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 spherical 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.

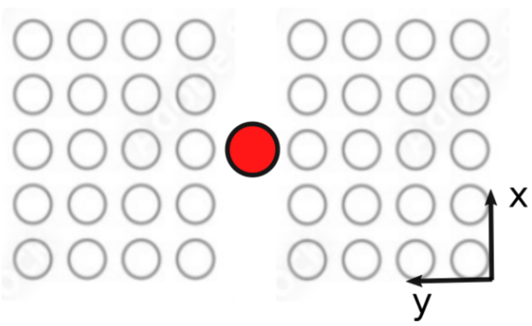

Figure 1: Top view of the room

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 for $7s$ Settling Time:

- $Kp = (4/7)^2 \approx 0.327$ for critically damped response
- $Kd = 2\sqrt{Kp} \approx 1.14$ 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.

4.2. Target Achievements

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

- **IK Convergence**: Successfully achieved within tolerance
- **Orientation Accuracy**: $< 0.2°$ pitch error
- **Settling Time**: $7.0s$ as designed (critically damped)

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

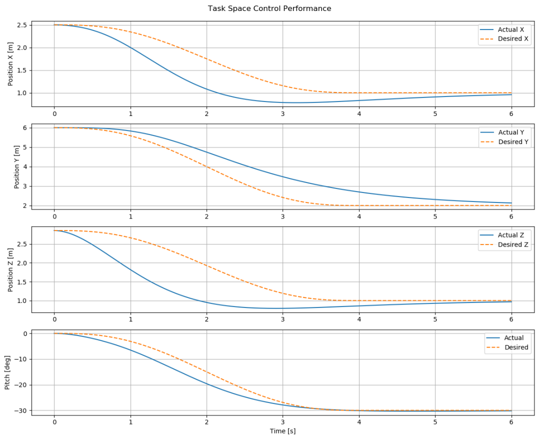

Figure 2: Task Space Control Perfomance

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
5. **Robust IK convergence** for reachable targets