Multi-Sensory Based Robot Dynamic Manipulation – Final Project Report

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09.03.2022

1 Approach

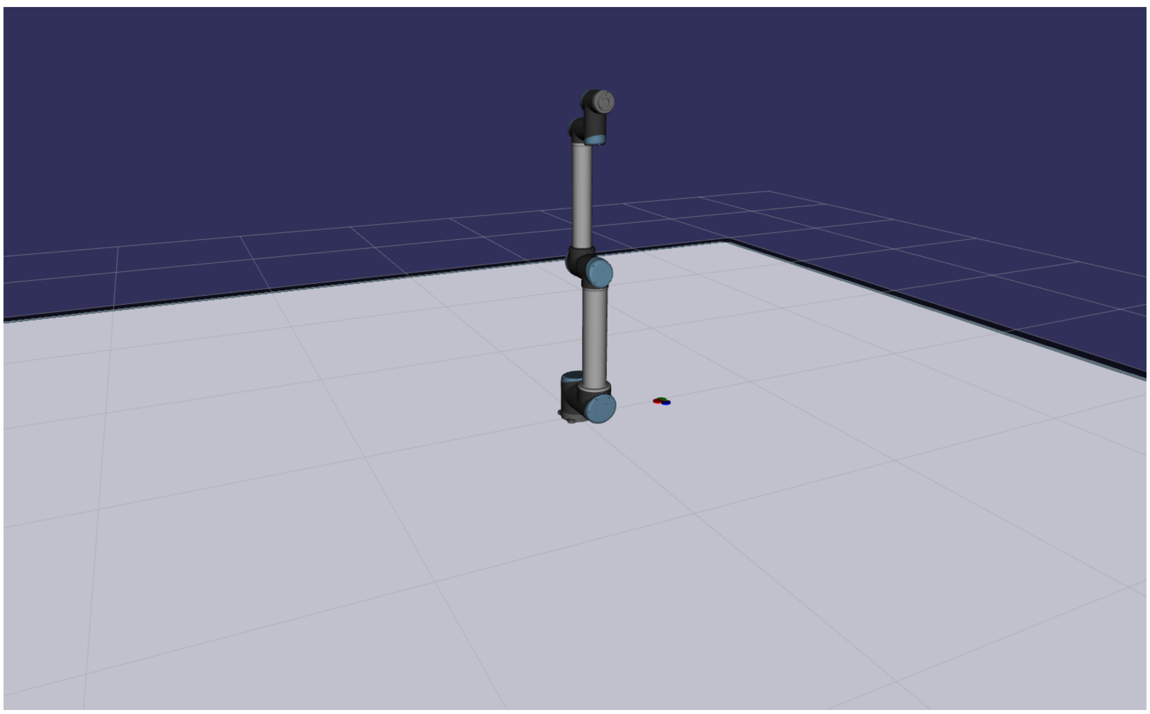

Figure 1: UR10 Environment

The task is to move the UR10 (Figure 1) from its initial position to a non-singular position. Secondly, the robot needs to move to a target in cartesian space and try to hold this position and orientation. One can describe the UR10 with the following general robot dynamic equation:

$$\mathbf{M}(q)\ddot{q} + \mathbf{C}(q, \dot{q})\dot{q} + \mathbf{G}(q) = \tau, \tag{1}$$

with $\mathbf{M}$ is the mass and inertia matrix, $\mathbf{C}$ is the centripetal and coriolis matrix and $\mathbf{G}$ is gravity matrix and τ is the torque vector. We can see in

$$\ddot{q} = \mathbf{M}^{-1}\big(\tau - \mathbf{C}(q, \dot{q})\dot{q}) - \mathbf{G}(q)\big), \tag{2}$$

that we can control the robot's acceleration based on a control torque input τ.
For the first task, a **Joint Space Controller** was implemented with an Adaptive Control Regressor-based Control Design:

