

End-effector Position Analysis of SCORBOT-ER Vplus Robot

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Abstract

This paper features the kinematic analysis of a SCORBOT-ER Vplus robot arm which is used for doing successful robotic manipulation task in its workspace. The SCORBOT-ER Vplus is a 5-dof vertical articulated robot and all the joints are revolute [1]. The kinematics problem is defined as the transformation from the Cartesian space to the joint space and vice versa. The Denavit-Harberterg (D-H) model of representation is used to model robot links and joints in this study along with 4x4 homogeneous matrix. SCORBOT-ER Vplus is a dependable and safe robotic system designed for laboratory and training applications. This versatile system allows students to gain theoretical and practical experience in robotics, automation and control systems. The MATLAB 8.0 is used to solve this mathematical model for a set of joint parameter.

Keywords: Forward kinematics, Vertical articulated robot, D-H model

1. Introduction

Robot kinematics is the study of the motion (kinematics) of robotic mechanisms. In a kinematic analysis, the position, velocity, and acceleration of all the links are calculated with respect to a fixed reference coordinate system, without considering the forces or moments. The kinematic models are needed for off-line and on-line program generation and for tracking functional trajectories. A robotic manipulator is designed to perform a task in the 3-D space. The tool or end-effector is required to follow a planned trajectory to manipulate objects. The Kinematic model gives relationship between the position and orientation of the end-effector and spatial positions of joint-links.

The kinematic modeling is split into two problems as forward kinematics & inverse kinematics. General methods do exist for solving forward kinematics (2-5). Forward kinematics problem is to determine the position and orientation of the end-effector, given the values for the joint variables of the robot. Inverse kinematics problem is concerned with determining values for the joint variables that achieve a desired position and orientation for the end-effector of the robot.

2. Kinematic Model of SCORBOT-ER Vplus Robot

SCORBOT-ER Vplus is a vertical articulated robot, with five revolute joints. It has a stationary base, shoulder, elbow, tool pitch and tool roll. Figures 1 & 2 identify the joints and links of the mechanical arm.

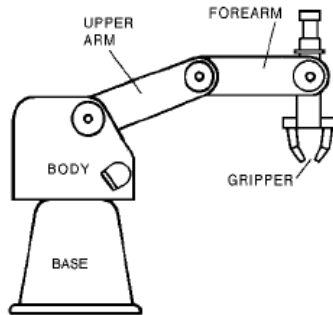


Figure 1: Robot Arm Links

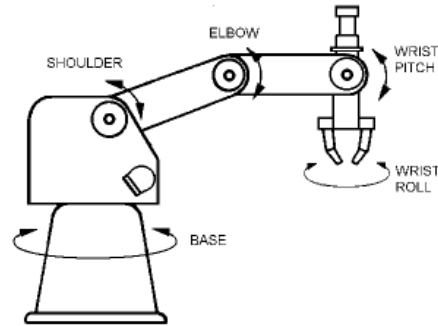


Figure 2: Robot Arm Joints

2.1. Denavit & Hartenberg (D-H) Notation

The definition of a manipulator with four joint-link parameters for each link and a systematic procedure for assigning right-handed orthonormal coordinate frames, one to each link in an open kinematic chain, was proposed by Denavit & Hartenberg, so is known as Denavit -Hartenberg (DH) notation [6-7]. Figure 3 shows a pair of adjacent links, link(i-1) and link i, their associated joints, joint (i-1), i and (i+1), and axis (i-2),(i-1) and i respectively. A frame {i} is assigned to link i as follows:

- i. The Z_{i-1} lies along the axis of motion of the i th joint.
- ii. The X_i axis is normal to the Z_{i-1} axis, and pointing away from it.
- iii. The Y_i axis completes the right – handed coordinate system as required.

