Problem Formulation

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We consider a scenario where the human might or might not require the help of the robot in grabbing the object in the following picture.

The human can choose to either grab it on both handles or only one of them. If he grabs the object on both handles, it means that assistance from the robot is not required and therefore the robot should not react to the human behavior. In case the human approaches only one handle, the robot is expected to reach the other one. Therefore, the behavior of the hands of the human lies in one of the following three categories:

- a motion towards the right handle x_r^O;
- a motion towards the left handle x_l^O;
- a motion towards the attractor x_0, corresponding to a location away from the object.

We define the attractor x_0 as the attractor of the idle state, i.e. the state in which the human is not showing interest in approaching the basket with any of his hands. We set x_0 to the location of the hip of the human.

Let $b_{ij}^H \in \mathbb{R}$, where $i = r, l$ and $j = r, l, 0$, be the belief on the i-th hand of the human approaching the j-th attractor. For each hand, these beliefs are computed through an adaptation mechanism similar to the one presented in [1]. What differs are the belief updates. These are definied in order to minimize the error between the current state of one of the hands and its prediction, which is obtained by simulating its evolution toward the attractors x_r^O, x_l^O and x_0 for N_w steps. For the attractors on the object, we simulate the evolution of the state x_i^H along the path obtained normalizing the velocity obtained via the LPVs learned by demonstrations. For the attractor x_0, we consider the evolution along the direction obtained by normalizing the vector $x_0 - x_i^H$.
To obtain the velocity along the three directions, we then multiply the directions for the norm of the average velocity of x_i^H over the last N_w steps. The resulting belief updates can be found below.

$$\begin{cases} \hat{\dot{b}}_{rr}^H(t) = \epsilon(x_r^H - \hat{x}_r^H)^T x_{rr,sim}^H \\ \hat{\dot{b}}_{rl}^H(t) = \epsilon(x_r^H - \hat{x}_r^H)^T x_{rl,sim}^H \\ \hat{\dot{b}}_{r0}^H(t) = \epsilon(x_r^H - \hat{x}_r^H)^T x_{r0,sim}^H \end{cases} \quad \begin{cases} \hat{\dot{b}}_{lr}^H(t) = \epsilon(x_l^H - \hat{x}_l^H)^T x_{lr,sim}^H \\ \hat{\dot{b}}_{ll}^H(t) = \epsilon(x_l^H - \hat{x}_l^H)^T x_{ll,sim}^H \\ \hat{\dot{b}}_{l0}^H(t) = \epsilon(x_l^H - \hat{x}_l^H)^T x_{l0,sim}^H \end{cases} \tag{1}$$

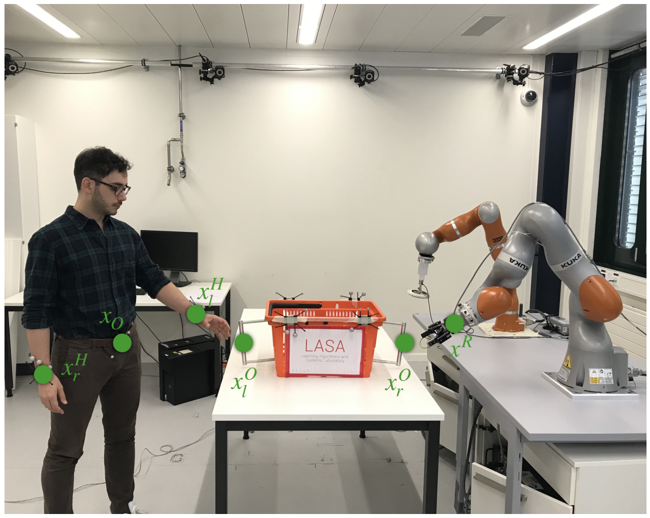

Figure 1: The setup considered for the simulation.

Where $\epsilon \in \mathbb{R}^+$ is the *adaptation rate*. The more $x^H_{ij,sim}$ will be closer to the real state x^H_i, the higher the corresponding belief update $\hat{\dot{b}}^H_{ij}$ will be and viceversa. For each hand, the beliefs are then modified based on a Winner-Takes-All process that ensures only one increasing belief and two decreasing one [1]. These adaptation mechanisms ensure that $\sum_i b^H_{ri} = 1$ and $\sum_i b^H_{li} = 1$, where $i = r, l, 0$.

Finally, the beliefs for the behavior of the robot are computed as follows.

$$\begin{cases} b^R_r = b^H_{rl} b^H_{ll} + b^H_{r0} b^H_{ll} + b^H_{rl} b^H_{l0} \\ b^R_l = b^H_{rr} b^H_{lr} + b^H_{r0} b^H_{lr} + b^H_{rr} b^H_{l0} \\ b^R_0 = b^H_{rl} b^H_{lr} + b^H_{rr} b^H_{ll} + b^H_{r0} b^H_{l0} \end{cases} \tag{2}$$

The robot will approach the handle x^O_r when the human is approaching with one of his hands only the handle x^O_l. Similarly, the robot will approach the handle x^O_l when the human will approach with one of his hands only the handle x^O_r. In case the human will approach none of the handles or both of them, the assistance of the robot will not be required and therefore the robot will be in idle state.

References

[1] Mahdi Khoramshahi and Aude Billard. A dynamical system approach to task-adaptation in physical human–robot interaction. *Autonomous Robots*, 43(4):927–946, 2019.