control)
10	Nonlinear control part 3 (QP based nonlinear control)	[4] Lecture 25	

11	L1: Midterm 2 L2: Trajectory optimization part 1 (overview)	[4] Lecture 13	HW6 (Trajectory Optimization)
12	Trajectory optimization part 2 (Direct collocation and multiple shooting approaches)	[4] Lecture 14, 15	Final project announcement
13	L1: Control of legged robots (part 1) L2: ROS tutorial and Final project Q&A	[4] Lecture 18, 19, 21	Final project's team selection due
14	L1: Control of legged robots (part 2) L2: Final project's progress update	[4] Lecture 22, 24, 27	Final project's progress report due
15	Final project preparation (no class)		
16	Final project presentation	Time/place as shown in the Schedule of Classes	Final report due

Textbooks

There is no required textbook for the course. However, readings will be assigned from the following resources:

[1]. "*Modern Robotics: Mechanics, Planning, and Control*", Kevin M. Lynch and Frank C. Park, Cambridge University Press, 2017, [link].
[2]. "*Robot Modeling and Control*", Mark W. Spong, Seth Hutchinson, and Mathukumalli Vidyasagar, John Wiley & Sons, 2020. [link]
[3]. *Introduction to Robotics* (Notre Dame AME 50551) [link]
[4]. *Optimization-based Robotics* (Notre Dame AME 60621) [link]
[5]. "*Nonlinear Contro*l", Hassan K. Khalil, Pearson Education, 2015 [link]

Description and Assessment of Assignments

Exams: There will be two Midterm Exams held during the regular lecture time. All written exams will be closed book and closed notes. Homework sets will be assigned bi-weekly. Midterms will utilize the entire section-time (9:00-10:50a). In order to receive credit for your work, all quiz and exam problems must be presented in a clear, organized manner. Solutions must show evidence of work; "magic" answers will not be accepted. Partial credit may be given if the solution is presented in a logical fashion.

Homework: Homework will be assigned every two weeks and will be due two weeks after being assigned at the start of the first lecture of the week. There will be 6 HWs in total for the course. Students are encouraged to study the assigned HW sets together. However, each individual must ensure they obtain an understanding of the material. Between the instructor and the Teaching Assistant, there are office hours throughout the week to help you through the course. This time is best utilized when students come prepared with an attempt at a solution, thus allowing us to help you through your thought process.

All HWs, exams are to be completed as an individual. Failure to comply with this requirement will result in a failing grade for the course. Read the section titled **Academic Conduct** below.

Final Project: The final project will focus on the challenges of quadruped robot control. Depending on enrollment, the class will be divided into groups of up to 4-5 students for the project. The goal of the project is to design and implement state-of-the-art controllers for quadruped robots to complete a list of tasks in a high-fidelity simulation environment. A potential list of tasks could include balancing, walking, running, climbing stairs and obstacle courses, etc. There will be a single project for the entire class. The grade for the final project will be evaluated based on the overall team performance and all team members will receive the team grade. Two weeks before the final project's presentation, each team will need to present their final project's progress update and submit a brief report for that. The final project's report is due 1 week after the final project presentation.

The team with the best performance will have a chance to implement their approach on a real quadruped robot in the Dynamic Robotics and Control Laboratory. The instructor will discuss the implementation details with the winning team members at the end of the semester. A demonstration event will be organized in the lab and the rest of the class will be invited to witness the result and learn more about the implementation details.

Grading Breakdown

Assignment	% of Grade
HWs (6)	25
Midterms (2)	40
Final Project	35
Total	**100**

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, policy.usc.edu/scientific-misconduct.

Support Systems:

Counseling and Mental Health - (213) 740-9355 – 24/7 on call
studenthealth.usc.edu/counseling
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.
National Suicide Prevention Lifeline - 1 (800) 273-8255 – 24/7 on call
suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.
Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-9355(WELL), press "0" after hours – 24/7 on call
studenthealth.usc.edu/sexual-assault
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED) - (213) 740-5086 | Title IX – (213) 821-8298
equity.usc.edu, titleix.usc.edu
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298
usc-advocate.symplicity.com/care_report
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity |Title IX for appropriate investigation, supportive measures, and response.

The Office of Disability Services and Programs - (213) 740-0776
dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

USC Campus Support and Intervention - (213) 821-4710
campussupport.usc.edu
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity at USC - (213) 740-2101
diversity.usc.edu
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
dps.usc.edu, emergency.usc.edu
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-120 – 24/7 on call
dps.usc.edu
Non-emergency assistance or information.

Office of the Ombuds - (213) 821-9556 (UPC) / (323-442-0382 (HSC)
ombuds.usc.edu
A safe and confidential place to share your USC-related issues with a University Ombuds who will work with you to explore options or paths to manage your concern.