ME 327: Design and Control of Haptic Systems
Syllabus
Spring Quarter 2019

Description
Study of the design and control of haptic systems, which provide touch feedback to human users interacting with virtual environments and teleoperated robots. Focus is on device modeling (kinematics and dynamics), synthesis and analysis of control systems, design and implementation, and human interaction with haptic systems. Coursework includes homework/laboratory assignments and a hands-on project. Directed toward undergraduate and graduate students in engineering and computer science. Prerequisites: dynamic systems, feedback controls, and MATLAB programming.

Course Times/Locations
Lectures: Tuesdays and Thursdays 9:00-10:20 am, Y2E2-111 (Note: Lecture attendance is required.) Laboratory space: Bldg. 520, Room 145 (d'Arbeloff Teaching Lab; https://tinyurl.com/dArbeloff) Selected laboratories will also be held in Bldg. 550, Room 108.

Instructor
Allison Okamura
Email: aokamura@stanford.edu
Office hours: Thursdays 10:30 am-12 pm held in 550-107 or 520-145

Course Assistants
Julie Walker, juliewalker@stanford.edu
Cara Nunez, nunezc@stanford.edu
Michael Cheung, mycheung@stanford.edu
Office hours: TBD held in 520-145

Course Website
For assignments, solutions, and the latest syllabus: http://me327.stanford.edu
For grades: http://canvas.stanford.edu
For announcements and questions about course content and assignments: http://piazza.com
The best way to contact instructors and receive student input about assignment problems and class concepts outside of class and office hours is through the forum provided at Piazza. Simply navigate to piazza.com, create an account, and add ME 327 to your list of courses. There you can post a new question, search through previous posts, answer other student's posts, and receive instructor feedback. This site allows the entire teaching team to know what questions students have, and we can provide answers in a centralized location. Please use this resource.

Prerequisites
You should have a basic understanding of dynamic systems such as that covered in EE 102 or ME 161, and introductory feedback control such as that covered in ENGR 105. You should also be familiar with and have access to MATLAB, which is required for some of the assignments. (Student version is available online and at the Stanford Bookstore.) In addition, you will be better prepared for this course if you:
- have significant experience with programming (any language is fine)
- have experience with prototyping facilities at Huang Room 36, e.g. laser cutter and 3D printer
If you have any questions about whether or not you have the appropriate background for this class, let Allison know.

Logistics and Organization
This class meets two times a week, on Tuesdays and Thursdays. You are expected to attend all class sessions and actively participate in the discussions that transpire. If you must miss a class, notify the instructor in advance. Late arrivals and unexcused absences will reduce your learning in this class and negatively affect your participation grade.

For the first part of the quarter, assignments will usually be handed out weekly and due the following week. The deadline will be written on the assignment. Assignments will include a variety of activities, including written responses, problem solving, and building and programming haptic devices. Note: There is laboratory fee of $50 to partially offset the cost of lab materials, due to Brittany Coffer in Bldg. 550, Room 114 by April 9 by cash or check payable to Stanford University. Students may keep the "Hapkit" they construct for this course. In addition, for constructing your final project, we recommend that you purchase a $60 quarter pass to the Product Realization Lab and sign up for training, following the instructions on https://productrealization.stanford.edu.

For the latter part of the quarter, students will focus on a course project and reviews of haptics papers. The course project this year is to (1) create a haptic device, (2) analyze its behavior from a dynamic systems and control perspective, and (2) demonstrate an interesting application or use the device to measure an aspect of human
perception/movement control. An experiment demonstrating the performance of the device must be conducted. There will be project discussions and checkpoints along the way to guide your endeavors. You will complete the project during the last five weeks of the quarter, and the class will conclude with final project demonstrations and a written paper in a conference paper format. Toward the end of the quarter, student teams will also present published haptics papers (relevant to their projects) to their peers during class periods.

The Stanford Honor Code applies to this course. Students who need an academic accommodation based on the impact of a disability must initiate the request with the Office of Accessible Education (OAE). Professional staff will evaluate the request with required documentation, recommend reasonable accommodations, and prepare a current Accommodation Letter for faculty. Students should contact the instructor and the OAE in the first week of classes since timely notice is needed to coordinate accommodations. The OAE is located at 563 Salvatierra Walk; phone: 723-1066; their web site is http://studentaffairs.stanford.edu/oae.

Objectives
Haptics is a dynamic, multi-disciplinary field that is actively being researched by engineers, computer scientists, 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 interfaces
- Implement controllers to render various dynamics (stiffness, damping, inertia)
- Describe and implement basic telemanipulation 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

If there is something else you want to learn about, please tell the instructor. Because of the significant effort that must be put into the project for this course, we suggest that you do not take another course with a major project component.

