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Design, simulation, and analysis of a 6-axis robot using robot visualization software

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Abstract : In this advanced technological world, robots play an important role in achieving the tasks of a human. Robots have become an essential aspect of the industry, need well-trained engineers to optimize the robot manipulator. To obtain the optimum elements of the work to be carried, a systematic approach required to design, simulate, and analysis of customized robots. This paper presents the design, simulation, and analysis of a 6-axis robot for n-number of applications using solid works simulation and RoboAnalyzer visualization software. The SolidWorks software is used to design the robot and analyzed using the SolidWorks Simulation Xpress and motion study. The robot visualization software: RoboAnalyzer used to analyze the robot kinematics and dynamics. This 3-dimensional software's help to improve the skills and knowledge of industrial robots. Robot design, simulation, and analysis require the use of 3-dimensional software in the event of an invention needed to develop the high-quality design and improved speed where the industry needs.

Keywords: Robot visualization, SolidWorks, RoboAnalyzer, Robot manipulator, Industrial robots

1. INTRODUCTION

In the 21st century, the automation industries are growing with the increasing market and with huge demand in the development of advanced technology. The huge demand in the automation, the conventional technique has been replaced. Many industries are nowadays looking for automation technology rather than the traditional method due to the market. The disadvantages of the traditional way, force the industrialists to look towards the automation technology. In the automation technology, flexible automation creates massive demand in the automobile, aerospace, electronics, medical, etc. as compared to fixed automation. In the field of flexible automation, industrial robots have reached almost all the industries due to its n-number of applications. With the increasing demand for industrial robots, the engineers must design, simulate, and analyze the optimization of manipulator joints and end effectors using robot visualization software[1].

The robot manipulator is a combination of link lengths, joint angles, and kinematic mechanisms, regarded as a complex system. It includes engineering principles and laws during the design and development of the robot. Exceptional design decisions are required while integrating complex components during the beginning of the design. A combined knowledge such as mechanical, electrical, electronics, and computer software is essential to develop robotic systems and manage the functionalities of the robotic system. To minimize the system complexity and functionalities of the system, the proposed software tools help the robotic engineers to optimize the design and help to analyze the robot system from the beginning of the process[2].

In this paper, an attempt has been made to optimize the design and analyze the system specifications. The article enumerates the kinematic model, visualization of robot motion, and motion study of the 6-axis robot using solid works and RoboAnalyzer visualization software.

2. DENAVIT-HARTENBERG (DH) REPRESENTATION OF THE 6-AXIS ROBOT

Many industrial robots have a serial architecture consisting of several rigid links connected via joints. The degree of freedom is the number of independent inputs needed to correctly place all rigid links of the robot concerning the ground or fixed link[3]. The stiff links are connected via joints. These joints can be prismatic (P) exhibits translation motion and revolute (R) joint exhibits revolute motion[4]. To understand the effect of the joint variable on the position and orientation of the robot, it is essential to establish a correlation between the coordinate frames attached to the base and end-effector of the robot. Using the four Denavit-Hartenberg (DH) parameters as shown in table 1, a Homogenous Transformation Matrix can be derived to represent the relative position and orientation of DH frame (i+1) concerning to DH frame i as shown in Figure 1.

Table 1. Description of DH Parameters

Parameter	Symbol	Description	Variable/Constant	Relation
Joint angle	θ_i	Rotation about z-axis	Variable	Joint
Link offset	d_i	Translation along z-axis	Variable	
Link length	a_i	Translation about x-axis	Constant	Link
Joint type	α_i	Rotation about x-axis	Constant	

$$^{b}T_{ee} = T_{rot}(\theta_i,z) * T_{Trans}(d_i,z) * T_{Trans}(a_i,x) * T_{rot}(\alpha_i,x) \tag{1}$$

Which can be expanded in homogeneous matrix form as

$$^{j-1}T_j = \begin{bmatrix} cos(\theta_j) & -sin(\theta_j)cos(\alpha_j) & sin(\theta_j)cos(\alpha_j) & a_j\, cos(\theta_j) \\ sin(\theta_j) & cos(\theta_j)cos(\alpha_j) & -cos(\theta_j)cos(\alpha_j) & a_j\, sin(\theta_j) \\ 0 & sin(\alpha_j) & cos(\alpha_j) & d_j \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

