Project Report

4 DOF Robotic Arm Gripper

Department of Mechatronics Engineering

Subject

Robotics

Group Members

Muhammad Junaid(211176)

Muhammad Mubeen Rubbani (211263)

Instructor:

Dr. Neelum Yousaf

INTRODUCTION:

Understanding the motion and position of complex segments is important in several fields, this project aims to perform a position analysis of a robotic arm using petercorke robotics tToolbox, which is a MATLAB-based software package for robot kinematics, dynamics, and control. The project also involves simulating the motion of the on any robotic arm. The simulation results will provide insights into the motion and position of the given trajectory, which can be used to design effective rehabilitation strategies and improve performance of manipulators.

Objectives:

Designing, implementing, and analyzing the performance of a 4 DOF robotic arm gripper for specific tasks in industrial automation.

Applications:

1. Manufacturing and Assembly: The robotic arm can be used in manufacturing plants for tasks such as picking, placing, and assembling components in a production line. Its precision and repeatability make it ideal for automating repetitive tasks, thereby increasing efficiency and reducing production costs.

2. Laboratory Automation: In research and development laboratories, the robotic arm can be utilized for handling samples, conducting experiments, and performing precise measurements. Its ability to operate in controlled environments and follow predefined paths makes it valuable for various scientific applications.

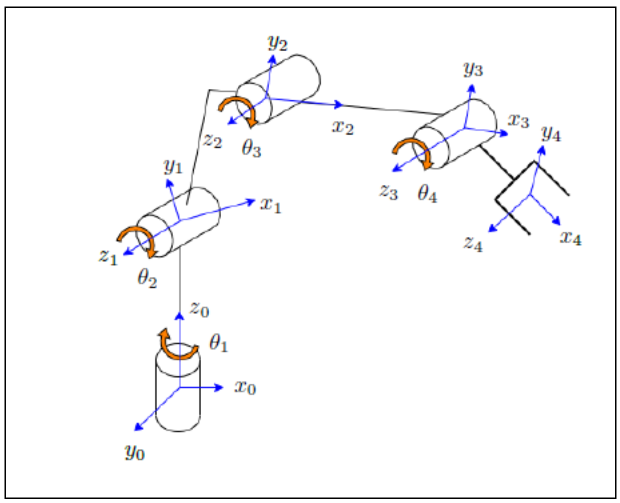
3. Medical Robotics: Robotic arms are increasingly being used in surgical procedures for tasks such as holding instruments, making incisions, and suturing wounds. A 3DOF robotic arm can assist surgeons in performing minimally invasive surgeries with greater precision and dexterity, leading to improved patient outcomes and reduced recovery times.

4. 3D Printing: The robotic arm can serve as a positioning tool in 3D printing applications, where it precisely deposits material layer by layer to create complex three-dimensional objects. Its flexibility and accuracy make it suitable for additive manufacturing processes in industries such as aerospace, automotive, and healthcare.

5. Teleoperation and Remote Handling: In hazardous environments such as nuclear facilities or underwater exploration sites, the robotic arm can be remotely operated to perform tasks without exposing humans to danger. Its ability to manipulate objects in confined spaces makes it valuable for tasks that are difficult or dangerous for humans to perform directly

Forward kinematics:

This method is used to determine the position and orientation of a rigid body in space, given the joints angles or displacements in simple it calculates the end-effector position base on the joints angles or displacements



Dh table:

Frame (i)	a_i	a_i	d_i	θ_i
1	0	90	l_1	θ_1
2	l_2	0	0	θ_2
3	l_3	0	0	θ_3
4	l_4	0	0	θ_4

