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Research paper

Integration of ROBO-analyzer for forward and inverse kine-mastics of 6 DOF robot to check flexible DH parameters.

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Abstract

The installation of the robotic arm is based on the type of application to be carried out. On the basis of the application, the task performs by the industrial robotic arm is the command of inputs provided by the operator. The changes in the design of industrial robotic arm are associated with the changes in the parameters such as required work volume, payload capacity, link length, type of joint, degree of freedom. The need for industries to carry out efficient work focuses on the features of the robotic arm. The main feature associated with a robotic arm is its flexibility. This paper proposes a methodology to obtain flexibility in robotic arm and its impact on the DH parameters along with velocity, acceleration, forces associated with the joint. To solve the inverse kinematics of complex robotic arm the integration is done with RoboAnalyzer software.

Keywords: *Command Inputs; DH Parameters; Flexibility; Installation; Payload.*

1. Introduction

In the field of manufacturing, medical surgery and hazardous environmental situations there is a need for human assistance. Nowadays robots are installed to perform difficult operations which cannot be easily done by humans. Development in the field of robotics takes a straight path which will never end. Installation of industrial robots in the industries increases the productivity and reduce the labor cost. There are several challenges faced in the integration of various features like flexibility, accuracy, workabil- ity, dexterity, reliability, repeatability with the robotic arm. To achieve these features in the robotic arm several methods are de- veloped. The structure of industrial robotic arm consists of an arm body and end effector. The ram body consists of links and joints associated with neighboring links. The motion of the robotic arm is based on the selection of the motion at joints. The key element of the robotic arm after the controller is kinematics. There are two types of kinematics, one is forward kinematics and second is the inverse kinematics. Forward kinematics is used to calculate the end effector position from known joint parameters and inverse kinematics is used to calculate the joint configuration by fixing the end effector position. There are several challenges to solve the inverse kinematics of the complex robotic arm. There are various approaches to solve inverse kinematics by use of geometric, alge- braic and iterative methods. Triangulation method based on the geometric approach of inverse kinematics to find out joint parame- ters by using cosine rule [1]. To solve the kinematics, the robotic arm is integrated with various software making it easy. Wong Guan Hao et.al [2] integrated 6-DoF robotic arm with SMART ARM software, which makes simplicity in solving the inverse kinematics and efficient trajectory planning. The inverse kinematics of the robotic arm is used to obtain the joint parameters also known as DH parameters. These DH parameters are used to find out the configuration of the robotic arm. Maintaining flexibility in the robotic arm is depending on the design and its associated DH parameters.

In these paper, we present a methodology to check the flexibility of robotic arm by solving inverse kinematics. In this experiment, we use Roboanalyzer software integrated with a robotic arm. These software helps to visualize DH parameters and efficiently solve kinematics. The rest of the paper follows section (2) consist of manipulator design, section (3) consist of kinematics, section
(4) consist of DH parameters, section (5) consist of Flexible DH parameters, section (6) consist of result and discussion and section (7) consist of conclusion.

2. Design

Design of the robotic arm is based its area of application. Mainly there are two types of robotic manipulator one is serial manipulator in which links are connected serially and second is parallel manipulator in which platform is placed on the parallel arms of the robot. The design of the robotic arm is based on the several factors such as axis, Degrees of Freedom, links, types of joints, payload capacity, workspace etc. The motion of the robotic arm is based on the type of motion associated with each joint. Fig 1. Shows the schematics of the 6DoF robotic arm.

To obtain the flexibility in the robotic arm, the various joint mechanism used. Farhad Aghili et.al [4] used cylindrical lockable joint inside the link to obtain the flexibility in the workspace. El Hansali Hasnaa et.al [5] developed a 6-DoF HEXA robot which is the combination of bottom fixed base and top flat parallel platform
joined by using six actuated joints which assigns 6-DoF to the moving platform. Also, payload capacity plays an important role in the design of the robotic arm. The maximum range of the pay- load

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capacity varies between 0.5 to 14 Kg [6]. In these paper we design a six DoF robotic arm having adjustable offset by using a cylindrical joint mechanism which will increase the flexibility in the specified workspace.

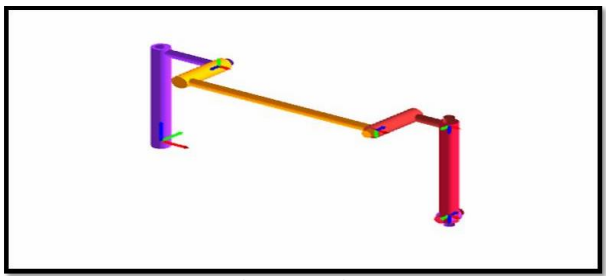


Fig. 1: Configuration of Robotic Arm.

