Foundations of Robotics: Project-3

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1 Objective

Implement a trapezoidal velocity profile and inverse dynamic control using second order inversion kinematic algorithm for the given SCARA manipulator

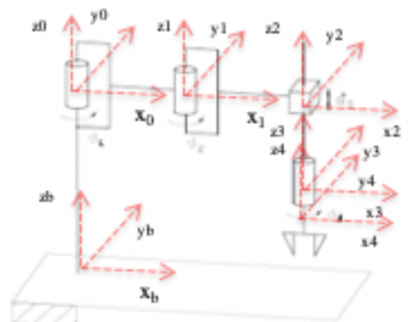


Figure 1: DH diagram for SCARA manipulator.

2 Part-1

Implement a trapezoidal velocity profile for 4s such that the robot does not stop at any of the given waypoints.

We implement a trapezoidal profile by calculating the hold position, velocity and acceleration using different equations depending on the time interval

$$P_e = P_0 + \sum_{j=1}^{4} \frac{S_j}{\|P_j - P_{j-1}\|}(P_j - P_{j-1}) \tag{1}$$

$$S_j(t) = \left\{ \begin{array}{cc} S_i + (0.5) \times \ddot{q}_c t^2 & 0 \le t \le t_c \\ S_i + \ddot{q}_c t_c (t - \frac{t_c}{2}) & t_c \le t \le t_f - \Delta t_c \\ S_f - \frac{1}{2}\ddot{q}_c (t_f - t)^2 & t_f - t_c \le t \le t_f \end{array} \right\} \tag{2}$$

$$t_c = \frac{t_f}{2} - \frac{1}{2}\sqrt{\frac{t_f^2 \ddot{q}_c - 4(q_f - q_i)}{\ddot{q}_c}} \tag{3}$$

$$\|\ddot{q}_c\| >= \frac{(4(q_f - q_i))}{t_f^2} \tag{4}$$

Graphs

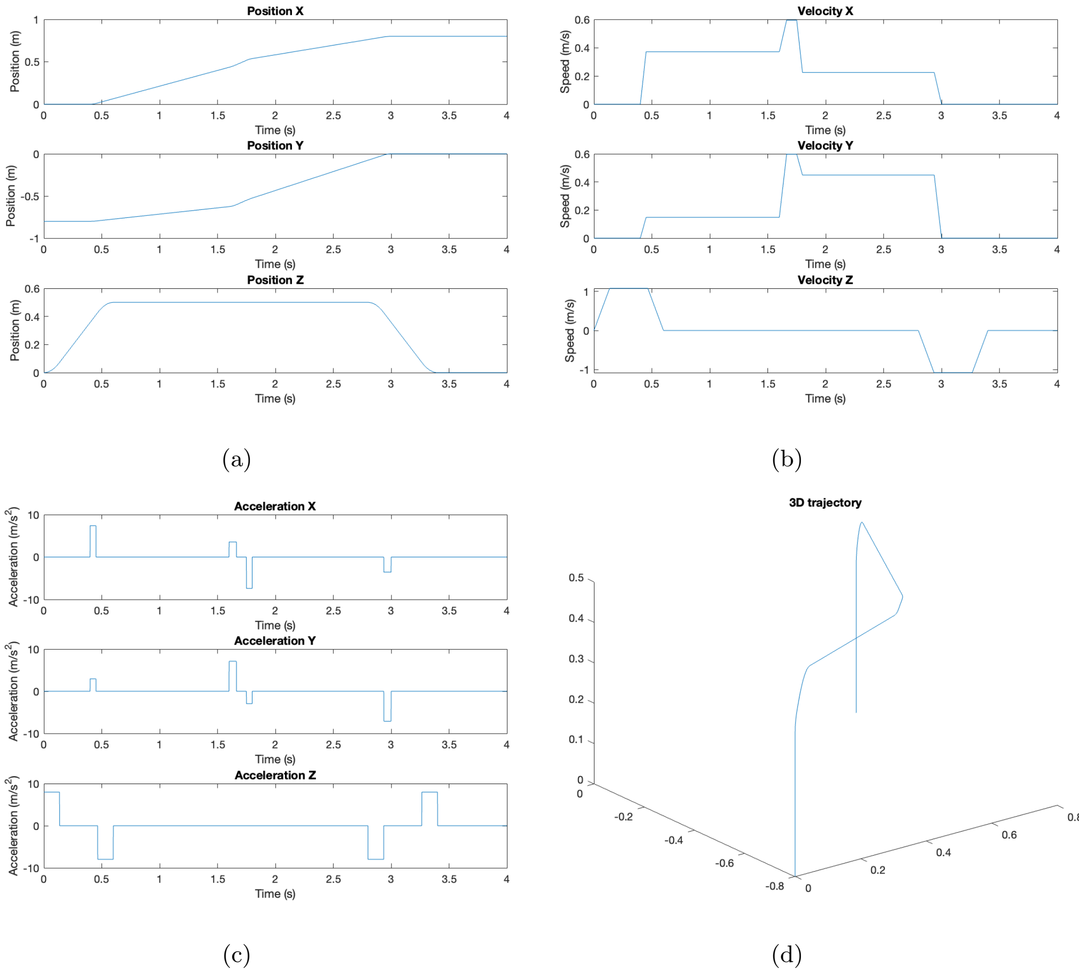


Figure 2: Graphs generated when plotting a trapezoidal velocity profile.**(a)**Variation of position over time. **(b)**Variation of velocity over time. **(c)**Variation of acceleration over time. **(d)**Plotted trajectory in 3D space.

