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Kinematic Analysis and Simulation of a 6-DOF Industrial Manipulator

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Abstract: ***Firstly, model of a 6-DOF articulate manipulator was set up in MATLAB, then kinematic analysis and simulation of this manipulator was studied. Secondly, it was found to acquire the desired configuration within the given time limits with irregular motion pattern along the end-effector path. Simulation results showed that the manipulator was capable of light material handling and transfer in an assembly line at low speeds.***

Keywords: manipulator, modeling, kinematic analysis, simulation

1. Introduction

1.1 Background

An industrial manipulator is basically a mechanical arm operating under computer control, in other words a robot arm. Robots are modeled as rigid bodies (Links) and joints. The joints are assumed to induce either pure rotation or translation motion. These links and joints make up kinematic chains which form the basic structure of the equipment. Manipulators are fitted with reprogrammable multifunctional arm designed to move materials, parts or tools through variable programmed motions for the performance of a variety of tasks in modern industries. Its advantages include decreased cost of labor, increased precision and productivity, and increased flexibility. Its reprogram ability is its major advantage over other specialized machines. The major industrial application of manipulators include loading or unloading materials in a production line like injection molding, stamping, assembly, packaging, etc. (i.e. point to point (PTP) application), or in specialized machine operations like welding, cutting, grinding, etc. (i.e. continuous path robots). Other applications include under water and planetary exploration, satellite retrieval and repair, the defusing of explosive devices and working in radioactive or hazardous environments not suitable for humans like petrochemical installations, etc.

1.2 Robot Kinematics

Robot kinematics studies the relationship between the links and joints in the kinematic chain as regards the position, velocity and acceleration of the system, so as to properly control the movement of the equipment. Kinematic analysis is therefore the first step in designing an industrial manipulator, it is used to obtain information on the position of each component within the mechanical system, which is necessary for subsequent dynamic and control analysis. The movement of kinematic chains is modeled by the kinematics equations of the chain. These equations define the configuration of the chain in terms of its joint parameters. Forward kinematics uses the joint parameters to compute the configuration of the chain, and inverse kinematics reverses this calculation to determine the joint parameters that achieves a desired configuration and Specification of the movement of a robot so that its end-effector achieves a desired task is known as motion planning

2. Objective

In [1] and [2], the kinematic analysis of 6-DOF industrial manipulators was described and the trajectory simulated using the roboanalyser software. This paper is aimed at developing the kinematic analysis of a known industrial manipulator which shall be modeled and simulation in MATLAB environment. The manipulator hereby proposed is a Fanuc-type manipulator which is a 6 DOF industrial manipulator as shown in figure 1 below. The kinematic chains shall be analyzed based equations discussed in [3] and [4], while the advanced computability of MATLAB shall present a suitable environment for simulation. MATLAB is widely used in industrial applications to solve problems or accomplish tasks. It I a high level computer language which does not require a compiler to generate executable files, the computer directly interpret instructions into, translating them into machine codes then execute [5].

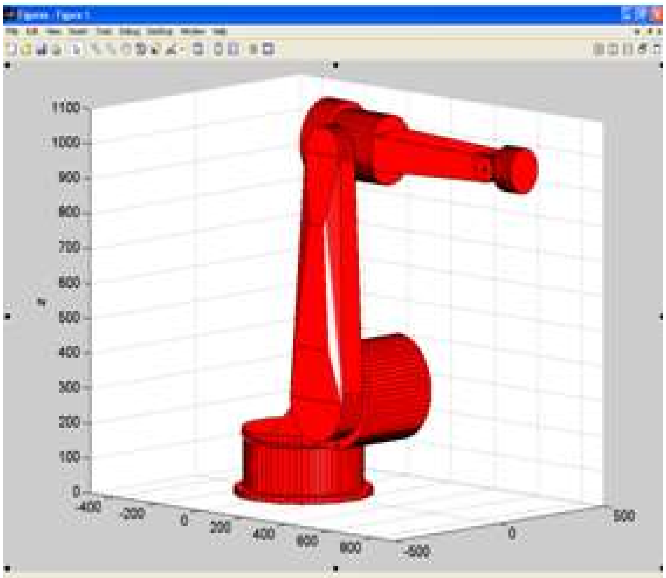

Figure 1: A 6 DOF Articulate Manipulator modelled in MATLAB

3. Theory

The kinematics equations of a manipulator are used to map the joint parameters to the configuration of the robot system. They may either be forward kinematics as in the case where the joint positions are known and the manipulator configuration is required or inverse kinematics where the manipulator's configuration is known and the joint angles are required.

