ASE389 - Spring 2023
Human-Centered Robotics

Unique number:	14510
In-Person Classroom:	ASE 2.134
Zoom link for lectures:	https://utexas.zoom.us/j/92960578791
Times:	TTh 5:00-6:30pm
Instructor:	Prof. Luis Sentis
Email:	Use Canvas
Office hours:	Wednesdays 11am-noon
Google Meets link for office hours:	https://meet.google.com/tki-ievy-fia

Description

This course is oriented towards graduate students interested in algorithms and software architectures for end-to-end trajectory generation and optimal control of real-world human-centered robotic systems. Human-centered robots include humanoid robots, quadrupedal robots, and exoskeletons, in particular those that operate around humans. The course will reinforce the premise that current barriers in human-centered robotics can be diminished by exploring unifying traits of motion planning, control and software frameworks that can be used to provide performance, learning, versatility and safety guarantees. We will pursue this exploration by delving into the following key research topics:

1. Whole-body control methods for human-centered robots
2. Trajectory generation and optimization for robotics
3. Algorithms for bipedal and quadrupedal locomotion
4. Synthesis of legged manipulation behaviors
5. Human-in-the-loop exoskeleton control

A team-oriented project will be developed during the course to consolidate new ideas, encourage the publication of papers, and build software for future research.

Connection to Ethics of AI and Robotics

Human Centered Robotics is not only about achiving human like physical behavior such as walking and manipulating in a dexterous fashion. It's also about how people and communities feel and accept robots operating in our environments such as indoor and urban setups. In addition, UT recently launched a multi-disciplinary program called Good Systems, https://bridgingbarriers.utexas.edu/good-systems, focusing on the design of AI technologies that benefit society. As part of this effort we launched a new Ethics of AI Portfolio Program, https://sites.utexas.edu/ethicalai.

In order to connect the course to these wider topics, this year we will dedicate a few minutes every lecture to discuss topics related to (1) responsible robotic systems, (2) privacy and legal issues with robotics, (3) technology acceptance of robotic systems, (4) living and working with robots, (5) community embedded robotics, (6) data informatics for robotic systems in the wild, (7) people responses to delivery robots through interviews and surveys, (8) the use of phsycophisiological sensors such as EEG to measure safety and trust when interacting with robots,(9) human awareness of robots to make them safer around people, and (10) social navigation among several lighting topics.

Prerequisites

Prerequisite for graduate students with focus on robotics: Linear System Analysis, Dynamics, Feedback Control, Basic Probability Theory, Programming in C++ or Python.

Prerequisites for graduate student with focus on ethics of AI: Willingness to delve in some of the mathematical concepts and develop a project in the topics outline under the section “Connection to Ethics of AI and Robotics” described above.

Prerequisites for undergraduate students: ASE 367K, ASE330M and ASE370C or equivalent courses with a grade of A- or A, plus knowledge of programming in C++ or Python.

Materials

Weekly Lecture Notes by Instructor.

The online book, Modern Robotics by Kevin Lynch and Frank Park, 2019, is a great reference for catching up with basic concepts in robotic modeling and control. You can use it to reinforce the basic concepts of robotics in the class.

The book chapter, Compliant Control of Whole-Body Multi-Contact Behaviors in Humanoid Robots by Luis Sentis, 2010, is a great reference for the initial lectures describing whole-body and operational space control.

The book, Introduction to Linear Algebra, by Gilbert Strang, 2016, can help with advanced algebra questions.

Feedback Systems: An Introduction for Scientists and Engineers, by Karl J. Åström and Richard M. Murray, 2020, can help with state space control systems

Attendance

Note that regular in-person attendance is expected.

