University of Tehran
Campus of Technical Faculties
Electrical and Computer Faculty

Robotics Course
Fall 2024

Project 3

Instructor:

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Teaching Assistants:

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Deadline: 22 Jan 2025 (3 Bahman), 23:59

List of Problems

Important Notes

- Any potential similarities with other works must be explained by the students.
- The use of AI tools for code preparation or report writing for this project is strictly prohibited. If detected, a score of zero will be assigned.
- All graphs and outputs must be interpreted and supported by clear explanations.

Problem 1: Two-Link Arm Robot Dynamics and Control

Consider a two-link arm robot as shown in the Figure 1:

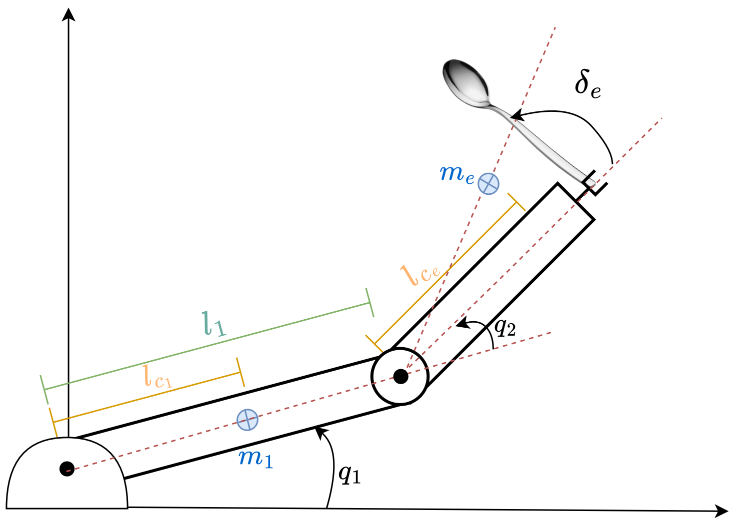

Figure 1: Two-link arm robot with an unknown object at the end-effector.

where the geometric specifications of the arm are depicted in the figure, and the numerical values are given as follows:

Table 1: Robot Parameters.

Parameter	**Value**
m_1	1
l_{c1}	0.5
l_1	1
m_e	2
δ_e	30°
I_1	0.12
I_e	0.25
l_{ce}	0.6

a. Derive the dynamic equations of the robot.

b. Assume the robot operates in a horizontal plane ($g(q) = 0$) and the system state variables $(q, \dot{q})$, are available. Starting from ($q = 0, \dot{q} = 0$), the objective is for the robot to reach the desired positions ($q_{d1} = 60°, q_{d2} = 90°$). Design a PD controller and evaluate its performance through simulation using MATLAB. As outputs, provide:

- Position error curves.
- Torque generated by the controller.
- Analyze the effect of controller gains on system performance and control signal output.

c. Solve part (b) for the desired position trajectory:

$$q_{d1}(t) = 30(1 - \cos(2\pi t)), \quad q_{d2}(t) = 45(1 - \cos(2\pi t)).$$

- Analyze the performance of the controller designed in part (b).
- If the desired outcomes are not achieved, modify the controller to meet the problem requirements.

d. Consider:

$$\begin{aligned} a_1 &= I_1 + m_1 l_{c1}^2 + I_e + m_e l_{ce}^2 + m_e l_1^2 \\ a_2 &= I_e + m_e l_{ce}^2 \\ a_3 &= m_e l_1 l_{ce} \cos\delta_e \\ a_4 &= m_e l_1 l_{ce} \sin\delta_e \end{aligned}$$

Assume the desired trajectory is the same as in part (c), but the robot parameters are unknown and the initial values of the unknown system parameters are zero. Design an adaptive controller to reach the desired specifications and evaluate its performance through MATLAB simulation. As outputs, provide:

- Position error curves
- Torque generated by the controller
- Estimation error of the parameters (a_i)
- Finally, analyze the effect of controller gains and the adaptation gain (P) on the performance and control signal output.

e. If substitute the actual values of the robot's parameters into the above equation, we will have:

$$\mathbf{a} = \begin{bmatrix} a_1 & a_2 & a_3 & a_4 \end{bmatrix}^T = \begin{bmatrix} 3.3 & 0.97 & 1.04 & 0.6 \end{bmatrix}^T$$

Do the estimated parameters converge to the actual parameter values over time?

