ME 327: Design and Control of Haptic Systems
Syllabus
Winter Quarter 2018

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 research-oriented project. Directed toward graduate students and advanced undergraduates in engineering and computer science. Prerequisites: dynamic systems and MATLAB programming. Suggested experience with programming, feedback control design, and hardware prototyping.

Course Times/Locations
Lectures: Tuesdays and Thursdays 10:30-11:50 am, 530-127 (Note: Lecture attendance is required.)
Laboratory space: Bldg. 520, Room 145 (d'Arbeloff Teaching Lab)

Instructor
Allison Okamura
Email: aokamura@stanford.edu
Office hours: Mondays 11 am-12 pm
held in 520-145

Course Assistants
Nathan Usevitch, usevitch@stanford.edu
Jake Suchoski, jsucho@stanford.edu
Office hours: Mondays 10-11 am and Wednesdays 3-5 pm
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
For submission of code and project papers: http://box.stanford.edu

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. 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 taken an introductory controls class like ENGR 105: Feedback Control Design
• 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, please talk with Allison. Enrollment will be limited at the discretion of the instructor.

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. (Code will be submitted electronically and hardcopy assignments can be submitted in class or to the ME 327 lockbox near Allison's office.) Assignments will include a variety of activities, including written responses, problem solving, and building and programming custom haptic devices. Note: There is laboratory fee of $50 to partially offset the cost of lab materials, due by January 18 by check payable to Stanford University. Each student will get to keep the "Hapkit" he or she constructs 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 build a haptic device and either demonstrate an interesting application of haptics or use it 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
- 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 ask that you do not take another course with a major project component. We strongly suggest avoiding taking ME 218B simultaneously!

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.

30% 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 2016 IEEE Haptics Symposium Conference or the 2017 IEEE World Haptics Conference, and 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.

50% Project
You will conduct a 3- or 2-person 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 an IEEE conference-style 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 suggestions.

Schedule (as of January 31, 2018)

<table>
<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 1/9</td>
<td>Introduction to haptics and course overview</td>
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<td>Kinesthetic haptic devices</td>
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<td>2</td>
<td>2</td>
<td>Thurs 1/11</td>
<td>Kinesthetic haptic devices: design, kinematics, and dynamics</td>
<td>Assignment 1 out</td>
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<td>Friday 1/12</td>
<td>Tactile sensing (Robotics and Autonomous Systems Seminar) with Mark Cutkosky in 420-040 (Jordan Hall)</td>
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<td>3</td>
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<td>Tues 1/16</td>
<td>Kinesthetic haptic devices: sensors and actuators</td>
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<td>Thurs 1/18*</td>
<td>Hapkit Distribution and Assembly</td>
<td>Assignment 2 out</td>
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<td>5</td>
<td>Tues 1/23</td>
<td>Kinesthetic haptic devices: rendering</td>
<td>Assignment 3 out</td>
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<td>Thurs 1/25</td>
<td>Kinesthetic haptic devices: control</td>
<td>Assignment 4 out</td>
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<td>4</td>
<td>7</td>
<td>Tues 1/30</td>
<td>Human haptics: Mechanoreceptors and Kinesthesia</td>
<td>Assignment 5 out</td>
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<td>8</td>
<td>Thurs 2/1</td>
<td>Tactile haptic devices</td>
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<td>Tues 2/6</td>
<td>Teleoperation: Implementation and Transparency</td>
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<td>10</td>
<td>Thurs 2/8*</td>
<td>Teleoperation: Stability and Setup</td>
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<td>6</td>
<td>11</td>
<td>Tues 2/13</td>
<td>Project discussion and matchmaking</td>
<td>Project ideas due</td>
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<td>12</td>
<td>Thurs 2/15</td>
<td>Human subjects experiments: Design and statistics</td>
<td>Project meetings</td>
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<td>13</td>
<td>Tues 2/20</td>
<td>Haptic device evaluation</td>
<td>Project proposal due</td>
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<td>14</td>
<td>Thurs 2/22</td>
<td>Haptic device evaluation</td>
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<td>7</td>
<td>15</td>
<td>Tues 2/27</td>
<td>Student paper presentations – Teams 1 &amp; 2</td>
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<td>16</td>
<td>Thurs 3/1</td>
<td>Student paper presentations – Teams 3 &amp; 4</td>
<td>Project checkpoint 1</td>
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<td>Tues 3/6</td>
<td>Student paper presentations – Teams 5 &amp; 6</td>
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<td>Thurs 3/8</td>
<td>Student paper presentations – Teams 7 &amp; 8</td>
<td>Project checkpoint 2</td>
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<td>Student paper presentations – Teams 9 &amp; 10</td>
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<td>Thurs 3/15</td>
<td>Project demonstrations 10:30-11:50 am (in 520-145)</td>
<td>Project demos due</td>
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<td>Tues 3/20</td>
<td>Project Paper due 4:30 pm</td>
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+ Extra lecture; required attendance  
*Allison is traveling on these dates; course assistants will give lectures