# Two Armed Elbow Manipulator Robot - To Pick Transfer and Place a Test Object

Nakul Gawatre, Sai Ronit Kaza and Shashank Sharma (Group 11)
Department of Mechanical Engineering
Stony Brook University

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# Chapter 1

# INTRODUCTION

The elbow manipulators are one of the most recognized forms of a manipulator and are often employed in practical scenarios in Robotics. It is important to simulate such an elbow manipulator and its motion, given its importance in the field of kinematics.

The industrial robots are being developed to possess human traits like sensing, memory and dexterity .With such capabilities like being smarter and faster, they are able to carry out tasks like picking, transferring and placing various objects. Such tasks involves an understanding of the kinematics of the robot, workspace and motion planning.

This project deals with a robot comprising of two elbow manipulators fixed to a body. The aim of this project is to solve the pick and place problem of an object including transfer of the same object from one manipulator to other. Also, different scenarios of picking and placing the object using the two manipulators was studied and solved simultaneously.

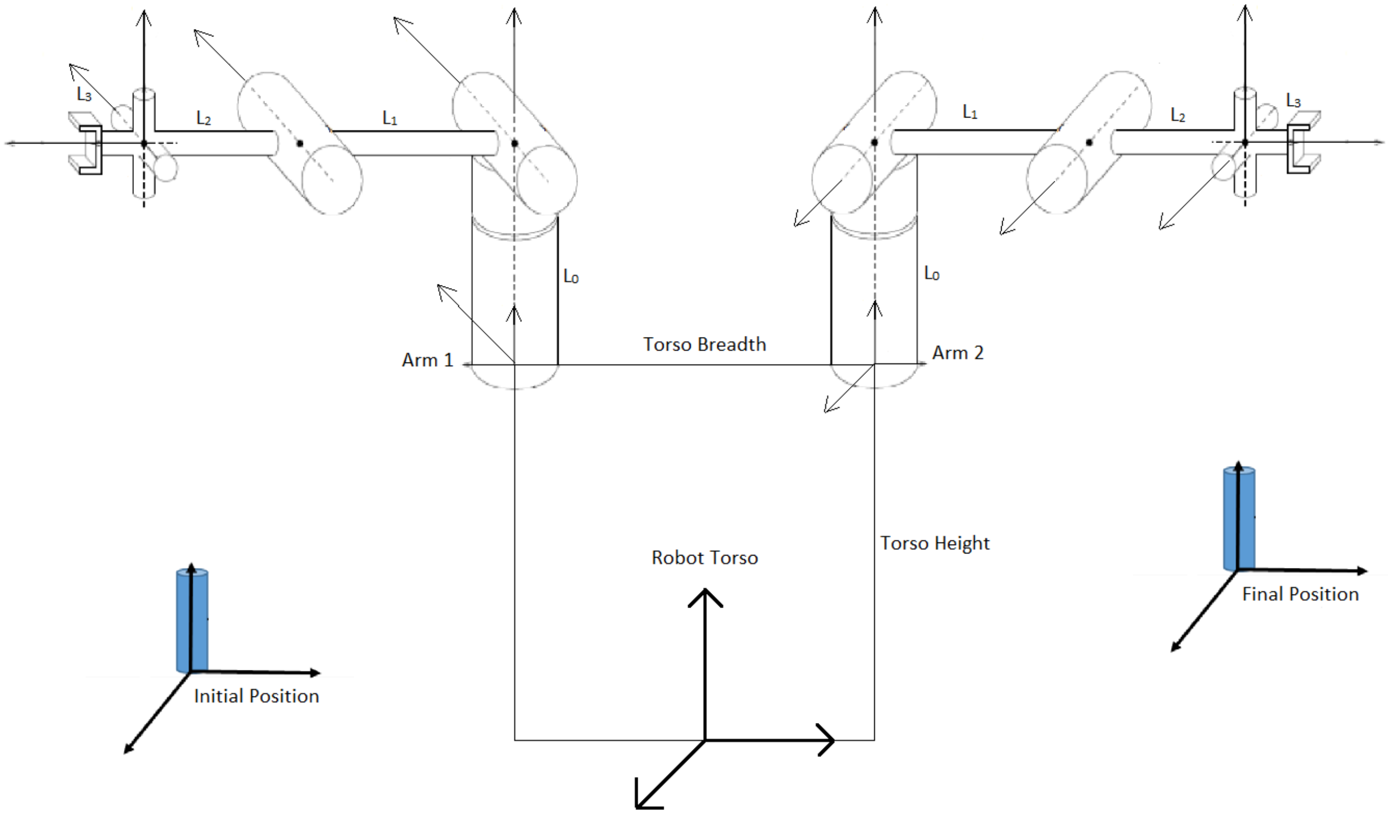



Figure 1.1: TWO ARMED ROBOT WITH ELBOW MANIPULATORS

## 1.1 Problem Statement

Given the Robotic parameters and Initial and Final configuration of the test object, the robot has to:

1. Identify which manipulator can reach and place the given test object and if transferring is actually required,
2. Pick the object with one manipulator,
3. Transfer the object, if required, to the other manipulator,
4. Place the object in another given location.

In other words design a procedure for the case of solving pick, transfer and place problem.

# Chapter 2

# THEORY

## 2.1 Robot Kinematics

Robot manipulator kinematics is essential to calculate the relationship between rigid bodies and end-effector without any forces. The kinematics of a robot manipulator describes the relationship between the motion of the joints of the manipulator and the resulting motion of the rigid bodies which form the robot.

Most modern manipulators consist of a set of rigid links connected together by a set of joints. Motors are attached to the joints so that the overall motion of the mechanism can be controlled to perform a given task. A tool, typically a gripper of some sort, is attached to the end of the robot to interact with the environment.

Study of kinematics is fundamental to design a robot with acceptable performance, and finally test in real situations and particular applications.