The DH representation of a rigid link depends on four geometric parameters associated with each links. These four parameters completely describe any revolute or prismatic joint as follows:

- i. Link length (a_i) – distance measured along x_i axis from the point of intersection of x_i axis with z_{i-1} axis to the origin of frame {i}.
- ii. Link twist (α_i) – angle between z_{i-1} and z_i axes measured about x_i -axis in the right hand sense.
- iii. Joint distance (d_i) - distance measured along z_{i-1} axis from the origin of frame {i-1} to intersection of x_i axis with z_{i-1} axis.
- iv. Joint angle (θ_i) – angle between x_{i-1} and x_i axes measured about the z_{i-1} axis in the right hand sense.

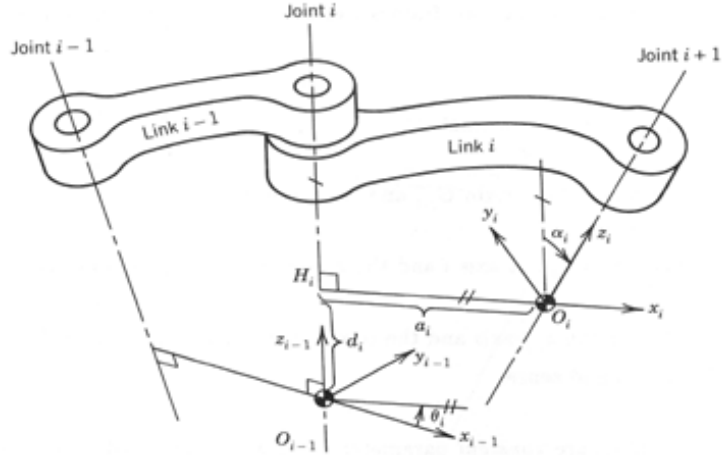


Figure 3: DH Conventions for Frame Assigning

The kinematic model is shown in Figure 4 with frame assignments according to the Denavit & Hartenberg (D-H) notations. The kinematic parameters according to this model are given in Table 1.

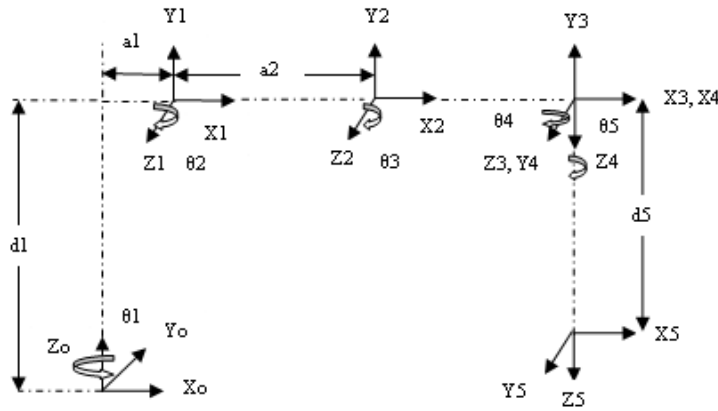


Figure 4: Frame Assignment

Table 1: D-H Parameter for Scorbot ER-Vplus

Joint i	α_i	a_i (mm)	d_i (mm)	θ_i	Operating range
1	$\pi/2$	101.25	334.25	38.15°	-155° to $+155^\circ$
2	0	220	0	-30°	-35° to $+130^\circ$
3	0	220	0	45°	-130° to $+130^\circ$
4	$\pi/2$	0	0	-63.54°	-130° to $+130^\circ$
5	0	0	137.35	0°	-570° to $+570^\circ$

2.2. Kinematic Relationship Between Adjacent Links

Once the DH coordinate system has been established for each link, a homogeneous transformation matrix can easily be developed considering frame $\{i-1\}$ and frame $\{i\}$. This transformation consists of four basic transformations as shown in Figure 4 and the joint link parameter as given in Table 1.

