CSCI 649: Haptic Interfaces and Virtual Environments

Units: 4
Spring 2025—MW 2-3:50 pm:

Location: KAP 148

Course Website:
For grades, assignments, announcements, and questions:
https://brightspace.usc.edu

Instructor: Heather Culbertson
Office: RTH 403
Office Hours: TBD
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Course Description

This course provides a graduate-level introduction to the field of haptics, which involves human interaction with real, remote, and virtual objects through the sense of touch. Haptic interfaces employ specialized robotic hardware and unique computer algorithms to enable users to explore and manipulate simulated and distant environments. Topics for the course include human haptic sensing and control, haptic interface design, virtual environment rendering methods, teleoperation control algorithms, and system evaluation. Current applications for these technologies will be highlighted, and important techniques will be demonstrated in a laboratory setting. Coursework includes homework/laboratory assignments and a research-oriented project. This class is appropriate for graduate students in computer science or any related engineering discipline with interest in robotics, dynamic systems, controls, or human-computer interaction.

Learning Objectives and Outcomes

Haptics is a multi-disciplinary field that is actively being researched by computer scientists, engineers, product designers, psychologists, and neuroscientists. By the end of the course, you should be able to:

- Identify the primary mechanisms of human haptic sensing
- Understand a number of methods for sensing the position of and actuating haptic interfaces
- Describe the differences between grounded and ungrounded force feedback
- Identify salient features of a haptic device design
- List a variety of different types of haptic devices
- Implement controllers to render various dynamics (stiffness, damping, inertia)
- Describe and implement basic teleoperation controllers
- Understand the causes of instability in virtual reality and teleoperation systems
- Design psychophysical and perceptual tests
- Describe applications of haptic devices
- Develop a new haptic device or application of a haptic device
- Read, evaluate, and critique research papers
- Design and deliver a research presentation

Prerequisite(s): None

Recommended Preparation: C++ programming experience on the level of CSCI 103; doctoral standing in computer science or engineering, or the permission of the instructor.

Logistics and Organization

The class meets two times a week, on Mondays and Wednesdays. You are expected to attend all class sessions and actively participate in class discussions. If you have to miss a class, notify the instructor in advance. Late arrivals and unexcused absences will reduce learning in the class and negatively affect your participation grade.

The first part of the semester will focus on lectures, readings, and discussions designed to introduce you to the field of haptics and haptic interface design both from a hardware and software perspective. Assignments will be handed out biweekly, and due biweekly. The deadline will be written on the assignment. Assignments will include a variety of activities, including written responses, problem solving, and programming haptic interfaces and virtual environments. All assignment materials will be submitted electronically on Blackboard.

Assignments will include programming the 3D Systems Touch haptic device. For these assignments, you will be given starter code. Five Touch haptic devices and computers will be available for class use in RTH 419. You must sign up for timeslots to work on the assignments as the devices must be shared with your classmates.

For the second part of the semester, students will form two- or three-person teams and select a current research problem in the field of haptics to pursue. There will be project discussion and checkpoints along the way to help guide your endeavors. You will complete most of the work on your project during the last ten weeks of the semester, and the class will conclude with final project demonstrations and a written report. Towards the end of the semester, students will also present published haptics papers (relevant to their projects) to their peers during class periods.

Textbook

Because a comprehensive book on the field of haptics does not yet exist, this class has no textbook. Instead, selected readings will be handed out each lecture and made available on the course Piazza website. You will learn quite a lot by doing these readings. You will be expected to turn in a short summary (1-2 paragraphs) on each reading to Blackboard before the indicated lecture. You must complete 10 reading summaries by the end of the semester.

Online Resources

Please log in to Blackboard for grading and submitting assignments for this course. Lecture notes and assignments will be posted on Piazza. This is also the best way to contact instructors and receive student input about assignment problems and class concepts outside of class and office hours. Simply navigate to piazza.com, create an account, and add CSCI 699 to your list of courses (http://piazza.com/usc/spring2023/csci649). There you can post a new question, search through previous posts, answer other student's posts, and receive instructor feedback. This site allows the instructor to know what questions students have, and I can provide answers in a centralized location. Please use this resource.

