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การวิเคราะห์จลนศาสตร์ไปข้างหน้าของ หุ่นยนต์แขนกลรุ่น Denso VS-6577

FORWARD KINEMATIC ANALYSIS OF DENSO VS-6577 ROBOT MANIPULATOR

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บทคัดย่อ

ในปัจจุบันอุตสาหกรรมทั้งขนาดเล็กและขนาดใหญ่ มีการใช้หุ่นยนต์แขนกลเพื่อทำงานให้บรรลุตามเป้าหมายเพิ่มขึ้นเป็นจำนวนมาก เช่นการหยิบจับชิ้นงานและวางชิ้นงาน หรือ กระบวนการเชื่อม การทาสี และการจัดเก็บชิ้นงาน แต่เพื่อให้งานเหล่านี้ ประสบผลสำเร็จ จำเป็นต้องศึกษาการใช้งานของหุ่นยนต์แขนกลอย่างรอบคอบ และปัญหาที่สำคัญที่สุดในการควบคุมหุ่นยนต์แขนกล ประการหนึ่งคือ การได้รับพิกัดตำแหน่งที่แม่นยำ และแนวทางการหาตำแหน่งของ หุ่นยนต์ มีสองวิธี ในการวิเคราะห์หุ่นยนต์ วิธีหนึ่งคือการวิเคราะห์จลนศาสตร์ไปข้างหน้า และอีกวิธีหนึ่งคือการวิเคราะห์จลนศาสตร์ย้อนกลับ โดยบทความนี้มีวัตถุประสงค์เพื่อศึกษาและจำลองการเคลื่อนที่ของหุ่นยนต์แขนกล แบบจลนศาสตร์ไปข้างหน้า ของหุ่นยนต์ Denso VS-6577 ซึ่งเป็นหุ่นยนต์แขนกลแบบ 6 ตัวแปรอิสระ การวางแผนเส้นทางของการเคลื่อนที่ โดยใช้วิธีการ แบบ DH parameter เพื่อคำนวณค่าตำแหน่งของปลายแขน ทำการศึกษา จลนศาสตร์แบบไปข้างหน้า และเปรียบเทียบผลลัพธ์ ของการจำลอง (Simulation) วิเคราะห์ การทำงานของหุ่นยนต์ เพื่อตรวจสอบข้อผิดพลาดที่ยอมรับได้ ด้วยฟังก์ชันการใช้งานของหุ่นยนต์ใน โปรแกรม Matlab

คำสำคัญ: จลนศาสตร์ไปข้างหน้า, อันดับตัวแปรอิสระ, การเปลี่ยนแปลง, DH parameter, แขนกล

ABSTRACT

At present, both small and large industries. Robots are used to accomplish goals and increased a lot, such as handling and placing workpieces, or welding processes, painting and storage. But to complete these tasks, Success It is necessary to study the applications of the mechanical arm robot carefully. And the most critical problem in the control of robots, robotic arms. One is Obtaining accurate location coordinates. There are two methods for analyzing the robot. One way is forward kinematic analysis. And another method is reverse kinetic analysis. The purpose of this article is to study and simulate the motion of a mechanical arm robot. The forward kinematics of the Denso VS-6577, a six independent robotic arm, plotted movement. Using the DH parameter method to calculate end-effector position values, forward kinetics were studied. And compare the results of the simulation (Simulation). Analyze the robot's performance. To check for acceptable errors with the functionality of the robots in the Matlab program

Keywords: Forward kinematic, DOF (degree of freedom), transformation, DH parameter, Robotic arm.

1. Introduction

Robot is a machine that collects the information about the environment using some sensors and makes a decision automatically. Today robots are used in various field like as medical, industry, military operation, in space and some dangerous place. Where human don't want to work. But the controlling of robot manipulator has been challenges with higher DOF. Position and orientation analysis of robotic manipulator is an essential step to design and control. In this paper a basic introduction of the position and orientation analysis of a serial manipulator is given. A robot manipulator consists set of links connected together this either serial or parallel manner. The FK analysis is simple to analysis of model and calculate the position and orientation using the joint angle. Complexity of the FK increases with increase the DOF. So, to analyze FK in this paper use the DH convention and transformation type solution.