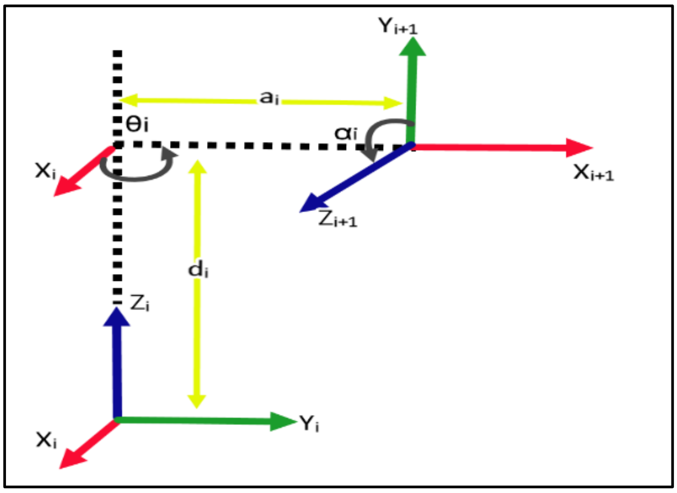

Figure 1. Representation of Denavit-Hartenberg (DH) parameters.

2.1. Assigning of DH parameters

Most industrial robots are designed and developed to cover 3D-workspace more efficiently with the help of joints[5]. The procedure for assigning coordinate frames for DH parameters is as shown in figure 2.

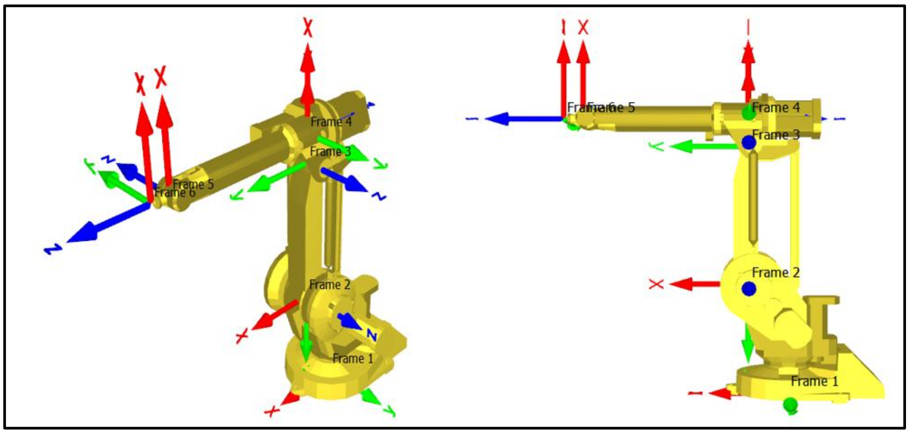

Figure 2. Representation ofDH frames for ABB IRB1410.

The DH parameters methodology is explained below by considering the ABB IRB1410 robot as an example:

1. Attach a reference frame for base or grounded part as shown in the figure above. The coordinate frames are distinguished by the colour coding, e.g. blue colour for z-axis, green colour for the y-axis, and red colour for the x-axis. First frame 1 is attached to the base of the robot, as shown in figure 2.
2. As per the DH-table, the frame 2 is constructed by translating by 475 mm in the z-axis, followed by a translation of 170 mm in the x-axis, and followed by a rotation of -90 degree about the x-axis. The rotation direction follows the right-hand rule and a positive sign indicates rotation in a counter clockwise vice-versa. The other remaining frames are created similarly by following the DH-parameters up to frame 6.
3. Additionally, one can verify the assignment, as shown in figure 3 of the coordinate frame by the specification sheet from the manufacturer from the website or brochure.

The DH parameters of IRB1410 are reported in table 2. The attributes reported in table 2 were verified to match those circled in a diagram for the specification sheet of the robot, shown in Figure 3.