3. Kinematics

The kinematics of the robotic arm is associated with the link, joint, frame. It is used to define the motion strategy of the robotic arm by evaluating the position, velocity, and acceleration at each joint in 3D space. Kinematic analysis is of two types one is Forward kinematics and second is inverse kinematics. The forward kine- matics is used to find out end effector position in the work volume by solving a kinematic equation which is created by making a contribution of DH parameters.

$$X = a1.\cos(\theta1) + a2.\cos(\theta1 + \theta2) + a3.\cos(\theta1 + \theta2 + \theta3) + a4.\cos(\theta1 + \theta2 + \theta3 + \theta4) + a5.\cos(\theta1 + \theta2 + \theta3 + \theta4 + \theta5) + a6.\cos(\theta1 + \theta2 + \theta3 + \theta4 + \theta5 + \theta6) \quad (1)$$

$$Y = a1.\sin(\theta1) + a2.\sin(\theta1 + \theta2) + a3.\sin(\theta1 + \theta2 + \theta3 + \theta4) + a4.\sin(\theta1 + \theta2 + \theta3 + \theta4) + a5.\sin(\theta1 + \theta2 + \theta3 + \theta4 + \theta5) + a6.\sin(\theta1 + \theta2 + \theta3 + \theta4 + \theta5 + \theta6) \quad (2)$$

From this equation (1) and equation (2), the actual () position of the end effector in 3D space is calculated.
The inverse kinematics is used to solve the configuration of the Robotic arm by fixing the end effector position. The inverse kinematic equation for 3D of freedom robotic arm.

$$\theta2 = \cos^{-1}\left\{\frac{(X3.X3)+(Y3.Y3)-(L1.L1)-(L2.L2)}{2.L1.L2}\right\} \quad (3)$$

$$\theta1 = \tan^{-1}\left\{\frac{Y3(L1+L2.\cos\theta2)-X3(L2.\sin\theta2)}{X3(L1+L2.\cos\theta2)+Y3(L2.\sin\theta2)}\right\} \quad (4)$$

The values of X3 and Y3 are calculated from end effector position- and its angle of orientation with joint 3. These equations are

X3=X-L3.cosφ

Y3=Y-L3.sinφ.

These calculations are done for a simple 3DoF robotic arm. From equation (3) and (4) the values of rotation angle at joint1 and joint2 are calculated. But as the number of DoF associated with arm increases the complexity of this evaluation also increases. To reduce down this complexity most of the robotic arm having high- er degrees of freedom are integrated with robotics software. In [2] the 6-DoF robotic arm is integrated with SMART ARM software for efficient trajectory planning. There are various methods to solve inverse kinematics such as analytical, algebraic, iterative etc. Eimei Oyama et.al [8] proposed methodology to perform inverse

4. DH parameters

The Denavit and Hartenberg parameters are used to configure the manipulator. The interchangeability between the end effector position co-ordinate and configuration of the arm body is based on the type of kinematics used. In forward kinematics, end-effector coordinates are the function of DH parameters whereas in inverse kinematics DH parameters are the function of end effector co- ordinate [7]. The calculation of DH parameters in inverse kinemat- ics is difficult due to non-linearity in the equation and also gener- ates multiple solutions for a single orientation of the end effector. There are four types of DH parameters on which configuration of the arm body developed. These are linked length(a), joint offset(d), the angle of rotation(θ), twisting angle(α). Out of four, only the angle of rotation(θ) is flexible while others are fixed. The perfor- mance of the trajectory is based on the change in the value of the angle of rotation (θ). In inverse kinematics due to possible multi- ple solutions of the single orientation of the end effector, the selec- tion of best solution gives effective and efficient trajectory by gradually transferring the load from the end effector to base. For this selection of best solution visualization of the trajectory is required and these can be possible only with the integration of Robotic arm and Roboanalyzer software.

Table 1: Values of DH Parameters for 6R 6-Dof Robotic Arm

Joint No	Link (a)	Offset (d)	Joint angle (θ)	Twist angle(α)
Joint1	0.18	0.4	Variable	90
Joint2	0.6	0.135	Variable	180
Joint3	0.12	0.135	Variable	-90
Joint4	0	0.62	Variable	90
Joint5	0	0	Variable	-90
Joint6	0	0	Variable	0

The values of DH parameters are used to configured the robotic arm shown in fig.1.

