Haptic Human-Robot interfaces: Lab 3

Assistants : *Giulia Ramella (giulia.ramella@epfl.ch)*
Mouhamed Zorkot (mouhamed.zorkot@epfl.ch)
Jonathan Louis Muheim (jonathan.muheim@epfl.ch)
Aiden Xu (aiden.xu@epfl.ch)

Lab goals

- Identify the dry and viscous friction of the Haptic Paddle.
- Actively compensate for the identified frictions and gravity in the control program.
- Implement a programmable viscoelastic behavior, to achieve a "virtual wall" effect.
- Evaluate the "Z-width" of the controller, by making a K-B plot of the system.

1 Grading

This lab will be graded. One report per group should be submitted on Moodle, no later than one week after the last session of this lab. The report should contain at least the following elements:

- Friction/gravity compensation:
    - How did you proceed to identify the static friction? Which values did you obtain?
    - How could you identify the sliding friction if you had to? (Only suggest the approach)
    - How did you implement the compensation of the friction and the gravity? Why is this kind of implementation called "feed-forward" compensation? How could you do "feed-back" compensation?
    - Comment on the obtained behavior with the compensation and the effect of the different terms. Discuss the conditions (type of movement, range of movement, etc.) under which each of the terms becomes more important.
    - How would you proceed for a robot with multiple degrees-of-freedom (DoF)?
- K-B plots and Z-width:
    - Show the four K-B plots of the haptic paddle, with different conditions in terms of sampling period, filtering, and compensation.
    - Is the filtering useful? How does it affect the K-B plot and why?
    - How does a higher sampling frequency affect the K-B plot? Why?
    - How does the friction/gravity compensation affect the quality of haptic rendering?
    - Imagine you used the Hall-effect sensor instead of the incremental encoder (you do not need to redo the measurements with the Hall-effect sensor). Would you filter the signals differently? How would the K-B plot change?
    - Discuss the different challenges in rendering virtual environments with a haptic device, and suggest possible solutions for each.

2 Lab instructions

General remark: for this lab, only work with the encoder. Do not use the Hall-effect sensor!

2.1 Identification of the paddle friction

The paddle is not an ideal mechanical assembly, so there is friction. The main components are the dry friction (nearly constant), and the viscous friction (proportional to the speed). The dry friction is difficult to identify, and its value at rest (static friction, or "stiction") is usually higher than the dynamic state (i.e. after the 2 surfaces start sliding on one another).

2.1.1 Static friction torque

- Program the paddle to slowly increase the motor torque until a movement is detected. Repeat this experiment 5 times, and compute the average static friction torque ($\tau_{stiction}$), and its dispersion (standard deviation). Report your torque increment step as well.
- Do it again in the other direction (using a negative torque). Do you obtain the same results? How can you explain this?

Please show your results to the assistants.

2.1.2 Viscous friction torque

Compute the theoretical damping B_m at the "no load speed" from the datasheet of the motor (see the Hardware Documentation on Moodle), with the hypothesis that the dry friction in negligible. You can then use the following formula:

$$\left.\begin{aligned} T_m &= I_m \cdot k_t \\ T_m &= B_m \cdot \omega_m \end{aligned}\right\} \Rightarrow I_m \cdot k_t = B_m \cdot \omega_m \qquad \text{with} \begin{cases} T_m & \text{motor torque} \\ I_m & \text{motor current} \\ k_t & \text{torque constant} \\ B_m & \text{viscous friction coefficient} \\ \omega_m & \text{motor speed} \end{cases}$$

2.2 Friction and gravity compensation

- Program the paddle microcontroller in order to compensate for the effects of friction and gravity. From the remote-control interface, you should be able to switch the assistance ON and OFF quickly, for each term (dry friction, viscous friction, gravity).
  Remarks:
  - You can find the paddle characteristics (mass, position of the center of mass) in the Hardware Documentation.
  - Make sure that when the program starts, the paddle is in the vertical position. Otherwise, the encoder will not be initialized properly, and the gravity compensation will not work.
  - In order to get good performance for the friction torque compensation, you will probably need to filter the speed.
- Test your controller. Do you feel the difference when you switch each compensation part ON and OFF, one-by-one or all together? Comment on how tangible each of the compensated effects is, and under which condition it becomes more dominant.
  How "transparent" is the paddle now? How could this transparency be improved? (You are

free to suggest methods that require minor modifications of the design of the paddle or additional components)

Show your results to the assistants.

2.3 Virtual wall

The main purpose of haptic devices is to give users the sensation of interacting with a (virtual) object or environment via the sensation of touch. In haptics jargon, this is also called "rendering" a virtual object/environment. A simple virtual environment would be a stiff wall, which we will try to render in this part.

2.3.1 Implementation of the virtual wall

The goal of this part is to implement a virtual "wall" effect. This consists in applying a "reaction force" when the paddle reaches the wall, to prevent it from going further. The challenge is to make this wall as "stiff" as possible, to give the user a realistic sensation of touching a hard wall.