Table 2. DH parameters of ABB IRB1410 robot

Link, i	θ_i(degree)	d_i(mm)	a_i(mm)	α_i(degree)
1	-124.9482	475	170	-90
2	-24.1595	0	600	0
3	-86.755	0	120	90
4	122.3737	-720	0	90
5	-60.3542	0	0	90
6	-16.017	85	0	0

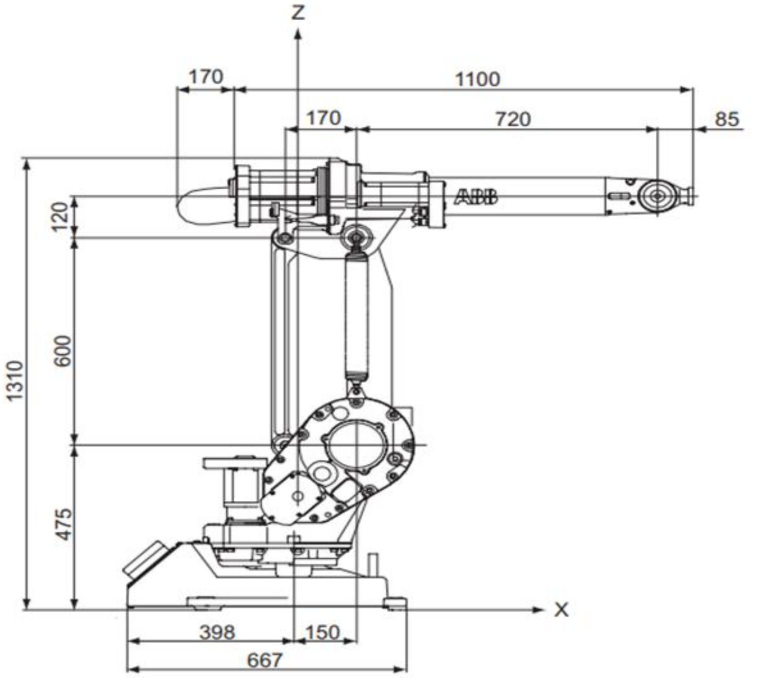

Figure 3. Dimensions in ABB IRB1410 specifications [6].

2.2. Overview of Robo Analyzer

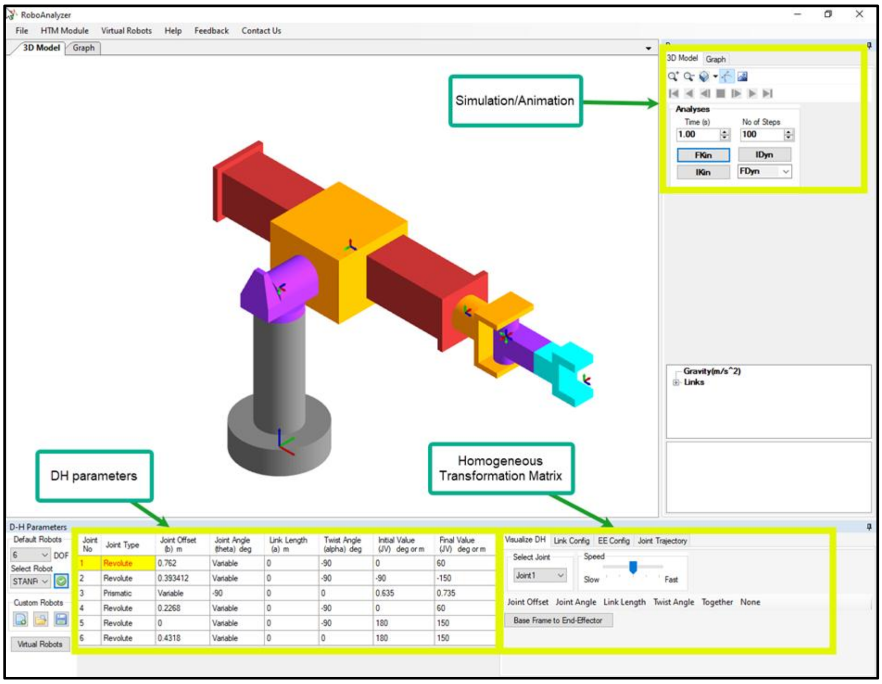

Figure 4. GUI of RoboAnalyzer 7.5.