2. Kinematics

Kinematics is the branch of mechanics that deals with the motion of the bodies and system without considering the force. And the robot kinematics applies geometry to the study movement of multi DOF kinematic chains that form the structure of robot manipulator [1] Robot kinematic studies the relationship between the linkages of robot with the position, orientation and acceleration. The robot kinematic can be categorized into two main parts: forward and inverse kinematics. Forward kinematics problem is not difficult to perform and there is no complexity in deriving the equation in contrast to the inverse kinematics, which both types are related to DH Parameter and in this paper will consider only in Forward Kinematic.

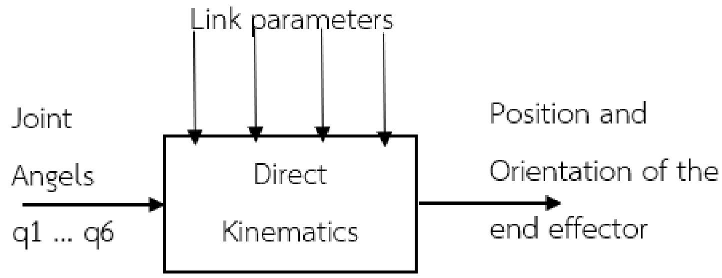

Fig. 1 Operational Structure

3. Forward Kinematic Analysis

This specified the joint parameter and kinematic equation is used to compute the position of end effector from specified value for each joint parameter. Or calculation of the position and orientation of the robotic manipulator in terms of the joint variable is called forward kinematic. The forward kinematics problem is related between the individual joints of the robot manipulator and the position and orientation of the tool or end-effector. The joint variables are the angles between the links for revolute or prismatic joints, and the link extension in the prismatic or sliding joints. A systematic way of describing the geometry of a serial chain of links and joints was proposed by Denavit and Hartenberg and is known today as Denavit-Hartenberg (DH) notation. DH convention is used for selecting frame of reference for the robotic arm. In this convention, coordinate frame are attached to the joints between two link to describe the location of each link relative to its previous. There are four parameter used in DH parameter representation. These parameters describe the relative rotation and translation between consecutive frames. **Link length** (a_i) : the distance between the axis Z_0 and Z_1 and this distance measure along the X_1 axis. **Link offset** (d_i) : distance from origin O_0 to the intersection of the X_1 axis with Z_0 measured along the Z_0 axis (Tran, Z , a_i). **Joint angle** (θ_i) : angle from X_0 and X_1 measured in plane normal to Z_0 (ROT, Z, θ_i). **Link twist** (α_1) : angle between Z_0 and Z_1 measured in plane normal to X_1 axis (ROT, X, α_i)