3 Part-2

Implemented an inverse dynamic control using second order inversion kinematic algorithm for the given 5Kg load on the end effector on a SCARA manipulator.

$$B(q)\ddot{q} + n(q, \dot{q}) = \tau \tag{1}$$

$$n(q, q) = c(q, q)q + Fq + g(q) \tag{2}$$

$$u = B(q)y + n(q, \dot{q}) \tag{3}$$

$$y = K_d\ddot{\widetilde{q}} + K_p\widetilde{q} + \ddot{q}_d \tag{4}$$

$$HT\_matrix = \begin{bmatrix} \cos(\theta_1+\theta_2+\theta_4) & -\sin(\theta_1+\theta_2+\theta_4) & 0 & a_2\ \cos(\theta_1+\theta_2)+a_1\ \cos(\theta_1) \\ \sin(\theta_1+\theta_2+\theta_4) & \cos(\theta_1+\theta_2+\theta_4) & 0 & a_2\ \sin(\theta_1+\theta_2)+a_1\ \sin(\theta_1) \\ 0 & 0 & 1 & base-d3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

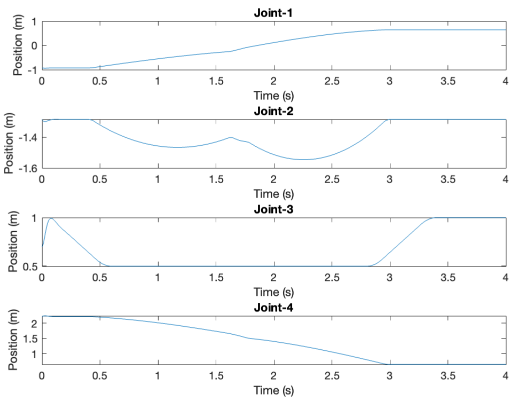
$$jacobian\_matrix = \begin{bmatrix} -a_2\ \sin(\theta_1+\theta_2)-a_1\ \sin(\theta_1) & -a_2\ \sin(\theta_1+\theta_2) & 0 & 0 \\ a_2\ \cos(\theta_1+\theta_2)+a_1\ \cos(\theta_1) & a_2\ \cos(\theta_1+\theta_2) & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 1 & 1 & 0 & 1 \end{bmatrix} \tag{6}$$

$$jacobian\_dot\_pre = \begin{bmatrix} -a_2\ \cos(\theta_1+\theta_2)*(\theta_1+\theta_2)-a_1\ \cos(\theta_1)*\theta_1 & -a_2\ \cos(\theta_1+\theta_2)*(\theta_1+\theta_2) & 0 & 0 \\ -a_2\ \sin(\theta_1+\theta_2)*(\theta_1+\theta_2)-a_1\ \sin(\theta_1)*(\theta_1) & -a_2\ \sin(\theta_1+\theta_2)*(\theta_1+\theta_2) & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{7}$$

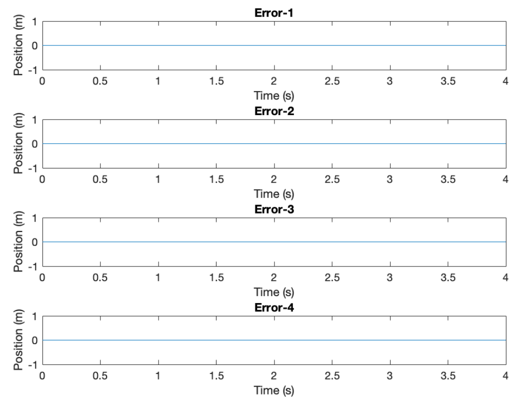
$$jacobian\_dot = jacobian\_dot\_pre \cdot q\_dot \tag{8}$$

$$\ddot{q} = J_A^{\dagger}(\ddot{x}_d + K_d\dot{e} + K_p e - \dot{J}_A(q,\dot{q})\dot{q}) + (I_n - J_A^{\dagger}J_A)\ddot{q}_0 \tag{9}$$

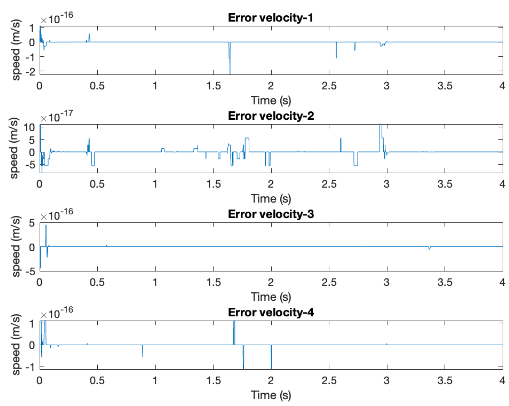
Graphs



(a)



(b)



(c)

Figure 3: Graphs generated for inverse dynamic control on the SCARA manipulator. **(a)** Position of joints across time. **(b)** Error of joints across time. **(c)** Error of joint velocity across time.