Robot Arm Control

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Introduction

Main Objectives

- To develop a control system for a two-link robotic arm
- Analyze the sytem’s behavior with and without PID controllers.
- Check how well the arm moves.

Mathematical Modeling

1.Dynamic Equation

- $\tau = J * \ddot{\theta} + b * \dot{\theta}$
- τ: Torque (force to rotate the joint).
- J: Inertia (resistance to movement).
- b: Damping (friction).
- θ: Joint angle.

2.Using Laplace Transform

- Open-loop transfer functions:
- G1(s) = 1 / (J1 * s^2 + b1 * s)
- G2(s) = 1 / (J2 * s^2 + b2 * s)
- These equations describe how the system reacts to torque inputs in the frequency domain.

Joint Parameters

- Link Lenghts (L1,L2): (L1 = 1.0) Provides a longer reach. (L2 = 0.75) Improves precision but reduces reach.

- Join Inertias (J1,J2): (J1 = 0.01) Supports entire arm and adding stability but reducing responsiveness. (J2 = 0.005) Faster movement for the end effector but less stability

- Damping Coefficients (b1,b2): (b1 = 0.1) Higher damping for stability under load. (b2 = 0.08) Lower damping for smooth and precise movements.

Open-Loop and Closed Loop Analysis

1. Open Loop System

- Open-loop means the system has no feedback to fix errors
- The system reacts to torque inputs based on its dynamics:
- Joint 1: G1(s) = 1 / (J1 * s^2 + b1 * s)
- Joint 2: G2(s) = 1 / (J2 * s^2 + b2 * s)
- Observations:
- Open-loop is not stable for sudden changes in torque.
- The system shakes a lot and is hard to control.

2. Closed Loop System

- Closed-loop uses feedback to fix errors while the system runs.
- PID controllers help make the system more stable:
- Joint 1: PID1(s) = Kp1 + Ki1/s + Kd1 * s
- Joint 2: PID2(s) = Kp2 + Ki2/s + Kd2 * s
- Closed-loop transfer functions:
- Joint 1: CL1(s) = feedback(PID1(s) * G1(s), 1)
- Joint 2: CL2(s) = feedback(PID2(s) * G2(s), 1)
- Observations:
- Closed-loop reduces shaking and improves control. It works better, but it needs good PID tuning.
- Open-loop is simple but not good for real control.
- Closed-loop helps the robotic arm reach the right position better.

Equations

1. Dynamic Equation of Motion

- Equation : $\tau = J * \ddot{\theta} + b * \dot{\theta}$
- What it does: 1. Explains how torque moves the joint.
- 2. Includes inertia and damping to show resistance.
- Why it is important:
- This equation helps to understand how the robotic arm moves.

2. Transfer Function (Laplace Transform)

- Equation: $G(s) = 1 / (J * s^2 + b * s)$
- What it does:
- 1. Charges the motion equation into a form used in control system design.
- Shows how torque input affects the joint angle output.
- Why it is important:
- Transfer functions make it easier to design and study control systems.