5. Flexible DH parameters

The flexibility of the DH parameters is based on the angle of rotation at each joint. While performing an operation on specified trajectory the values of angle of rotation changes from an initial value to final value. The trajectory is the function of time. The flexibility of the robotic arm can also be increased by making offset joint vary. These will require an additional mechanism in the neighboring joint. The variability in the offset distance in- creases the workspace and flexibility in the robotic arm.

a) Values of Joint parameters and velocity, acceleration, and forces associated without changing the offset distance

Table 2: Shows the Values of Joint Angle in Inverse Kinematics

Joint No	Link (a)	Joint offset (d)	Joint angle(θ1)	Joint angle(θ2)	Twist angle
Joint 1	0.18	0.4	180	0	90
Joint2	0.6	0	-149.28	-57.02	0
Joint3	0.12	0	-139.79	30.84	-90
Joint4	0	0.62	180	0	90
Joint5	0	0	71.924	26.2	-90
Joint6	0.12	0	0	0	0

Orientation matrix of end effector=$\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}$End effector position X=1, Y=0, Z=0.4

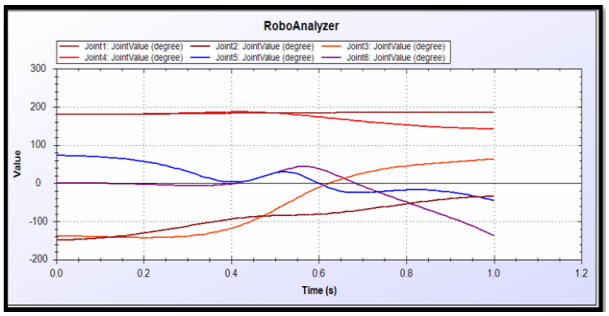


Fig. 2: Joint [1-6] Values of the Robotic Arm.

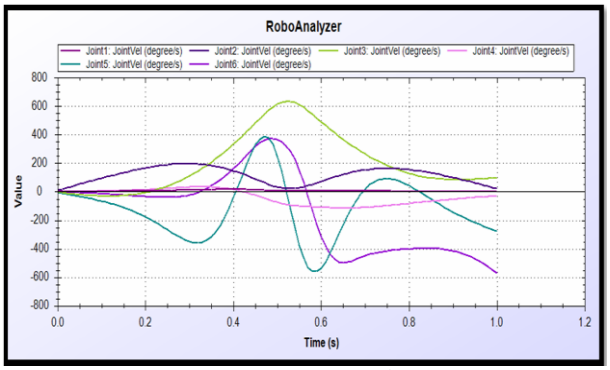


Fig. 3: Shows Joint [1-6] Velocities of the Robotic Arm.

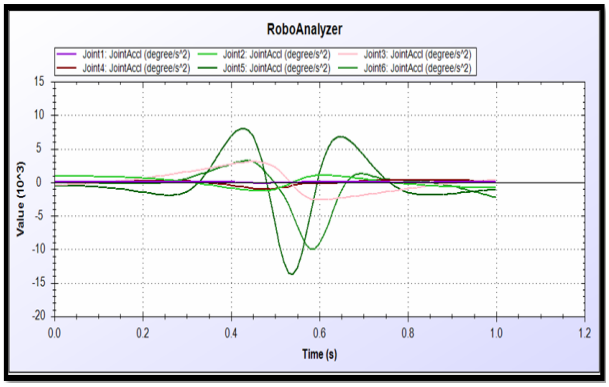


Fig. 4: Shows Joint [1-6] Acceleration Values of the Robotic Arm.

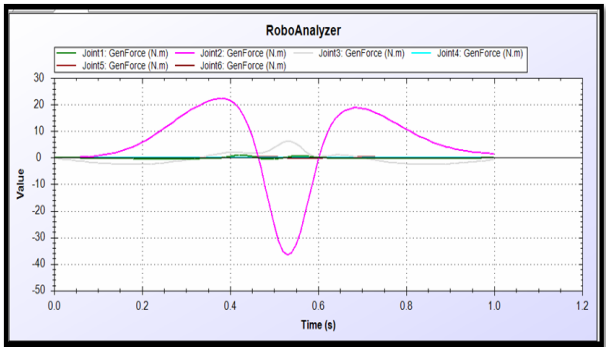


Fig. 5: Shows Joint [1-6] Forces/Torques Values.

b) Values of Joint parameters and velocity, acceleration, and forces associated with changing the offset distance.