$$\tau = -K_d S_q + \mathbf{Y}_r \hat{\Theta}, \tag{3}$$

where

$$Y_r \Theta = \mathbf{M}(q)\ddot{q} + \mathbf{C}(q, \dot{q})\dot{q} + \mathbf{G}(q) \tag{4}$$

is the robot regressor and

$$S_q = \dot{q} - \dot{q}_r \tag{5}$$

is the joint error space. K_d is the damping matrix related to the velocities. Based on the gradient update law

$$\dot{\hat{\Theta}} = -\Gamma^{-1} \mathbf{Y}_r^T S_q, \tag{6}$$

the parameter vector $\hat{\Theta}$ can be estimated. The whole control architecture is based on a PD-like control $\dot{q}_r = \dot{q}_d - K_p \Delta q$, where $\dot{q}_r$ is the joint velocity reference, $\dot{q}_d$ is the desired velocity, K_p is the proportional gain matrix, and $\Delta q = q - q_d$ is the error between the current joint configuration and the desired one.
For the second task, a **Cartesian Space Controller** is implemented to get to a desired target. The method is similar to the former approach but now in the cartesian space domain. There, the cartesian error space can also be calculated as

$$S_x = \dot{x} - \dot{x}_r, \tag{7}$$

where $\dot{x}$ is the cartesian velocity and $\dot{x}_r$ the cartesian velocity reference. With the help of the forward and inverse kinematics, we can obtain the mapping between cartesian and joint space: $S_q = J(q)^{-1} S_x$

2 Results

The pose error for the second task is depicted in Figure **?**. We can see the position is reached quickly thanks to the gains that are set. The proportional and derivative gains are $[15, 15, 15, 6, 6, 6]^T \mathbb{1}$, and $[100, 75, 75, 73, 15, 5]^T \mathbb{1}$ respectively with $\mathbb{1}$ is the 6×6 identity matrix.

DH tables

DH table for joints of UR10 robot (Figure 2)

Link i	θ_i	α_i	a	d
Link 1	q_1	$-90°$	0	L_1
Link 2	q_2+90°	0	-L_3	0
Link 3	q_3	0	-($L_5 - 115.7mm$)	0
Link 4	q_4+90°	+90°	0	L_2
Link 5	q_5	$-90°$	0	+115.7mm
Link 6	q_6	0	0	L_4

DH table for Center of Mass (CoM) of UR10 robot (Figure 3)

CoM i	θ_i	α_i	a	d
CoM 1	q_1	0	0	L_6
CoM 2	q_2+90°	0	-L_8	L_7
CoM 3	q_3	0	-L_{10}	$\frac{L_2}{2}$
CoM 4	q_4	0	0	L_2
CoM 5	q_5+90°	0	0	+115.7mm
CoM 6	q_6+90°	0	0	L_4

$$L_1 = 128mm$$
$$L_2 = 163.9mm$$
$$L_3 = 612.7mm$$
$$L_4 = 92.2mm$$
$$L_5 = 687.3mm$$
$$L_6 = 100mm$$
$$L_7 = 150mm$$
$$L_8 = \frac{L_3}{2}$$
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MSBRDM – Differential Kinematics: Jacobians & Singularities

