Analysis Industrial Robot Arm with Matlab and RoboAnalyzer

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Abstract— The industrial robot arm to be analyzed is the Motoman K10S, with configuration has 7 parts, namely Base, Rotary Head, Lower Arm, Upper Arm, Wrist Roll, Wrist Pitch Yaw, and Wrist Twist. The first joint connects the Base section with the Rotary Head (joint range of 340º or ± 170º). The second joint connects the Rotary Head section with the Lower Arm (joint range of 240º or ±120º). The third joint connects the Lower Arm section with the Upper Arm (joint range of 275º or ± 137.5º). The fourth joint connects the Upper Arm section with the Wrist Roll (joint range of 360º or ± 180º). The fifth joint connects the Wrist Roll section with the Wrist Pitch Yaw (joint range of 270º or ± 135º). The sixth joint connects the Wrist Pitch Yaw section with the Wrist Twist (joint range of 400º or ± 200º). Based on the configuration of the industrial robot arm, further kinematic modeling of the six joints and the placement of the coordinate axis on each joint. Forward and inverse kinematic calculations are made in Matlab software. Then with RoboAnalyzer as a robot arm simulator to verify the results of the calculations.

Keywords— industrial robot arm, forward kinematic, inverse kinematic, Matlab, RoboAnalyzer.

I. INTRODUCTION

Definition of industrial robots is automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications [1]. An industrial robot is a multipurpose manipulator that is automatically controlled [2]: Three or more axes; (Re)programmable: Translations and Rotations, Movement pattern, and Possibly sensor guided; Can be equipped with different end-effectors for industrial applications: Gripper, Tools, Sensors, etc. Basically, the main components of an industrial arm robots are designed to refer to existing standards as shown in Figure 1 below. In the picture you can see the Base, Rotary Head, Lower Arm, Upper Arm, Wrist Roll, Wrist Pitch Yaw, and Wrist Twist sections. Base as a holder that will be mounted on the location where the robot is placed. The Rotary Head is a horizontal rotating part (S axis) above the Base, and above the Rotary Head there is a Lower Arm section connected to the joint - Waist (waist) that rotates vertically (L axis). Upper Arm is the part that is above the Lower Arm and is connected by a joint - Shoulder (shoulder) that rotates vertically (U axis).
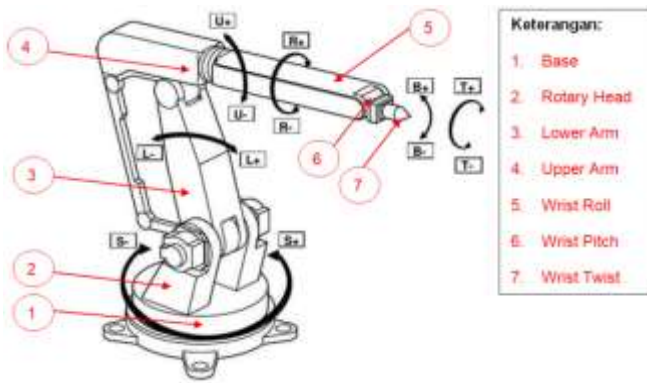
Fig. 1: Industrial Robot Arm Configuration [3]

After the Upper Arm there is the Wrist Roll and it is connected to the joint - Wrist (wrist) which rotates about the axis of the Upper Arm (R axis). After the Wrist Roll there is a part of the Wrist Pitch Yaw and it is connected to the joint - Wrist (wrist) that rotates to the perpendicular to the axis of the Upper Arm (axis B). Then at the very end after the Wrist Pitch Yaw there is a part of the Wrist Twist and it is connected with a joint - Wrist (wrist) that rotates about the upper arm axis of the arm (T axis).

