ES 656: Human-Robot Interaction Spring 2025

Activity 2: Modelling a Limb and Generating Movement

Two-Joint Arm Project

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1. Introduction

This project focuses on the development and analysis of a two-joint robotic arm model, designed to simulate human arm movements in a simplified 2D plane. The model is part of the ES 656: Human-Robot Interaction course, specifically for Activity 2, which aims to explore the principles of limb modeling and movement generation.

Our robotic arm consists of two main segments: an upper arm and a forearm, connected by an elbow joint. The shoulder is fixed at a point on the negative X-axis, serving as the origin for all movements. This configuration allows for a realistic representation of human arm kinematics while maintaining a manageable level of complexity.

The arm is actuated by a system of three cables:

1. One attached to the upper arm near the elbow
2. Two attached to the forearm near the wrist

This cable-driven design enables precise control over the arm's movements, mimicking the function of human muscles and tendons. By manipulating these cables, we can achieve a variety of motions in the 2D plane, demonstrating key concepts in robotic control and biomechanics.

The primary objective of this project is to demonstrate three distinct movement patterns:

1. Movement along the X-axis
2. Movement along the Y-axis
3. Diagonal movement at a 45-degree angle

These movements showcase the arm's ability to perform targeted reaching tasks, essential in many human-robot interaction scenarios. Through this model, we explore the relationship between joint-space and task-space movements, cable actuation strategies, and the challenges of controlling a multi-joint system.

2. Mechanism Description

The two-joint robotic arm model in this project is designed to simulate basic human arm movements in a 2D plane. The mechanism consists of the following key components:

Structure

1. Base: The shoulder joint is fixed at a point on the negative X-axis. This serves as the origin and anchor point for all arm movements.

2. Upper Arm (Proximal Link): This segment represents the humerus. It is connected to the fixed base at the shoulder joint.

3. Forearm (Distal Link): This segment represents the radius and ulna. It is connected to the upper arm at the elbow joint.

4. Elbow Joint: A hinge joint connecting the upper arm and forearm, allowing for flexion and extension movements.

Actuation System

The arm is controlled by a cable-driven system consisting of three cables:

1. Upper Arm Cable: Attached near the elbow joint on the upper arm segment. This cable primarily controls the elevation and depression of the entire arm.

2. Anterior Forearm Cable: Attached near the wrist on the forearm segment. This cable is responsible for elbow flexion (bending).

3. Posterior Forearm Cable: Also attached near the wrist on the forearm segment. This cable controls elbow extension (straightening).

3.Movement Mechanism

- X-Axis Movement: Achieved primarily through elbow joint actuation. The posterior forearm cable extends the arm, while the anterior forearm cable retracts it.
- Y-Axis Movement: Accomplished by coordinating the upper arm cable with the forearm cables. The upper arm cable elevates the entire arm, while the forearm cables maintain the wrist's vertical trajectory.
- 45-Degree Diagonal Movement: Requires simultaneous actuation of all three cables. The upper arm cable and posterior forearm cable work together for diagonal extension, while controlled release of the upper arm cable and actuation of the anterior forearm cable achieve diagonal retraction.

Key Features

1. Fixed Shoulder: Simplifies the model while still allowing for a wide range of movements in the positive X and Y quadrants.

2. Cable-Driven System: Mimics the antagonistic muscle pairs in human arms, allowing for precise control of joint angles and end-effector position.

3. Two-Joint Configuration: Provides a balance between simplicity and functionality, allowing for complex movements while maintaining a manageable control system.

This mechanism demonstrates fundamental principles of robotic arm kinematics and control, serving as a practical model for studying human-robot interaction in a simplified 2D environment.

4. Task Space

Task space, also known as operational space, represents the space in which the robot's end-effector operates. It typically describes the position and orientation of the robot's end-effector in a Cartesian coordinate system (Craig, 2018).

The task space in our two-joint robotic arm project is defined as the two-dimensional plane where the end-effector (the "hand" at the end of the forearm) operates. This 2D task space uses a Cartesian coordinate system with X and Y axes, with the origin located at the fixed shoulder joint on the negative X-axis. The task space encompasses the area in the positive X and Y quadrant, extending from the fixed shoulder point. Within this space, we demonstrate three primary movement patterns: X-axis movement (horizontal), Y-axis movement (vertical, forming an arc), and 45-degree diagonal movement (combined X and Y motion).

Key points of our task space:

- 2D plane with Cartesian coordinate system (X and Y axes)
- Origin at fixed shoulder joint on negative X-axis
- Focuses on end-effector position rather than joint configuration
- Positions measured in linear units from the origin

Understanding this task space is crucial for defining target positions, analyzing the arm's workspace, developing control algorithms, and translating real-world tasks into actionable commands for the robotic system. By working within this defined task space, we can effectively plan and execute movements that simulate real-world reaching and positioning tasks, providing valuable insights into human-robot interaction and robotic control systems.

5. Joint Space

The joint space in our two-joint robotic arm project refers to the configuration of the arm's joints, specifically the shoulder and elbow joints. This space is defined by the angles of these two joints, which together determine the arm's position and shape.

Another similar definition for better understanding and clarification is Joint space refers to the configuration of a robot's joints, typically represented by the angles or positions of each joint. It describes the internal state of the robot's articulated structure (Siciliano & Khatib, 2016).

Key aspects of the joint space in our project:

- Two-dimensional, representing the angles of the shoulder and elbow joints
- Shoulder joint angle measured relative to a fixed reference line
- Elbow joint angle measured relative to the upper arm
- Joint angles typically measured in degrees or radians

In this joint space, the arm's configuration is fully described by specifying these two joint angles. The relationship between joint space and task space is governed by the arm's kinematics, where changes in joint angles result in movements of the end-effector in the task space.

Understanding joint space is crucial for:

- Controlling the arm's internal configuration
- Implementing joint-level control algorithms
- Analyzing the arm's range of motion and potential singularities
- Solving inverse kinematics problems to achieve desired end-effector positions

By manipulating the joint space through our cable-driven system, we can indirectly control the end-effector's position in the task space, allowing for precise and coordinated movements of the robotic arm.

6. Conclusion

In conclusion, this two-joint robotic arm project has provided valuable insights into the principles of human-robot interaction and robotic control systems. By developing a simplified

2D model with a fixed shoulder and movable elbow joint, we have explored the fundamental concepts of task space and joint space in a practical context.

The project demonstrated three key movements - along the X-axis, Y-axis, and at a 45-degree angle - showcasing the arm's ability to perform targeted reaching tasks in a 2D plane. These movements highlighted the interplay between joint space control and task space objectives, a crucial aspect of robotic manipulation.

Our cable-driven actuation system, mimicking the antagonistic muscle pairs in human arms, allowed for precise control of joint angles and end-effector positioning. This design choice provided a balance between simplicity and functionality, making it an excellent platform for studying human-inspired robotic systems.

References

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3.Hu, C., Lin, S., Wang, Z., & Zhu, Y. (2022). Task Space Contouring Error Estimation and Precision Iterative Control of Robotic Manipulators. IEEE Robotics and Automation Letters, 7(3), 7826–7833. https://doi.org/10.1109/LRA.2022.3180430