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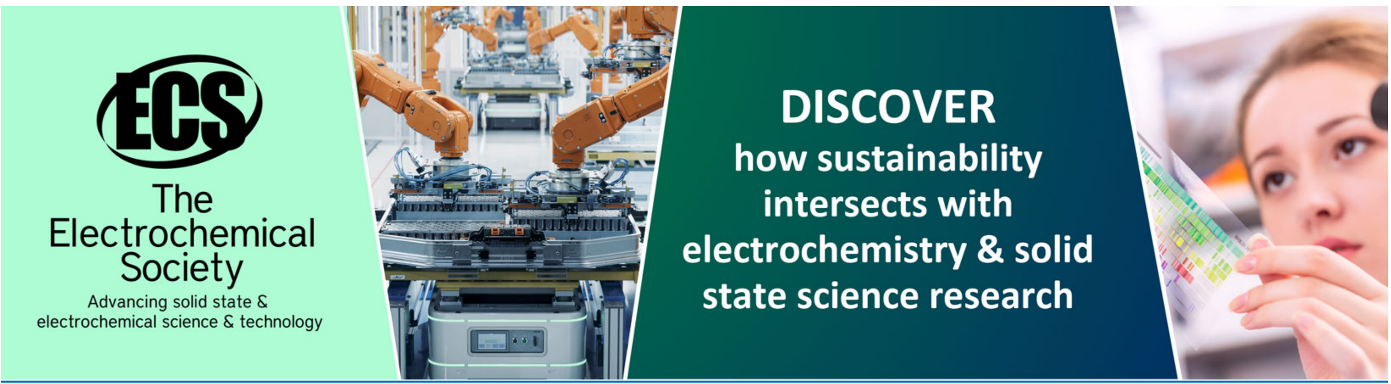

Kinematics analyses for robot motion

Wandro Siregar[1,*], Parulian Siagian[1], Lin Rong-Shine[2], Richard AM.Napitupulu[1], MidukTampubolon[1],Sutan LMH Simanjuntak[1]

[1] Mechanical Engineering Nommensen HKBP University . JlnSutomo 4A Medan Indonesia

[2] Department EngineeringAdvanced Institute of Manufacturing with HI- techInnovations. National Chung Cheng University, Chia-Yi 621, Taiwan, R.O.C.

[*]parulian.nommensen@gmail.com

Abstract. This project is a part of the analysis which aims to find solutions to the kinematics problem that exists in the movement of the robot arm. In order to control the robot manipulator as desired, so it is important to consider kinematics models in the design of control algorithms. Which in this report presents a mathematical model and kinematics parameter for the robot kinematics. The solution of the forward kinematics based on the matrix transformation method are given and the results are obtained using Matlab software.

1. Introduction

A robot is a software-controllable mechanical device that uses sensors to guide one or more end-effectors through programmed motions in a workspace in order to manipulate physical objects [1]. Today robot is used in various field like as industry, medical, military operation in space and some dangerous place where human don't want to work. But the controlling of robot manipulator has been challenged with higher DOF. In determining the position and orientation of the robot manipulator is a challenging step to design and control the robot's movement in a three-dimensional workspace. The Forward kinematics analyzes and calculates the end-position of robot arm using the joint angle. But the challenge to analyze the inverse kinematics solution using the position of the end-effector to find the joint angles. The complexity of the inverse kinematics increases with the number of DOF.

Kinematics analysis of robot motion is an analytical movement of a robot arm against a stationary system coordinate frame without considering the force that causes the movement. In analyzing robot motion kinematics there are two topics of discussion that must be carried out, called forward/direct kinematics and inverse kinematics [2]. The two topics are interrelated and complementary, as shown below figure 1.

