Haptic Human-Robot Interfaces: Lab 1

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Lab goals

- Characterize and calibrate an analog Hall-effect sensor.
- Evaluate the repeatability of the position, velocity and acceleration obtained from the Hall sensor output.
- Compare it to another sensor, the optical incremental encoder.
- Implement simple filters.
- Characterize the relation between the motor control input (motor current), acceleration, velocity and position.

1 Grading

This lab is not graded. But you should show your results and discuss with the assistants.

2 Lab instructions

2.1 Preparation

- Check that the Hall sensor is correctly wired to the board:

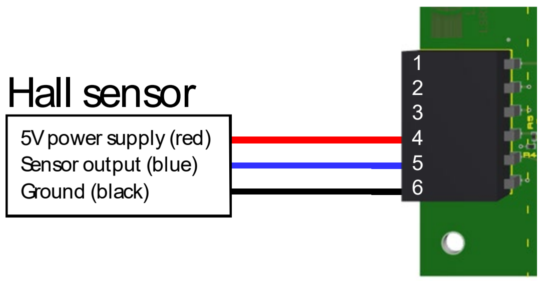

Figure 1: wiring of the Hall sensor to the board

- Check that the steel cable is attached properly to the motor shaft and the paddle anchor points. If this is not the case, follow the procedure described in the "HRI paddle - hardware documentation" document available on Moodle.

2.2 Hall sensor calibration

A Hall-effect sensor measures the magnetic field in one direction, and outputs an analog voltage proportional to its intensity. The paddles are equipped with a A1301EUA or A1324LUA[1] Hall-effect sensor chip, which respectively have sensitivities of 2.5 and 5 mV/G. The output voltage goes linearly from about -0.3 to 4.7 V as the magnetic field strength changes from the maximum measurable negative value to the maximum positive, and at 0 G the output voltage is around 2.5 V (Figure 2).

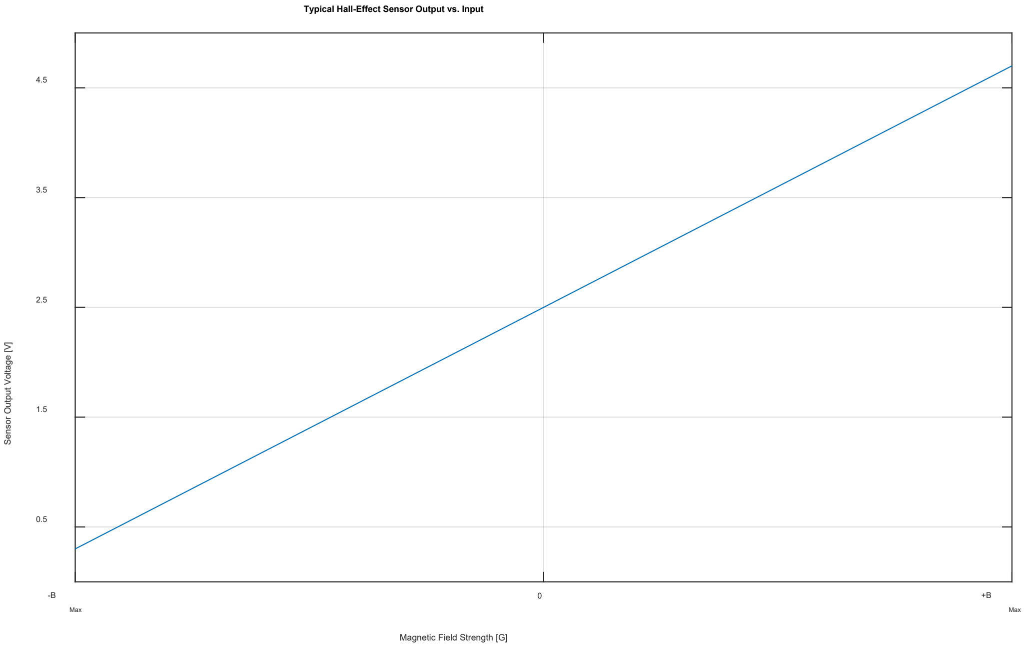

Figure 2: Typical Hall-effect sensor characteristic curve

A radially-polarized magnet is fixed to the moving part of the paddle, close to the sensor. The Hall-effect sensor is fixed to the base, at a distance such that the measured magnetic field is strong enough (not too far), but without saturating the sensor (not too close).