- Design and implement two virtual walls, applying a viscoelastic (a spring with a damper) behavior once the paddle reaches $\Phi_{wall} = \pm 15°$ (see Figure 1).
  Keep the active compensation of the friction and the gravity.
- The following variables should be editable from the remote-control interface:
  - K: the virtual spring stiffness, typically in N.m/deg.
  - B: the virtual damping factor, typically in N.m/(deg/s).
  - The cut-off frequency of the position/velocity filter, in Hz.
- The goal is to tune these three values to get a wall that is as stiff as possible (maximize K), but stable (non-vibrating).

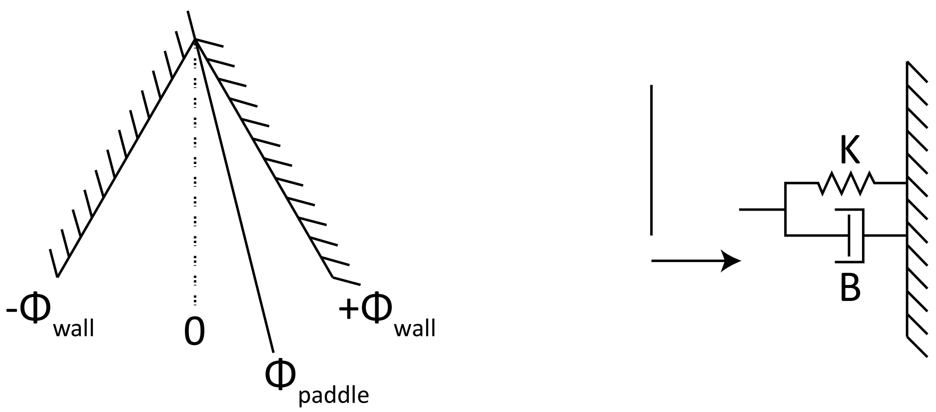

Figure 1: virtual wall angular range (left), and physical modelling (right)

Show your results to the assistants.

2.3.2 Measurement of the Z-width

In the previous part, we tried to render the virtual wall by applying a force/torque calculated based on a (virtual) mechanical stiffness and damping. Both stiffness and damping are properties that determine the output force resulting from an input movement (angle and angular velocity, in our case) to a mechanical system. A general relationship between an input movement and an output force can be expressed through "mechanical impedance", typically denoted by the letter "Z" in an analogy with electrical systems and electrical impedance. An ideal haptic device would be able to simulate a very wide range of virtual environments, which means it can render a wide range of mechanical impedances. Real haptic devices are, however, limited in the range of impedances that they can render. A metric for the quality of a haptic device is thus its "Z-width", which represents the range of impedances that it can render. A common way to illustrate the Z-width of a haptic device is through the K-B plot, showing the upper limits of stiffness and damping that it can render for a virtual wall.

- To make a K-B plot of one of the walls, you can follow this procedure:
  1. Select the cut-off frequency of the position/velocity filter.
  2. Start with B = 0 (no damping).
  3. Start with K = 0 (no stiffness). Keep the paddle pressed against the virtual wall with your finger[1]. Increase gradually the stiffness K until the paddle feels unstable (you feel a sustained vibration when touching the wall). Write down both B and K values.
     If the paddle is unstable even when K = 0 (typically when B is too high), then go to step 5.
  4. Increase the value of B, and go back to step 3.
  5. With the points you collected, plot the stiffness (Y axis) against the damping (X axis). You should have at least 5 points, otherwise, go back to step 2, and use smaller steps when increasing B.
- Make a K-B plot for each of the following conditions:
  - A. Without low-pass filtering the speed, sampling period: 350 µs.
  - B. Without low-pass filtering the speed, sampling period: 10,000 µs (10 ms).
  - C. With low-pass filtering the speed (cut-off frequency: 50 Hz), sampling period: 350 µs.

How do low-pass filtering and sampling period affect the K-B plot? Why?

2.3.3 Influence of the gravity and friction compensation

- Disable the gravity and friction compensation, and try to interact with the virtual walls again. Does the performance change? In which region is the change in performance more tangible (near the walls or in the region between them)?
- Repeat the K-B plot of condition C this time without the compensation. Is the K-B plot affected? Why or why not?

In the virtual wall scenario, the user experiences two types of environments: the free region (zero impedance), and the wall (high impedance). A realistic haptic rendering must give the user a realistic experience in both regions. Ideally, in the free region the user should feel zero interaction force, and a very high interaction force when hitting the wall. What are the challenges for improving the quality of the rendering in each region? How can this quality be improved in the levels of device design/hardware and control/software? Discuss your ideas with the assistants.

[1] How you hold the paddle, i.e. how many fingers you use to grab the handle and how firmly you grip it, can influence the limits of stability (can you guess why?). So try to be consistent in how you hold the handle when finding the stability limits for the K-B plot.