The industrial robot configuration that is designed has 6 joints and the names of each joint and their maximum-minimum limits can be seen in Table 1 below:

Table 1   Joint Robot Arm Rotation Limitation and Direction

No	Joint i	Structur	Max.	Min.	Joint Range	Axis
1	1	Turning	170° (kekiri)	-170° (kekanan)	340°	S
2	2	Lower arm	120° (kebawah)	-120° (keatas)	240°	L
3	3	Upper arm	137,5° (kebawah)	-137,5° (keatas)	275°	U
4	4	Wrist roll	180° (CCW)	-180° (CW)	360°	R
5	5	Wrist pitch/ yaw	135° (kebawah)	-135° (keatas)	270°	B
6	6	Wrist twist	200° (CCW)	-200° (CW)	400°	T

And in Figure 2 and Figure 3 below, you can see the placement of the coordinate axis (frame) at each joint of the industrial robot arm that is designed, as follows:
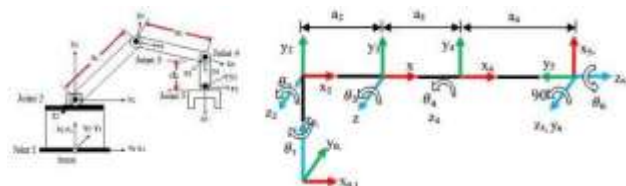

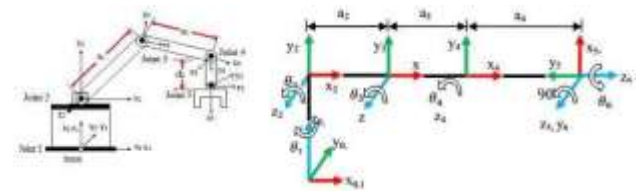*Fig. 2: Industrial Robot Arm Configuration [4]*

Fig. 3: Robot Arm Construction [4]

II.   KINEMATICS MODELING OF INDUSTRIAL ARM ROBOT

To be able to determine the orientation and link position of the robot, kinematic modeling is needed. In robotics, kinematic modeling is a form of statement containing a mathematical description of the geometry of a moving robot structure without considering the force causing it. Based on the forward kinematic analysis, the input reference for each actuator can be determined in the form of an angle so that the robot can make movements to achieve the desired orientation and position. Figure 4 shows the placement of the coordinate axis (frame) on the joint simulator arm robot based on the right hand rule.
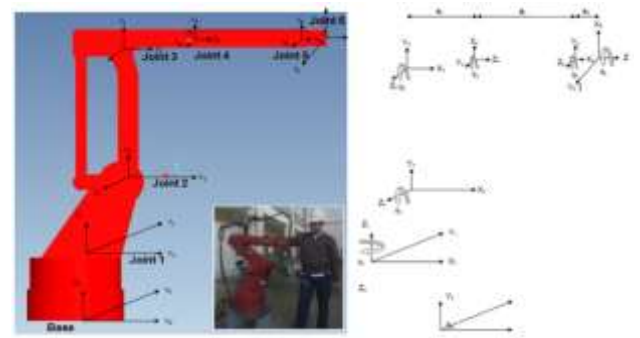

Fig. 4: Coordinate Frames for the Industrial Robot Arm

III.   MATHEMATICAL FORMULATION

The robot arm simulator consists of several links and joints. Joints are used to connect any existing links where each joint represents one degree of freedom. To describe the translational and rotational relationships between adjacent links, the Denavit Hartenberg (DH) parameter method is used as a matrix method that systematically builds a coordinate system from each link. Table 2 shows the DH parameters of the robot arm simulator. Based on the DH parameter, then the matrix transformation of each frame coordinate can be determined from link i to i + 1 using the following equation:

$$^{i-1}_iT = \begin{bmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Table 2   DH Parameters for the industrial Robot Arm

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0°	0	0	θ_1
2	90°	0	0	θ_2
3	0°	a_1	0	θ_3
4	0°	a_2	0	θ_4
5	0°	a_3	0	θ_5
6	90°	0	0	θ_6