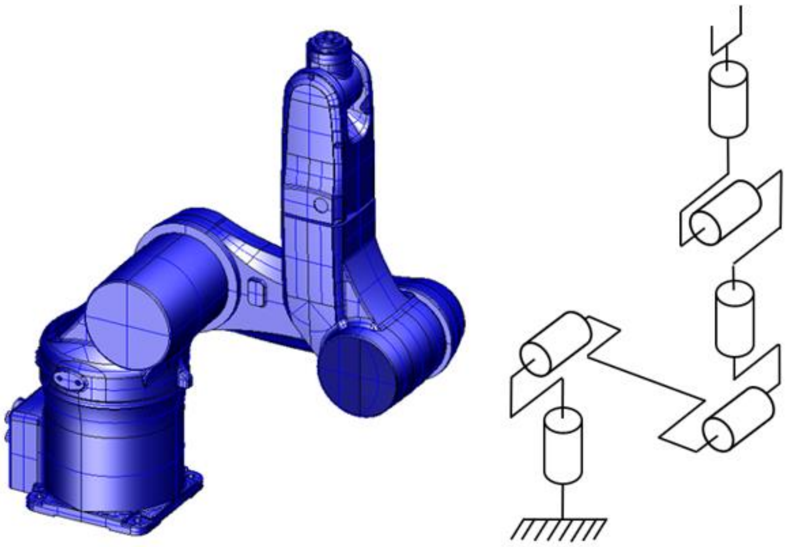

Fig. 2 Frame for the Denso VS-6577G robot Arm

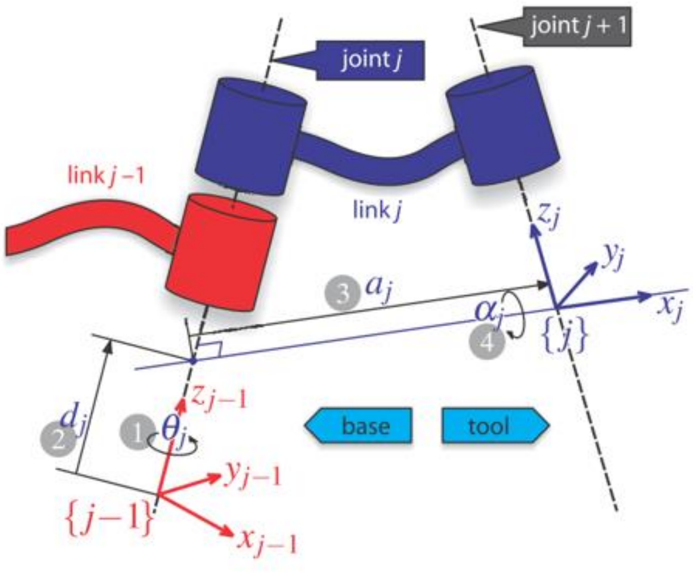

Fig. 3 DH representation of a general-purpose joint-link combination

Table 1 DH Parameter of the Denso VS 6577G Robot Arm

Joint i	θ_i	d_i	a_i	α_i	Joint Limit (degrees)
1	q_1	d_1	0	$\pi/2$	-160, 160
2	q_2	0	a_2	0	-120, 120
3	q_3	0	a_3	$-\pi/2$	20, 160
4	q_4	d_4	0	$\pi/2$	-160, 160
5	q_5	0	0	$-\pi/2$	-120, 120
6	q_6	d_6	0	0	-360, 360

Transformation between two joints in a generic form [3] is given in Eq. (1). Denso Robot is a 6 Degree of Freedom (DOF) robotic manipulator. World frame and joint frames used in calculations and home position of Denso robot are shown in Figure 4

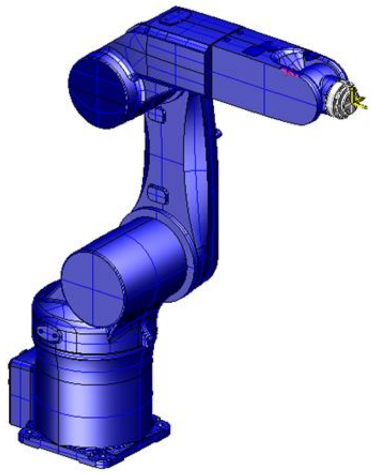

Fig. 4 Home position of Denso VS-6577G robot arm.

Transformation matrix for each joint can be obtained by using Eq. (1). The parameters given in Table 1 are substituted into Eq. (1) to find each of them. Six Transformation matrices are presented in Eq. (2)

$$T_j^{j-1} = \begin{bmatrix} \cos\theta_j & -\sin\theta_j \cos\alpha_j & \sin\theta_j \sin\alpha_j & a_j \cos\theta_j \\ \sin\theta_j & \cos\theta_j \cos\alpha_j & -\cos\theta_j \sin\alpha_j & a_j \sin\theta_j \\ 0 & \sin\alpha_j & \cos\alpha_j & d_j \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$T_1 = \begin{bmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad T_2 = \begin{bmatrix} C_2 & -S_2 & 0 & a_2C_2 \\ S_2 & C_2 & 0 & a_2S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3 = \begin{bmatrix} C_3 & 0 & -S_3 & a_3C_3 \\ S_3 & 0 & C_3 & a_3S_3 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad T_4 = \begin{bmatrix} C_4 & 0 & S_4 & 0 \\ S_4 & 0 & -C_4 & 0 \\ 0 & 1 & 0 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_5 = \begin{bmatrix} C_5 & 0 & -S_5 & 0 \\ S_5 & 0 & C_5 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad T_6 = \begin{bmatrix} C_6 & -S_6 & 0 & 0 \\ S_6 & C_6 & 0 & 0 \\ 0 & 0 & 1 & d_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Where Cos and Sin are abbreviated to C and S, respectively. The total transformation between the base of the robot and the hand is:

$$T_6^0 = T_1T_2T_3T_4T_5T_6 = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