- i. A rotation about z_{i-1} axis by an angle θ_i

- ii. Translation along z_{i-1} axis by distance d_i
- iii. Translation by distance a_i along x_i axis and
- iv. Rotation by angle α_i about x_i axis

$${}^{i-1}T_i = T_z(\theta_i) T_z(d_i) T_x(a_i) T_x(\alpha_i)$$

$${}^{i-1}T_i = \begin{bmatrix} C\theta_i & -S\theta_i & 0 & 0 \\ S\theta_i & C\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C\alpha_i & -S\alpha_i & 0 \\ 0 & S\alpha_i & C\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^{i-1}T_i = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where $S\theta_i = \sin \theta_i$, $C\theta_i = \cos \theta_i$, $S\alpha_i = \sin \alpha_i$, $C\alpha_i = \cos \alpha_i$, $S_{ijk} = \sin(\theta_i + \theta_j + \theta_k)$, $C_{ijk} = \cos(\theta_i + \theta_j + \theta_k)$

The overall transformation matrix, ${}^0T_5 = {}^0T_1 * {}^1T_2 * {}^2T_3 * {}^3T_4 * {}^4T_5$

$${}^0T_1 = \begin{bmatrix} c_1 & 0 & s_1 & a_1 c_1 \\ s_1 & 0 & -c_1 & a_1 s_1 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^1T_2 = \begin{bmatrix} c_2 & -s_2 & 0 & a_2 c_2 \\ s_2 & c_2 & 0 & a_2 s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^2T_3 = \begin{bmatrix} c_3 & -s_3 & 0 & a_3 c_3 \\ s_3 & c_3 & 0 & a_3 s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^3T_4 = \begin{bmatrix} c_4 & 0 & s_4 & 0 \\ s_4 & 0 & -c_4 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^4T_5 = \begin{bmatrix} c_5 & -s_5 & 0 & 0 \\ s_5 & c_5 & 0 & 0 \\ 0 & 0 & 1 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^0T_5 = \begin{bmatrix} c_1 c_{234} c_5 + s_1 s_5 & c_1 c_{234} s_5 + s_1 c_5 & c_1 s_{234} & c_1 (d_5 s_{234} + a_3 c_{23} + a_2 c_2 + a_1) \\ s_1 c_{234} c_5 - c_1 s_5 & -s_1 c_{234} s_5 - c_1 c_5 & s_1 s_{234} & s_1 (d_5 c_{234} + a_3 s_{23} + a_2 c_2 + a_1) \\ s_{234} c_5 & -s_{234} s_5 & -c_{234} & (-d_5 c_{234} + a_3 s_{23} + a_2 s_2 + d_1) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^0T_5 = T_e = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where T_e is end-effector transformation matrix.

This kinematic model can also be expressed by 12 equations as:

$$\begin{aligned}
 n_x &= c1*c234*c5+s1*s5 \\
 n_y &= s1*c234*c5-c1*s5 \\
 n_z &= s234*c5 \\
 o_x &= c1*c234*s5+s1*c5 \\
 o_y &= -s1*c234*s5-c1*c5 \\
 o_z &= -s234*s5 \\
 a_x &= c1*s234 \\
 a_y &= s1*s234 \\
 a_z &= -c234 \\
 p_x &= c1*(s234*d5+a3*c23+a2*c2+a1) \\
 p_y &= s1*(s234*d5+a3*c23+a2*c2+a1) \\
 p_z &= -c234*d5+a3*s23+a2*s2+d1
 \end{aligned}$$

3. Result

For the given set of parameter, a program in MATLAB 8.0 is made and its output is compared with the experimental result as follows.

Experimental Result:

$${}^0T_5 = \begin{bmatrix} 0.5212 & 0.6177 & -0.5887 & 315.48 \\ 0.4094 & -0.7863 & -0.4625 & 247.88 \\ -0.7487 & 0.0000 & -0.6628 & 190.27 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{bmatrix}$$

Matlab Program Output:

$${}^0T_5 = \begin{bmatrix} 0.5207 & 0.6177 & -0.5893 & 315.6175 \\ 0.4090 & -0.7864 & -0.4629 & 247.9208 \\ -0.7494 & 0.0000 & -0.6621 & 190.2512 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{bmatrix}$$

4. Conclusion

The forward kinematic analysis of 5-dof SCORBOT-ER Vplus Robot is investigated. The mathematical model is prepared and solved for positioning and orienting the end effector by preparing a programme in MATLAB 8.0. The experimental and theoretical results are approximately same. Hence this proves the utility of the SCORBOT-ER Vplus robot arm as an educational tool for undergraduate robotics courses.

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