Grading
10% Class Participation

As mentioned above, 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 the presentation of the material. Similarly, if you have an observation or an idea, please share it with everyone. A great deal of the learning in this class will be facilitated by peer interaction, as we come from a variety of academic and professional backgrounds.

50% Assignments
Assignments will generally be distributed on a weekly basis and be due one week later. Assignments/checkpoints that pertain to the project will contribute to that portion of your grade instead of this one. 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 or her own work. Apparent academic ethics violations will be reported. Late assignments will be penalized by 25% per day.

10% Paper Presentation
Each project team will pick a recent research paper to read, understand, and present in detail to the class with an interactive demonstration. You will select this paper from the set of papers presented at the 2018 IEEE Haptics Symposium Conference, and ideally the paper should be related to your project. 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.

30% Project
You will conduct an group final project (team size dependent on the size of the class). Your team will work with the instructor over the course of the quarter to select your topic and teammates, study the relevant literature, define your haptic experiment and device, develop a working demonstration, conduct an experiment, and write a research paper documenting the results. Your project will be evaluated by the functionality of your end-of-quarter demonstration, the significance of your experiment, the correctness and completeness of your...
presentation, the technical strength of your contribution, and the organization, style, and clarity of your paper.

Acknowledgments
Many individuals have contributed to the development of this course by sharing materials from their own haptics research or courses. These include: Katherine Kuchenbecker (University of Pennsylvania), Will Provancher and Jake Abbott (University of Utah), Karon MacLean (University of British Columbia), and Blake Hannaford (University of Washington). Previous Stanford students and course assistants including Tania Morimoto and Melisa Orta Martinez have also provided many valuable contributions to the course design.

Schedule (TENTATIVE – as of April 1, 2019)

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<thead>
<tr>
<th>Week</th>
<th>Lec #</th>
<th>Date</th>
<th>Lecture Topics</th>
<th>Assignments</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Tues 4/2</td>
<td>Introduction to haptics and course overview</td>
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<td>2</td>
<td>Thurs 4/4</td>
<td>Kinesthetic haptic devices: design and kinematics</td>
<td>Assignment 1 out</td>
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<td>3</td>
<td>Tues 4/9</td>
<td>Kinesthetic haptic devices: dynamics and control</td>
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<td>4</td>
<td>Thurs 4/11</td>
<td>Kinesthetic haptic devices: sensors and actuators</td>
<td>Assignment 1 due</td>
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<td>5</td>
<td>Tues 4/16</td>
<td>Hapkit Distribution and Assembly</td>
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<td>6</td>
<td>Thurs 4/18</td>
<td>Kinesthetic haptic devices: 1-DOF rendering</td>
<td>Assignment 2 due</td>
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<td>Tues 4/23</td>
<td>Kinesthetic haptic devices: multi-DOF design and</td>
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<td>8</td>
<td>Thurs 4/25</td>
<td>Kinesthetic haptic devices: multi-DOF rendering</td>
<td>Assignment 3 due</td>
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<td>9</td>
<td>Tues 4/30</td>
<td>Teleoperation: Implementation and Transparency</td>
<td>Assignment 4 due</td>
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<td>10</td>
<td>Thurs 5/2</td>
<td>Teleoperation: Stability and Setup</td>
<td>Assignment 5 due</td>
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<td>Tues 5/7</td>
<td>Project discussion and matchmaking</td>
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<td>12</td>
<td>Thurs 5/9</td>
<td>Human haptics: Mechanoreceptors and Kinesthesia</td>
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<td>Tues 5/14</td>
<td>Project team advising meetings</td>
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<td>14</td>
<td>Thurs 5/16</td>
<td>Project team advising meetings</td>
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<td>Tues 5/21*</td>
<td>Human haptics: user studies</td>
<td>Project checkpoint 1</td>
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<td>16</td>
<td>Thurs 5/23</td>
<td>Student paper presentation – Teams 1, 2, 3</td>
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<td>17</td>
<td>Tues 5/28</td>
<td>Student paper presentations – Teams 4, 5, 6</td>
<td>Project checkpoint 2</td>
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<td>Thurs 5/30</td>
<td>Student paper presentations – Teams 7, 8, 9</td>
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<td>19</td>
<td>Tues 6/4</td>
<td>Project demonstrations 9:30-10:30 am (in 520-145)</td>
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<td>Wed 6/5</td>
<td>Project Paper due 4:00 pm</td>
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*Allison is traveling on this date; course assistants will give lecture