When n (normal), o (orientation), a (approach) elements are for orientation and P (position) element are position elements relative to the reference fream. The elements of the matrix shown in left hand side of Eq. (3) are given in Eqs. (4, 5, 6, and 8).

$$\begin{aligned} n_x &= c6*(s5*(c1*c2*s3 + c1*c3*s2) - c5*(s1*s4 - c4*(c1*c2*c3 - c1*s2*s3))) \\ &\quad - s6*(c4*s1 + s4*(c1*c2*c3 - c1*s2*s3)) \\ n_y &= c6*(s5*(c2*s1*s3 + c3*s1*s2) + c5*(c1*s4 + c4*(c2*c3*s1 - s1*s2*s3))) \\ &\quad + s6*(c1*c4 - s4*(c2*c3*s1 - s1*s2*s3)) \\ n_z &= c6*(s5*(c2*c3 - s2*s3) - c4*c5*(c2*s3 + c3*s2)) + s4*s6*(c2*s3 + c3*s2) \end{aligned} \tag{4}$$

$$o_x = - s6*(s5*(c1*c2*s3 + c1*c3*s2) - c5*(s1*s4 - c4*(c1*c2*c3 - c1*s2*s3))) - c6*(c4*s1 + s4*(c1*c2*c3 - c1*s2*s3))$$
$$o_y = c6*(c1*c4 - s4*(c2*c3*s1 - s1*s2*s3)) - s6*(s5*(c2*s1*s3 + c3*s1*s2) + c5*(c1*s4 + c4*(c2*c3*s1 - s1*s2*s3)))$$
$$o_z = c6*s4*(c2*s3 + c3*s2) - s6*(s5*(c2*c3 - s2*s3) - c4*c5*(c2*s3 + c3*s2)) \quad (5)$$

$$a_x = c5*(c1*c2*s3 + c1*c3*s2) + s5*(s1*s4 - c4*(c1*c2*c3 - c1*s2*s3))$$
$$a_y = c5*(c2*s1*s3 + c3*s1*s2) - s5*(c1*s4 + c4*(c2*c3*s1 - s1*s2*s3))$$
$$a_z = c5*(c2*c3 - s2*s3) + c4*s5*(c2*s3 + c3*s2) \quad (6)$$

$$p_x = a1*c1 + d6*(c5*(c1*c2*s3 + c1*c3*s2) + s5*(s1*s4 - c4*(c1*c2*c3 - c1*s2*s3))) + d4*(c1*c2*s3 + c1*c3*s2) + a2*c1*c2 - a3*c1*s2*s3 + a3*c1*c2*c3$$
$$p_y = a1*s1 + d6*(c5*(c2*s1*s3 + c3*s1*s2) - s5*(c1*s4 + c4*(c2*c3*s1 - s1*s2*s3))) + d4*(c2*s1*s3 + c3*s1*s2) + a2*c2*s1 - a3*s1*s2*s3 + a3*c2*c3*s1$$
$$p_z = d1 - a2*s2 + d4*(c2*c3 - s2*s3) + d6*(c5*(c2*c3 - s2*s3) + c4*s5*(c2*s3 + c3*s2)) - a3*c2*s3 - a3*c3*s2 \quad (7)$$

4. Robot Simulation in Matlab

The toolbox performs many functions for analyzing and simulation of arm type robotic in fields of kinematics, dynamics, and trajectory generation. The Toolbox is based on a very general method of representing the kinematics and dynamics of serial link manipulators. These parameters are included in MATLAB® objects. Designed model by robotics toolbox is given in Fig. 5. The joint space trajectories can be calculated by forward kinematics and a simulation for robot can be done to move robot from initial position to final position in work space as follow Figure 5, 6, 7