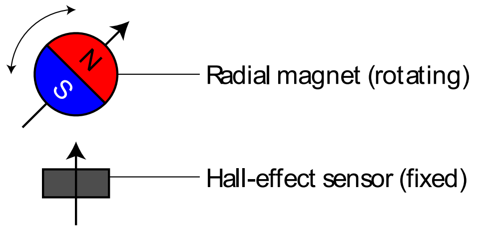

Figure 3: magnet and Hall-effect sensor positioning

The goal of this first part is to find the calibration function of this sensor, which converts the sensor voltage to the angle of the paddle.

[1] The full datasheet of these sensors can be found on Allegro's website:
http://www.allegromicro.com/~/media/Files/Datasheets/A1301-2-Datasheet.ashx
https://www.allegromicro.com/~/media/Files/Datasheets/A1324-5-6-Datasheet.ashx

a) What sensor output do you get, over a full rotation (360°) of the magnet? Since the paddle has a limited angular range, you will have to manually turn the magnet (enclosed in the yellow plastic housing) with your fingers, making it slip on the paddle shaft. If the sensor chip is blocking the way when trying to rotate the magnet, you do not need to make a full rotation but you can go all over the possible range.
From this sensor only, is it possible to compute the angular position of the magnet over 360°? If not, what could you change to be able to do it with this sensor technology?

Holding the paddle in the vertical (0°) position, turn the magnet such that the Hall-effect sensor voltage is approximately at the middle of the range (2.5V). Check that you get the expected output when moving the paddle handle, and that the voltage is not saturating when you move the paddle over the full range. Check with the assistants if you are not sure.

b) Characterize the sensor noise when the paddle does not move. To do so, you can record the Hall voltage and use the standard deviation function (std) of MATLAB.
c) Identify the characteristic function of the sensor (voltage to angle), using the incremental encoder as a reference. Compute the best linear model coefficients using the least-square method.
d) Is a linear approximation accurate enough? What is the maximum linearity error?
e) Implement your calibration function in the board firmware, and check that it works as expected.

Please show your results to the assistants.

2.3 Velocity and acceleration computation (in the firmware)

The goal of this part is to compare the performance of the optical encoder and the Hall-effect sensor. Perform the steps a) to e) with the encoder, and then repeat with the Hall-effect sensor.

a) Compute the paddle velocity by implementing numerical differentiation over 1 sampling period. Characterize the noise when the paddle is still.
b) Do the same, but differentiating over 2 sampling periods. How does the noise change?
c) Compute the paddle acceleration by implementing numerical differentiation of the speed over 1 sampling period.
Characterize the noise when the paddle is still.
d) Do the same, but differentiating over 2 sampling periods. How does the noise change?
e) Why do you get noise in the speed computed from the sensor?

f) Is the Hall-effect sensor suitable for control? Despite its limitations, what is the advantage of this sensor compared to the encoder in this device?

Please discuss your results with the assistants.

2.4 Filter implementation (in the firmware)

a) Implement a first-order low-pass filter to smooth the velocity and the acceleration.
What is the effect on the noise?

b) Filter the speed calculated from the encoder position with cut-off frequencies of 20 and 200 Hz. Plot the raw and filtered speeds at the same time while moving the paddle back and forth at different speeds. How does the filtered speed compare to the raw signal? What are the advantages and disadvantages of applying this filter with a very low cut-off frequency?

2.5 Motor characteristics

First, remove the steel cable to free the motor shaft. **Make sure that the cable never touches the board, otherwise it may short-circuit it.** Make the motor apply a step of torque, from 0 to 5 mN.m. Record the motor shaft position, velocity and acceleration measured with the encoder.

a) What is the step response of the motor (position, velocity and acceleration)?
b) Compute the theoretical step response with a simplistic model, considering only the motor torque and the inertia of the shaft. How can you explain the differences between the theoretical model and the measurements?

Please show your results to the assistants.

2.6 Reinstalling the cable

After you are done with the previous part, install the steel cable again. Follow the instructions in the paddle hardware documentation. There is also a video on Moodle showing the procedure. When you are done, verify that:

- The cable does not slip on the shaft. That is, if you hold the shaft wormscrew, the paddle cannot be easily moved.
- There is no excessive friction in the transmission, especially when you approach the two ends of the range. Excessive friction will prevent smooth movement of the paddle, and you can hear a friction noise when trying to move.

The cable slipping means that the cable is not tight enough. Excessive friction means that the cable is too tight. The optimal cable tension thus means finding a good trade-off between the two.