3. PID Controller Equation

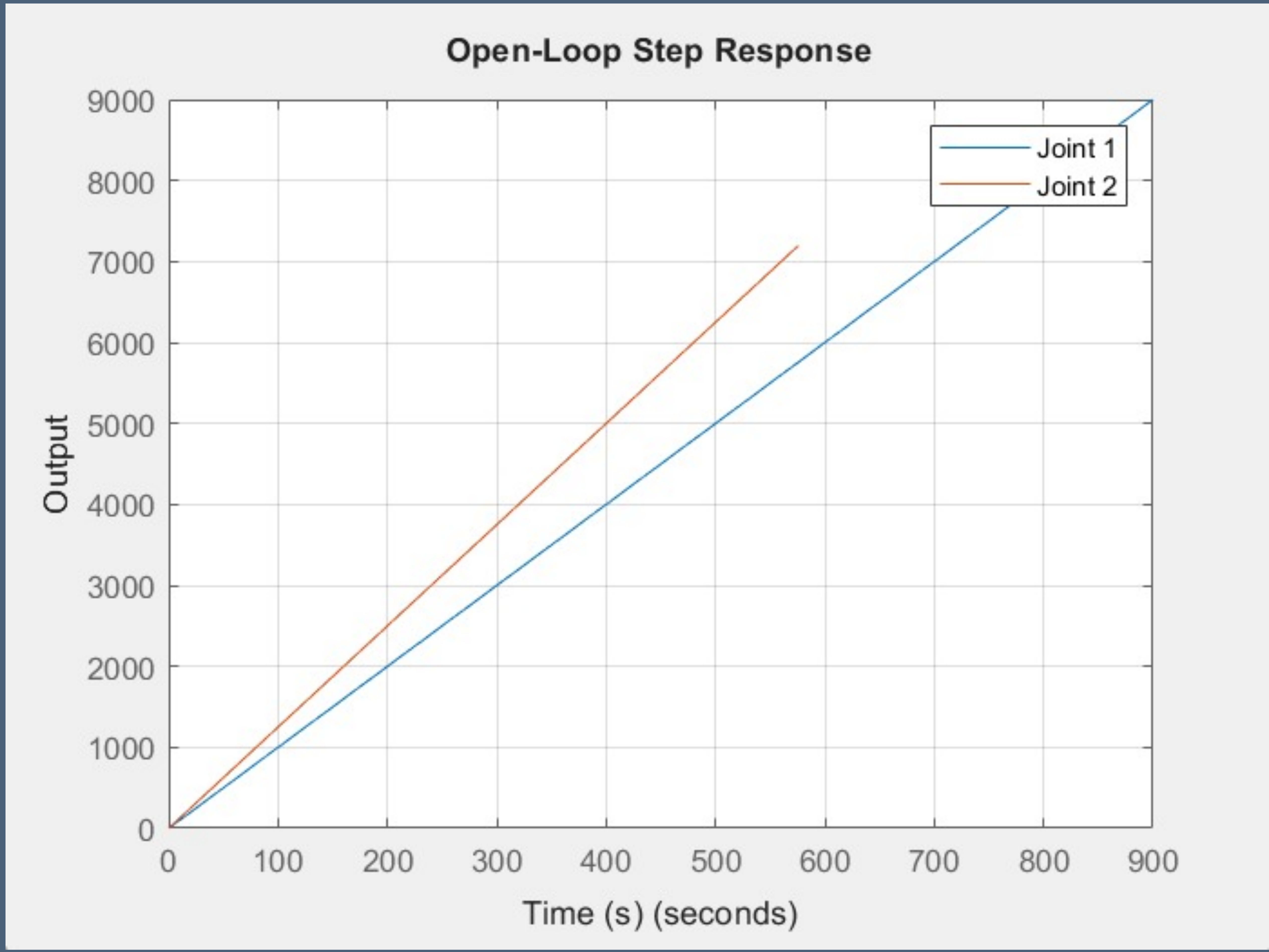
- Equation : $u(t) = Kp * e(t) + Ki * \int e(t)\, dt + Kd * de(t)/dt$
- What it does:
- 1. Calculates the control signal (u(t)) to reduce the error (e(t)).
- 2. Uses three terms:
- - Proportional (Kp): Reacts to current error.
- - Integral (Ki): Corrects accumulated past errors.
- - Derivative (Kd): Anticipates future errors.

4. End-Effector Position Equation

- Equations: $x = L1 * \cos(\theta 1) + L2 * \cos(\theta 1 + \theta 2)$, $y = L1 * \sin(\theta 1) + L2 * \sin(\theta 1 + \theta 2)$
- What it does: Computes the position of the robotic arm's end-effector in the 2D plane.
- Why it is important:
- Allows checking if the arm reaches the target point.
- Helps visualize the arm’s motion and trajectory accuracy.