Table 2 Position value for End Effector of 6 DOF

Position	Reference Data	Simulation	Angles
	(X, Y, Z) (mm)	(X, Y, Z) (mm)	
0	(0, 790, 597)	(0.01, 793, 594)	P0 = [0; 0; 0; 0; 0; 0]
1	(96.8, 58.6, 549.0)	(96.4, 58.9, 548.6)	P1 = [-170; -100; -119; -180; -120; -360]
2	(0, 790, 597)	(0.01, 793, 594)	P2 = [0; 0; 0; 0; 0; 0]
3	(0.97, 610.2, 5.51)	(0.95, 610.18, 5.53)	P3 = [170; -90; 75; 180; 120; 360]
0	(0, 790, 597)	(0.01, 793, 594)	P4 = [0; 0; 0; 0; 0; 0]

Table 2 shows the trajectory of the robot in the Zero position, as shown in Figure 2. After the travel time reaches 20 sec, the robot will continue to position 1, as shown in Figure 6, and then at 40 sec, it will come to position 2. Then, at the time of 60 sec, it will be position 3 and finally continue to position 4.

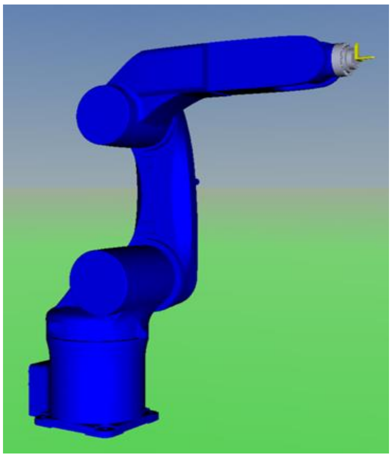

Fig. 5 Position 0

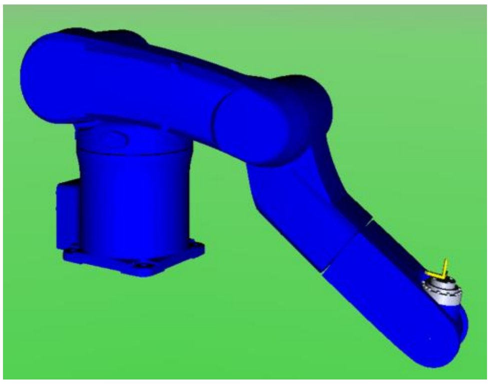

Fig. 6 Position 1

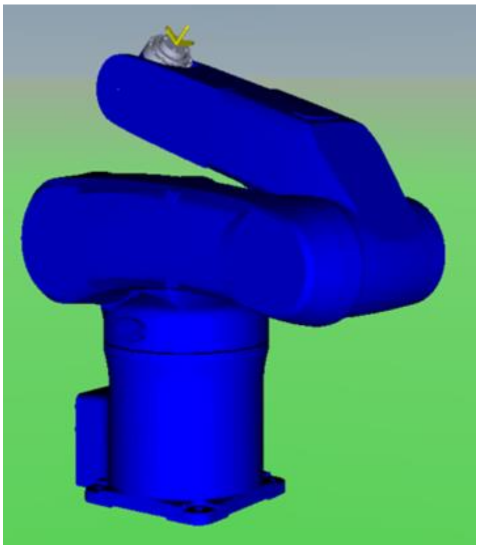

Fig. 7 Position 2

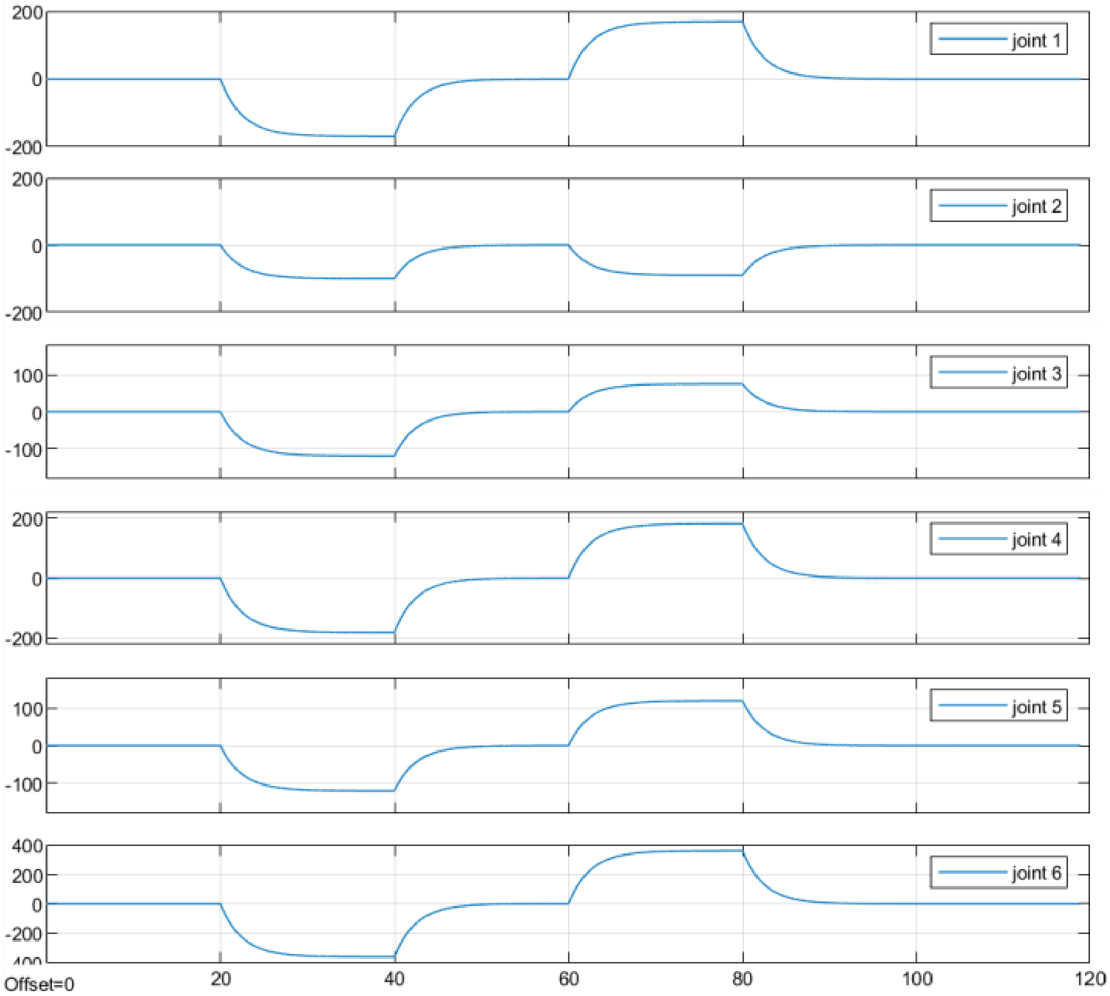

Fig. 8 Angular displacements of the robot links

Figure 8 shows the simulation results of each joint, with the robot Denso VS 6577 having a total of 6 joints when moving simultaneously. It found that the values obtained from the simulation were consistent with the designed values and to study the behavior of each joint that the movement in each joint has a setting time of 10 sec.

5. Conclusion

In this study, it is focused on determining the analytical solution of forward kinematic of the Denso VS-6577 6 axis robot which is available in the laboratory. Robotics toolbox on Matlab is provided a great simplicity to us about kinematics of robots with the ready function on it. However, making calculation in traditional way is important in order to control the robot and to form a background for further studies. Toolbox is then used to verify the results obtained by analytical way. According to the simulation test results, the robot takes the time to move each joint by moving simultaneously on all 6 joints, each coordinate by rotation and translation as designed. And found that the most error of X axis = 2.06%, Y = 0.51%, Z = 0.50%. This study is contained a part of theoretical and numerical kinematics analysis of Denso VS-6577 robot arm. It is performed to build a background study for advance robotics issues.

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