Robotics 1

September 9, 2022

Exercise 1

The Fanuc cr15ia is a collaborative robot with six revolute joints and a spherical wrist. Two views are shown in Fig. 1. The drawing with a back view contains the numerical values (in [mm]) of all geometric lengths that are needed for describing the robot kinematics.

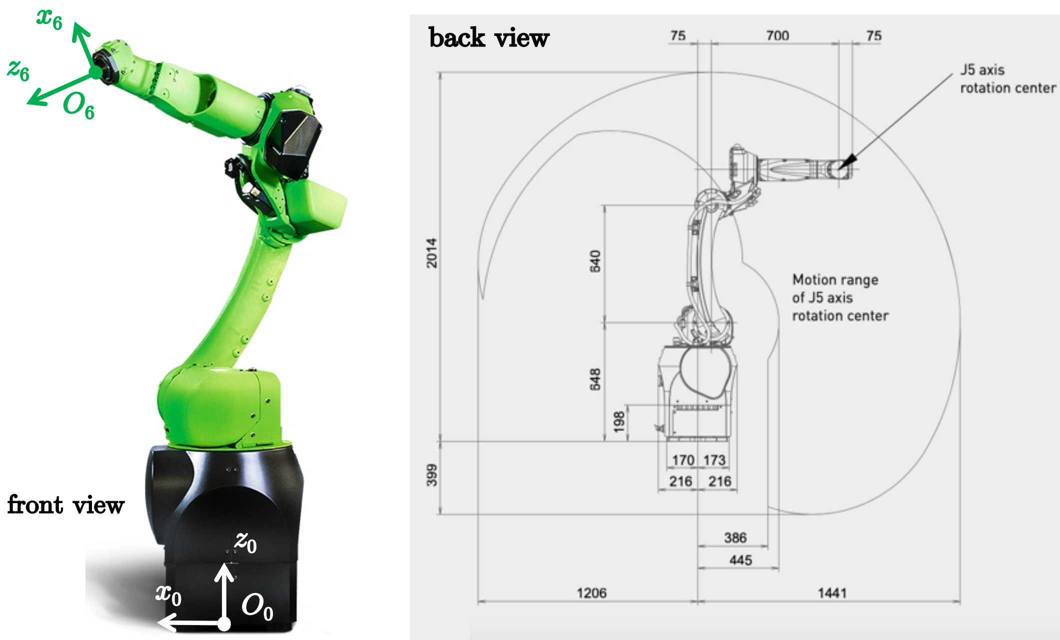

Figure 1: A front view and a drawing from the back of the 6R Fanuc cr15ia collaborative robot.

Assign the link frames according to the Denavit-Hartenberg (DH) convention and fill in the associated table of parameters, specifying the numerical values of the constant parameters (given directly in the drawing of the robot or derived from those data). Moreover, provide the values of the joint variables when the robot is in the configuration shown in the back view. Draw the frames and fill in the table directly on the extra sheet #1 provided separately. The two DH frames 0 (at the robot base) and 6 (at the center of the final flange) are assigned and should not be modified.

Exercise 2

A number of statements are reported on the extra sheet #2, regarding the inverse kinematics problem of robot manipulators. Check if each of the statements is **True** or **False**. Each answer will be considered **only if** you provide also a *very short* motivation/explanation sentence.

Exercise 3

For a 3-dof robot, the task kinematics is given by

$$\boldsymbol{r} = \boldsymbol{f}(\boldsymbol{q}) = \begin{pmatrix} q_2 \cos q_1 + L \cos(q_1 + q_3) \\ q_2 \sin q_1 + L \sin(q_1 + q_3) \\ q_1 + q_3 \end{pmatrix},$$

with a constant $L > 0$.

- Find the singularities of the mapping from $\dot{\boldsymbol{q}}$ to $\dot{\boldsymbol{r}}$.
- Determine all possible task velocities $\dot{\boldsymbol{r}}$ that can be realized when the robot is in a singularity.
- When the robot is at rest ($\dot{\boldsymbol{q}} = \boldsymbol{0}$), is it possible to obtain a task acceleration $\ddot{\boldsymbol{r}} = \boldsymbol{0}$ by commanding a non-zero joint acceleration $\ddot{\boldsymbol{q}}$? Support your answer with one or more numerical examples.
- Set now $L = 1$. At $\boldsymbol{q} = (\pi/2, 1, 0)$, with the robot having a joint velocity $\dot{\boldsymbol{q}} = (1, -1, -1)$, determine a joint acceleration $\ddot{\boldsymbol{q}}$ that realizes $\ddot{\boldsymbol{r}} = \boldsymbol{0}$. Is this joint acceleration unique?

Exercise 4

A single revolute joint of a robot needs to move between $q_i = \pi/2$ [rad] and $q_f = 0$, under the velocity and acceleration bounds

$$|\,\dot{q}\,| \leq V = 2 \ \text{[rad/s]}, \qquad |\,\ddot{q}\,| \leq A = 4 \ \text{[rad/s}^2\text{]}.$$

Determine:

- the minimum time T_0 for a rest-to-rest motion;
- the minimum time T_1 for a motion from $\dot{q}_i = 1.5$ [rad/s] to $\dot{q}_f = 0$.

Sketch the position, velocity and acceleration profiles of the two resulting time-optimal motions.

[180 minutes, open books]