Trajectory Circular and Zigzag paths for 3DOF Planar Robot by using Matlab

Saadi Talib Habl, Hatem Hadi Obeid and Abdul-Kareem Jaleel

The University of Babylon, College of Engineering, Department of Mechanical Engineering.

E-mail: eng.hatem.hadi@uobabylon.edu.iq

Abstract. The Denavit- Hardenberg (D-H) method is widely used to calculate the kinematic properties of various types of robots, where it is possible to obtain a complete description of the robot's operation. Based on this method's parameters, it is possible to provide the typical arrangement of all robotic joints. In this work, the kinematic properties such as displacement, velocity, and acceleration of a 3DOF Planar Robot are analyzed using MATLAB software. Two types of paths are traced in this paper, the straight path, and the zigzag path.

Keywords. Denavit- Hardenberg(D-H) method, Manipulator robot, Kinematic analysis.

1. Introduction

Robotics are an important new technology in all fields of industry and on a wide range of applications; therefore, studying the motion of robots in its working space is very important to know the extent of the robot's success in performing the tasks specified for it with different surrounding conditions and parameters. To know the robot’s movement and reduce the time and effort, a simulation is developed to study its kinematic properties using the mathematical model to analyze the robot’s kinematic properties, such as the method (Denavit- Hardenberg (D-H)). Velarde [1] studied the kinematic and dynamic properties of the CATALYST5 5-DOF Manipulator robot using MATLAB Simulink. From the obtained results in this research, the positions of the end-effector and all links were clearly found by representing the model in three dimensions. The results showed the importance of this methodology and the possibility of applying it to the other types of robots. Sivasamy [2] used the Matlab GUI to verify the Scrobot 5u Plus robot’s kinematic motion to obtain the arms’ position and direction while working to obtain the best performance of the robot tasks. The Scrobot 5u Plus model was designed by Rob cell software, and the results obtained were compared with the values measured by Labview software. Himanshu[3] applied the DH algorithm to conduct the kinematic analysis of the SCORBOT-ER V Plus robot tracking. Two paths lines were tracked in this paper, the first is a straight line in Cartesian coordinates, and the second path is also a straight line in space. Considered disposal from impact for the end-effector it is, presentation to unknown external factors is essential. Therefore, these algorithms are designed to track the respondent, and the simulation results are considered to be of high accuracy in identifying and tracking the path with minimal effort.
In the literature review, it is noted to study the kinematic and dynamic properties of different types of robots by using different simulation and experimental methods. In this work, the kinematic properties (location, velocity, and acceleration) of a 3DOF Planar Robot are analyzed and verified for each joint. By using MATLAB/SIMULATION, the results are compared with the SOLIDWORK results.

2. Geometrical and material properties of (3DOF planar robot)
3DOF Planar Robot has three revolute joints and. Figure (1) depicts a 3DOF model of a Planar Robot; the Solidwork software was used to design it.

![Figure 1. Model of 3DOF planar robot.](image)

Table (1) presents the simulation parameters of the 3DOF Planar Robot.

| Parameter       | Link1 | Link2 | Link3 | Base     |
|-----------------|-------|-------|-------|----------|
| Length (m)      | 0.5   | 0.5   | 0.5   |           |
| Mass (kg)       | 0.427 | 0.362 | 0.428 | 2.034    |
| Material        | Aluminum (1060alloy) | Aluminum (1060alloy) | Aluminum (1060alloy) | cast alloy steel |

2.1. Forward kinematics for 3DOF planar robot
The Denavit-Hartenberg or D-H is a standard method of representing robots and modeling their motions. In this convention, each homogenous transformation $T_i$ is represented as a product of “four” fundamental transformations [4], as shown in Figure (2) [5].

$$T_i = Rot.(z, \theta_i).Trans(z, d_i).Trans(x, a_i).Rot.(x, \alpha_i)$$

![Figure 2. D-H Frame assignment[6].](image)
Where the notation $\text{Rot}(x, \alpha_i)$ stand for rotation about $X_i$ axis by $\alpha_i$, $\text{trans}(x, a_i)$ is translation along $X_i$ axis by a distance $a_i$, $\text{Rot}(z, \theta_i)$ stand for rotation about along $Z_i$ axis by $\theta_i$, and $\text{Trans}(z, d_i)$ is the translation along $Z_i$ axis by a distance $d_i$.

