Assignment 3:  
Haptic Rendering

Submit to ME327 box (near Allison’s office) by 4:30 pm on Thursday, February 1, 2018

Notes: You can discuss this assignment with your classmates, but when you write your responses, they should be your own. Please write clearly or type your responses.

1. Readings

No new reading this week, but review the previously assigned papers and get ready to discuss in class the week of January 29.

2. Render basic haptic virtual environments (40 pts.)

Create the following haptic effects in a single program, added to the template you used in the previous assignment. Use #define commands to select which haptic effect is active, so that your program can easily be changed to switch between effects for testing. Answer any questions posed in each part and get checked off by a peer in the class using the peer-grading sheet attached.

For many of these effects, you will need an estimate of the Hapkit handle velocity. We have provided you with a discrete differentiation of the position signal and included an appropriate low-pass filter in order to get a sufficiently smooth (but not too laggy!) velocity estimate. This velocity estimate uses an approximation of the Arduino loop speed. Adding print statements will cause the velocity estimate to be less accurate (and could affect other parts of your virtual renderings).

A. (5 pts.) Virtual wall. Program a virtual wall at $x_{\text{wall}} = 0.5$ cm and the maximum stiffness $k$ (N/m) that you can implement without encountering significant noise or stability issues.

You should compute your virtual wall interaction in $x$ coordinates, which means that you will need to use your position sensor calibration and kinematics computed in the previous problem to measure the $x$ position of your handle along the arc that is travels. Note that $x = 0$ is when the handle points straight up. You can print the position and force to the screen for debugging, as you did in Part A.

Show any calculations you performed. Give the maximum value of $k$ you could display stably and relatively noise-free in units of N/m.

B. (5 pts.) Linear damping. The user should feel a significant, constant, linear damping as the Hapkit handle is moved back and forth. What is the maximum damping coefficient you can use that feels good (i.e. stable, noise-free) in units of N-s/m?

C. (5 pts.) Nonlinear friction. The user should feel significant friction as the Hapkit handle is moved back and forth. (This is supposed to feel like Coulomb friction with additional damping during dynamic friction – this is called the Karnopp model.) Show your model graphically and algorithmically, and explain how you selected the parameter values of the model to maximize the effectiveness of the friction simulation.

D. (5 pts.) A hard surface. Create a surface that feels harder than the maximum stiffness that can be stably displayed by the Hapkit using stiffness alone. Do this by generating a decaying sinusoid upon impact with a virtual wall. Select values for the amplitude-scaling factor (so that the amplitude depends on the impact velocity) and decay rate that generate a compelling sensation of contact, without it
feeling unnaturally active. Write an explanation (including sketches and equations) explaining what you did. When you demonstrate this effect to your peer reviewer, show him or her the virtual wall with the same underlying stiffness without the impact vibrations, then with the impact vibrations.

E. (5 pts.) Bump and valley. Create a virtual environment in which there is a bump on the left side of the Hapkit workspace (where \( x < 0 \)) and a valley on the right side of the Hapkit workspace (where \( x > 0 \)). The bump and valley should be sufficiently separated in space so that they are recognized as two separate haptic effects. The effects should feel the same whether the user is moving right to left or left to right. Remember that you can create such effects with a one-degree-of-freedom haptic device by using lateral forces.

F. (5 pts.) Texture. Create a texture of your own design that generates a compelling sensation of moving across a rough/textured surface (with high spatial frequency) as you move the Hapkit handle back and forth. Provide an explanation with sketches and any calculations used to develop your texture model.

G. (10 pts.) Mass-spring-damper simulation. Create a mass-spring-damper simulation. The user can make and break contact with the mass via the Hapkit handle, and applying forces to the mass should cause the system to oscillate. To make the simulations consistent throughout the class, please make the mass-spring-damper system at equilibrium at \( x = 1 \text{cm} \) (so that the system will apply zero force if it begins at rest and the handle is vertical), and the Hapkit position should always be to the left of the mass. (The Hapkit position should not “pop through” to the other side of the mass.) You can select the mechanical properties of the system, i.e. \( m, b, \) and \( k \), as well as the stiffness of the interaction between the user and the mass, \( k_u \) – although we advise that the mass-spring-damper effect will be most compelling if you create an underdamped (i.e., oscillatory) system. As usual, begin with small parameters values and work your way up. You can end with values that clearly demonstrate the mass-spring-damper effect; you do not need to push the limits of stability on this one.

H. Clean up your code and submit it to the box directory created for you, in a subfolder you create called Assignment3. Please comment well -- you should clearly explain the purpose of each line of code you added.

3. Peer grading (10 pts.)

For each part of Problem 2, you should demonstrate your haptic effects to two peers, and you should in turn a peer reviewer sheet for each of these demonstrations. In turn, you must feel and write a peer reviewer sheet for the demonstrations of at least two of your classmates.

Give a copy of the attached table to each of your peer reviewers. Peer reviewers should provide ratings on a scale of 1 to 5 (where 1 is least and 5 is most) for the following criteria:

1. Noticeability: The haptic effect is clearly noticeable. There is an obvious difference when the haptic effect is “on” versus when it is “off”
2. Stable and noise-free: The haptic effect should not feel “active” or unnaturally noisy.
3. Realism: Outside of noise and stability, does the underlying haptic effect feel like you think it should, given what you know about the desired mechanical properties of the effect?

In the comments section, the peer reviewer should write a few words about the feeling generated by the haptic effect. Submit two peer reviews with your assignment. We will also check that you have performed at least two peer reviews submitted by others.
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<thead>
<tr>
<th>Effect</th>
<th>Noticeability (1-5)</th>
<th>Stable and noise-free (1-5)</th>
<th>Realism (1-5)</th>
<th>Comments</th>
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<tbody>
<tr>
<td>A. Virtual wall</td>
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<td>B. Linear damping</td>
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<td>C. Nonlinear friction</td>
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<td>D. Hard surface</td>
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<td>E. Bump and valley</td>
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<td>F. Texture</td>
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<td>G. Mass-spring-damper</td>
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