Haptic Human-Robot interfaces: Lab 3

Assistants : *Alireza Manzoori (ali.manzoori@epfl.ch)*
Zeynep Özge Orhan (zeynep.orhan@epfl.ch)
Evgenia Roussinova (evgenia.roussinova@epfl.ch)

1 Lab goals

- Identify the dry and viscous friction of the Haptic Paddle.
- Actively compensate for the identified friction 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.

2 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 measure the sliding friction?
  - How did you implement the compensation of the friction and the gravity? Why is it called “feed-forward” compensation? How could you do “feed-back” compensation?
  - Comment on the obtained behavior. What do you feel?
  - How would you proceed for a robot with multiple degrees-of-freedom (DoF)?
- K-B plot:
  - Show the K-B plots of the haptic paddle, with different position/speed filters.
  - Is the filtering useful? How does it affect the stability?
  - Does the friction/gravity compensation affect the performance?
  - 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?
  - How could you improve the Z-width?

3 Lab instructions

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

3.1 Identification of the paddle friction

The paddle is not an ideal mechanical assembly, so there is friction. The main components are the dry friction (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).

3.1.1 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.

3.1.2 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:

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

3.2 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 component (paddle dry friction, motor 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 are.
  How "transparent" is the paddle now? How could this be improved?

Show your results to the assistants.

3.3 Virtual wall

3.3.1 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 position, to prevent it from going further. The challenge is to make this wall as "stiff" as possible.

- Design and implement two virtual walls, applying a viscoelastic (a spring with a damper) behavior once the paddle reaches $\pm\Phi_{wall} = 15°$ (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 bandwidth (or strength) of the position/velocity filter.
- Roughly tune these three values to get a wall that is as stiff as possible (maximize K), but stable (non-vibrating).

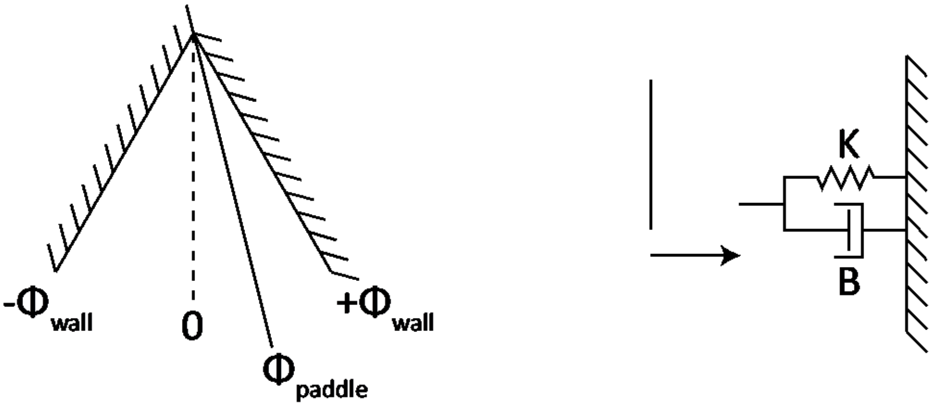

Figure 1: virtual wall angular range (left), and physical modelling (right)

Show your results to the assistants.

3.3.2 Measurement of the Z-width

- Make a K-B plot of one of the walls, following this procedure:
  1. Select the bandwidth/strength 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. Increase gradually the stiffness K until the paddle feels unstable. Then 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.

6. Go back to step 1, and use a different filter bandwidth/strength. Make three K-B plots, each one with a different amount of filtering.

3.3.3 Influence of the gravity and friction compensation

- Disable the gravity and friction compensation, and try to feel your virtual wall again. Does the performance change?