Class Format

1. The materials and content will be centered around control systems and theory as well as cutting edge academic papers, several of them from the Human Centered Robotics Lab (HCRL) at UT.
2. Lectures will be both theory and problem solving oriented.
3. We will use as the main software the PnC (planning and control) software for the HCRL lab for humanoid legged and humanoid robots.
4. Theory and robot programming oriented homework will be assigned weekly for the first half of the course.
5. We will ask students to form teams for a comprehensive team oriented project.
6. The second part of the course will focus on developing the team project.
7. Students with focus on ethics of AI will mostly focus on developing a project on the topics outlined in the section “Connection to Ethics of AI and Robotics”

Grading Policy (for students focusing on robotics track)

Homeworks	40%
Project:	60%

Grading Policy (for students focusing on ethics of AI)

Class presentations:	40%
Project:	60%

Scores for assignments will be posted on UT Canvas. Access to Canvas http://canvas.utexas.edu requires your UT Electronic ID (UTEID) and password.

Schedule (tentative)

DAY	DATE	TOPIC
1	Tu 1/10	Syllabus. Review of previous class projects. Introduction to human centered robots. Modeling human centered robots. Floating robot generalized coordinates.
2	Th 1/12	Whole-body dynamics. Contact constraints.
3	Tu 1/17	Contact redundancy. Whole-body behaviors. Contact consistent Jacobian. **Start forming project teams.**
4	Th 1/19	Modeling contact centers of pressure. Virtual linkage model for human-centered robots.

5	Tu 1/24	Contact stability constraints. Task space equation of motion. Introduction to operational space control.
6	Th 1/26	Introduction to PnC (Planning and Control) software and its usage for whole-body control. Repo: GitHub Ahn 2021.
7	Tu 1/31	Task motion control. Introduction to priorities. Algebraic null-space. Control of secondary tasks. Stability of prioritized whole-body controllers. **HW1 Assigned.**
8	Th 2/2	General form of prioritized multi-task control. Prioritized task singularities.
9	Tu 2/7	Extra day to catch up with theory
10	Th 2/9	Introduction to dynamic locomotion. Dynamic locomotion Type I. Dynamic locomotion Type II. Hardware: Series elastic actuators, IMUs, and ground contact sensors. Dynamic model of locomotion. Inverted pendulum. Type I walking controller: **HW1 Due. HW2 Assigned.**
11	Tu 2/14	UT's Time to Velocity Reversal (TVR) walking generator. Continuation dynamic locomotion Type I walking controller. Analysis of uncertainty. Lyapunov stability. State space region of stability.
12	Th 2/16	UT's Whole-Body Locomotion Control (WBLC) Algorithm. Parts of WBLC: KynWBC and DynWBC. WBLC block diagram.
13	Tu 2/21	Using PnC software to achieve dynamic balancing. Repo: GitHub Ahn 2021. German DLR's Whole-Body Control algorithm. DLR's Divergent Component (DCM) of Motion walking generator. **HW2 Due. HW3 Assigned.**
14	Th 2/23	**Student project ideas presentation**
15	Tu 2/28	Exploring Model Predictive Control (MPC) for whole-body control. Part I: whole-body trajectory tracking. 1 step optimization. Linear Quadratic Regulator (LQR). Whole-body dynamics in state space.
16	Th 3/2	Solving nonlinear MPC problems - Alternative 1: use of Differential Dynamic Programming (DDP). Solving nonlinear MPC problems - Alternative 2: Linearization of dynamics along trajectories and formulation of a convex-quadratic-cost-quadratic-programming problem (QCQP). **HW3 Due.**
17	Tu 3/7	Optimization based locomotion planning and control. Trajectory generation using nonlinear optimization and transcription methods. **HW4 Assigned.**