## 2.2 Forward Kinematics

The forward kinematics of a robot determines the configuration of the end-effector (the gripper or tool mounted on the end of the robot) given the relative configurations of each pair of adjacent links of the robot. In open-chain manipulators the links form a single serial chain and each pair of links is connected either by a revolute joint or a prismatic (sliding) joint.

The forward kinematics map for an open-chain manipulator is constructed by composing the rigid motions due to the individual joints.

The mechanism of elbow manipulator consists of two intersecting axes at the shoulder, an elbow, and a spherical wrist (modeled as three intersecting axes). The forward kinematics is computed by calculating the individual twist motions for each joint.

The forward kinematics map of the manipulator has the form,

$$g_{st}(\theta) = e^{\hat{\xi}_1\theta_1} e^{\hat{\xi}_2\theta_2} e^{\hat{\xi}_3\theta_3} e^{\hat{\xi}_4\theta_4} g_{st}(0)$$

## 2.3 Inverse Kinematics

In inverse kinematics, given a desired configuration for the tool frame, the joint angles must be determined which achieve the desired configuration. In solving an inverse kinematics problem, the problem is divided into specific subproblems, such as solving for $\theta 2$ given 'r' and then using $\theta 1$ to rotate the end-effector to the proper position.

Each subproblem may have zero, one, or many solutions depending on the desired end-effector location. If the configuration is outside of the workspace of the manipulator, then no solution can exist and one of the subproblems must fail to have a solution. Multiple solutions occur when the desired configuration is within the workspace but there are multiple joint configurations which all map to the same end-effector location. If a subproblem generates multiple solutions, then we must complete the solution procedure for all joint angles generated by the subproblem.

## 2.4 Dual-Quaternions

4x4 Transformation Matrix to Dual Quaternions,

$$\hat{\mathbf{Q}} = \mathbf{Q} + \varepsilon \mathbf{R}$$

Rotation Part (Q) — Translation Part (R)

**Q**=Quaternion from 3x3 Rotation Matrix $\quad \mathbf{R} = \frac{1}{2}\mathbf{dQ}$, where $\mathbf{d} = (0, d_1, d_2, d_3)$

Dual Quaternions to 4x4 Transformation Matrix,

$$\mathbf{d} = \frac{\mathbf{RQ}^* - \mathbf{QR}^*}{\mathbf{QQ}^*}$$

$$\begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} = \begin{bmatrix} 1-2(q_2^2+q_3^2) & 2(q_1q_2-q_0q_3) & 2(q_1q_3+q_0q_2) \\ 2(q_1q_2+q_0q_3) & 1-2(q_1^2+q_3^2) & 2(q_2q_3-q_0q_1) \\ 2(q_1q_3-q_0q_2) & 2(q_2q_3+q_0q_1) & 1-2(q_1^2+q_2^2) \end{bmatrix}$$

where $Q=(q_0,q_1,q_2,q_3)$

# Chapter 3

# SOLUTION APPROACH

## 3.1 Initialization

User provides the Robot parameters such as torso dimensions and lengths l0, l1, l2 and l3 of the elbow manipulators. The dimensions of both the manipulators is the same. Also, initial and final configuration of the object in world frame is provided.

