Assignment 4:
Kinesthetic Device Design, Sensors, and Actuators

PDF file due on Canvas by 11:59 pm PDT on Thursday, May 7, 2020
Please write clearly or type your responses.
Submit some parts using the MATLAB Grader assignment on Canvas.

Optional Readings

- B. Hannaford and A. M. Okamura. Chapter 42: Haptics. In B. Siciliano and O. Khatib, Eds., Handbook of Robotics. Springer, pp. 1063-1083, 2016. This book chapter provides an overview of the field of haptics. This will provide you with a good introduction to the breadth of the field.

- V. Hayward and K. E. MacLean. Do It Yourself Haptics, Part I. IEEE Robotics and Automation Magazine, 14(4):88-104, 2007. This magazine article also gives an introduction to the field of haptics, with more emphasis on device design and mechatronics than the article above.

You can download papers from Canvas > Files > Papers.

1. Transmission Mechanisms

List an least one advantage and one disadvantage of each of the following transmission mechanisms, in terms of their suitability for use in a kinesthetic haptic device:

A. Gears
B. Belt around two pulleys
C. Capstan drive
D. Friction drive
E. Direct drive

2. 1-DoF Kinematics: Motion

The values of kinematic constants (defined in Lecture 7) of the Hapkit are:
$r_{\text{handle}} = 90.0$ mm
$r_{\text{pulley}} = 5.00$ mm
$r_{\text{sector}} = 74.0$ mm

A. In the Hapkit kinematics example given in Lecture 7, we found a relationship between x_{handle} and θ_{pulley} based on the lengths you just measured. Compute the constant that relates x_{handle} to θ_{pulley}.

B. What is the constant that relates the velocities $\dot{x}_{\text{handle}}$ and $\dot{\theta}_{\text{pulley}}$? What is the constant that relates the accelerations $\ddot{x}_{\text{handle}}$ and $\ddot{\theta}_{\text{pulley}}$?

C. If the measurement resolution of the angle of the pulley (θ_{pulley}) is 1°, what is the resolution with which x_{handle} can be calculated in meters?

D. What would result in a more accurate measurement/calculation of x_{handle}: an r_{sector} that is *larger* or *smaller*?

3. 1-DoF Kinematics: Forces and Torques

A. Say that you want to generate a force of 1 N at the handle. Given your measurements of the Hapkit length parameters in the previous problem, what motor torque (τ_{pulley}) is required to generate that force?

B. Say that the motor can generate a torque with a resolution of 0.01 N-m. What is the resolution of force that can be displayed at the handle?

C. Say the motor can generate a torque $\tau_{\text{pulley}} = \tau_{\text{max}}$. What would you change about the design to increase F_{handle} without requiring a change in τ_{max}?

D. Are there any trade-offs resulting from changing length parameters? For example: Do you foresee any challenges with making any of the length parameters arbitrarily small or large?

E. Why are transmissions like the capstan drive in Hapkit designed so that the applied force to the pulley will be perpendicular to a line emanating from the center of the pulley?

F. If the motor (to which the motor pulley is attached) has a constant friction torque of 0.001 N-m, what is the friction force that will be felt by the user at the handle? Could a user notice this force? Note that humans can sense forces at least as small as 0.01 N.

4. Rendering a 1-D Wall

A. Consider the role of position sensing resolution in the case of rendering a 1-D wall with stiffness k = 100 N/m using the Hapkit. The 1-D wall is located at $x = 0$, which is at the center of the Hapkit's workspace. The "solid" wall is to the right of the center of the workspace, which is considered the positive x direction. What is the resolution of the force output from the rendering algorithm when the measurement resolution of the angle of the pulley (θ_{pulley}) is 1°? Consider the Hapkit parameters given in Problem 2, and remember that the rendering is done based on the position of the handle, x_{handle}. (2 pts.)

B. If the maximum torque the motor can output is τ_{max}, at what depth into the wall (with stiffness k = 100 N/m) will the motor saturate? Again, use your earlier Hapkit parameter measurements. Write your result in terms of τ_{max}.

C. The workspace of the Hapkit is approximately 5 cm in either direction from the position where the handle is in its vertical position. Imagine that you are rendering a virtual wall with stiffness k = 100 N/m. What is the maximum force that would need to be displayed if the user wants to move their hand through the whole workspace? What would be the minimum value of τ_{max} required for the motor not to saturate its output?