To calculate the forward kinematic, we determine the values a1 = 119 mm, a2 = 119 mm, a3 = 165 mm and a4 = 47.5 mm based on the link length of the robot arm designed, then determine the sampling angle value □i, for example θ1 = 60°, θ2 = 60°, θ3 = 60°, θ4 = 60°, θ5 = 90°, and θ6 = 60°. Furthermore, using the MATLAB software, a matrix transformation equation is obtained which states the orientation matrix and position vector from the base to the end effector as follows:

$$^0T_5 = {}^0T_1 \cdot {}^1T_2 \cdot {}^2T_3 \cdot {}^3T_4 \cdot {}^4T_5 \cdot {}^5T_6$$

$$^0T_6 = \begin{bmatrix} -0{,}0000 & 0{,}8660 & 0{,}5 & 28{,}1997 \\ 0{,}0000 & 0{,}5000 & -0{,}8660 & -48{,}8433 \\ -1{,}0000 & 0 & -0{,}0000 & 197{,}8006 \\ 0 & 0 & 0 & 1{,}0000 \end{bmatrix} \quad (2)$$

(Matriks orientasi | Vektor posisi)

To verify the results of the forward kinematic calculation, the RoboAnalyzer software will be used. By entering the link dimensions and angles with the same value when using MATLAB, the following results will be obtained:

$$^0T_6 = \begin{bmatrix} 1E-05 & 0{,}8660 & 0{,}4999 & 28{,}1979 \\ -1{,}8E-05 & 0{,}4999 & -0{,}8660 & -48{,}8419 \\ -1{,}0000 & 0 & 2{,}1E-05 & 197{,}8018 \\ 0 & 0 & 0 & 1{,}0000 \end{bmatrix} \quad (3)$$

IV.   FORWARD KINEMATICS

The calculation of forward kinematics of the industrial robot arm is carried out either with the help of MATLAB software or with the RoboAnalyzer software for verification. In the early stages, modeling of the robot was carried out, then continued by compiling the DH Parameters (Denavit-Hatenberg parameter) of the modeled industrial robot arm. And the next step is to calculate forward kinematics based on the initial value or the angle of each joint. The steps from this stage are as follows:

The modeling of the industrial robot arm that is carried out is to determine the position of the X-Y-Z axis for each joint, namely from joint 1 to joint 6. And for more details, see Figure 3 above.

4.1. FORWARD KINEMATICS WITH MATLAB

Based on the industrial robot arm modeling that has been done, the dimensions of each robot link can be determined which can be written in Matlab program. Then enter the initial value or the amount of rotation of each joint in radians written in Matlab program. Then it can display the robot in an X-Y-Z graph and calculate forward kinematics written in Matlab program (Figure 5).

```
6    % Dimension robot
7-   a1 = 0.119; a2 = a1; a3 = 0.165; a4 = 0.0475;
8
9    % Create Link using this code
10   % L = Link([Theta  d    a    alpha]);
11-  L(1)=Link([0 0 0   0]);
12-  L(2)=Link([0 0 0   pi/2]);
13-  L(3)=Link([0 0 a1 0]);
14-  L(4)=Link([0 0 a2 0]);
15-  L(5)=Link([0 0 a3 0]);
16-  L(6)=Link([0 0 a4 pi/2]);
17-  robo=SerialLink(L, 'name', 'Motoman')

19   % Putaran (initial value) tiap joint [rad]
20-  q1=-0.5137;
21-  q2=-0.5137;
22-  q3=1.7916;
23-  q4=-0.5124;
24-  q5=-1.9537;
25-  q6=-0.8474;

27   % Tampilkan robot dalam grafik x-y-z berdasarkan inputan sudut tiap joint
28-  robo.plot([q1 q2 q3 q4 q5 q6])
29
30   % Forward kinematik dengan inputan sudut tiap joint (q1 s/d q6)
31   % Tampilkan Homogenous Transformation Matrix
32-  robo.fkine([q1 q2 q3 q4 q5 q6])
```

