MT-365 Robotics.

CEP Report

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SESSION: BEMTS-F-21-A	
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4 DOF Robotic Arm

1. Objectives:

The objectives of our CEP are as follows:

- To design and implement a 4 DOF Robotic Arm.
- To design and implement a Pick and Place Robot of and RRRR Mechanism.

2. Forward Kinematics:

2.1 Configuration:

The configuration of our Robotic arm are as under:

- 4 DOF Robotic Arm.
- R-R-R-R Manipulator.

1.2 DH Table:

The DH Table of the 4 DOF Robotic arm is as under:

i	Link Length a_{i-1}	Link Twist α_{i-1}	Link Offset d_i	Joint Angle θ_i
1	0	$90°$	0	$0°$
2	0.249	$0°$	0	$45°$
3	0.141	$0°$	0	$-45°$
4	0	$90°$	0	$60°$

1.3 Transformation:

Generic Formula:

$$\begin{bmatrix} Cos\theta_i & -Sin\theta_i & 0 & \alpha_{i-1} \\ Sin\theta_i Cos\alpha_{i-1} & Cos\theta_i Cos\alpha_{i-1} & -Sin\alpha_{i-1} & -Sin\alpha_{i-1} d_i \\ Sin\theta_i Sin\alpha_{i-1} & Cos\theta_i Sin\alpha_{i-1} & Cos\alpha_{i-1} & Cos\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

By using the D-H Table:

$$ {}_{1}^{0}T = \begin{bmatrix} Cos(0) & -Sin(0) & 0 & 0 \\ Sin(0)Cos(90) & Cos(0)Cos(90) & -Sin(90) & -Sin(90)(0) \\ Sin(0)Sin(90) & Cos(0)Sin(90) & Cos(90) & Cos(90)(0) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_1 = {}^0_1T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^1_2T = \begin{bmatrix} Cos(45) & -Sin(45) & 0 & 0.249 \\ Sin(45)Cos(0) & Cos(45)Cos(0) & -Sin(0) & -Sin(0)(0) \\ Sin(45)Sin(0) & Cos(45)Sin(0) & Cos(0) & Cos(0)(0) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\boldsymbol{T_2} = {}^1_2T = \begin{bmatrix} 0.7071 & -0.7071 & 0 & 0.249 \\ 0.7071 & 0.7071 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^2_3T = \begin{bmatrix} Cos(-45) & -Sin(-45) & 0 & 0.141 \\ Sin(-45)Cos(0) & Cos(-45)Cos(0) & -Sin(0) & -Sin(0)(0) \\ Sin(-45)Sin(0) & Cos(-45)Sin(0) & Cos(0) & Cos(0)(0) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\boldsymbol{T_3} = {}^2_3T = \begin{bmatrix} 0.7071 & 0.7071 & 0 & 0.141 \\ -0.7071 & 0.7071 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^3_4T = \begin{bmatrix} Cos(60) & -Sin(60) & 0 & 0 \\ Sin(60)Cos(90) & Cos(60)Cos(90) & -Sin(90) & -Sin(90)(0) \\ Sin(60)Sin(90) & Cos(60)Sin(90) & Cos(90) & Cos(90)(0) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\boldsymbol{T_4} = {}^3_4T = \begin{bmatrix} 0.5 & -0.866 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0.866 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The Final Transformation will be:

$$\boldsymbol{T} = \boldsymbol{T_1} * \boldsymbol{T_2} * \boldsymbol{T_3} * \boldsymbol{T_4}$$

$$\boldsymbol{T} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} 0.7071 & -0.7071 & 0 & 0.249 \\ 0.7071 & 0.7071 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 0.7071 & 0.7071 & 0 & 0.141 \\ -0.7071 & 0.7071 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 0.5 & -0.866 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0.866 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\boldsymbol{T} = \begin{bmatrix} 0.5 & 0 & 0.866 & 0.31715 \\ 0.0 & -1.00 & 0.0 & 0.0 \\ 0.866 & 0 & -0.5 & 0.17617 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

2. Jacobian:

$$y_1 = f_1(x_1, x_2, x_3 \dots)$$

$$y_2 = f_2(x_1, x_2, x_3 \dots)$$

$$\dots$$

$$y_n = f_n(x_n, x_n, x_n \dots)$$

$$\partial y_1 = \frac{\partial f_1}{\partial x_1}\partial x_1 + \frac{\partial f_2}{\partial x_2}\partial x_2 + \cdots$$

$$\partial y = \frac{\partial f}{\partial x}\partial x$$

Jacobian Matrix Formula:

$$\dot{Y} = J\dot{X}$$

$$\begin{bmatrix} \dot{y_1} \\ \dot{y_2} \\ . \\ . \end{bmatrix} = \begin{bmatrix} & \\ & \\ & \\ & \end{bmatrix} \begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ . \\ . \end{bmatrix}$$