Table 3: Values of DH Parameters for 6R 6-Dof Robotic Arm

Joint No.	Link(a)	Offset(d)	Joint angle(θ1)	Joint angle(θ2)	Twist angle(α)
Joint1	0.18	0.3	137.493	42.507	90
Joint2	0.6	0.6	-138.288	-58.375	0
Joint3	0.12	0	-172.995	54.651	-90
Joint4	0	0.62	180	-180	90
Joint5	0	0	48.717	-3.724	-90
Joint6	0.112	0	42.507	137.493	0

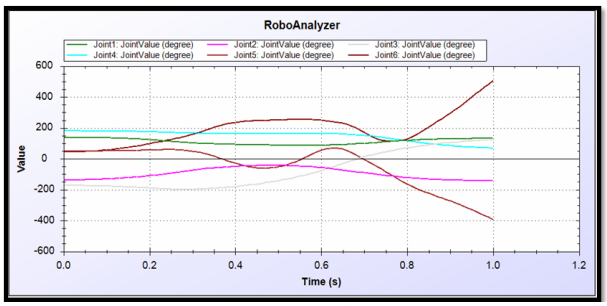


Fig. 6: Joint [1-6] Values of the Robotic Arm.

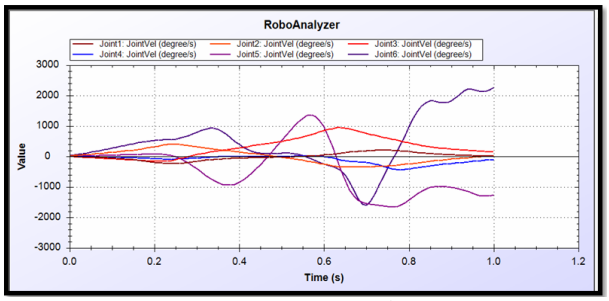


Fig. 7: Shows Joint [1-6] Velocities of the Robotic Arm.

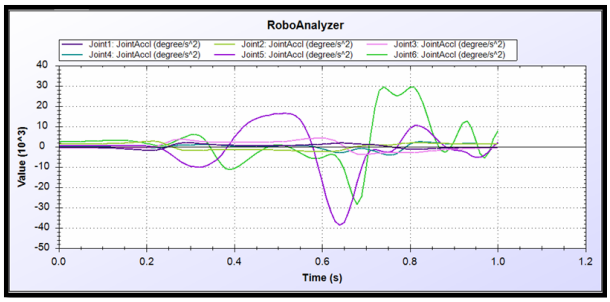


Fig. 8: Shows Joint [1-6] Acceleration Values of the Robotic Arm.

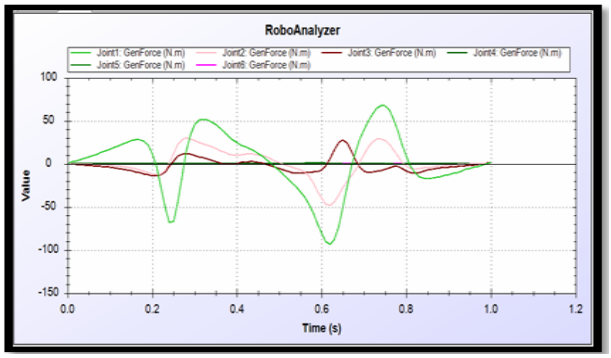


Fig. 9: Shows Joint [1-6] Forces/Torques Value.

6. Result and discussion

In these paper, we presented the graphs of Joint value, Joint velocity, Joint acceleration, Joint forces/torques for six joints. We discussed the flexibility of robotic arm with help of variable angle of rotation and flexible joint offset. We discussed the mechanism, which helps to obtain the flexibility in the joint offset.

On comparing the graph of joint values, velocity, acceleration, and torques of the robotic arm without changing the value of joint offset with the same parameters of a robotic arm with changing

The offset distance. These results show that workspace of the robotic arm increases and variability in the trajectory also increases. The integration of the RoboAnalyzer and Robotic arm is used to solve the inverse kinematics, as it gives a number of solutions for a single orientation of the end effector. Impact of the flexibility of offset joint on the DH parameters and dynamics of the Robotic arm

is discussed. The figures are shown in the paper are used to understand the fundamentals and dynamics of the Robotic arm. The variability of the Robotic arm is also discussed.

7. Conclusion

From this methodology, the flexibility in the robotic arm and its capacity to perform various trajectory increases. The values of velocity, acceleration, force /torque associated with joint shows variation with changing the offset joint. The flexibility in the DH parameters helps to increase the variability in the trajectory per- formance. We conclude that the effective integration of Robo- Analyzer and Robotic Arm solve the inverse kinematics problem by providing number of solutions of angle of rotation of each joint

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