Grading Breakdown

Your grade in this class will be computed as a weighted average of your scores in the four main course components.

5%	Class Participation	All students are expected to actively engage in lectures and discussions. If you have a question, ask it! It is certain that someone else in the room has the same concern. Such contributions will keep everyone on the same page and will help the professor improve her presentation of the material. Similarly, if you have an observation or an idea, share it with everyone! A great deal of the learning in this class will be facilitated by peer interaction, as we all come from different academic and professional backgrounds.
5%	Readings	Readings will be assigned for each class on that day's topic. It is important to complete these readings in order to understand the material presented in the course. Students should submit a short summary (1-2 paragraphs) of each reading to Blackboard before the beginning of class. Students may choose 10 of the readings to complete summaries for throughout the semester.
40%	Homework Assignments	Start on assignments early, and ask for help if you get stuck. Discussing the assignment with your classmates is encouraged, but everyone must turn in his/her own work. Apparent academic integrity violations will be reported to the Office of Student Conduct. Late assignments will be penalized by 20% per day.
10%	Paper Presentation	Each student will pick a recent research paper to read, understand, and present in detail to the class. You will select this paper from the set of papers presented at the 2022 Haptics Symposium. Your presentation will be evaluated on organization, subject knowledge, slides, presentation skills, and interactivity. You will also assist in evaluating the presentations of your peers.
40%	Course Project	You will conduct a final team project in teams of two or three. You will work with Dr. C over the course of the semester to select your topic and teammates, study the relevant literature, define your

		problem, and develop a novel technique or device to solve it. Your project will be evaluated by the functionality of your end-of-semester demonstration, the correctness and completeness of your presentation, the technical strength of your contribution, and the organization, style, and clarity of your written report, which will be due approximately one week after the project demonstration.

Assignment Submission Policy

Assignments will be submitted as a single .zip file on Blackboard. Late assignments will be penalized by 20% per day.

Course Project

The purpose of this assignment is for you to plan and execute a haptics project that provides a new contribution to the field of haptics. The project must result in a device with bidirectional haptic interaction between a person or a robot and a real, remote, or virtual environment. It is to be completed in teams of two (or three). Individual projects are not permitted. All team members will receive the same grade for the project. I encourage project teams consisting of people with diverse backgrounds and skills. Beyond that, the options are quite open. Your project must:

- be clear in its objectives: know how you define success!
- be informed by a thorough literature search
- be easily used and understood by a haptics novice on demonstration day
- have high "production values" (haptic and visual)

Project timeline

- Proposal due: February 26
- Checkpoint 1: March 26
- User study protocol due: April 9
- Checkpoint 2: April 16
- User studies: April 28, 30
- Final project presentations: May 12
- Final report: May 12

User studies

In the last week of the semester, you will conduct a small user study with at least 3 participants. This user study should be designed to provide you some interesting insight into your system, evaluate how well your system works, or better understand how users interact with your system. You will be given time during the last week of classes to conduct the studies during class. Half of the groups will conduct their study on each day to allow other class members the opportunity to participate.

Final report

You will write a short two-page extended abstract in the IEEE RAS Conference Format (http://ras.papercept.net/conferences/support/support.php). The summary is due by midnight Pacific time on Monday, May 12. This abstract should give the title and the authors for the work, introduce the reader to your topic (why does it matter?), share insights from previous research (what have other researchers done in this area?), state the goal of your project (what did you set out to?), explain your methods (how did you do it?), summarize your results (what did you discover?), summarize your conclusions (what does it mean?), and lay out future work (what would you do next?). This abstract should include diagrams and photos, and it should be well written and clear.

Project Grading

General

Concept	10 pts.	*Is the motivation good, and the general idea logical?*
Approach	10 pts.	*Is the approach the right one to solve the problem?*
Demonstration		
Functionality	15 pts.	*Did the system function compellingly throughout the demo?*
Completeness	15 pts.	*Was the working system complete?*
User study		
Design	10 pts.	*Is the study designed to capture the information of interest?*
Results	10 pts.	*Was insight gathered about the user or device design?*
Summary Report		
Technical strength	15 pts.	*Is the paper technically accurate and complete?*
Presentation	15 pts.	*Is it well written, with appropriate supporting graphics?*
TOTAL	100 pts.	

