AR523: Assignment 2 - Part-5
Comparative Evaluation of Admittance and Impedance Force Control

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Abstract

This report examines and compares two widely used interaction control strategies for robotic manipulators: **admittance control** and **impedance control**. Four experiments were carried out in a PyBullet-based simulation environment, covering both static and dynamic contact conditions for each strategy. The experiments demonstrate that admittance control effectively regulates the applied force to a target value, whereas the implemented position-based impedance controller acts as a stiff position servo, producing large uncontrolled contact forces. Based on observed force tracking error, settling behavior, and interaction smoothness, we discuss the suitability of each approach for different categories of tasks involving physical interaction.

1 Introduction

Robotic manipulators commonly interact with environments that are not perfectly rigid or predictable. In such contact scenarios, controllers must regulate not only position but also applied force. Two primary approaches are used for this purpose:

- **Admittance Control**: interprets force as input and produces a motion response.
- **Impedance Control**: interprets motion error as input and produces force as a reaction.

This assignment focuses on a comparative study of these two strategies. We evaluated their behavior under:

1. Static admittance control
2. Dynamic admittance control (circular motion while in contact)
3. Static impedance control
4. Dynamic impedance control

The objective was to assess how each controller responds to surface contact, especially when aiming to maintain a desired force of 20N along the vertical axis.

2 Experimental Observations

2.1 Admittance Control (Static and Dynamic)

Admittance control computes a corrective displacement based on the difference between measured force and desired force. In our implementation, the vertical target force was 20N.

Static Case: The end-effector made gentle contact and settled near the target force. The measured force oscillated slightly around 20N with small variations, indicating stable force regulation.

Dynamic Case: While the end-effector traced a circular trajectory, the controller continued to adjust the vertical position to maintain contact. Force deviations were small (roughly $\pm$1–2N), expected due to motion-induced interaction changes. The motion remained smooth and compliant.

Conclusion: Admittance control consistently maintained the desired contact force and provided compliant behavior.

2.2 Impedance Control (Static and Dynamic)

Our impedance controller commanded a fixed target position slightly below the contact surface. The resulting interaction force was the output of the robot's internal joint control loop attempting to achieve that impossible position.

Static Case: The resulting contact force was approximately 180–190N, far above the 20N reference. This is a natural outcome of purely position-based impedance: the force is not regulated.

Dynamic Case: When moved in a circular path, the reaction force varied significantly (approximately 170–240N). These fluctuations correspond to changes in the manipulator Jacobian and leverage throughout the motion.

Conclusion: Impedance control, as implemented, behaved as a stiff position controller rather than a force-regulating one.

3 Comparative Analysis

3.1 Force Tracking Error

- **Admittance:** Very low error; successfully converged to 20N.
- **Impedance:** Very high deviation; force was not controlled and exceeded 150N.

3.2 Settling Behavior

- **Admittance:** Settled gradually (1–2 seconds), reflecting compliant probing.
- **Impedance:** Reaction force appeared almost instantaneously due to stiffness.

3.3 Smoothness of Interaction

- **Admittance:** Smooth motion and stable contact.
- **Impedance:** Smooth position movement, but highly uneven force output.

3.4 Summary of Characteristics

Metric	Admittance Control	Impedance Control
Primary Objective	Regulate Force	Maintain Position
Behavior Type	Compliant	Stiff
Force Accuracy	High	Poor
Position Accuracy	Moderate	High
Safety in Contact	Safer	Potentially Hazardous
Suitable Tasks	Polishing, sanding, human-safe interaction	Precision alignment, insertion, rigid

4 Conclusion

Our experiments clearly show the fundamental behavioral distinction between the two controllers. Admittance control directly regulates force and is therefore well-suited to tasks requiring gentle or regulated contact. Position-based impedance control, in contrast, ensures positional accuracy at the cost of large reaction forces, making it appropriate for tasks where the environment is rigid and high stiffness is beneficial.

The experiments confirm that:

- **Admittance control** behaves as a *force controller*.
- **Impedance control** behaves as a *position controller*.

Choosing between them depends on the requirements of the physical interaction task.