# Physical Human Robot Interaction

Filippo Grotto VR460638

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## Contents



# 1 Four channel bilateral teleoperation architecture

## 1.1 HW1: Continuous and discretized implementation

Implement the SISO Four-channel bilateral teleoperation architecture with

$$C_m = B_m + \frac{K_m}{s} \quad C_s = B_s + \frac{K_s}{s}$$

$$Z_m^{-1} = \frac{1}{M_m s + D_m} \quad Z_s^{-1} = \frac{1}{M_s s + D_s}$$

where $Mm = 0.5$, $M_s = 2$. Moreover $D_s = 10$ and $D_m = 5$ or both zero in the initial case. In Fig 1 a simple plot of the positions and velocities (slave and master) are reported for proper selected tuning parameters of the related master and slave controller. In order to properly tune the controllers the following closed-loop systems were considered:

$$G_m = \frac{1}{M_m s^2 + B_m s + K_m} \quad G_s = \frac{1}{M_s s^2 + B_s s + K_s}$$

The proper parameters were selected considering the step reponse of the two second order systems. For the human intention controller the parameters were selected by comparing the reference position with the master/slave position and perform proper tuning (an analytical closed-loop system might also be considered for this analysis).

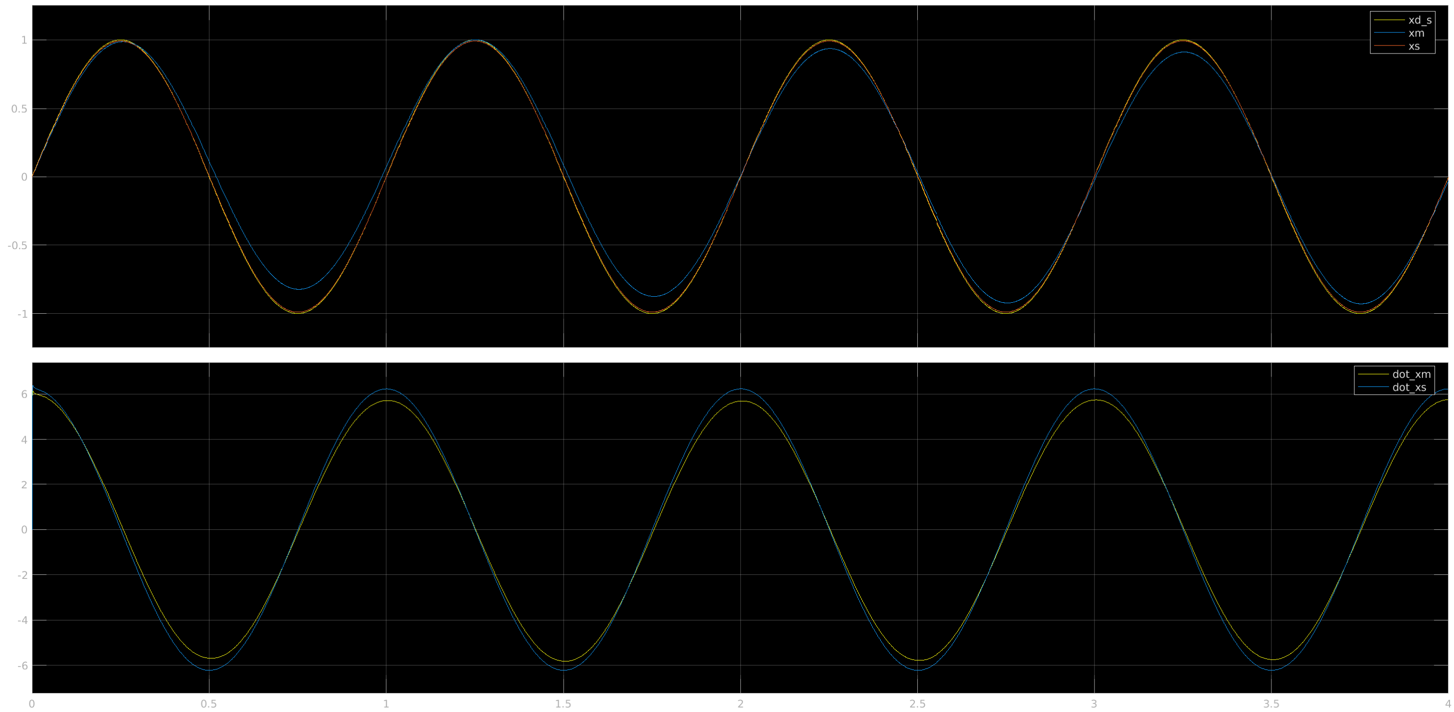


**Figure 1:** Reference slave and master position are depicted in the first plot. Slave and Master velocities are reported in the second plot

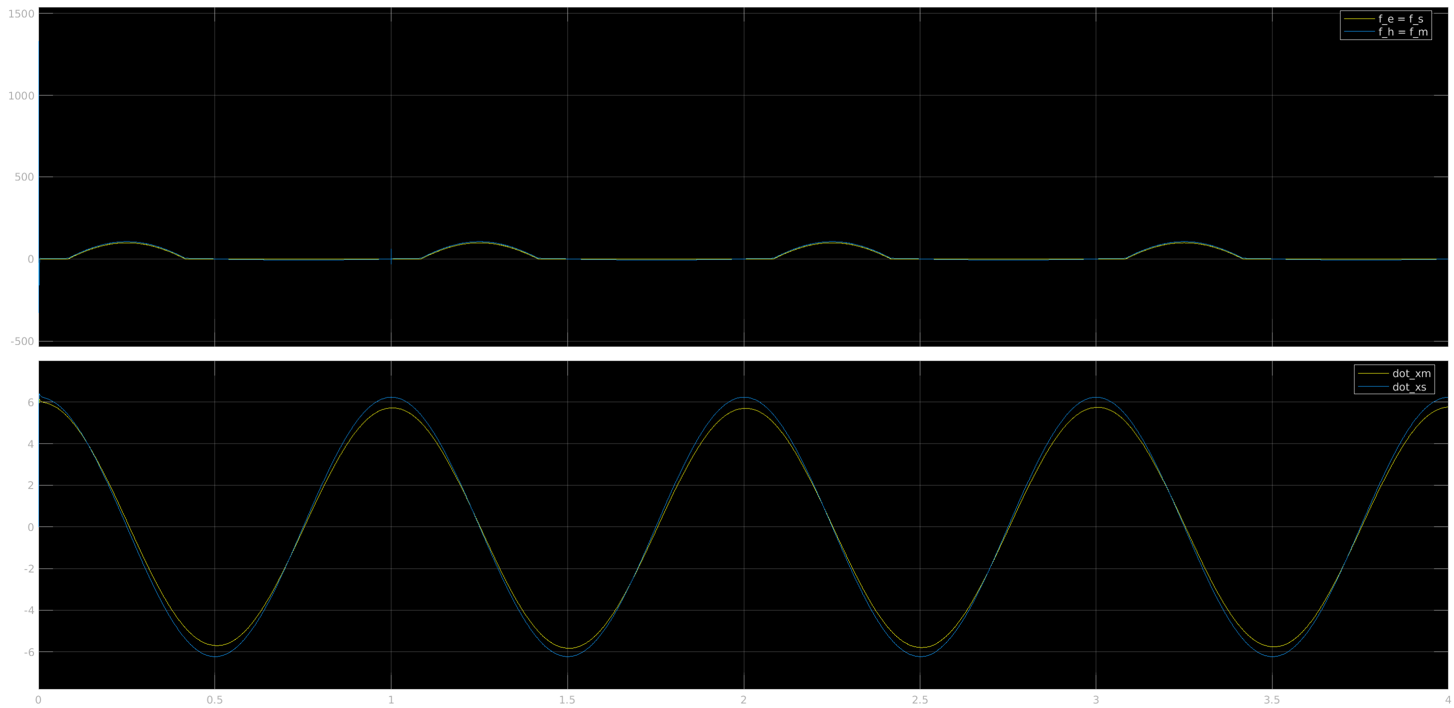


**Figure 2:** Master and slave velocity and forces compared when the environment is not attached to the end effector of the robot. The environment force has to be zero when not in contact