Transformation matrix:

$$\begin{bmatrix} R & P \\ 0\ 0\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} \dot{P_x} \\ \dot{P_y} \\ \dot{P_z} \end{bmatrix} = J \begin{bmatrix} \dot{\theta_1} \\ \dot{\theta_2} \\ \dot{\theta_3} \end{bmatrix}$$

$$\begin{bmatrix} \dot{P_x} \\ \dot{P_y} \\ \dot{P_z} \end{bmatrix} = \begin{bmatrix} -r_1 \sin\theta \\ -r_2 \cos\theta \\ 0 \end{bmatrix} [\dot{\theta}] \rightarrow \dot{Y} = J\dot{X}$$

$$V = \begin{bmatrix} \dot{P_x} \\ \dot{P_y} \\ \dot{P_z} \end{bmatrix} = \begin{bmatrix} {}^{\circ}V \\ {}^{\circ}W \end{bmatrix} = J \begin{bmatrix} \dot{\theta_1} \\ \dot{\theta_2} \end{bmatrix}$$

$$P_x = r_1 cos\theta$$

$$P_y = r_2 sin\theta$$

$$P_z = 0$$

$$P_{\dot{x}} = -r_1 sin\theta$$

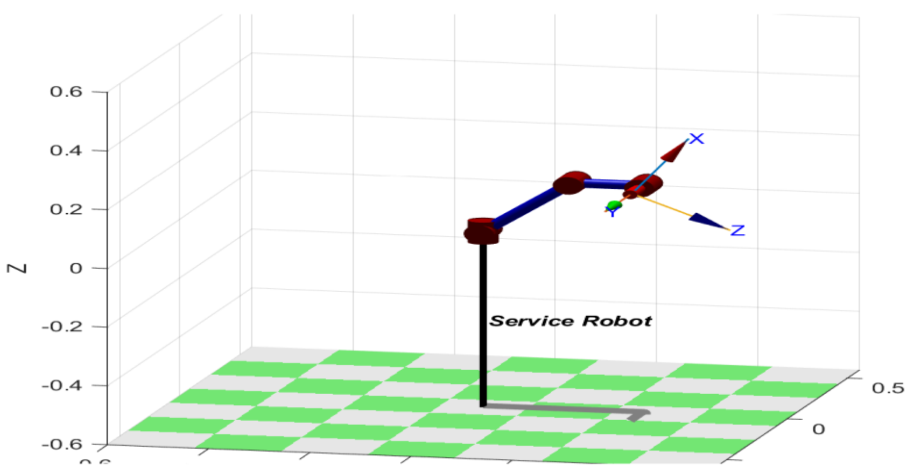
$$P_{\dot{y}} = r_2 cos\theta$$

$$P_{\dot{z}} = 0$$

3. Software Implementation:

3.1 MATLAB:

```
clc
clear all
%defining parameters of DH table
a = [0 0.249 0.141 0];% link lengths
al = [pi/2 0 0 pi/2];% twist between links
d = [0 0 0 0];%offset
theeta = [0 pi/4 -pi/4 pi/3];%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) 0 0; s1(1)*c2(1) c1(1)*c2(1) -s2(1) d(1)*-s2(1);
s1(1)*s2(1) c1(1)*s2(1) c2(1) d(1)*c2(1); 0 0 0 1];
T2 = [c1(2) -s1(2) 0 0.249; s1(2)*c2(2) c1(2)*c2(2) -s2(2) d(2)*-s2(2);
s1(2)*s2(2) c1(2)*s2(2) c2(2) d(2)*c2(2); 0 0 0 1];
T3 = [c1(3) -s1(3) 0 0.141; s1(3)*c2(3) c1(3)*c2(3) -s2(3) d(3)*-s2(3);
s1(3)*s2(3) c1(3)*s2(3) c2(3) d(3)*c2(3); 0 0 0 1];
T4 = [c1(4) -s1(4) 0 0; s1(4)*c2(4) c1(4)*c2(4) -s2(4) d(4)*-s2(4);
s1(4)*s2(4) c1(4)*s2(4) c2(4) d(4)*c2(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 = 'Service Robot';
%plotting the robot
SCORBOT.plot([theeta(1) theeta(2) theeta(3) theeta(4)]);
title('Service Robot');
```



3.2 Petercorke Toolbox:

The final Transformation from the Peter-Corke Toolbox is:

```
robot =
    0.5000         0    0.8660    0.3171
         0        -1         0         0
    0.8660         0   -0.5000    0.1761
         0         0         0         1
```

4. Hardware Implementation:

The project is done by using an Acrylic Robotic arm kit with 4 servo motors. The Arduino Uno is used for controlling the robotic arm at different angles. The hardware implementation is shown below:

Fig. 4.1: Hardware implementation of 4 DOF Robotic Arm.

5. Utilization of the Project:

The Robotic arm we made is the 4 DOF R-R-R-R manipulator used to pick and place things. It will pick and place the things at different angles. This robotic arm picks the things from one point and place that thing on the other point.

6. Cost Analysis:

S. No.	Component	No. of Items	**Price** (in PKR)
1.	Acrylic Robotic Kit	01	3000/-
2.	Arduino Uno	01	1000/-
3.	Arduino Cable	01	70/-
4.	Servo Motors	04	Included in the kit
Total			**Rs. 4070/-**

7. Work Division:

We divide our work into three major parts. The first group member focused on hardware components, the second on software development, particularly in MATLAB for Forward and Inverse Kinematics calculations, and the third member worked with the Arduino IDE to ensure the functionality of the Robotic Arm hardware.

8. Conclusion:

In this CEP, we have made a 4 DOF robotic arm with R-R-R-R manipulator. The main function of that robotic arm is to pick and place things. This robot will move in either direction to pick and place things based upon the thing where it is placed.