Manipulator which is on the left, has its axes aligned with the base frame, while the other manipulator on the right, has its X and Y axes inverted with respect to first manipulator.

## 3.2 Computing Joint Angles for Initial and Final Position

We calculate the tool frame configuration in global frame for respective initial and final positions. The Tool Frame Configuration in respective Elbow Frames is then calculated and inverse kinematics is applied using Paden Kahan sub-problems to get joint angles for respective initial and final Positions.

## 3.3 Identification of Pick and Place Scenarios

The previous step identifies which manipulator can reach the initial or final position. If either positions are not within the robot workspace then the joint angles cannot be computed. The following cases can be observed,

**Case-1**

If the initial and final position can be reached by both manipulators, the the transfer of object from one hand to other not required.

**Case-2**
If the initial position can be reached by both manipulators and final position only by one manipulator, then no transfer is required. The manipulator that can reach both the positions is selected for pick and place operation.

**Case-3**
If the initial position can be reached by one manipulator and final position by both then, transfer of object is not required and the manipulator that reaches both initial and final position will be selected for pick and place operation.

**Case-4**
If initial and final positions are reachable by one manipulator, two more cases arise:

1. If the same manipulator can reach both the positions then transfer is not required. Pick and place is done by this manipulator without the involvement of the other.

2. If initial and final position can be reached by different manipulators, then the manipulator that reaches initial position is selected to pick the object and move to transfer position.The other manipulator which can reach the final position collects the object at transfer position and places at the final position.

**Case-5**
If Initial and Final positions are not reachable by either manipulators then the positions are out of the Robot Workspace. The given configurations are not reachable to perform pick, transfer and place operations by the robot.

## 3.4 Transfer Position

Considering **Case-5**, where transferring is required to perform pick and place operations for given initial and final configurations,

We find the position of transferring the object to be approximately optimal in the middle of the workspace, which would be,

$$Z = l0 + \text{length of torso} ,$$
$$Y = \pm \text{(object length)} / 2,$$
$$X = (l1 + l2 + l3)/2.$$

## 3.5 Motion Planning

Two methods of Motion Planning are implemented.

**Motion Planning in Joint Space:**
Linear Interpolation between positions in joint angle space was done i.e. between initial position and transfer position of picking manipulator and secondly between transfer position of placing manipulator and final position. Direct kinematics was applied to get robot positions in real space.

**Motion Planning in Dual-Quaternion Space:**
Linear Interpolation in Dual-Quaternion space was done to find Dual-Quaternions between similar positions. Path quaternions are generated, transformed into 44 configuration of tool in base frame and then transformed in respective elbow frames. Now, inverse and forward kinematics is used to find joint angles and positions

## 3.6 Plotting

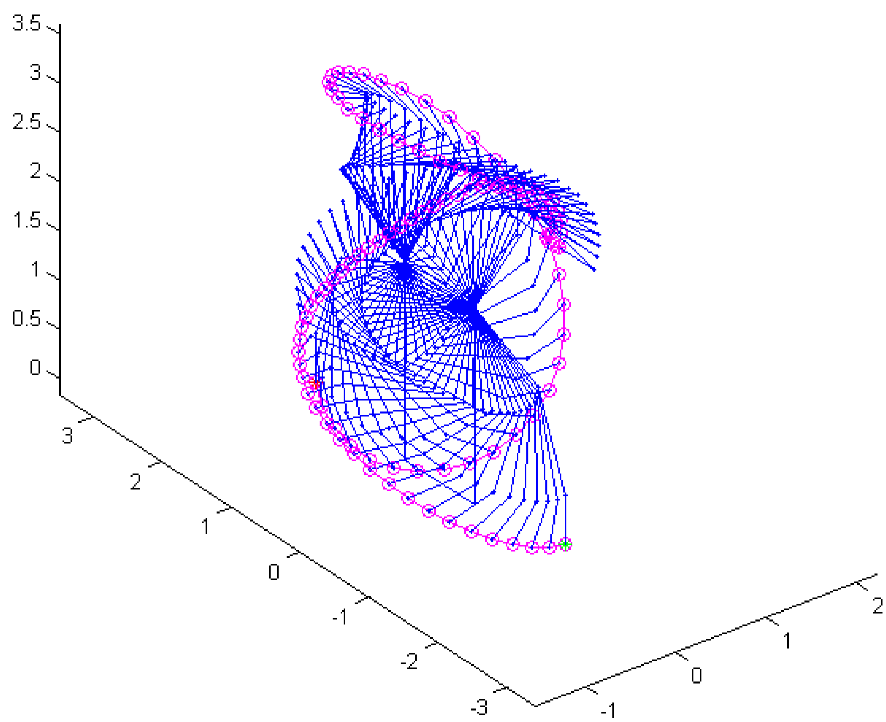
Finally, Plots are drawn for both methods of Motion Planning. In each method the plot demonstrates the path taken by the manipulator from picking position to transfer position and also the path of the second manipulator from transfer position to final position. The representation of the plot will be in world frame.