Fig. 5: Coordinate Frames for the Industrial Robot Arm

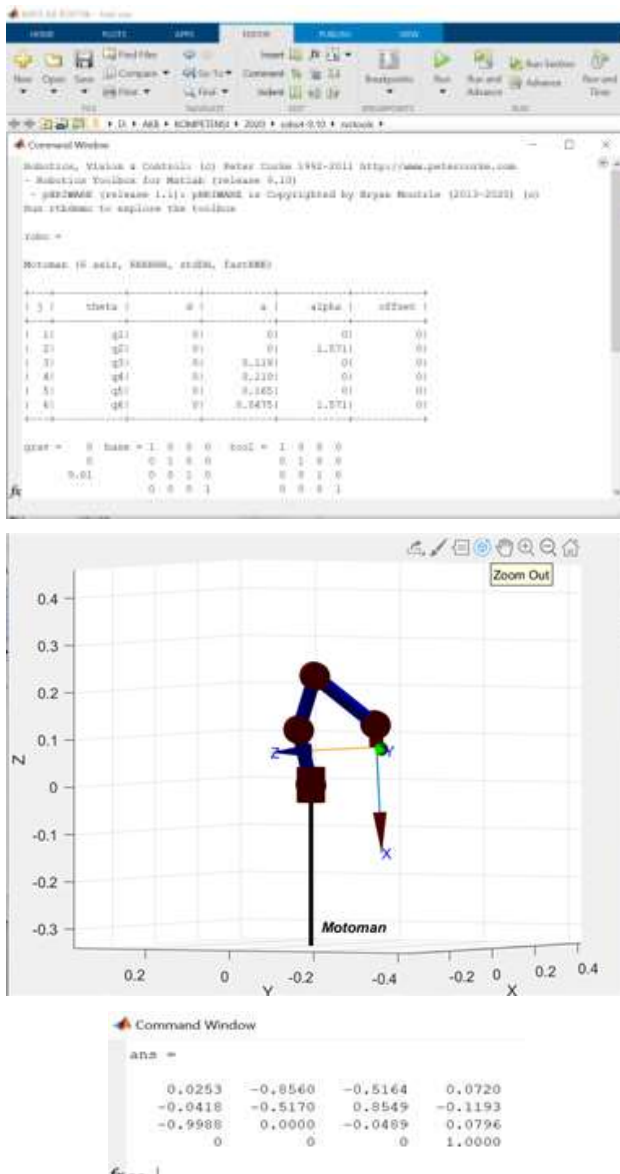And the results in matlab can be seen in Figure 6:

Fig. 6: Result of Forward Kinematics in Matlab

Fig. 7: Simulation of Forward Kinematics in RoboAnalyzer

Based on the results obtained above is a homogenous transformation matrix, which contains rotation and translation as well as the position of the end-effector, as follows:

X = 0.0720; Y = -0.1193; dan Z = 0.0796.

4.2. FORWARD KINEMATICS WITH ROBOANALYZER

And in addition to matlab, forward kinematics calculations can be carried out with the help of RoboAnalyzer software for verification and the results can be seen in Figure 7:

Based on the results of the calculation of forward kinematics using the RoboAnalyzer software above, it can be seen that the end-effector position is:

X = 0.072044; Y = -0.119267; and Z = 0.079601.

V. INVERSE KINEMATICS

In the inverse kinematics calculation of the industrial robot arm, it is carried out both with the help of MATLAB software and the RoboAnalyzer software for verification. In the early stages, modeling of the robot was carried out, then continued by compiling the DH Parameters (Denavit-Hatenberg parameter) of the modeled industrial robot arm. And the next step is to calculate inverse kinematics based on the initial value or the angle of each joint. The steps from this stage are as follows:

The modeling of the industrial robot arm that is carried out is to determine the position of the X-Y-Z axis for each joint, namely from joint 1 to joint 6. And for more details, see Figure 3 above.

5.1. INVERSE KINEMATICS WITH MATLAB

Based on the industrial robot arm modeling that has been done, the dimensions of each robot link can be determined which can be written in Matlab program. Then enter the position of the end effector, which is the translation on the X, Y, and Z axes in mm and the rotation on the X, Y, and Z axes in degrees written in Matlab program. Then the inverse kinematics calculation can be done and display the robot in an X-Y-Z graph written in Matlab program (Figure 8).

