IMPL-Assignment 3

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1 Git Link

The source code for this project is available on GitHub: `https://github.com/havenousername/libfranka`

2 Google Drive Link

The video of step 3 can be found on Google Drive: `https://drive.google.com/file/d/1BOk-PA2bxK_l6TTx6VPaWiDZS4XZZE6J/view?usp=drive_link`

3 Plots and Analysis for the Hand-guiding Trajectory and Trajectory Replay

3.1 Introduction

The purpose of this analysis is to evaluate two key aspects of our system:

- The performance of the hand-guiding system, which allows for intuitive manual positioning of the Franka robot arm.
- The accuracy of the trajectory replay, where the robot attempts to recreate the manually guided path.

3.2 Hand-Guided Trajectory

Our data collection methodology was designed to capture high-resolution movement data:

- We captured data of the robot's state every 0.01 seconds.
- The data collection period was set to a maximum duration of 5 seconds per trajectory.
- End-effector pose information was obtained using the **O_T_EE** (Origin to End-Effector Transform) command, which provided a $\mathbf{4} \times \mathbf{4}$ homogeneous transformation matrix representing position and orientation.

- The recorded data was output to a JSON file.
- We then used Python to visualize the trajectory data.

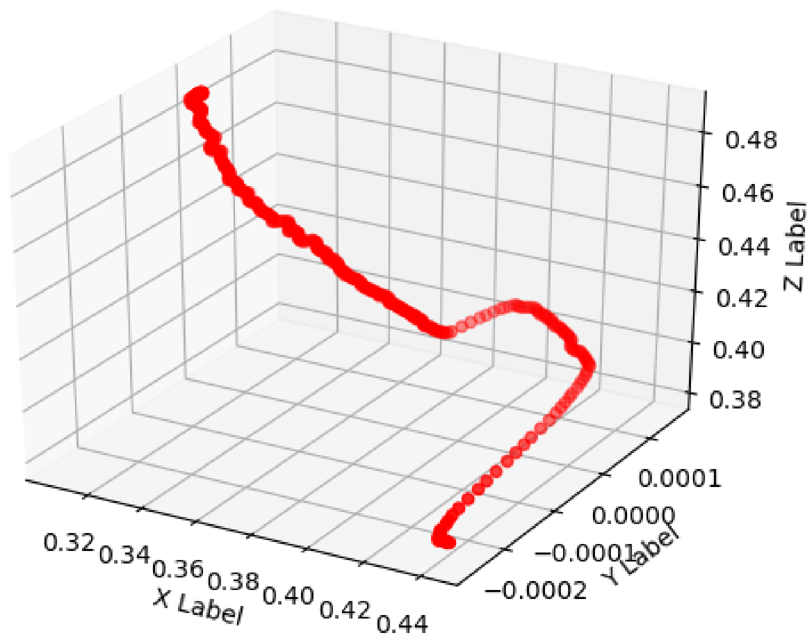

Figure 1: Hand-Guided Trajectory

3.3 Trajectory Replay

Our trajectory replay system used an impedance control method:

- Recorded positions were loaded from a JSON file.
- These positions were parsed into a queue of pose tuples.
- We converted the recorded trajectory data into joint torque.
- This conversion was key to our impedance control-based replay.

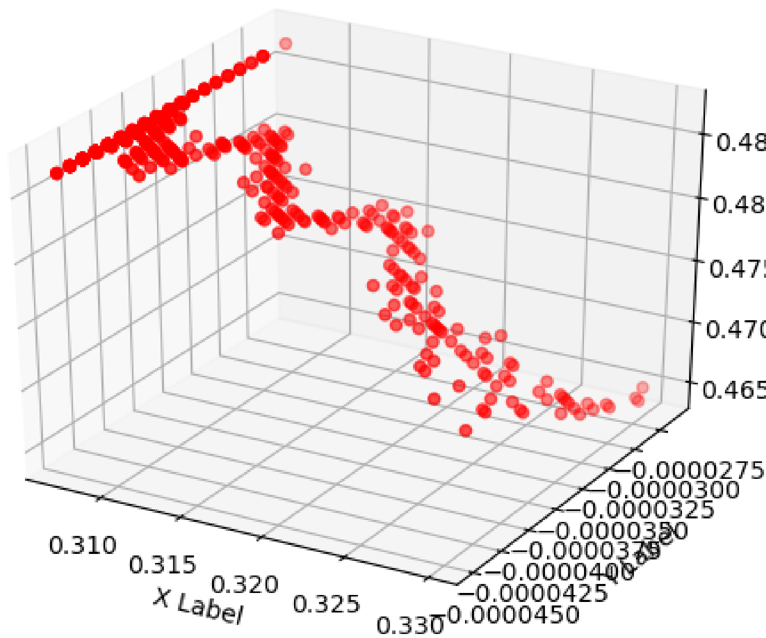

Figure 2: Replay Trajectory

3.4 Difference between Consecutive Coordinates

To evaluate the accuracy of our trajectory replay system, we plotted (Figure 3) these differences for each spatial dimension (X, Y, and Z) to visualize and quantify how closely the robot's replay matches the hand-guided path.