$T_i$ can be written as follows:

$$
T_i = \begin{bmatrix}
\cos \theta_i & -\sin \theta_i \cdot \cos \alpha_i & \sin \theta_i \cdot \sin \alpha_i & a_i \cdot \cos \theta_i \\
\sin \theta_i \cdot \cos \alpha_i & \cos \theta_i & -\cos \theta_i \cdot \sin \alpha_i & a_i \cdot \sin \theta_i \\
0 & \sin \alpha_i & \cos \alpha_i & d_i \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

(2)

Table (2) shows the robot parameters used in the transmission matrix for the D-H method.

**Table 2. Link parameters of (D-H) method for the 3D planr robot.**

| joint | $\theta_i$ | $d_i$(mm) | $a_i$(mm) | $\alpha_i$ |
|-------|-------------|------------|------------|-------------|
| $0 \rightarrow 1$ | $\theta_1$ | 0 | $a_1$ | 0 |
| $1 \rightarrow 2$ | $\theta_2$ | 0 | $a_2$ | 0 |
| $2 \rightarrow 3$ | $\theta_3$ | 0 | $a_3$ | 0 |

$$
T_1 = \begin{bmatrix}
c_1 & -s_1 & 0 & 0 \\
s_1 & c_1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

$$
T_2^2 = \begin{bmatrix}
c_2 & -s_2 & 0 & l_1 \\
s_2 & c_2 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

$$
T_3^2 = \begin{bmatrix}
c_3 & -s_3 & 0 & l_2 \\
s_3 & c_3 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

$$
T_{total} = \begin{bmatrix}
c_1 & -s_1 & 0 & l_1c_1 + l_2c_{12} \\
s_1 & c_1 & 0 & l_1s_1 + l_2s_{12} \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

(3)

at last, the final matrix ($T_{total}$) can be obtained by multiply the $T_{total}^2$ by $T_3^2$.

$$
T_{total} = \begin{bmatrix}
c_{123} & -s_{123} & 0 & l_1c_1 + l_2c_{12} + l_3c_{123} \\
s_{123} & c_{123} & 0 & l_1s_1 + l_2s_{12} + l_3s_{123} \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

(4)

Where;

$c_1 = \cos(\theta_1), \ldots, s_1 = \sin(\theta_1)$

$c_{12} = \cos(\theta_1 + \theta_2), \ldots, s_{12} = \sin(\theta_1 + \theta_2)$

$c_{123} = \cos(\theta_1 + \theta_2 + \theta_3), \ldots, s_{123} = \sin(\theta_1 + \theta_2 + \theta_3)$

Another generalization symbolic transformation matrix is:

$$
T = \begin{bmatrix}
n_x & o_x & a_x & p_x \\
n_y & o_y & a_y & p_y \\
n_z & o_z & a_z & p_z \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

(5)
The transformation given by Equation (5) is a function of all three joint variables. The Cartesian position and orientation of the last link may be computed using the above Equation (5) from the robot’s joint position. The first three columns in the matrices represent the orientation of the end effectors, whereas the last column represents the position of the end effectors.

2.2. Inverse kinematics for 3DOF planar robot
Inverse kinematics (IK) analysis determines the joint angles for the desired position and orientation of the robot (EE) in Cartesian space; analytical (algebraic) solution applied in this work is considered in this method [6].

3. Simulation results and discussion
Two path types (Straight and Zigzag) are chosen to validate the methodology used in determining the position and orientation of the end-effector and the robot joints.

3.1. Joint and End–effector in space tragic

3.1.1. Zigzag path. The motion of the end-effector is analyzed in the Cartesian plane (x, y). The total time is chosen to be 10 sec. The orientation, velocity, and acceleration of each joint are obtained as a function of time.

Figure (3) and figure (4) show the end-effector position for the zigzag path in the Cartesian space against time, which is a simulation from the set \([x = (1-0.9)]\) while the \([y_i]\), it is travel from \([1-(-0.08)\pm0.05]) m along the path.

![Figure 3](image.png)

**Figure 3.** End-effector in (x, y) Plan for zigzag path by MATLAB/SIMULINK.
Figure 4. EE Position zigzag path by using solid work program.
Figure (5) depicts the joint1 moves from the zero position at time zero to form the imaginary path with time total is approximately (7.8 sec). The displacement begins to change its direction to draw the zigzag path. It is noticed that the velocity curve in joint1 is fixed at a rate of 2 deg/sec along the imaginary path (0 -7.8) sec. After that, changes in its value and orientation are observed.