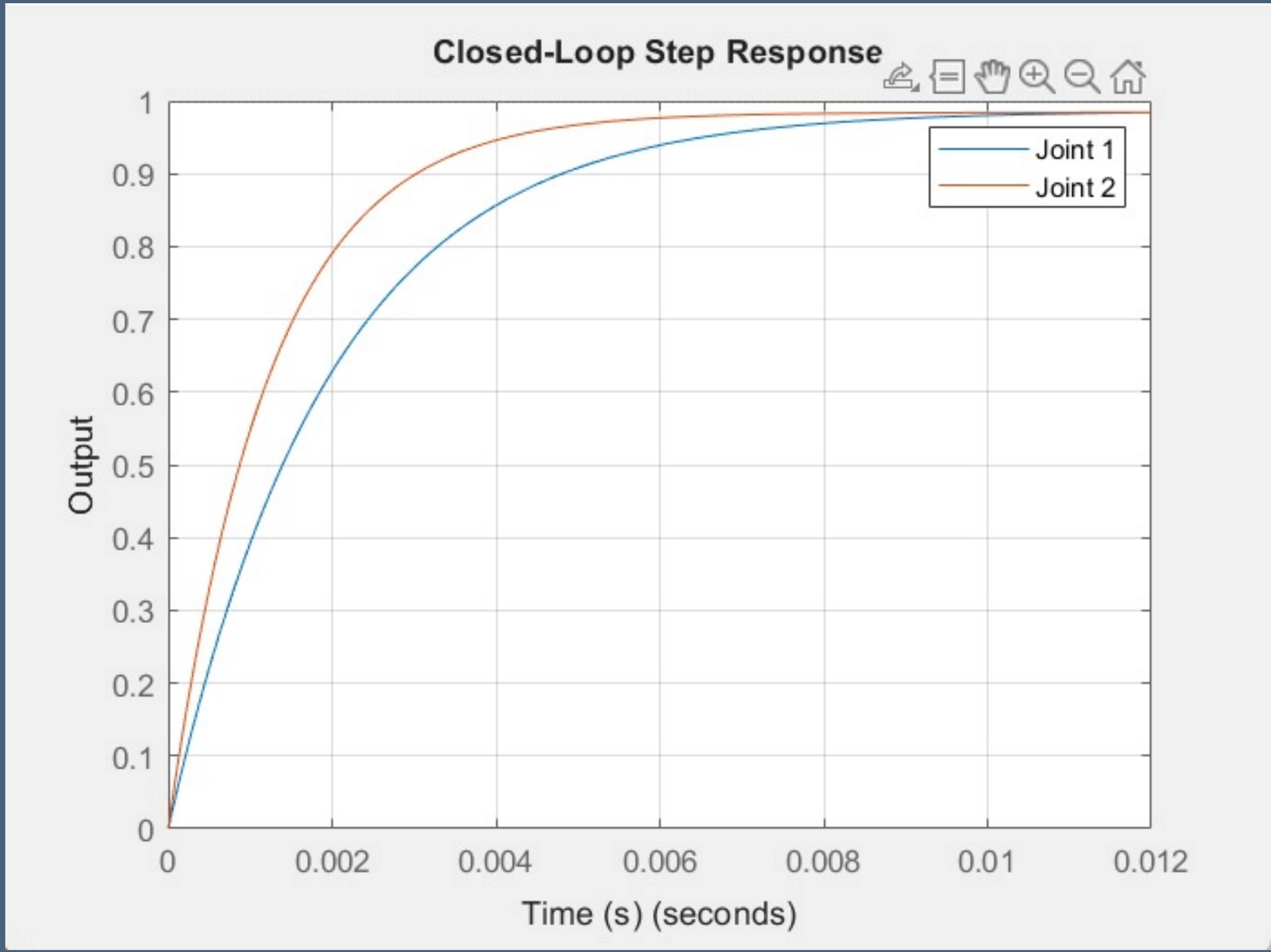
Open-Loop Step Response

- What does this graph show?
- 1. The graph shows how Joint 1 and Joint 2 move in open-loop system.
- 2. Open-loop means there is no feedback control.
- Observations:
- Joint 1 : Moves slowly because it has higher inertia and damping.
- Joint 2: Moves faster because it has lower inertia and damping.
- Problems with Open-Loop:
- The joints do not stop at a target position they keep moving.
- There is no stability or control