18	Th 3/9	Collocation methods for locomotion trajectory generation in rough terrains combined with end-effector boundary conditions. TOWR+ algorithm for locomanipulation in arbitrary terrains. Frontiers in Robotics and AI 2021 by Junhyeok Ahn.
	Week 3/13	**Spring Break**
19	Tu 3/21	Bits of theory on optimal control and overview of model free methods.
20	Th 3/23	**Student Project Updates 1. Student Teams Present Latest Progress on Project**
21	Tu 3/28	Whole-Body Impulse Control Gait and trajectory optimization for robust bipedal locomotion. Papers: ArXiv 2020 by Donghyun Kim. **HW4 Due.**
22	Th 3/30	Mixture of experts model learning. Paper: Learning for Dynamics and Controls L4DC 2021 by Junhyeok Ahn.
23	Tu 4/4	Trajectory Optimization for Robotic Systems Given Sequences of Rigid Contacts. Paper: ACC 2020 by Jaemin Lee.
24	Th 4/6	**Student Project Updates 2. Student Teams Present Latest Progress on Project**
25	Tu 4/11	Finding Locomanipulation Plans Quickly in the Locomotion Constrained Manifold. Slides and paper: ICRA 2020 by Steven Jorgensen.
26	Th 4/13	Control of exoskeletons. Frontiers in Robotics and AI 2021 by Gray Thomas.
27	Tu 4/18	**Final Student Project Presentations**
28	Th 4/20	**Final Student Project Presentations**

Classroom Safety and COVID-19

To help preserve our in person learning environment, the university recommends the following.

- Adhere to university mask guidance.
- Vaccinations are widely available, free and not billed to health insurance. The vaccine will help protect against the transmission of the virus to others and reduce serious symptoms in those who are vaccinated.
- Proactive Community Testing remains an important part of the university's efforts to protect our community. Tests are fast and free.
- Visit utexas.edu for more information.

Sharing of Course Materials is Prohibited

No materials used in this class, including, but not limited to, lecture hand-outs, videos, assessments (quizzes, exams, papers, projects, homework assignments), in-class materials, review sheets, and additional problem sets, may be shared online or with anyone outside of the class unless you have my explicit, written permission. Unauthorized sharing of materials promotes cheating. It is a violation of the University's Student Honor Code and an act of academic dishonesty. I am well aware of the sites used for sharing materials, and any materials found online that are associated with you, or any suspected unauthorized sharing of materials, will be reported to Student Conduct and Academic Integrity in the Office of the Dean of Students. These reports can result in sanctions, including failure in the course.

Class Recordings

Class recordings are reserved only for students in this class for educational purposes and are protected under FERPA. The recordings should not be shared outside the class in any form. Violation of this restriction by a student could lead to Student Misconduct proceedings. Guidance on public access to class recordings can be found here.

Miscellaneous:

- The deadline for dropping a course without possible penalty can be found in the current semester UT calendar, which can be accessed online at: http://www.utexas.edu/student/registrar/cals.html.
- Allegations of Scholastic Dishonesty will be dealt with according to the procedures outlined in Appendix C, Chapter 11 of the General Information Bulletin, http://www.utexas.edu/student/registrar/catalogs.
- The University of Texas at Austin provides, upon request, appropriate academic adjustments for qualified students with disabilities. For more information, contact the Office of the Dean of Students at 471-6259, 471-4241 TDD, or the College of Engineering Director of Students with Disabilities, 471-4321.

Course Website:

All materials will be posted on Canvas (https://canvas.utexas.edu). This includes: announcements, course syllabus, assignments, grades, and email communications.

Honor Code:

The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community. Any form of plagiarism (i.e. to use and pass off the ideas or writings of another as one's own) will be considered an offense and notify to the proper organs within the University to take proper action. (http://catalog.utexas.edu/general-information/the-university)

Students with Disabilities

Students with disabilities may request appropriate academic accommodations from the Division of Diversity and Community Engagement, Services for Students with Disabilities, 512-471-6259, http://ddce.utexas.edu/disability

Accommodation for Religious Holidays:

By UT Austin policy, you must notify the instructor of your pending absence at least fourteen days prior to the date of observance of a religious holy day. If you must miss a class, an examination, a work assignment, or a project in order to observe a religious holy day, you will be given an opportunity to complete the missed work within a reasonable time after the absence.