Acknowledgments

Many individuals have contributed to the development of this course by sharing materials from their own haptics research or courses. These include: Allison Okamura (Stanford University), Katherine J. Kuchenbecker (Max Planck Institute for Intelligent Systems), J. Edward Colgate (Northwestern University), Will Provancher and Jake Abbott (University of Utah), Karon MacLean (University of British Columbia), Blake Hannaford (University of Washington), and Jeremy Brown (Johns Hopkins University).

Course Schedule (subject to change)

Week	Lec #	Date	Lecture Topics	Assignments
1	1	1/13	Introduction and course overview	
	2	1/15	Applications of haptic devices	
2		1/20	**MLK Day (no class)**	
	3	1/22	Human haptic perception	
3	4	1/27	Tactile haptic devices	
	5	1/29	Surface haptic devices	
4	6	2/3	Mid-air haptics	
	7	2/5	Haptic Sketching	
5	8	2/10	Kinesthetic haptic devices: design and kinematics	Assignment 1 (due 2/19)
	9	2/12	Multi-DOF kinesthetic devices	
6		2/17	**President's Day (no class)**	
	10	2/19	Project discussions	Project proposal (due 2/26)
7	11	2/24	Programming virtual environments	
	12	2/26	Programming virtual environments (continued)	Assignment 2 (due 3/5)
8	13	3/3	Rendering surface haptic properties	
	14	3/5	Rendering complex objects	Assignment 3 (due 3/12)
9	15	3/10	Teleoperation	
	16	3/12	Pseudohaptics and haptic illusions	
			Spring Break (no class)	
10	17	3/24	Psychophysical methods	Assignment 4 (due 4/2)
	18	3/26	Project Checkpoint 1	
11	19	3/31	Affective haptics	
	20	4/2	User studies/experimentation	User study protocol (due 4/9)
12	21	4/7	Data-driven haptics	
	22	4/9	Wearable and ungrounded devices	
13	23	4/14	Tactile sensing	

	24	4/16	Project Checkpoint 2	
14	25	4/21	Paper presentations	
	26	4/23	Paper presentations	
15	27	4/28	Project user studies	
	28	4/30	Project user studies	
FINAL		**5/12**	**Final project presentations (2-4 pm)**	

Readings

Lecture 1 -- Keshav, Srinivasan. "How to read a paper." ACM SIGCOMM Computer Communication Review 37.3 (2007): 83-84.

Lecture 2 -- Giri, Gowri Shankar, Yaser Maddahi, and Kourosh Zareinia. "An application-based review of haptics technology." Robotics 10.1 (2021): 29.

Lecture 3 -- Lederman, Susan J., and Roberta L. Klatzky. "Haptic perception: A tutorial." Attention, Perception, & Psychophysics 71.7 (2009): 1439-1459.

Lecture 4 – Choi, Seungmoon, and Katherine J. Kuchenbecker. "Vibrotactile display: Perception, technology, and applications." Proceedings of the IEEE 101.9 (2012): 2093-2104.

Lecture 5 -- Winfield, L., and J. E. Colgate. "Variable friction haptic displays." *Haptic Rendering: Foundations, Algorithms, and Applications*. CRC Press, 2008. 93-122.

Lecture 6 -- Rakkolainen, I., Freeman, E., Sand, A., Raisamo, R., & Brewster, S. (2020). "A survey of mid-air ultrasound haptics and its applications." IEEE Transactions on Haptics, 14(1), 2-19.

Lecture 7 -- Bucci, P., Cang, X. L., Valair, A., Marino, D., Tseng, L., Jung, M., ... & MacLean, K. E. (2017, May). "Sketching cuddlebits: coupled prototyping of body and behaviour for an affective robot pet." In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (pp. 3681-3692).

Lecture 8 -- Puerto, M. J., Sánchez, E., & Gil, J. J. (2009, March). Control strategies applied to kinesthetic haptic devices. In 2009 IEEE Workshop on Robotic Intelligence in Informationally Structured Space (pp. 137-144). IEEE.

