Mini Project: Systems Thinking - 2025

Control of a 2-Link Manipulator

Team Formation: This project must be completed in teams of 5-6 members.
Submission Format: Submit a single zip file named `team_name.zip` containing:

- A folder named `codes` with all MATLAB and Simulink files.
- A folder named `plots` with all generated figures and graphs from MATLAB and Simulink. All plots must be properly labeled.
- A comprehensive project report as `Report.pdf`

Deadline: 9th October, 2025

2-Link Manipulator Dynamics: *Consider the following system dynamics of a 2-link manipulator:*

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

where the inertia matrix $\boldsymbol{M}$ *and joint vector* $\boldsymbol{q}$ *are defined as:*

$$\boldsymbol{M} = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}, \quad \boldsymbol{q} = \begin{bmatrix} q_1 \\ q_2 \end{bmatrix} \tag{2}$$

The individual matrix elements are:

$$M_{11} = (m_1 + m_2)l_1^2 + m_2 l_2(l_2 + 2l_1 \cos q_2) \tag{3}$$

$$M_{12} = M_{21} = m_2 l_2(l_2 + l_1 \cos q_2) \tag{4}$$

$$M_{22} = m_2 l_2^2 \tag{5}$$

$$\boldsymbol{C} = \begin{bmatrix} -m_2 l_1 l_2 \sin q_2 \cdot \dot{q}_2 & -m_2 l_1 l_2 \sin q_2 (\dot{q}_1 + \dot{q}_2) \\ 0 & m_2 l_1 l_2 \sin q_2 \cdot \dot{q}_1 \end{bmatrix} \tag{6}$$

$$\boldsymbol{G} = \begin{bmatrix} m_1 l_1 g \cos q_1 + m_2 g(l_2 \cos(q_1 + q_2) + l_1 \cos q_1) \\ m_2 g l_2 \cos(q_1 + q_2) \end{bmatrix} \tag{7}$$

System Parameters:

$$m_1 = 5\,\text{kg}, \qquad m_2 = 3\,\text{kg} \tag{8}$$

$$l_1 = 0.25\,\text{m}, \qquad l_2 = 0.15\,\text{m} \tag{9}$$

$$g = 9.81\,\text{m}\,\text{s}^{-2} \tag{10}$$

Initial Conditions:

$$\boldsymbol{q}(0) = \begin{bmatrix} q_1(0) \\ q_2(0) \end{bmatrix} = \begin{bmatrix} 0.2 \\ 0.15 \end{bmatrix} \; rad \tag{11}$$

Control Objective: *Drive the manipulator to the desired configuration:*

$$\boldsymbol{q}_{desired} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \; rad \tag{12}$$

Controller Analysis

For this manipulator system, implement and analyze three fundamental control strategies. Begin by developing a clear understanding of each controller's theoretical foundation and practical characteristics.

Implement each controller using MATLAB simulations with carefully chosen gain values. Compare the resulting joint trajectories $q_1(t)$ and $q_2(t)$, control torques $\tau_1(t)$ and $\tau_2(t)$, and key performance metrics including settling time, overshoot, and steady-state accuracy. Document your observations regarding the distinct behavioral characteristics and practical advantages of each approach. Submit the Simulink model along with simulation results.