# Chapter 4

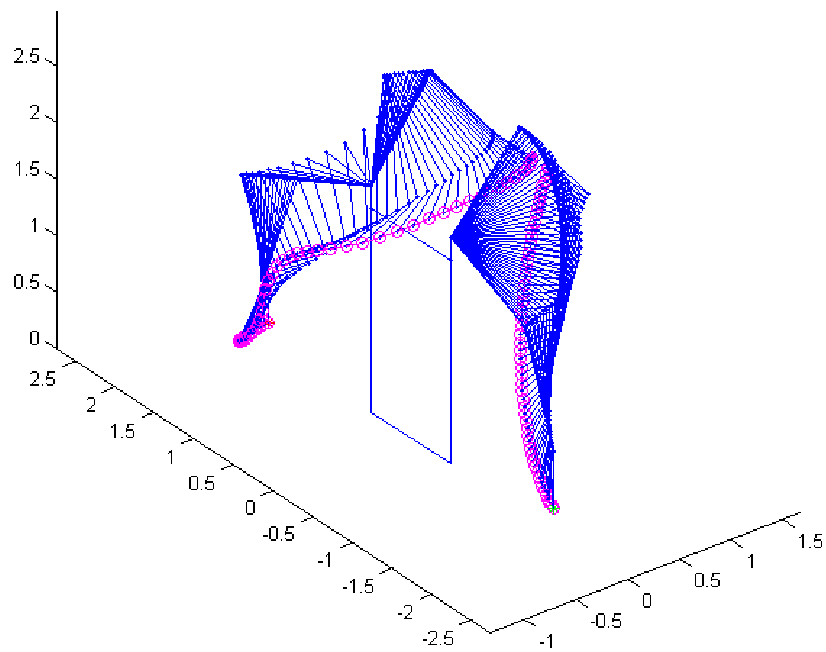
# OBSERVATION

1. Motion Planning using Dual-Quaternions yields a much optimal path for the robot to pick, transfer and place the object as compared to the Motion Planning in joint angle space.
2. Also, distance travelled by the manipulators is less in Dual-Quaternion space than the joint angle space.
3. Thus the Dual-Quaternion Motion Planning minimizes the probability of Manipulators collision.
4. However, Motion Planning in Dual Quaternion space does not guarantee all the intermediate positions to fall within dexterous workspace. This is not a problem in Joint Angles space.

## 4.1 Path generated by Joint Space motion planning



## 4.2 Path generated by Dual-Quaternion motion planning



# Chapter 5

# CONCLUSION

1. Different cases that arise in picking, placing and transferring the object have been identified and using Matlab coding the problems were solved.
2. The case of Initial Position reachable by one manipulator and Final Position by other is considered for demonstration purpose.
3. The two methods of Motion Planning that were discussed earlier, were applied to these configurations and the results are plotted.
4. Also, the pros and cons of Joint angle space and Dual-quaternion space were discussed and eloborated.

## 5.1 Future Scope

Robot Manipulator collision detection can be implemented and for these scenarios alternate Motion Planning Techniques and Strategies can be generated.

Also, the end effector can also be designed further to enable the robot to handle various objects with different dimensions.

# Chapter 6

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