Fig. 8: Matlab Program for Forward Kinematics

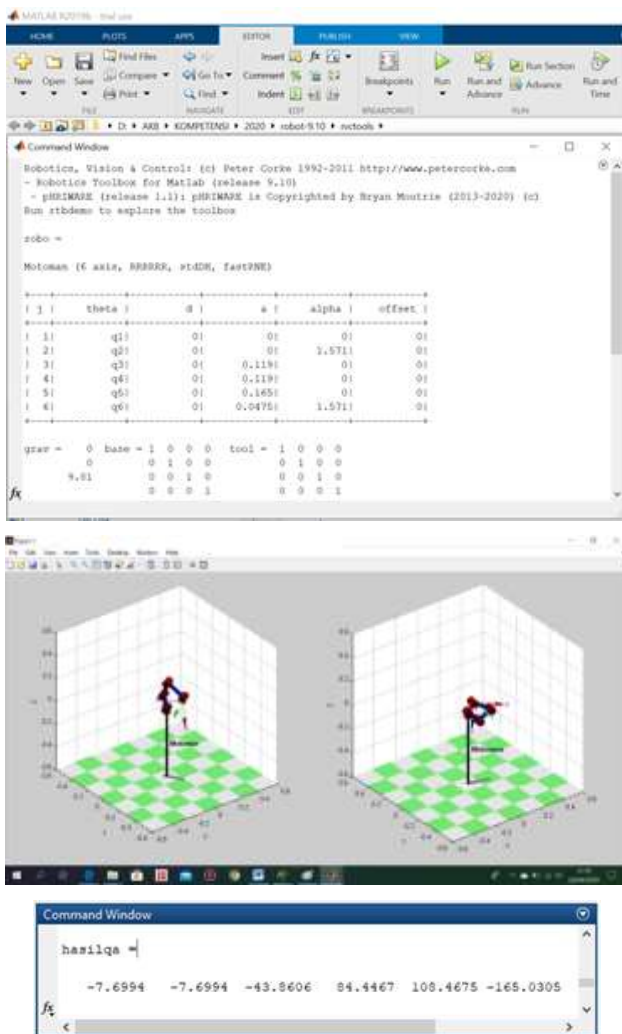And the results in matlab can be seen in Figure 9:

Fig. 9: Result of Inverse Kinematics in Matlab

Based on the results obtained above, the amount of rotation of each joint is in degrees, as follows:

q1 = -7.6994; q2 = -7.6994; q3 = -43.8606;

q4 = 84.4467; q5 = 108.4675; and q6 = -165.0305

V.1. INVERSE KINEMATICS WITH ROBOANALYZER

And in addition to matlab, inverse kinematics calculations can be done with the help of RoboAnalyzer software for verification and the results can be seen in Figure 10:

Fig. 10: Simulation of Inverse Kinematics in RoboAnalyzer

Based on the results of inverse kinematics calculations with the RoboAnalyzer software above, it can be seen that the rotation rate of each joint in radians is:

q1 = -7.6994; q2 = -7.6994; q3 = -43.8606;

q4 = 84.4467; q5 = 108.4675; and q6 = -165.0305

IV.   RESULTS AND DISCUSSION

Based on the simulation results of forward and inverse kinematics in Matlab and RoboAnalyzer for industrial robot arm. The results of simulation forward kinematics in RoboAnalyzer is almost the same as that generated from the Matlab program, And the results of simulation inverse kinematics in RoboAnalyzer is almost the same as that generated from the matlab program.

V.   CONCLUSION

Based on the paper results can be concluded as follows:

1. The forward kinematics calculations were successfully carried out in Matlab program and RoboAnalyzer software.

2. The inverse kinematics calculations were successfully carried out in Matlab program and RoboAnalyzer software.

3. The kinematic simulation that has been done can be

used as the basis for controlling the designed industrial arm robot.

ACKNOWLEDGEMENTS

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