Robotics 2

March 24, 2023

Exercise 1

The torque controlled 2R planar robot in Fig. 1 moves in a vertical plane, performing a one-dimensional trajectory task $r = r_d(t) \in \mathbb{R}$ for its end-effector that is specified *only* along the y-direction. The links have equal length l and equal and uniformly distributed mass m, with barycentric inertia $I_c = ml^2/12$ (links are thin rods). When the robot is in the configuration $\bar{\boldsymbol{q}} = (\pi/4, -\pi/2)$ [rad] and has a joint velocity $\dot{\bar{\boldsymbol{q}}} = (1, -1)$ [rad/s], a task acceleration $\ddot{r}_d$ is assigned.

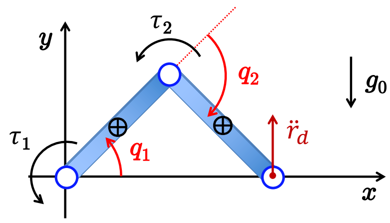

Figure 1: A 2R planar robot in a one-dimensional task.

Determine in a parametric way (with respect to l, m, $\ddot{r}_d$, and $\boldsymbol{K}_D$) the torque $\boldsymbol{\tau} \in \mathbb{R}^2$ that executes the task and instantaneously minimizes the cost

$$H = \frac{1}{2}\left(\boldsymbol{\tau} - \boldsymbol{\tau}_0\right)^T \boldsymbol{M}^{-1}(\boldsymbol{q})\left(\boldsymbol{\tau} - \boldsymbol{\tau}_0\right), \qquad \boldsymbol{\tau}_0 = -\boldsymbol{K}_D\,\dot{\boldsymbol{q}},$$

where $\boldsymbol{M}(\boldsymbol{q})$ is the inertia matrix of the robot and matrix $\boldsymbol{K}_D > 0$ is diagonal. Evaluate then numerically the obtained solution torque $\boldsymbol{\tau}$ using the following data:

$$l = 0.5 \text{ [m]}, \qquad m = 3 \text{ [kg]}, \qquad \ddot{r}_d = 1 \text{ [m/s}^2\text{]}, \qquad \boldsymbol{K}_D = \text{diag}\{2, 2\} \text{ [Nm·s]}.$$

Exercise 2

Consider the same robot of Fig. 1, now with all *kinematic* and *dynamic* parameters that appear explicitly in the model having uncertain/unknown values. In this situation, design an adaptive control law that is able to guarantee global asymptotic tracking of a desired smooth joint trajectory $\boldsymbol{q}_d(t)$.

Exercise 3

With reference to the situation in Fig. 2, a robot should move a triangular-shaped tool in continuous contact with the bottom surface of a rectangular guide, in which the tool is perfectly inserted, of a metallic object in order to remove excessive material and debris (*deburring*). Assign a task frame so as to define in a decoupled way the natural and artificial constraints associated to this hybrid task. Assume that no friction is present at any of the contacts. Specify then qualitatively how desired values should be assigned to the variables that can be controlled, in order to perform the task at best and with minimum effort.

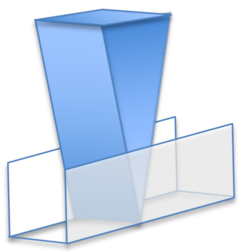

Figure 2: The set-up of a hybrid force-motion task.

[180 minutes; open books]