Transformation:

$$ {}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i \cos\alpha_{i-1} & \cos\theta_i \cos\alpha_{i-1} & -\sin\alpha_{i-1} & -\sin\alpha_{i-1} d_i \\ \sin\theta_i \sin\alpha_{i-1} & \cos\theta_i \sin\alpha_{i-1} & \cos\alpha_{i-1} & \cos\alpha_{i-1}\, d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{0}_{1}T = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{1}_{2}T = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{2}_{3}T = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & a_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{3}_{4}T = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & a_3 \\ 0 & 0 & 1 & d_4 \\ -\sin\theta_4 & -\cos\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation Matrix 0 to 1:

$$ {}^{0}_{1}T = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation Matrix 0 to 2:

$$ {}^{0}_{1}T = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * {}^{1}_{2}T = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{0}_{2}T = \begin{bmatrix} \cos\theta_1 \cos\theta_2 & -\cos\theta_1 \sin\theta_2 & \sin\theta_1 & 0 \\ \sin\theta_1 \cos\theta_2 & -\sin\theta_1 \sin\theta_2 & -\cos\theta_1 & 0 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation Matrix 0 to 3:

$$ {}_1^0T= \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * {}_2^1T= \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * {}_3^2T= \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & a_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

${}_3^0T=$

$$ \begin{bmatrix} \cos\theta_1\cos\theta_2\cos\theta_3 - \sin\theta_1\sin\theta_3 & -\cos\theta_1\cos\theta_2\sin\theta_2 - \sin\theta_1\cos\theta_3 & \cos\theta_1\sin\theta_2 & \cos\theta_1 a_2\cos\theta_2 \\ \sin\theta_1\cos\theta_2\cos\theta_3 + \cos\theta_1\sin\theta_3 & -\sin\theta_1\cos\theta_2\sin\theta_3 + \cos\theta_1\cos\theta_3 & \sin\theta_1\sin\theta_2 & \sin\theta_1 a_2\cos\theta_2 \\ -\sin\theta_2\cos\theta_3 & \sin\theta_2\sin\theta_3 & \cos\theta_2 & \sin\theta_2\, a_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation Matrix 0 to 4:

$$ {}_1^0T= \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * {}_2^1T= \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * {}_3^2T= \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & a_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * {}_4^3T= \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & a_3 \\ 0 & 0 & 1 & d_4 \\ -\sin\theta_4 & -\cos\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}_4^0T = \begin{bmatrix} c_1c_2c_3c_4 - s_1s_3c_4 - c_1s_2s_4 & -c_1c_2s_3c_4 - s_1c_1c_4 - c_1s_2c_4 & c_1c_2s_4 - s_1s_2s_3 & c_1(a_2c_2 + a_3c_3) \\ s_1c_2c_3c_4 + c_1s_3c_4 - s_1s_2s_4 & -s_1c_2s_3c_4 + c_1c_3c_4 - s_1s_2c_4 & s_1c_2s_4 + c_1s_3s_4 & s_1(a_2c_2 + a_3c_3) \\ -s_1c_3c_4 & s_2s_3c_4 & -s_2s_4 & s_2a_2 + d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^0\boldsymbol{T}_4 = {}^0T_1\, {}^1T_2\, {}^2T_3\, {}^3T_4 $$

$$ {}^0\boldsymbol{T}_4 = \begin{bmatrix} -0.7991 & -0.2558 & -0.5440 & 191.2055 \\ 0.5181 & -0.1658 & 0.8391 & 0.8391 \\ -0.3048 & -0.9524 & 0.0000 & 137.4695 \\ 0 & 0 & 0 & 1.0000 \end{bmatrix} $$

Jacobian:

Jacobian Analysis of a Manipulator:

We find the Jacobian Analysis of a manipulator with the help of the transformation matrix (^0_3T) of a given manipulator:

^0_3T=

$$\begin{bmatrix} \cos\theta_1\cos\theta_2\cos\theta_3 - \sin\theta_1\sin\theta_3 & -\cos\theta_1\cos\theta_2\sin\theta_2 - \sin\theta_1\cos\theta_3 & \cos\theta_1\sin\theta_2 & \cos\theta_1 a_2\cos\theta_2 \\ \sin\theta_1\cos\theta_2\cos\theta_3 + \cos\theta_1\sin\theta_3 & -\sin\theta_1\cos\theta_2\sin\theta_3 + \cos\theta_1\cos\theta_3 & \sin\theta_1\sin\theta_2 & \sin\theta_1 a_2\cos\theta_2 \\ -\sin\theta_2\cos\theta_3 & \sin\theta_2\sin\theta_3 & \cos\theta_2 & \sin\theta_2\, a_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation Matrix = $\begin{bmatrix} \cos\theta_1\cos\theta_2\cos\theta_3 - \sin\theta_1\sin\theta_3 & -\cos\theta_1\cos\theta_2\sin\theta_2 - \sin\theta_1\cos\theta_3 & \cos\theta_1\sin\theta_2 \\ \sin\theta_1\cos\theta_2\cos\theta_3 + \cos\theta_1\sin\theta_3 & -\sin\theta_1\cos\theta_2\sin\theta_3 + \cos\theta_1\cos\theta_3 & \sin\theta_1\sin\theta_2 \\ -\sin\theta_2\cos\theta_3 & \sin\theta_2\sin\theta_3 & \cos\theta_2 \end{bmatrix}$

Position Matrix = $\begin{bmatrix} \cos\theta_1 a_2\cos\theta_2 \\ \sin\theta_1 a_2\cos\theta_2 \\ \sin\theta_2\, a_2 \end{bmatrix}$

To find the Jacobian matrix:

Jacobian matrix = $\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix}$

Where, x = $\cos\theta_1 a_2\cos\theta_2$

$$\dot{\boldsymbol{x}} = \frac{\partial \boldsymbol{x}}{\partial \boldsymbol{\theta_1}}\dot{\boldsymbol{\theta}}_1 + \frac{\partial \boldsymbol{x}}{\partial \boldsymbol{\theta_2}}\dot{\boldsymbol{\theta}}_2 + \frac{\partial \boldsymbol{x}}{\partial \boldsymbol{\theta_3}}\dot{\boldsymbol{\theta}}_3$$

$$\dot{x} = (-s_1c_{23}l_3-s_1c_2l_2-s_1c_{23})\theta_1+(-c_{13}s_2l_3-c_1s_2l_2-s_2c_{13})\ \theta_2+(s_2c_3l_3+s_2c_3)\ )\ \theta_3$$

$$\dot{\boldsymbol{y}} = \frac{\partial \boldsymbol{y}}{\partial \boldsymbol{\theta_1}}\dot{\boldsymbol{\theta}}_1 + \frac{\partial \boldsymbol{y}}{\partial \boldsymbol{\theta_2}}\dot{\boldsymbol{\theta}}_2 + \frac{\partial \boldsymbol{y}}{\partial \boldsymbol{\theta_3}}\dot{\boldsymbol{\theta}}_3$$

$$\dot{y} =(c_{123}l_3+c_{12}l_2+c_{123})\theta_1+(-s_1s_2c_3l_3\ -s_{12}l_2\ -s_{12}c_3)\ \theta_2+(-s_1s_3c_2l_3-s_{13}c_2)\ \theta_3$$

Where, z = $\sin\theta_2\, a_2$

$$\dot{\boldsymbol{z}} = \frac{\partial z}{\partial \theta_1}\dot{\theta}_1 + \frac{\partial z}{\partial \theta_2}\dot{\theta}_2 + \frac{\partial z}{\partial \theta_3}\dot{\theta}_3$$

$$\dot{z} = (-s_1 s_2 c_3 l_3 - s_{12} l_2 - s_{12} c_3)\ \theta_2 + (-c_{12} s_3 l_3 - c_{12} s_3)\ \theta_3$$

Jacobian matrix = $\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix}$

$$= \begin{bmatrix} -s1c23l3 - s1c2l2 - s1c23 & -c13s2l3 - c1s2l2 - s2c13 & s2c3l3 + s2c3 \\ c123 + c12l2 + c123 & -s12c3l3 - s12l2 - s12c3 & -s13c2l3 - s13c2 \\ 0 & 2s3l3 + c2l2c2c3 & -c12s3l3 - c123 \end{bmatrix}$$