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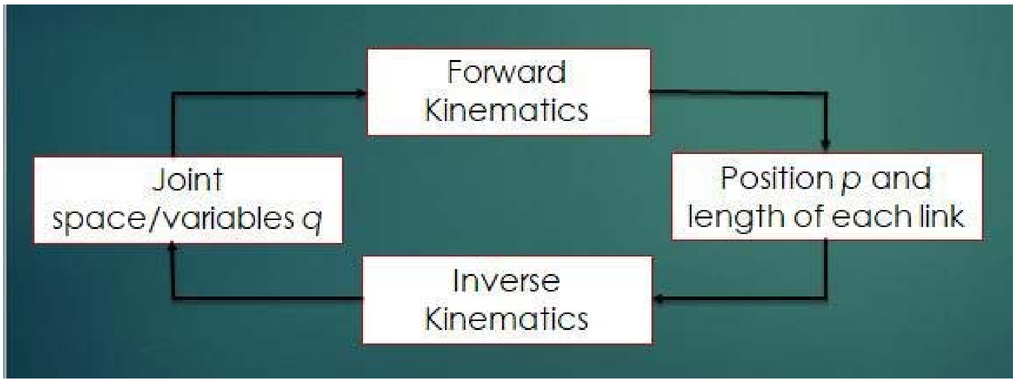

Figure 1. The relationship between forward kinematics and inverse kinematic

1.1 Forward Kinematics

Forward kinematics is the method for determining the orientation and position of the end-effector, given joint variables (joint angles) and the link lengths of the robot arm.[3]. Methods for a forward kinematics analysis: using transformation matrices and using straightforward geometry.

1.2 Inverse Kinematics

The inverse kinematics is the opposite to the forward kinematic, which examines the inverse problem to determine the joint variables with the given the desired position and orientation of the tool. The inverse kinematic problem is important because manipulation task is naturally formulated in terms of the desired tool position and orientation and the inverse kinematics problem is more difficult than the forward kinematic problem because a systematic closed-form solution applicable to robots, in general, is not available. Moreover, when closed-form solution to the arm equation can be found, they are seldom unique.[4].

1.3 D-H Parameter

This was first introduced by Jacques Denevit and Richard S. Hartenberg. DH convention is used for selecting the frame of reference for the robotic arm. In this convention, coordinate frame is attached to the joints between two link to describe the location of each link relative to its previous.[5].

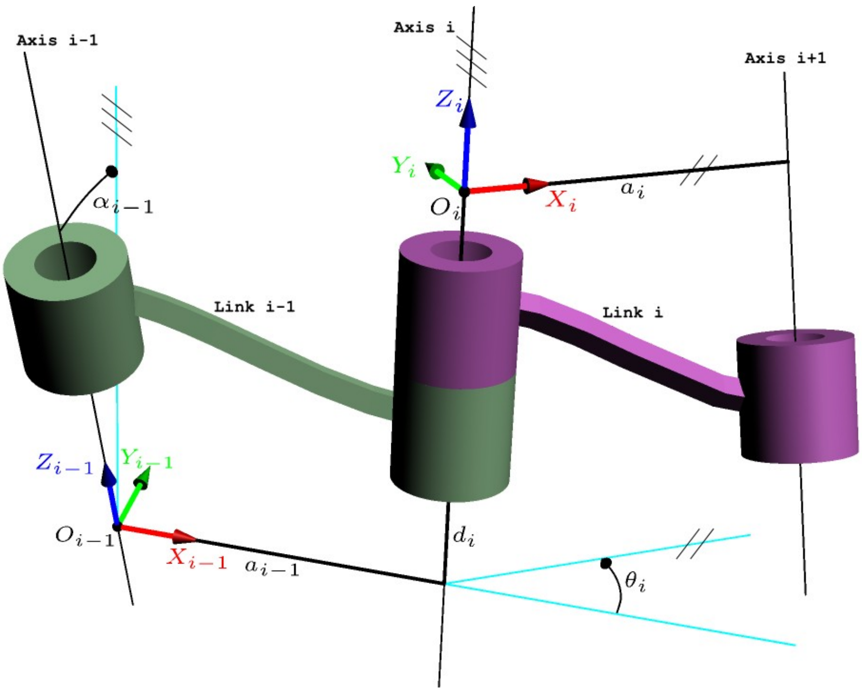

Figure 2. Modified DH Parameters.

The following four transformation parameters are known as D-H parameters :

- d_i: offset along previous to the common normal
- θ_i: angle about the previous z, from old x to new x
- a_i : length of the common normal (Assuming a revolute joint, this is the radius about the previous z.
- αi : angle about common normal, from old z to a new z axis.

2. Method and Experimental

The experimental is to make an analysis of robot arm movements in the form of mathematical equations whereby giving a value to each joint variables (Theta), the position of the end-effector will be found and make a mathematical equation if given the position of the end-effector and the length of each link. Then the angle degree will be found in each joint variables (Theta).