RoboAnayzer is 3D- visualization tool consisting of option entering the DH parameters of the robot arm, as shown in figure 4. The tool has an option to choose from one degree of freedom up to seven degrees of freedom[5]. A user can also create a custom robot by altering the type of joint and dimensions. Once the parameter is entered in the DH table, the initial and final joint values can be changed for forward kinematic analysis. The software tool has inbuilt virtual models of the robot from the various manufacturer such as ABB, FANUC, KUKA, & MTAB. The user can vary the values in the joint control panel and record the path travelled by the robot arm.

2.3. Robot model in RoboAnalyzer

Once the DH parameters of a robot arm are extracted, it is easy to create a skeleton model of the virtual robot in RoboAnalyzer software[7]. The simple GUI of the RoboAnalyzer allows to enter the values in DH parameters, and the virtual model of the robot is instantly created. A screenshot of IRB1410 robot's skeleton model is shown in Figure 5.

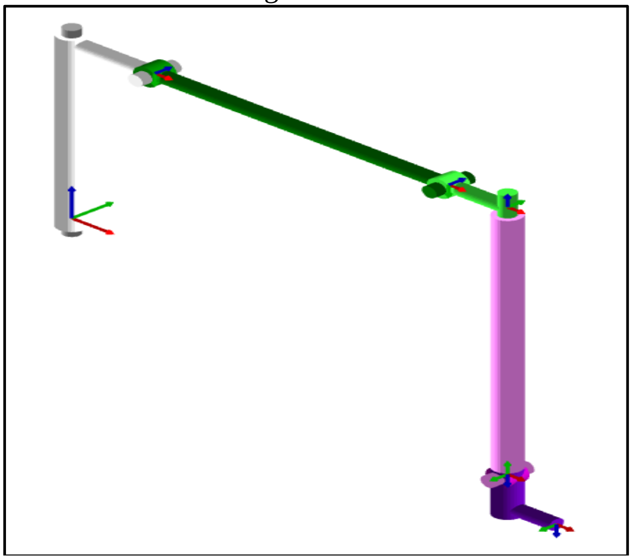

Figure 5. Skeleton model of ABB IRB1410 in the RoboAnalyzer visualization software.

3. FORWARD KINEMATICSOF THE 6-AXIS ROBOT

In forward kinematics, joint angles are prescribed, and the position and orientation of the end-effector of the robot arm are determined. A homogenous transformation matrix from the base of the robot to the end-effector of 4 X 4 dimension is derived based on the DH parameters[8]. The single homogenous transformation matrix between DH frames from base link to the end-effector link should be chained and multiplied to find the position of the end-effector for a 6-DOF serial robot in three-dimensional space, in the same order as below:

$$^{b}T_{ee} = {}^{0}T_1 * {}^{1}T_2 * {}^{2}T_3 * {}^{3}T_4 * {}^{4}T_5 * {}^{5}T_6$$

which can further be represented as

$$^{b}T_{ee} = \begin{bmatrix} & R & & x \\ & & & y \\ & & & z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where, R 3×3 represents the orientation of the end-effector using direction cosine methodology and $[x,y,z]^T$ represent its position vector concerning the reference frame. The homogenous transformation matrix operation can be visualized in the RoboAnalyzer by entering the input values in the DH table provided in the RoboAnalyzer. An example of the position of the end-effector is as given in Figure 6.

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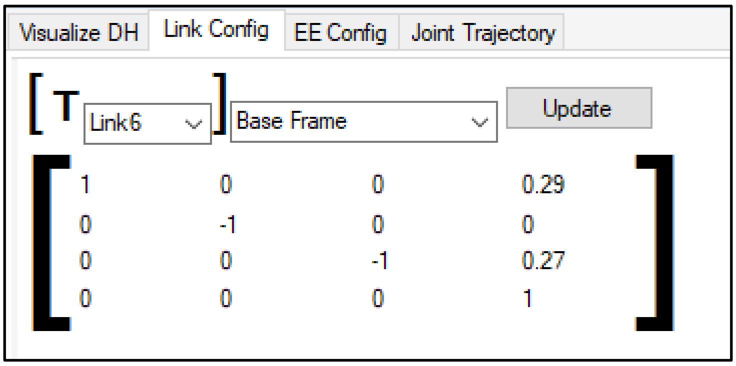

Figure 6. Homogenous Transformation Matrix in RoboAnalyzer.