The difference graph compares each point from the first plot (original trajectory) with every 10th point from the second plot (replayed trajectory). This comparison method was chosen to account for the difference in sampling rates between the original demonstration (100 Hz) and the replay (1000 Hz), ensuring that we compare points recorded at equivalent time steps.

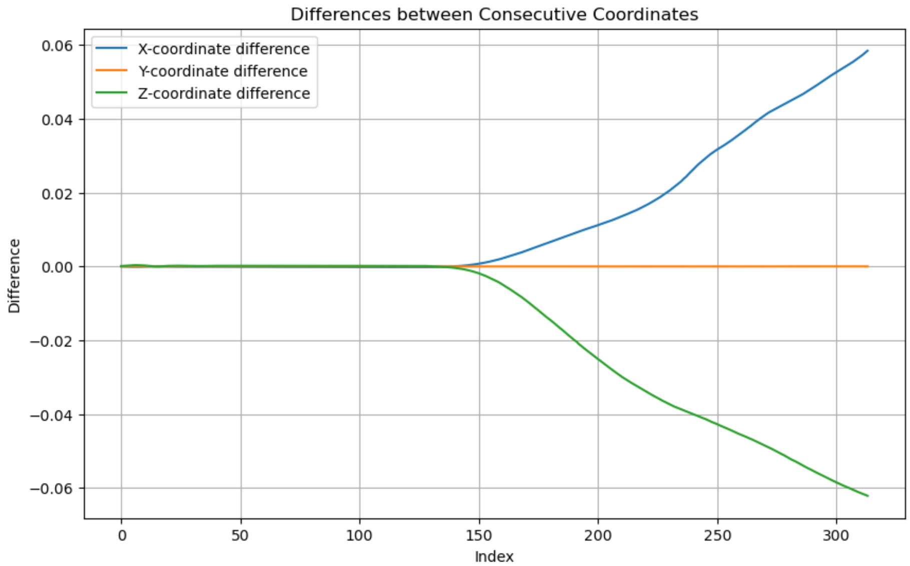

Figure 3: Difference between Consecutive Coordinates

We analyze the possible reasons for the difference:

1. The original hand-guided trajectory was recorded at a rate of 100 Hz (every 0.01 seconds), while during replay, we sampled the robot's position at a higher rate of 1000 Hz (every 0.001 seconds). This difference in sampling rate raises several considerations:

   - **Temporal Misalignment**: With 10 replay points for every original point, direct comparison becomes challenging.
   - **Accumulation of Small Errors**: Minor discrepancies in interpolation can compound over time, leading to increasing divergence between trajectories.
   - **Data Interpolation**: The replay system must estimate positions between original data points, potentially introducing inaccuracies.
   - **Physical Limitations**: The plot shows the distance between every two points representing 0.01 seconds of movement, but during replay, the same distance needs to be covered in 0.001 seconds. This could potentially exceed the robot arm's physical limits (maximum speed and acceleration).

2. We used the default settings for stiffness in our impedance control system, rather than optimizing these parameters for our specific task. This approach may have impacted our results:

- The default stiffness might be too low for precise position control in our application.
- Higher stiffness could improve trajectory tracking accuracy but might reduce compliance and safety.
- We should consider experimentally parameterizing the stiffness for our specific tasks to find an optimal balance between precision and compliance.

Even if the aforementioned issues are addressed and the replay trajectory closely matches the hand-guided trajectory, some differences may still persist between the two plots.

The reasons in this case could be:

- **Sensor Noise and Measurement Errors:** The sensors which measure position, velocity, acceleration, and force may have inherent noise and inaccuracies, which can cause accumulated errors and deviations from the desired trajectory.
- **Control Loop Timing and Sampling Rate:** Even when the points in the first plot are recorded every millisecond, the control loop might still not be able to synchronize with this rate perfectly due to processing delays and other factors.
- **Uncertainties in Mass, Stiffness, and Damping:** The robot system itself might have inaccuracies in parameters such as mass, stiffness, and damping. This could also cause deviations from the desired trajectory.
- **External Disturbances:** External disturbances (such as minor air currents) may affect the replay but not the hand-guiding mode (or vice versa), potentially leading to discrepancies.
- **Internal Friction:** The joint frictions could vary due to different poses of the robot in the two situations. These different joint frictions can cause inaccuracies and deviations as well.