Finally the entire architecture was translated in the related discretized version according to our specification in terms of encoders and the related derivative were performed using the simulink block. In the following section a proper estimation tool will be analysed.

## 1.2 HW2: Derive hybrid matrix

Derive the hybrid matrix for the four channel bilateral teleoperation considering the inner force loop at the master and slave side. We will consider $Z_{cm} = C_6$ and $Z_{sm} = C_5$.

$$\begin{bmatrix} f_m \\ -v_s \end{bmatrix} = \begin{bmatrix} \overline{H_{11}} & \overline{H_{12}} \\ \overline{H_{21}} & \overline{H_{22}} \end{bmatrix} = \begin{bmatrix} v_m \\ f_s \end{bmatrix}$$

Let's start by defining:

$$v_m = Z_{cm}^{-1}(f_m - C_2 f_s - C_4 v_s + C_6 f_m) \tag{1}$$

$$v_s = Z_{cs}^{-1}(-f_s + C_5 f_s + C_1 v_m + C_3 f_m) \tag{2}$$

Finally let's compute the 4 components of the hybrid matrix considering one component to zero at each step.

$$\overline{H_{11}} : f_m \to v_m \qquad f_s = 0$$

$$Z_{cm} v_m = f_m - C_4 Z_{cs}^{-1} C_1 v_m - C_4 Z_{cs}^{-1} C_3 f_m + C_6 f_m$$

$$v_m (Z_{cm} + C_4 Z_{cs}^{-1} C_1) = f_m (1 - C_4 Z_{cs}^{-1} C_3 + C_6)$$

$$\overline{H_{11}} = \frac{Z_{cm} Z_{cs} + C_1 C_4}{(1 + C_6) Z_{cs} - C_3 C_4}$$

$$\overline{H_{12}} : f_m \to f_s \qquad v_m = 0$$

$$0 = f_m - C_2 f_s - C_4 Z_{cs}^{-1} C_5 f_s + C_4 Z_{cs}^{-1} f_s - C_6 f_m$$

$$f_m (1 - C_6 - C_4 Z_{cs}^{-1} C_3) = f_s (C_2 + C_4 Z_{cs}^{-1} C_5 - C_4 Z_{cs}^{-1})$$

$$\overline{H_{12}} = \frac{C_2 Z_{cs} - C_4 (1 + C_5)}{(1 + C_6) Z_{cs} - C_3 C_4}$$

$$\overline{H_{21}} : -v_s \to v_m \qquad f_s = 0$$

$$v_s Z_{cs} = -(C_1 v_m + C_3 f_m)$$

$$v_s (Z_{cs} - \frac{C_3 C_4}{1 + C_6} = -v_m (C_1 + \frac{C_3 Z_{cm}}{1 + C_6})$$

$$\overline{H_{21}} = -\frac{C_1 (1 + C_6) + C_3 Z_{cm}}{(1 + C_6) Z_{cs} - C_3 C_4}$$

$$\overline{H_{22}} : -v_s \to f_s \qquad v_m = 0$$

$$v_s Z_{cs} = -(C_5 f_s - f_s + C_5 f_s)$$

$$v_s(Z_{cs} - \frac{C_3 C_4}{1 + C_6}) = -f_s(C_5 - 1 + \frac{C_3 C_2}{1 + C_6})$$

$$\overline{H_{22}} = \frac{(1 - C_5)(1 + C_6) - C_2 C_3}{(1 + C_6) Z_{cs} - C_3 C_4}$$