Code

```
syms theta1 theta2 a2;


% Define the position matrix

pos_matrix = [cos(theta1)*a2*cos(theta2); sin(theta1)*a2*cos(theta2); sin(theta2)*a2];


% Calculate the Jacobian matrix symbolically

J_sym = jacobian(pos_matrix, [theta1, theta2]);


% Display the symbolic Jacobian matrix

disp('Symbolic Jacobian matrix:');
```

```
disp(J_sym);

% as we above find the transformation matrix by the help of forward
% kinematic, we are using those values of theta1, theta2, a2

theta1_val = 2*pi;
theta2_val = pi;
a2_val = 7;

% Substitute values into the symbolic Jacobian matrix
J_numeric = double(subs(J_sym, [theta1, theta2, a2], [theta1_val, theta2_val, a2_val]));

% Display the numerical Jacobian matrix
disp('Numerical Jacobian matrix:');
disp(J_numeric);
```

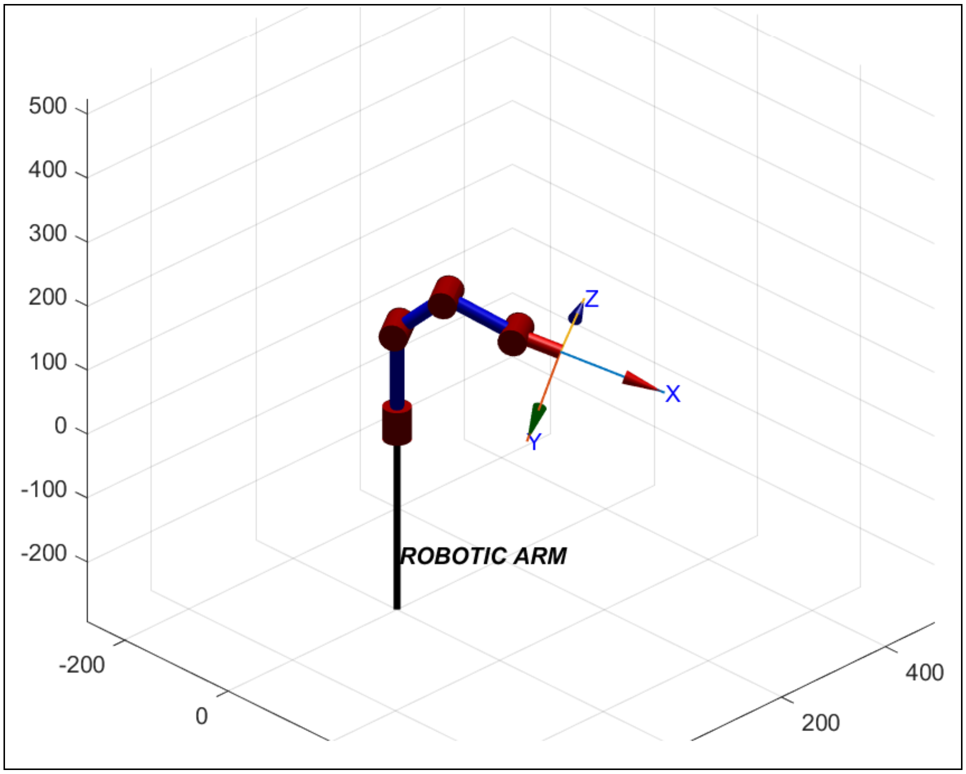
Results in Petercorke robotics toolbox:

Code:

```
clc
clear all
% defining parameters of DH table
a = [0 90 108 65 ];% link lengths
```

```
al = [pi/2 0 0 0 ];% twist between links

d = [145 0 0 0 ];%offset

theeta = [10 15 20 25];%angle between links

% Storing angles( both coordinates)for each link in an array

c1 = [cosd(theeta(1)) cosd(theeta(2)) cosd(theeta(3)) cosd(theeta(4)) ];

s1 = [sind(theeta(1)) sind(theeta(2)) sind(theeta(3)) sind(theeta(4)) ];

c2 = [cosd(al(1)) cosd(al(2)) cosd(al(3)) cosd(al(4))];

s2 = [sind(al(1)) sind(al(2)) sind(al(3)) sind(al(4))];

% transformation matrix for each link

T1 = [c1(1) -s1(1)*c2(1) s1(1)*s2(1) 1.2*c1(1); s1(1) c1(1) -c1(1)*s2(1) 1.2*s1(1); 0 s2(1) c2(1) d(1); 0 0 0 1];

T2 = [c1(2) -s1(2)*c2(2) s1(2)*s2(2) 22*c1(2); s1(2) c1(2) -c1(2)*s2(2) 22*s1(2); 0 s2(2) c2(2) d(2);0 0 0 1];

T3 = [c1(3) -s1(3)*c2(3) s1(3)*s2(3) 22*c1(3);s1(3) c1(3) -c1(3)*s2(3) 22*s1(3);0 s2(3) c2(3) d(3);0 0 0 1];

T4 = [c1(4) -s1(4)*c2(4) s1(4)*s2(4) 0*c1(4);s1(4) c1(4) -c1(4)*s2(4) 0*s1(4);0 s2(4) c2(4) d(4);0 0 0 1];

% transformation of whole system/robot

T = T1*T2*T3*T4;

%link command to contact coordinate of each joint

L(1) = Link([theeta(1) d(1) a(1) al(1)]);

L(2) = Link([theeta(2) d(2) a(2) al(2)]);

L(3) = Link([theeta(3) d(3) a(3) al(3)]);

L(4) = Link([theeta(4) d(4) a(4) al(4)]);

SCORBOT = SerialLink(L);

% command for forward kinematics from base to gripper

robot = fkine(SCORBOT, [theeta(1) theeta(2) theeta(3) theeta(4) ])

SCORBOT.name = 'ROBOTIC ARM';

%plotting the robot

SCORBOT.plot([theeta(1) theeta(2) theeta(3) theeta(4) ]);

title('4 DOF Pick & Place');
```

Result:



The end effector is a gripper.

Hardware implementation:

Utilization of Project:

Industrial Automation:

4 DOF robotic arm grippers are essential tools in industrial settings, automating tasks like pick-and-place operations, assembly, and material handling. They improve efficiency and accuracy while reducing labor costs.

Warehouse and Logistics:

In warehouses and logistics centers, these grippers play a crucial role in palletizing, depalletizing, sorting, and inventory management tasks. They streamline processes, optimize supply chain operations, and increase throughput.

Research and Development:

In research laboratories, 4 DOF robotic arm grippers are utilized for prototyping, experimentation, and testing purposes. They facilitate hands-on learning experiences and enable the exploration of advanced control algorithms and motion planning techniques.

Education and Training:

Educational institutions and training facilities use these grippers to teach students about robotics, automation, and mechatronics. They provide practical learning opportunities and prepare students for careers in robotics industries.

Healthcare and Service Robotics:

These grippers assist with patient care, medication delivery, and surgical procedures in healthcare settings. They also find applications in service robotics for tasks like household chores and eldercare services.

Cost Analysis:

Components	Cost
Servo Motors (4)	1200
Variable Resistors (4)	150
Variable Resistors Cover (4)	40
Connecting Wires	50
Arduino UNO	1300
Ice cream Sticks	80
TOTAL	2820/-

Work Division:

Working	Muhammad Junaid	Muhammad Mubeen Rubbani
Design	✓	
Forward Kinematics	✓	✓
Simulation in MATLAB		✓
Fabrication		✓
Programming	✓	
Testing		✓
Documentation	✓	✓

Conclusion:

In conclusion, the 4 DOF robotic arm gripper revolutionizes industrial automation by streamlining tasks like pick-and-place operations and assembly. Its versatility extends to warehouse logistics, research, and education, making it a cornerstone of innovation in various fields. With applications in healthcare and service robotics, its impact on efficiency and precision is profound, promising continued advancements in automation technology.