After obtaining mathematical equations for the two existing problems, namely forward kinematics and inverse kinematics then the equations are combined or entered into the Matlab program to get the desired results.

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3. Results and Discussion

3.1 Analytical Forward Kinematics

The forward kinematics of a robot determines the configuration of the end-effector (the gripper or tool mounted on the end of the robot) given the relative configuration of each pair of an adjacent link of the robot.

A link-coordinate diagram based on the Denavit-Hartenberg algorithm in figure 3.

Figure 3.a. Robot HIWIN RA 610

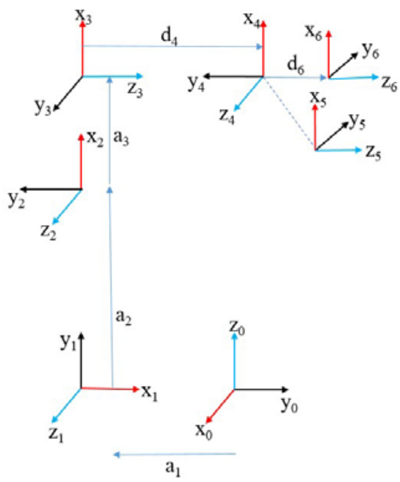

Figure 3.b. Link coordinate of a six-axis robot (Hiwin RA610)

From the fig.3.a can be seen that the Robot arm Hiwin RA 610 has a serial 6 DoF (Degree of Freedom) with six revolute joints.

Table 1. Denavit-Hartenberg Parameter of the six-axis robot Hiwin RA 610

Joint,i	θi	αi	ai	di
1	$\theta 1$	$\frac{\pi}{2}$	0.14 (m)	0
2	$\theta 2$	0	0.64 (m)	0
3	$\theta 3$	$\frac{\pi}{2}$	0.16 (m)	0
4	$\theta 4$	$\frac{\pi}{2}$	0	1.078 (m)
5	$\theta 5$	$\frac{\pi}{2}$	0	0
6	$\theta 6$	0		0.101 (m)

In analyzing the forward kinematics, the homogeneous transformation matrix method is used here.

T = Rotation matrix (θi) .translation matrix,i

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$$T = \begin{bmatrix} & & & 0 \\ & R(\theta), i & & 0 \\ & & & 0 \\ 0 & & 0 & 0\,1 \end{bmatrix} x \begin{bmatrix} 1 & 00px \\ 0 & 10py \\ 0 & 01pz \\ 0 & 00\,1 \end{bmatrix} \quad (1)$$

According to equations (1) it is obtained a matrix of homogeneous transformation for each link and calculate the kinematics equations of the robot arm : T0_6

=T0_1.T1_2.T2_3T3_4.T4_5.T5_6

$$T_{0\_6} = \begin{bmatrix} -s1 & 0c1 - a1s1 \\ c1 & 0s1\ a1c1 \\ 0 & 1\,0\quad 0 \\ 0 & 0\,0\quad 1 \end{bmatrix} . \begin{bmatrix} -s2 & -c20 - a2s2 \\ c2 & -s20\ a2c2 \\ 0 & 0\ \ 1\quad 0 \\ 0 & 0\ \ 0\quad 1 \end{bmatrix} .$$

$$\begin{bmatrix} c3 & 0\ s3\ a3c3 \\ s3 & 0 - c3a3s3 \\ 0 & 1\ \ 0\quad 0 \\ 0 & 0\ \ 0\quad 1 \end{bmatrix} . \begin{bmatrix} c4 & 0\ -s4\ 0 \\ s4 & 0\ \ c4\ \ 0 \\ 0 & -1\ \ 0\ \ d4 \\ 0 & 0\ \ 0\ \ 1 \end{bmatrix} .$$

$$\begin{bmatrix} c5 & 0\ s5\ 0 \\ s5 & 0 - c50 \\ 0 & 1\ \ 0\ \ 0 \\ 0 & 0\ \ 0\ \ 1 \end{bmatrix} . \begin{bmatrix} c6 & -s60\ 0 \\ s6 & c6\ 0\ 0 \\ 0 & 9\ \ 1d6 \\ 0 & 0\ \ 0\,1 \end{bmatrix}$$

