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-Harbenterg (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.

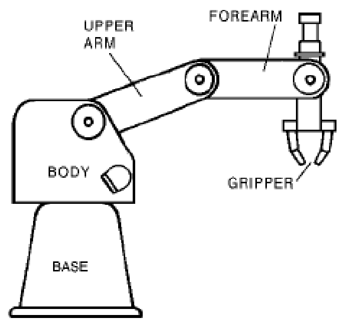

Figure 1: Robot Arm Links

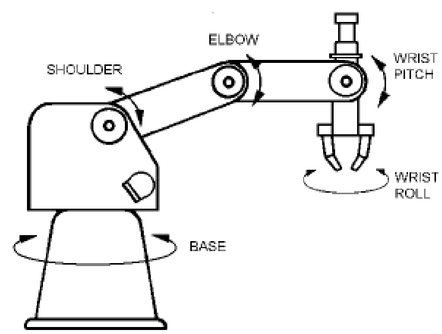

Figure 2: Robot Arm Joints

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 Zi -1 lies along the axis of motion of the ith joint.
ii. The Xi axis is normal to the Zi-1 axis, and pointing away from it.
iii. The Yi 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 (ai) – distance measured along xi axis from the point of intersection of xi axis with zi-1 axis to the origin of frame {i}.
ii. Link twist (αi) – angle between zi-1 and zi axes measured about xi-axis in the right hand sense.
iii. Joint distance (di) - distance measured along zi-1 axis from the origin of frame {i-1} to intersection of xi axis with zi-1 axis.
iv. Joint angle (θi) – angle between xi-1 and xi axes measured about the zi-1 axis in the right hand sense.

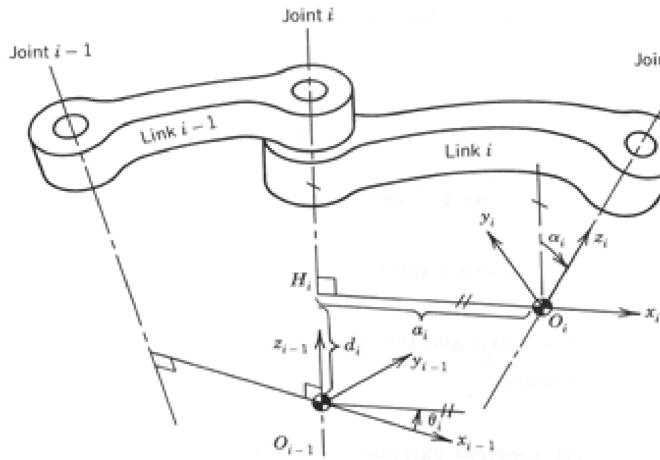

Figure 3: DH Conventions for frame assigning

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.

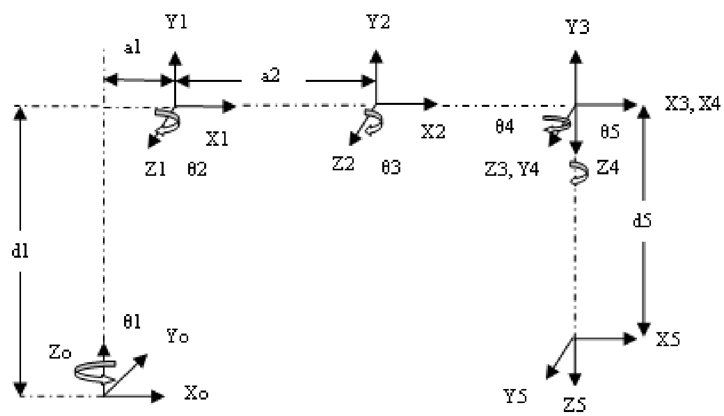

Figure 4: Frame Assignment

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^o	-155^o to $+155^o$
2	0	220	0	-30^o	-35^o to $+130^o$
3	0	220	0	45^o	-130^o to $+130^o$
4	$\pi/2$	0	0	-63.54^o	-130^o to $+130^o$
5	0	0	137.35	0^o	-570^o to $+570^o$

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

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

$$^{i-1}T_i = \begin{bmatrix} C\theta i & -S\theta i & 0 & 0 \\ S\theta i & C\theta i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & di \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & ai \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C\alpha i & -S\alpha i & 0 \\ 0 & S\alpha i & C\alpha i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{i-1}T_i = \begin{bmatrix} C\theta i & -S\theta iC\alpha i & S\theta iS\alpha i & aiC\theta i \\ S\theta i & C\theta iC\alpha i & -C\theta iS\alpha i & aiS\theta i \\ 0 & S\alpha i & C\alpha i & di \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where $S\theta_i$=sin θ_i, $C\theta_i$ =cos θ_i, $S\alpha_i$=sin α_i, $C\alpha_i$=cos α_i, S_{ijk}=sin(θ_i+ θ_j+ θ_k), C_{ijk}=sin(θ_i+ θ_j+ θ_k)

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

$$^0T_1 = \begin{bmatrix} c_1 & 0 & s_1 & a_1c_1 \\ s_1 & 0 & -c_1 & a_1s_1 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^1T_2 = \begin{bmatrix} c_2 & -s_2 & 0 & a_2c_2 \\ s_2 & c_2 & 0 & a_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^2T_3 = \begin{bmatrix} c_3 & -s_3 & 0 & a_3c_3 \\ s_3 & c_3 & 0 & a_3s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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

$$^0T_5 = \begin{bmatrix} c_1c_{234}c_5 + s_1s_5 & c_1c_{234}s_5 + s_1c_5 & c_1s_{234} & c_1(d_5s_{234} + a_3c_{23} + a_2c_2 + a_1) \\ s_1c_{234}c_5 - c_1s_5 & -s_1c_{234}s_5 - c_1c_5 & s_1s_{234} & s_1(d_5c_{234} + a_3s_{23} + a_2c_2 + a_1) \\ s_{234}c_5 & -s_{234}s_5 & -c_{234} & (-d_5c_{234} + a_3s_{23} + a_2s_2 + d_1) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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

where T_e is end-effector transformation matrix.

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

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

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:

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

Matlab Program Output:

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

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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