The homogenous transformation matrix can be verified and visualized in the graph. Figure 7 shows the position of the end-effector in $[x,y,x]^T$ space. The x-axis of the graph represents the simulation time, and the y-axis represents the position value.

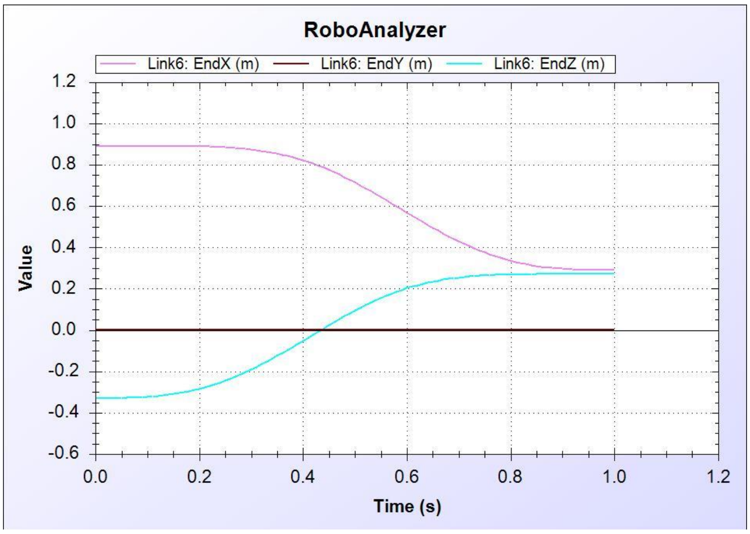

Figure 7. Graphical representation ofthe position of the robot end-effector in RoboAnalyzer software.

3.1. Visualization of the Robot Motion

Visualization of the motion of the robotics is quite tricky without any aid of a software tool. Robot visualization software plays an important role here by helping to visualize the robot path in 3D space along with the path traced by the end-effector[9]. Roboanalyzer allows the user to enter the required DH-parameter. Once the parameters are entered, the forward kinematics operation is performed to simulate the robot. It also shows the pose of the end-effector in the matrix, as shown in figure 8.

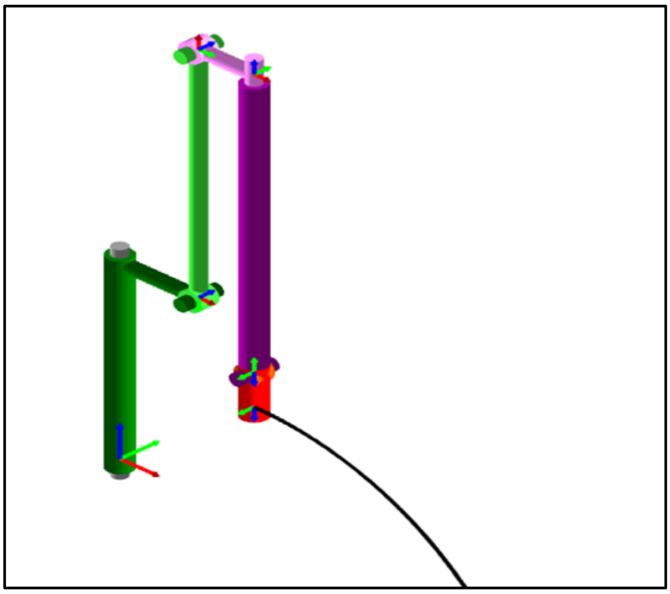

Figure 8. Path tracing and simulation of ABB IRB 1410 in RoboAnalyzer.

RoboAnalyzer also includes a Virtual Robot Module (VRM) that allows a user to use a teach pendant-style interface to operate one of the preloaded industrial robots, as shown in figure 9.