Figure (6) shows all the directions that joint2 moves (from the start of the end of the path) counterclockwise. Velocity curve depicts it gradually increases its value until it reaches 14.65 deg/sec at the time 3.85 sec in the middle of the imaginary path and then begins to slope in its value until the time 7.66 sec plot the path. Also, the acceleration curve shows the presence of oscillations at a time of approximately (7.9-10) sec. The joint3 moves from the zero position at time zero to form the imaginary path with a total time of approximately (5.7 sec). The velocity curve began to increase from (t = 5.07 sec) until the end of the path4, while oscillations are observed in the acceleration curve at a time of approximately (4.8-5.13) sec, as shown in Figure (7).

![Kinematic analysis result (Joint1) zigzag path, (a) by SOLIDWORK, (b) by (MATLAB/Simulink).]

![Kinematic analysis result (Joint2) zigzag Path, (a) by SOLIDWORK, (b) by (MATLAB/Simulink).]
3.1.2. Circular path. The motion of the end-effector is analyzed in the Cartesian plane (x, y). The total time is chosen to be (16 sec). The orientation, velocity, and acceleration of each joint gets as a function of time. Figure (8) and Figure (9) depict the circular path, which is a simulation from set [$x_1=0.3+RR\cdot\cos \theta$] and [$y_1=0.5+RR\cdot\sin \theta$]; RR=0.35. The EE moves from the (x= 1.5m), and it crosses the imaginary path until it reaches a distance of (x=0.68, y=0.55) m at a time of (3.5 sec) at which the circular path begins to form from that point it completes its course and returns to the same point.

Figure 8. End-effector in (x,y) plan for circular path by MATLAB.
Figure 9. End-effector in (x,y) plan for circular path by solid work.

It is noted that the motion of joint1 in this path in a clockwise direction, and its highest displacement is (-100.34 deg/sec) in time (10.7 sec), as shown in Figure (10).

Figure (11) shows that the velocity curve is increasing gradually until the middle of the imaginary path, where its value reaches (-1.1 deg/sec) at the time (1.91 sec). After the velocity starts to decrease until it reaches the end of the imaginary path at a time of (3.6 sec), then it starts to oscillate until you complete the path.

From the acceleration curve, it can be noticed that its value fluctuates at approximately (3.6 sec) at the beginning of the path due to the change in the velocity value. Acceleration also shows fluctuation in its value over time (7-11.9) sec. This is roughly the time it begins to draw the second half of the circle’s path, as shown in Figure (12).

Figure 10. Kinematic analysis result (Joint1) circular path, (a) by SOLID-WORK, (b) by (MATLAB/Simulink)
4. Conclusions
A simulation methodology for a 3DOF Planar Robot is proposed to analyze the kinematic properties, such as displacement, velocity, and acceleration, for the end-effector, joint, and for different types of paths. The methodology was applied based on the MATLAB program. The two paths were also plot in the Cartesian space (X, Y) by the SolidWork program. Through the current study, the results obtained by the MATLAB program were very similar to the results obtained by the SolidWork program.
5. References

[1] Velarde J A, Rodriguez S A, Garcia L G and Pedraza J C 2010 5-DOF Manipulator Simulation Based on MATLAB/Simulink Methodology (IEEE. Published in: 2010 20th International Conference on Electronics Communications and Computers (CONIELECOMP))

[2] D. Sivasamy, M Dev and K Anitha 2019 Robot Forward and Inverse Kinematics Research using Matlab ((IJRTE) Issue-2S3, Published By: Blue Eyes Intelligence Engineering & Sciences Publication) vol 8 pp 2277–3878

[3] Himanshu, Rajendra and N Sukavanum 2012 Trajectory Tracking of Scorbot- Er V Plus Robot Manipulator Based on Kinematic Approach (International Journal of Engineering Science and Technology (IJEST), ISSN : 0975-5462) vol 4 no3 pp 1174–1182

[4] Sam Cubero 2006 Industrial-Robotics-Theory- Modelling- Control (Germany) p 964

[5] J Denavit and R S Hartenberg 1955 A kinematics Notation For Lower-Pair Mechanisms Based On Matrices (ASME Journal of Applied Mechanics) vol 22 pp 215–221

[6] M W Spong and M Vidyasagar 2005 Robot Modeling and Control (1st Edition, John Wiley & Sons.)