Giraffe Robot for Q&A Sessions

Introduction to Robotics, Master's Degree in Artificial Intelligence Systems

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1. Introduction

This report presents the design and implementation of a 5-DOF ceiling-mounted giraffe robot for automated microphone handling during Q&A sessions in conference rooms. The robot is designed to position a microphone at any location within a 5×12 meter conference room while maintaining a 30° pitch orientation for optimal speaker comfort.
Robot requirements:

- Ceiling-mounted at $4m$ height in room center
- 5 DOF: 2 revolute joints + 1 prismatic + 2 revolute joints
- 4D task space control (position + pitch orientation)
- Redundancy exploitation for secondary objectives
- Target workspace: $5 \times 12m$ area at $1m$ height

2. System Desing and Modeling

2.1. URDF Model Design

The robot consists of five joints configured as follows:

- **Joint 1**: Base rotation (Z-axis) - spherical joint component 1

- **Joint 2**: Shoulder tilt (Y-axis) - spherical joint component 2
- **Joint 3**: Telescopic extension (Z-axis) - prismatic joint for reach
- **Joint 4**: Wrist 1 rotation (Z-axis) - end-effector orientation
- **Joint 5**: Wrist 2 pitch (Y-axis) - microphone pitch control

2.2. Coordinate frames

The robot uses a ceiling-mounted coordinate system with the world frame at the south-east angle of the room, as shown in figure 1. The end effector frame (`ee_link`) is positioned at the microphone location.

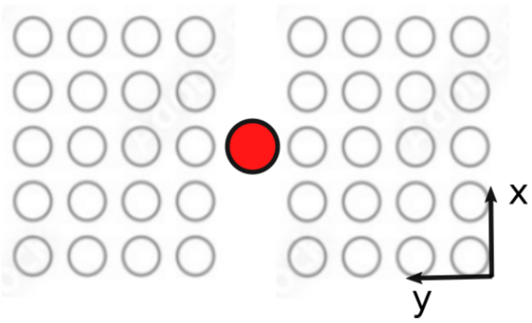

Figure 1: Top view of the room

3. Implementation and Control

3.1. Forward and Inverse Kinematics

Forward kinematics was implemented using Pinocchio's frame transformation functions, providing end-effector position and orientation. The inverse kinematics solver uses a damped least-squares approach with the 4D task constraint (3D position + pitch angle).

3.2. RNEA Dynamics Simulation

The **Recursive Newton-Euler Algorithm** was implemented using Pinocchio's native functions to compute joint torques and simulate robot dynamics. This provides the foundation for physics-based simulation and control design.

3.3. Task Space Control

A computed torque controller was designed to linearize the system in task space

$$\tau = M(q)\left[\ddot{x}_d + K_p(x_d - x) + K_d(\dot{x}_d - \dot{x})\right] + h(q,\dot{q})$$

PD Gains:

- $K_{p,pos} = 100$
- $K_{p,pitch} = 50$
- $K_{p,null-space} = 5$
- $K_d = 2\sqrt{K_p}$ for optimal damping

3.4. Trajectory Planning

5th-order polynomial trajectories were generated in task space to ensure smooth motion from home configuration to target poses. The trajectory planning includes the following:

- **Position trajectory**: smooth 3D path to target location
- **Orientation trajectory**: gradual pitch adjustment to 30°

3.5. Null-Space Control

The redundant DOF (5 joints for 4D task) is exploited to maintain proximity to a default postural configuration (home configuration) while achieving the primary task.

4. Results and Performance

4.1. Workspace analysis

The robot successfully covers the required $5 \times 12m$ workspace area with the telescopic joint providing necessary reach extension. Maximum reachable distance is approximately $6.5m$ from the ceiling mount point.
The Null-space task effectively helps to maintain a posture close to the home configuration. Without it, the robot performs the primary task but, for example, could be leaning to the side (especially for the microphone, setting the pitch correctly but not the roll and yaw).

4.2. Target Achievements

Test Case: Move to position [1, 2, 1] with a pitch of 30°

- **Position Accuracy**: $< 3mm$ error
- **Orientation Accuracy**: $< 0.07°$ pitch error
- **Settling Time**: $7.0s$ as designed

Actual and desired position and pitch through time can be seen in figure 2.

4.3. Control Performance

The task space controller demonstrates the following:

- Smooth trajectory following without overshoot

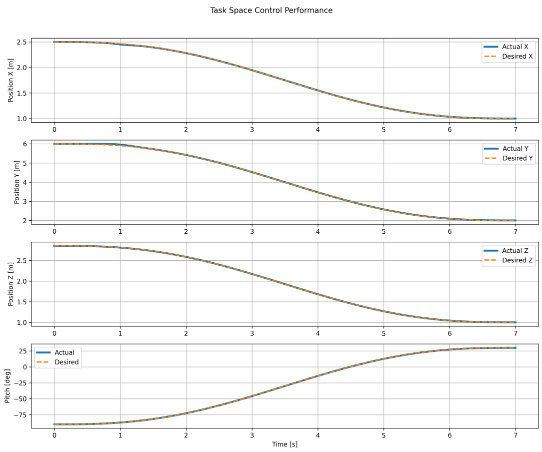

Figure 2: Task Space Control Perfomance

- Stable convergence to target configurations
- Effective null-space utilization for postural control
- Robust performance across the workspace

5. Conclusions

The giraffe robot successfully meets all design requirements for automated microphone positioning in conference environments. Key achievements include:

1. **Complete 4D task space control** (position + pitch orientation)
2. **Workspace coverage** of required $5 \times 12m$ area
3. **Settling time specification** (7s without overshoot)
4. **Redundancy exploitation** for secondary objectives