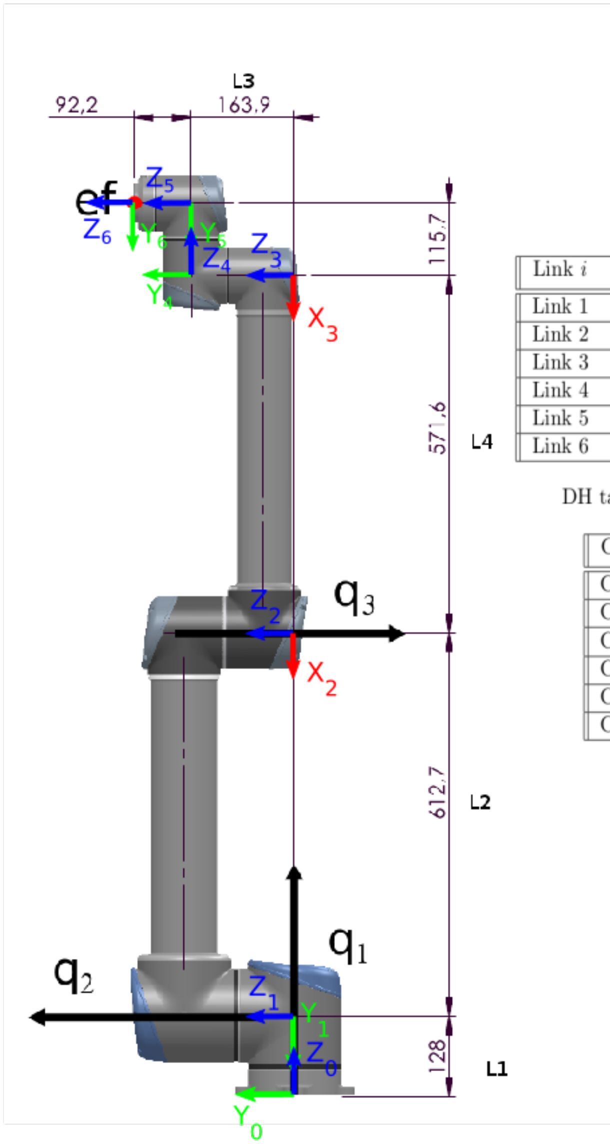

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Figure 7.4: Universal Robot UR-10 with dimensions and kinematic parameters. The black arrows depict the 3 axis of motion. For this exercise, the last 3 joints are considered as f xed joints (no actuation).

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Figure 2: Coordinate Frames of Links

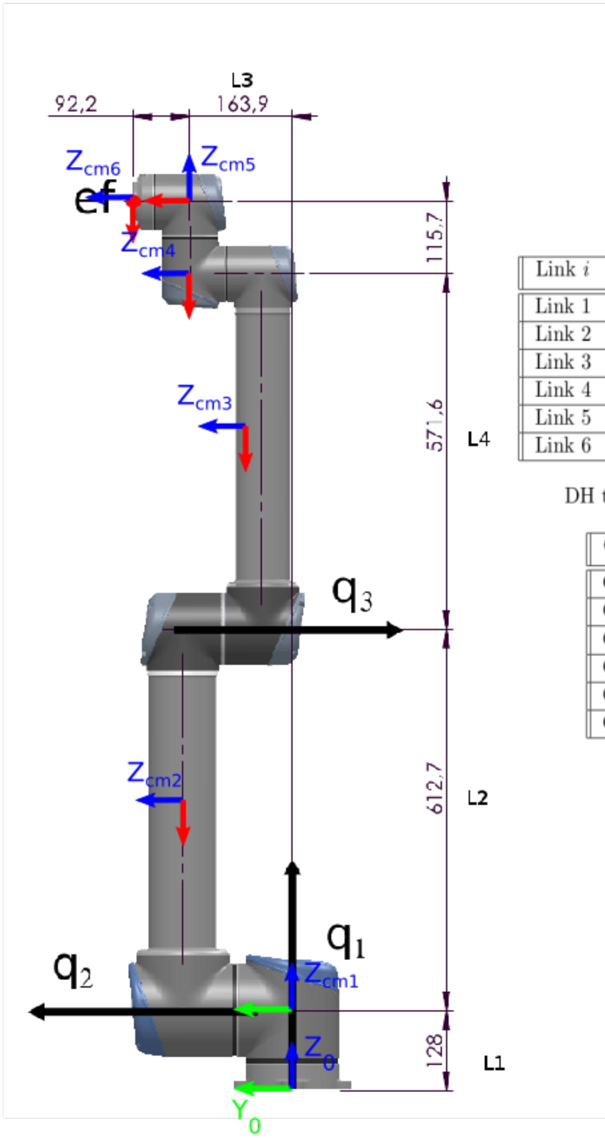

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Figure 3: Coordinate Frames of CoMs