Simulation and kinematic analysis of KUKA KR5 Arc robot

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Abstract. Nowadays robots have become an indispensable part of manufacturing systems, for gripping needs manipulators are needed. Trade sector is touching industry 4.0 and asks for a much-advanced automation process. In which commercial robots play an essential role in automating the methods such as material handling, palletizing, painting, assembly lines, and numerous applications. With the increase in demand and need to have more research on engineering robots, artificial intelligence, and machine learning. A systematic design and analysis study is needed to get the best output for a specific robot. In India, there is scarcity of Indian based robot manufacturers to satisfy the rising need. Hence, there is more influence of foreign robot manufacturer in Indian markets. Due to the deficient information in robotics, robot part and resources are unavailable. More and more open source and easily access information regarding industrial robot is needed. So, this work emphasis on the developing and designing six degrees of freedom robotic arm and its kinematic analysis particularly forward and inverse kinematics. This paper gives an idea of the Denavit Hartenberg method for forward and inverse kinematics of a 6 axis KUKA KR5 Arc robot and uses RoboAnalyzer simulation software. The RoboAnalyzer is simulation software that is used for design, kinematics, and dynamic analysis.

1. Introduction

In a new era of engineering automation, Robotics has to turn out to be fundamental and economical manpower in the field of research and mass manufacturing. In robotic research, robotic kinematic parameters and end position of end effectors play a very crucial role in its control strategy [1]. In the studies of robotics, kinematic study is the footing of robot technology study and the prominent characteristics to know robot pathway planning as well as its motion regulator [2]. The Denavit Hartenberg process is most considered to define the relation among forward and inverse solutions to study the kinematics in the robot kinematic model. To perform the kinematic analysis and establishing a correlation b/w the end effector and its characteristics, the transformation matrix given by Denavit Hartenberg is used [3].

RoboAnalyzer is simulation software comprising of option putting the Denavit Hartenberg features of the robotic arm. This software gives an option to select from one to seven degrees of freedom [4]. An operator may also make a customized robot after changing kinds of joints and sizes. Kinematic transformations are proved using Roboanalyser software simulation [5]. When any value is put in the (DH) Denavit Hartenberg table, initial as well as the final manipulator joint dimensions may be altered for the forward kinematic investigation. This simulation software also has an integral simulation representation of robots from numerous creators such as MTAB, FANUC, ABB, KUKA, etc. Any handler may differ numeric values inside the input column and trace the path covered by the manipulator.
1.1. Characteristics of Roboanalyze:
This software is utilized to get the kinematic analysis and dynamic analyses of robotic manipulators. Mainly it is used to get the following results:

- DH characteristics simulation,
- Forward Kinematics,
- Forward Dynamics
- Inverse Kinematics,
- Inverse Dynamics
- Path Planning

2. Denavit-Hartenberg Illustration of the Kuka 3r Arc Robot

Countless industrial robots are made up of quite a lot of rigid links associated with joints. The degrees of freedom show the no. of self-determining input desired to rightly put all the fixed links of any robot about the stationary or any fixed link [3]. All rigid links being coupled through such joints. These joints may be the (P) prismatic joints displaying translatory motion and (R) revolute joint displaying revolution motion [4]. For calculating the outcome of the joint adjustable on a location as well as the orientation of the robotic arm, it is crucial to make a relationship among base as well as end-effectors of the manipulator. Figure 1 shows the graphic user interface, in which the upper window shows the build of the robot and bottom boxes of the window shows D-H parameters.

Numerous industrial robots are made up of several rigid links fixed to each other by joint. The degrees of freedom give a sum of the autonomous inputs required to accurately position all of the links of the robotic manipulator about ground or the immovable link [6]. All rigid links are coupled through joints. All these linkage joints may be the (P) prismatic joint that shows the translation motion as well as the (R) revolute joint that shows revolution motion [7]. For calculating any result of the joint adjustable on the position along with the alignment of the robot, where it is crucial to create a relation among coordinate planes fixed to its base position and the end-effectors of the robot [8].