Thus. we finally obtain;

$$T_{0\_6} = \begin{bmatrix} nx & oxaxpx \\ ny & oyaypy \\ nz & ozazpz \\ 0 & 0\ \ 0\ \ 1 \end{bmatrix}$$

Where :

$$\begin{aligned}
n_x &= c_1(c_4s_6+s_4c_5c_6)+s_1(s_{23}c_4c_5c_6-s_{23}s_4s_6+c_{23}s_5c_6) \\
n_y &= s_1(c_4s_6+s_4c_5c_6)+c_1(-s_{23}c_4c_5c_6+s_{23}s_4s_6-c_{23}s_5c_6) \\
n_z &= c_{23}(c_4c_5c_6)-s_{23}s_5c_6 \\
o_x &= c_1(c_4c_6-s_4c_5s_6)-s_1(s_{23}s_4c_6+c_{23}s_5s_6+s_{23}c_4c_5s_6) \\
o_y &= s_1(c_4c_6-s_4c_5s_6)+c_1(s_{23}s_4c_6+c_{23}s_5s_6+s_{23}c_4c_5s_6) \\
o_z &= -c_{23}(c_4c_5s_6+s_4c_6)+s_{23}s_5s_6 \\
a_x &= c_1s_4s_5-s_1(c_{23}c_5-s_{23}c_4s_5) \\
a_y &= s_1s_4s_5+c_1(c_{23}c_5-s_{23}c_4s_5) \\
a_z &= c_{23}c_4s_5+s_{23}c_5 \\
p_x &= -a_1s_1+a_2s_1s_2+a_3s_1s_{23}-d_4s_1c_{23}+d_6(c_1s_4s_5-s_1c_{23}c_5+s_1s_{23}c_4s_5) \\
p_y &= a_1c_1-a_2c_1s_2-a_3c_1s_{23}+d_4c_1c_{23}+d_6(s_1s_4s_5+c_1c_{23}c_5-c_1s_{23}c_4s_5) \\
p_z &= a_2c_2+a_3c_{23}+d_4s_{23}+d_6(s_{23}c_5+c_{23}c_4s_5)
\end{aligned} \quad (2)$$

In the above equation the following notation is made :

$C_{23} = c_2c_3-s_2s_3$ and $S_{23} = s_2c_3+c_2s_3$

After getting equation (2), then by giving the value of θi to each joint variables so that, we get the value of the end-effector position. It was implemented the equation (2) in the Matlab function in order to calculate the forward kinematics based on the algorithm presented below. Examples of solving kinematic forward problems using Matlab software.

Given ;

1. $\theta 1 = 45^0$, $\theta 2 = 10^0$, $\theta 3 = 0^0$, $\theta 4 = 90^0$, $\theta 5 = 0^0$, $\theta 6 = 45^0$

The Position of the end-effector, namely :

P_X = -0.8221,.P_y = 0.8221,.P_Z = 0.9895

2. $\theta 1 = 90^0$, $\theta 2 = 0^0$, $\theta 3 = 30^0$, $\theta 4 = 0^0$, $\theta 5 = 90^0$, $\theta 6 = 0^0$

The Position of the end-effector, namely :

P_X = -0.9431,.P_y = 0,.P_Z = 1.3176

3. $\theta 1 = -45^0$, $\theta 2 = 30^0$, $\theta 3 = 30^0$, $\theta 4 = 60^0$, $\theta 5 = 0^0$, $\theta 6 = 90^0$

The Position of the end-effector, namely :

P_X = 0.1916,.P_y = 0.1916,.P_Z = 1.6806

4. Conclusion

Robot kinematics is divided into two types: forward kinematics and inverse kinematics. Forward kinematic involves solving the forward transformation equation to find the location of the hand if given the angles of between the link. Inverse kinematics involves solving the inverse transformation equation to find the relationship between the link of the manipulator from the location of the hand in space. In the robot kinematics, the tool of the end-effector can be moving to where wanted with using the rotation of link and joints. For that purpose, links and joints are accepted as a coordinate system individually, as using homogeneous transformation. To conclude, this project uses a mathematical approach for solving the forward kinematics problem for six-axis Hiwin RA 610 robotic manipulators. The experimental result is obtained by using Matlab software. The inverse kinematics solutions are not addressed in this report due to the complicated solving procedures.

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