Simulation of Robotic Manipulation with Dual-Hand Robots Using PyBullet

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***Abstract*—Robotic manipulation plays a crucial role in various industries from manufacturing to healthcare. This paper focuses on the simulation of a dual-hand robotic system performing object manipulation tasks using PyBullet. The proposed algorithm addresses inverse kinematics, joint coordination, and stable grasping for efficient manipulation.**

***Index Terms*—Robotic manipulation, dual-hand robots, PyBullet, inverse kinematics, grasping.**

I. Introduction

A. Background

Robotic manipulation is essential in industries ranging from manufacturing to healthcare. This project explores the programming of dual-hand robotic systems for object manipulation tasks using PyBullet's physics engine.

B. Problem Formulation

The primary challenge is to develop an algorithm for programming a dual-hand robot to manipulate a cube. This involves solving the inverse kinematics for precise positioning, coordinating multiple joints for smooth movement, and ensuring a stable grasp.

C. Proposed Methodology

The simulation leverages PyBullet to:

- Calculate inverse kinematics to determine joint configurations.
- Use position control for robot arm and finger movements.
- Gradually close fingers for a stable grasp.

D. Summary of the Project

The project successfully simulates a dual-hand robot performing a grasping task. The algorithm efficiently handles inverse kinematics and motor control, ensuring precise manipulation.

II. Related Work

A. Survey of Methods

Prior studies have proposed various approaches:

- *Grasp Multiple Objects with One Hand*: Introduces MultiGrasp for multi-object grasping.
- *Bimanual Grasp Synthesis for Dexterous Robot Hands*: Presents the BimanGrasp algorithm for synthesizing bimanual grasps.

These studies emphasize the importance of efficient grasp planning and joint coordination.

III. Method

A. Algorithm Description

The simulation method comprises the following steps:

1) **Initialization**: The simulation begins with setting up the environment in PyBullet. The dual-hand robot, a plane, and a cube are loaded into the simulation. Initial positions and parameters, such as friction for the cube, are defined to create a realistic setup.
2) **Inverse Kinematics**: Using PyBullet's p.calculateInverseKinematics function, the joint angles are calculated to achieve the desired position and orientation of the end-effector. This step is crucial for ensuring that the robot's hand can precisely approach and interact with the object.
3) **Control Strategy**:
   - Position control is employed to move the robot's arm joints and fingers. Each joint is controlled to reach specific target positions that align with the computed inverse kinematics.
   - Gradual motion interpolation is used to smoothly transition the hand from its starting position to the target position near the cube.
4) **Finger Movement**:
   - Interpolating joint positions for the thumb and other fingers from their initial to final states.
   - Adjusting control parameters like force and gain to achieve a stable grasp without overshooting or causing instabilities.
5) **Simulation Execution**: The simulation progresses in discrete time steps, where the robot's joints are updated iteratively to reflect the calculated movements. The cube's position is monitored throughout the simulation to verify the effectiveness of the grasping process.

B. Equations

The inverse kinematics optimization problem is defined as:

$$\min_{\theta} E(\theta) = ||f(\theta) - X_d||^2 \tag{1}$$

subject to:

- $\theta_{min} \leq \theta \leq \theta_{max}$ (joint limits),
- $g(\theta) \geq 0$ (collision avoidance constraints).

Here, θ represents joint angles, $f(\theta)$ maps angles to end-effector position, and X_d is the desired state.

The optimization is solved iteratively, with the PyBullet function p.calculateInverseKinematics approximating to minimize E(). This method ensures feasible solutions while respecting physical and operational constraints.

IV. Results

A. Demonstration of Outcomes

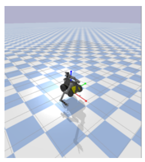

Fig. 1. The simulation begins with the dual-hand robot in its initial configuration. The robot's right arm is slightly extended, positioned under the cube, while its base is stationary on the plane.

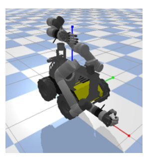

Fig. 2. At the end of the simulation, the robot successfully manipulates the cube, demonstrating its ability to grasp and lift the object. The robot's arms and hands are in a coordinated pose, securely holding the cube. This final configuration highlights the effective implementation of inverse kinematics and the stability of the gripping mechanism. .

B. Performance Discussion

The algorithm demonstrates high accuracy in positioning the end-effector. Robustness is evident as the grasping motion adapts to slight variations in the cube's position. However, occasional instability in finger movements suggests areas for refinement.

V. Discussion

A. What Worked

- Effective inverse kinematics and motor control.
- Smooth joint coordination for object manipulation.

B. Challenges

- Occasional instability in finger movements.
- Need for improved control parameters and gain settings.

VI. Conclusion

A. Summary

This project implements a dual-hand robotic manipulation system in PyBullet. The algorithm achieves accurate positioning and robust grasping through inverse kinematics and position control.

B. Results

The robot successfully grasps the cube, demonstrating precise coordination of joints and effective implementation of the proposed algorithm. During the simulation, joint angles smoothly adjusted to the desired configurations, and the fingers closed incrementally to secure the cube.

Effective grasping requires fine-tuning of control parameters, such as joint gains and force thresholds, to ensure stability and prevent overshooting. Additionally, optimizing motion interpolation techniques can further enhance the smoothness of movements and reduce instabilities.

References

https://ieeexplore.ieee.org/document/70907102