Closed-Loop Step Response

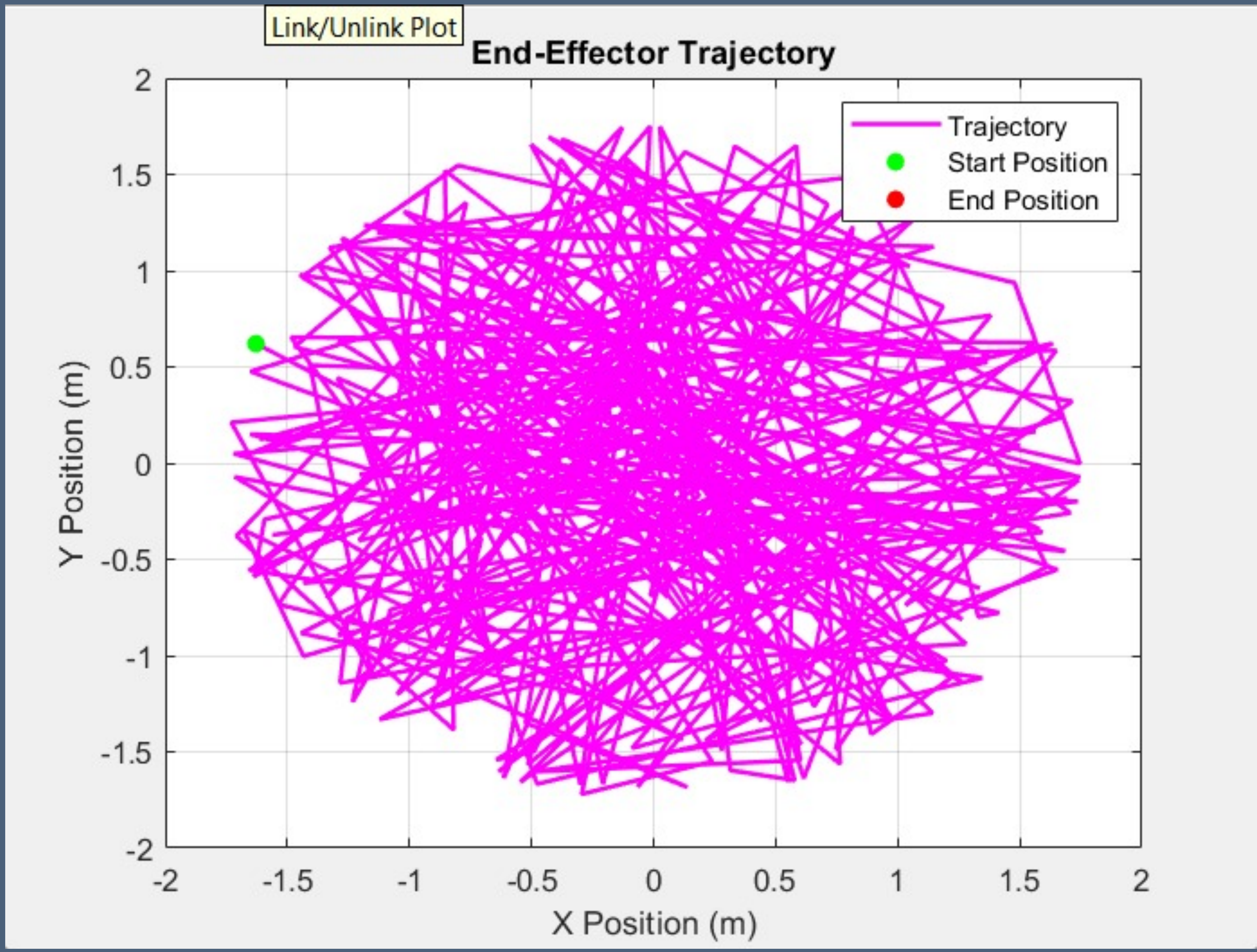
- This graph shows the step response with PID controllers.
- Observation:
- Joint 1 : Moves slower than Joint 2 because it carries a bigger load.Reaches its target without overshooting.
- Joint 2 : Moves faster because it has a smaller load. Also reaches its target smoothly and without overshooting.
- Why is this important?
- With PID controllers, the system: Stabilizes quickly, stops at the correct target position and reduces errors and avoid instability.
- Comparison with Open-Loop:
- In the Open-Loop system, the joints are kept moving without control.
- In the closed-loop system, the joints are stopped where they should.



End-Effector Trajectory Analysis

Graphic Analysis

- This graph shows how robotic arm's end-effector moves in x-y.
- Observations:
- 1. Irregular Motion:
- The arm moves in a messy, overlapping path.
- The movement is not smooth or controlled.
- 2.Final Position:
- The end-effector does not clearly stop at the target position.
- Why is this important:
- The robotic arm needs to move smoothly and stop at the target to perform tasks like picking objects.
- The current system shows that the control is not working as expected.



Problems Identified at the End-Effector Trajectory

- Unstable movement: The arm keeps moving without reaching the target.
- Control issues: The PID controller is not able to guide the arm smoothly.
- System Settings: The damping and inertia values may not be good enough to control the arm.

End-Efector Trajectory Graphic Analysis

Next steps for improvement

- 1. Fix PID gains:
- Increase Kd to reduce shaking.
- Adjust Kp and Ki to help the arm reach target more accurately.
- 2. Change Damping Values:
- Increase the damping values to make the system more stable.
- 3. Adaptive Control:
- Add real time feedback to adjust PID values during movement for smoother motion.

Results

Main Results

- A robotic arm was modeled using dynamics equations and Laplace transforms.
- The project used mathematical modeling and Laplace analysis to understand the arm's dynamics.
- Open-loop and closed-loop analyses were performed to understand system.
- PID controllers were implemented to stabilize the joints and minimize errors.

Observations

- In the open-loop system, joints showed unstable movement.
- Closed-loop system with PID control improved stability and reduced errors.
- Even with improvements, the arm's movement and end-effector position were still not smooth.

Future Improvements and Final Thoughts

- Try different PID gain values.
- Adjust damping and inertia to improve stability.
- Final: The project helped learn about controlling a robotic arm and importance of PID.
- While current system shows room for improvement, the system still shows the basic ideas of robotic arm control well.