- (a) Twist angle: angle among orthogonal projections of joint axes onto a plane normal to common normal
- (θ) Joint angle: angle among orthogonal projections of common normal to plane normal to joint axes.
- (d) Joint offset: lengths of intersections of common normal on joint axis
- (a) Link length: a measure of the path among common normal to the axis.

α, θ - varies if the joint is revolute and prismatic respectively [9]
3. Analysis of Forward Kinematics

For calculating forward kinematics analysis, measures of joint angles are entered, position and orientation of end-effectors of the robot are obtained. According to the D-H formulation, a homogenous matrix transformation is achieved in the form of a 4x4 matrix using the orientation of the base of the robotic arm to the end-effectors [10]. In the homogenous transforming matrix, the DH parameters from the base of the link to end-effectors link must be attached, further, it is multiplied to calculate the position of end-effectors in the KUKA 3R Arc robot in 3-D space, with the below equation:

\[ \begin{bmatrix} b_{T_{ee}} \end{bmatrix} = \begin{bmatrix} 0 & T_1 & T_2 & T_3 & T_4 & T_5 & T_6 \end{bmatrix} \]

which can further be represented as

\[ b_{T_{ee}} = \begin{bmatrix} R & \chi \\ y & z \\ 0 & 1 \end{bmatrix} \]

In which, R (3x3) denotes the positioning of end-effectors utilizing the direction cosine procedure as well as [x,y,z]T signifies the position vectors regarding its reference coordinate frame. Transformation homogenous matrix process could be pictured in RoboAnalyzer software by putting input value in the DH table which is given in said software. In figure 2 an illustration is shown, (position of end-effectors).
In the graph, Transformation homogenous matrix could be proved as well as pictured. The final location of end-effectors in the $[x,y,z]^T$ 3D space is shown in Figure 3, where the (x)-axis in the graph denotes the estimated time of simulation, and here (y)-axis denotes the position value of the end-effectors.

3.1. Robot Motion Visualization
It is very difficult to visualize the motion of the robot without the support of any software tool. 3D software for Robot visualization has played a very important role by enabling viewers to visualize the path traced by the robot in 3D space as well as the path followed by end-effectors. The said software permits an operator to enter essential D-H characteristics. As soon as all inputs are provided, the forward kinematics processes are being executed in the simulation of the robot. As given in figure 4, this also gives the location of the end-effectors in the matrix.
Figure 4. Path drawing and visualization of KUKA KR5 Arc.

The RoboAnalyzer software also comprises of Virtual Robot Module (VRM) that allows an operator the usage of a teach pendant-style user interface for the operation of any one of the already loaded industrial robots, which figure 5 also shows.

Figure 5. The virtual model of the KUKA KR5 Arc in RoboAnalyzer is displayed.
4. Analysis of Inverse Kinematics
Inverse kinematics demarks with defining a joint angle for any given position and orientation of end-effectors of a robotic manipulator in the 3-D space [11]. Analysis of Inverse kinematics deals with computational equations to attain solutions for any specified position of the robot. With the increase in numbers of the degrees of freedom, there is also an increase in the total number of solutions of inverse kinematics. RoboAnalyzer software has an inbuilt inverse kinematics module in which an operator may select a robot from the set menu to achieve inverse kinematic analysis. This software displays several solutions in situation of inverse kinematic analysis. Figure 6 show the illustration of the inverse kinematics analysis.

![Inverse Kinematics](image)

Figure 6. Solutions of Inverse Kinematics.

5. Conclusion
The KUKA 3R Arc robot is selected and the motion study is calculated by the means of robot picturing software. Kinematic studies of the said robot can act as the laid foundation for the proposed designs of robot for further use in industries like electronics, warehouses, automobiles, etc. With the help of such analysis, it's easier to understand the kinematic structure and verification can be done to check the correctness. This paper can be helpful for analysis of the kinematic studies of the robotic gripper having
different dimensions of the link lengths, forward and inverse analysis of kinematic model can be achieved using D-H model in this software (Roboanalyzer).

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