Figure 9. Virtual Robot Module (VRM) of ABB IRB 1410 in RoboAnalyzer.

4. INVERSE KINEMATICS

Inverse kinematics analysis deals with determining the joint angles for the prescribed position and orientation of the end-effector of the robot arm in 3D-space[10]. Inverse kinematics requires mathematical derivations to achieve the solutions for the given pose of the robot. As the number of degree of freedom increases the amount of inverse kinematics solution also increases. The RoboAnalyzer has inverse kinematics module where a user can choose a robot from the menu to perform the inverse kinematics analysis. The software shows multiple solutions in the case of inverse kinematics. Figure 10 shows an example of inverse kinematics in RoboAnalyzer.

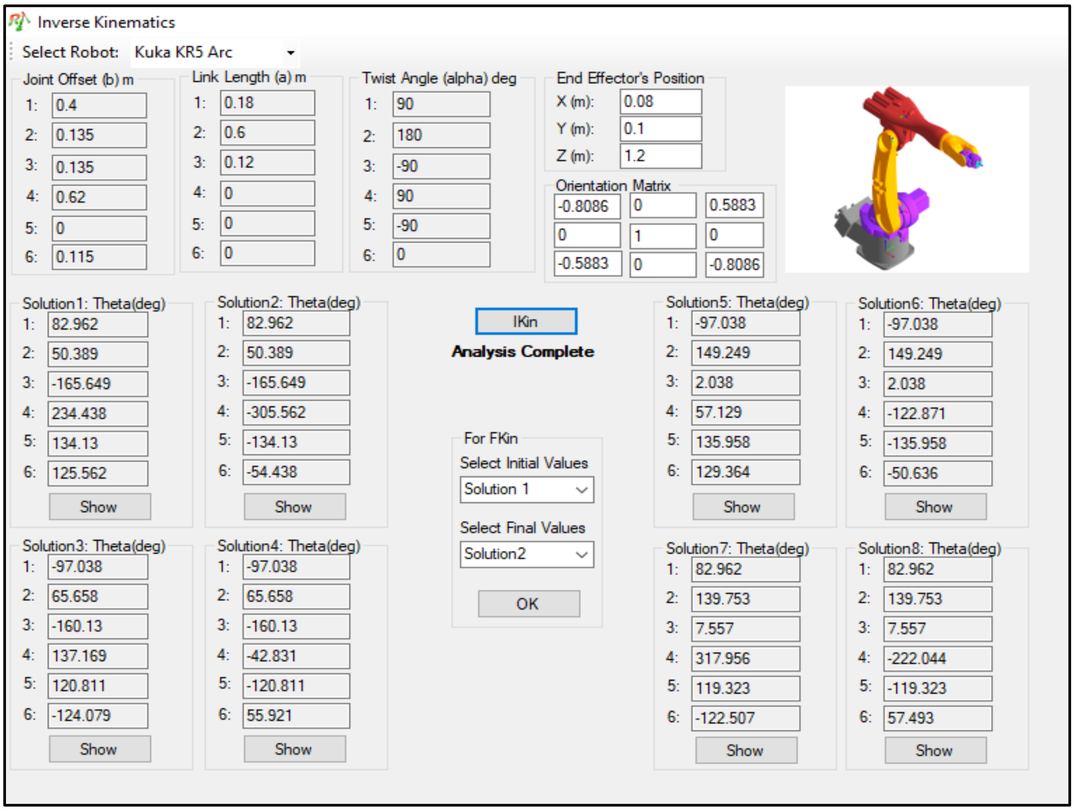

Figure 10. Inverse Kinematics analysis showing all possible solutions.

5. CONCLUSION

The 6-axis robot is designed using SolidWorks software and studied the motion analysis using robot visualization software. The robot kinematic and dynamic model of the 6-axis robot has been developed based on the customized design using robot visualization software such as RoboAnalyzer. The optimization of the design, kinematic and dynamic model and motion studies has been successfully analysed and proposed to the robotic engineers to reduce the effort and cycle time in the automobile, aerospace, electronics, medical, etc. industries.

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