- If yes, explain why.
- If not, suggest modifications to the desired trajectory to achieve convergence.

Problem 2: Implementation Controller with ROS

In this problem, we aim to implement the controller designed in the previous problem using ROS. To achieve this, the model and the controller must be implemented as nodes. You are required to implement a node named `robot_driver` that publishes the robot's joint position and velocity data on a topic named `/joint` and receives control commands via a topic named `/torque`. The following step-by-step instructions are provided for you to accomplish this task.

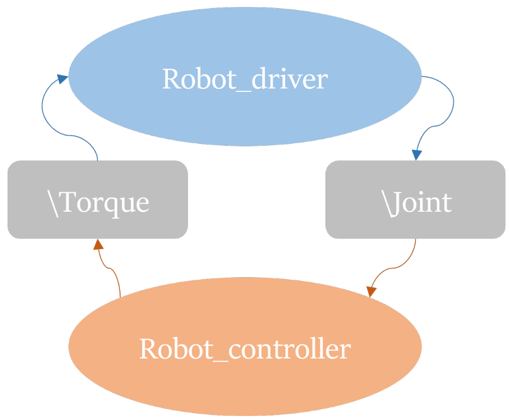

Figure 2: Schematic of requested implementation.

a. In the first step, you are required to discretize the robot equations derived in the previous section. To achieve this, you can use methods such as Forward Euler (Explicit Euler), Backward Euler (Implicit Euler), or other similar techniques to convert the equations into a discrete form. Implement these equations as the robot model within the `robot_driver` node.

b. In this part, you are tasked with creating a node named `robot_controller` that includes a PD controller to follow the desired position ($q_{d1} = 60°, q_{d2} = 90°$), starting from ($q = 0, \dot{q} = 0$). As outputs, you are required to:

   - Report position error curves.
   - Report the torque generated by the controller.
   - Study the effect of controller gains and the impact of sampling period (T) in the discrete equations on the performance and control signal output.

Project Submission Requirements

- Submit the final project files as a package, including all scripts required for successful execution. To receive full marks, ensure that all node, service, and custom message files are correctly placed in the package folder. Even if individual nodes are correct, the task must be completed exactly as instructed.

- In addition to addressing technical requirements for the robot's behaviour during control, your report should also include a detailed implementation plan to complete the project.
- It is critical that the report provide a detailed overview of the project workflow.

Homework Guidelines and Instructions

- The deadline for sending this exercise will be until the end of Wednesday, Jan 22th.
- This time cannot be extended and you can use time grace if needed.
- The implementation must be in Python programming language and your codes must be executable and uploaded along with the report.
- This exercise is done by one person.
- If any similarity is observed in the work report or implementation codes, this will be considered as fraud for the parties.
- Using ready-made codes without mentioning the source and without changing them will constitute cheating and your practice score will be considered zero.
- If you do not follow the format of the work report, you will not be awarded the grade of the report.
- Handwritten exercise delivery is not acceptable.
- All pictures and tables used in the work report must have captions and numbers.
- A large part of your grade is related to the work report and problem solving process.
- Please upload the report, code file and other required attachments in the following format in the system: `Prj3_[Lastname]_[StudentNumber].zip`
  For example, the: `HW1_Ezzati_12345678.zip`
- If you have questions or doubts, you can contact the assistants through the following e-mail with the subject Prj3-Robotics. Stay in touch educationally:
  - `Ezzati.z@ut.ac.ir` (Zeynab Ezzati)
  - `Balazadeh.elnaz@gmail.com` (Elnaz Balazadeh)
- Be happy and healthy!