Lecture 9 – Massie, Thomas H., and J. Kenneth Salisbury. "The phantom haptic interface: A device for probing virtual objects." In Proceedings of the ASME winter annual meeting, symposium on haptic interfaces for virtual environment and teleoperator systems, vol. 55, no. 1, pp. 295-300. 1994.

Lecture 11 – Salisbury, Kenneth, Francois Conti, and Federico Barbagli. "Haptic rendering: introductory concepts." IEEE computer graphics and applications 24, no. 2 (2004): 24-32.

Lecture 12 – Minsky, Margaret, Ouh-young Ming, Oliver Steele, Frederick P. Brooks Jr, and Max Behensky. "Feeling and seeing: issues in force display." In ACM SIGGRAPH Computer Graphics, vol. 24, no. 2, pp. 235-241. ACM, 1990.

Lecture 13 – Zilles, Craig B., and J. Kenneth Salisbury. "A constraint-based god-object method for haptic display." In Proceedings 1995 IEEE/RSJ International Conference on Intelligent Robots and Systems. Human Robot Interaction and Cooperative Robots, vol. 3, pp. 146-151. IEEE, 1995.

Lecture 14 – Hollerbach, John M., and David E. Johnson. "Virtual environment rendering." Human and Machine Haptics 7 (2000): 56-58.

Lecture 15 – Niemeyer, G., Preusche, C., Stramigioli, S., & Lee, D. (2016). "Telerobotics". In Springer Handbook of Robotics (pp. 1085-1108). Springer.

Lecture 16 – Lederman, Susan J., and Lynette A. Jones. "Tactile and haptic illusions." IEEE Transactions on Haptics 4, no. 4 (2011): 273-294.

Lecture 17 – Jones, Lynette A., and Hong Z. Tan. "Application of psychophysical techniques to haptic research." IEEE Transactions on Haptics 6, no. 3 (2012): 268-284.

Lecture 19 -- Eid, Mohamad A., and Hussein Al Osman. "Affective haptics: Current research and future directions." IEEE Access 4 (2015): 26-40.

Lecture 20 -- Hoffman, G., & Zhao, X. (2020). A primer for conducting experiments in human–robot interaction. ACM Transactions on Human-Robot Interaction (THRI), 10(1), 1-31.

Lecture 21 – Okamura, Allison M., Katherine J. Kuchenbecker, and Mohsen Mahvash. "Measurement-based modeling for haptic rendering." *Haptic Rendering*. AK Peters/CRC Press, 2008. 440-464.

Lecture 22 – Adilkhanov, A., Rubagotti, M., & Kappassov, Z. (2022). Haptic Devices: Wearability-Based Taxonomy and Literature Review. IEEE Access.

Lecture 23 – Girão, P. S., Ramos, P. M. P., Postolache, O., & Pereira, J. M. D. (2013). Tactile sensors for robotic applications. Measurement, 46(3), 1257-1271.

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 Research and Scholarship Misconduct.

Students and Disability Accommodations:

USC welcomes students with disabilities into all of the University's educational programs. The Office of Student Accessibility Services (OSAS) is responsible for the determination of appropriate accommodations for students who encounter disability-related barriers. Once a student has completed the OSAS process (registration, initial appointment, and submitted documentation) and accommodations are determined to be reasonable and appropriate, a Letter of Accommodation (LOA) will be available to generate for each course. The LOA must be given to each course instructor by the student and followed up with a discussion. This should be done as early in the semester as possible as accommodations are not retroactive. More information can be found at osas.usc.edu. You may contact OSAS at (213) 740-0776 or via email at osasfrontdesk@usc.edu.

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 for Equity, Equal Opportunity, and Title IX (EEO-TIX) - (213) 740-5086
eeotix.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 for Equity, Equal Opportunity, and Title for appropriate investigation, supportive measures, and response.

The Office of Student Accessibility Services (OSAS) - (213) 740-0776
osas.usc.edu
OSAS ensures equal access for students with disabilities through providing academic accommodations and auxiliary aids in accordance with federal laws and university policy.
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, Equity and Inclusion - (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
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