3.1 Forward Kinematics

The matrices representing each of the six links of the manipulator are derived from the DH- parameter as tabulated in table 1.0,

Table 1: Margin specifications

Joint	*α(◦)*	*Link (a)*	*Offset (d)*	*Joint angle θ(◦)*
1	$\pi/2$	a_1	0	Variable (θ_1)
2	0	a_2	0	Variable (θ_2)
3	$\pi/2$	a_3	0	Variable (θ_3)
4	$-\pi/2$	0	d_4	Variable (θ_4)
5	$\pi/2$	0	0	Variable (θ_5)
6	0	0	d_6	Variable (θ_6)

Therefore the DH transformation matrix:

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

The configuration of the system;

$A = A_1 * A_2 * A_3 * \ldots .* A_n$ (2)

3.2 Inverse Kinematic

Given the initial and final orientation (Q) and position (q) of the manipulator, the screw-axis formulation can be applied to the orientation to acquire an arbitrary orientation. This orientation can be concatenated with the given position into one homogeneous transformation matrix (T) that describes the orientation and position of the end effector, and then the inverse kinematics is applied to determine each joint angle.

$$|T_{(e,\alpha,q)}| = \begin{vmatrix} e_x^2 \cos'\alpha + \cos\alpha & e_x e_y \cos'\alpha - e_z \sin\alpha & e_x e_z \cos'\alpha + e_y \sin\alpha & q_x \\ e_x e_y \cos'\alpha + e_z \sin\alpha & e_y^2 \cos'\alpha + \cos\alpha & e_y e_z \cos'\alpha - e_x \sin\alpha & q_y \\ e_x e_z \cos'\alpha - e_y \sin\alpha & e_y e_z \cos'\alpha - e_x \sin\alpha & e_z^2 \cos'\alpha + \cos\alpha & q_z \\ 0 & 0 & 0 & 1 \end{vmatrix}$$
(3)

$\alpha_1 = \tan^{-1}2(q_y, q_x)$ (4)

Since the link 05 and 06 do not affect the positioning of the end effector and the position of the link 01 can be determined directly, then the solution for the 2nd and 3rd joints can be reduces to that of a planar system:

$$\begin{vmatrix} \tilde{q}_x \\ \tilde{q}_y \\ \tilde{q}_z \\ 1 \end{vmatrix} = \begin{vmatrix} q_x \\ q_y \\ q_z \\ 1 \end{vmatrix} - \begin{vmatrix} 0 \\ 0 \\ -1 \\ 0 \end{vmatrix} * d_6 - \begin{vmatrix} a_1 \sin\alpha_1 \\ a_1 \sin\alpha_1 \\ d_1 \\ 0 \end{vmatrix}$$ (5)

$\sin\alpha_3 = (\tilde{q}_x^2 + \tilde{q}_y^2 + \tilde{q}_z^2 - d_4^2 - a_2^2)/(2 * d_4 * a_2)$ (6)

$\cos\alpha_3 = \sqrt{1 - \sin\alpha_3}$ (7)

$\alpha_3 = \tan^{-1}(\sin\alpha_3 , \cos\alpha_3)$ (8)

$$\sin\alpha_2 = \frac{\sqrt{\tilde{q}_x^2 + \tilde{q}_y^2} * (\cos\alpha_3 * d_4) + \tilde{q}_z * (a_2 + d_4 + \sin\alpha_3)}{a_2^2 + d_4^2 + (2 * a_2 * d_4 * \sin\alpha_3)}$$ (9)

$$\cos\alpha_2 = \frac{\sqrt{\tilde{q}_x^2 + \tilde{q}_y^2} * (a_2 + d_4 + \sin\alpha_3) - \tilde{q}_z * (\cos\alpha_3 * d_4)}{a_2^2 + d_4^2 + (2 * a_2 * d_4 * \sin\alpha_3)}$$ (10)

$\alpha_2 = \tan^{-1}(\sin\alpha_2 , \cos\alpha_2)$ (11)

$|A| = |A_1| * |A_2| * |A_3| * |A_4|$ (12)

$|\tilde{Q}| = |Q_f| * |A^{-1}|$ (13)

$\alpha_4 = \tan^{-1} 2(\tilde{Q}_{23}, \tilde{Q}_{13})$ (14)

$\alpha_5 = \tan^{-1} 2\left(\sqrt{\tilde{Q}_{23}^2 + \tilde{Q}_{13}^2}, \tilde{Q}_{33}\right)$ (15)

$\alpha_6 = \tan^{-1}2(\tilde{Q}_{32}, \tilde{Q}_{31})$ (16)

4. Simulation and Results

The manipulator was modeled and simulated in MATLAB environment using easily verifiable orientation and position as input. The manipulator was required to move from rest position to a given position A [500, 500, 500], then to position B [500, 0, 500] in 2.5 seconds and finally to position C [500, -500, 500] in another 2.5 seconds. Given the initial and final orientation and position of the end-effector, the joint angles were easily determined from the inverse kinematic equations and thereby simulated. During simulation,

1. The manipulator was found to move in a rather irregular pattern (i.e. not linear and not circular) but achieved the required orientation and position in the given time frame as shown in figure 2.
2. The joints of the manipulator were found to move at constant speed with initial and final discontinuities as shown in figure 3. Therefore inducing shock loads which are capable of reducing the life span of the equipment

5. Recommendations and Conclusion

It was observed that the manipulator did not follow any specific path/trajectory and did not allow any control over the velocity or acceleration of the joints but was able to accurately locate the desired configuration. It is therefore suitable for light material transfer in an assembly line with low speeds so as to minimize the shock loads on the equipment and increase the life span. The future thrust of this work shall be to solve the trajectory control problem of the manipulator to ensure better control of the manipulator's end-effector, velocity and acceleration of the joints thereby reducing shock loads on the equipment.

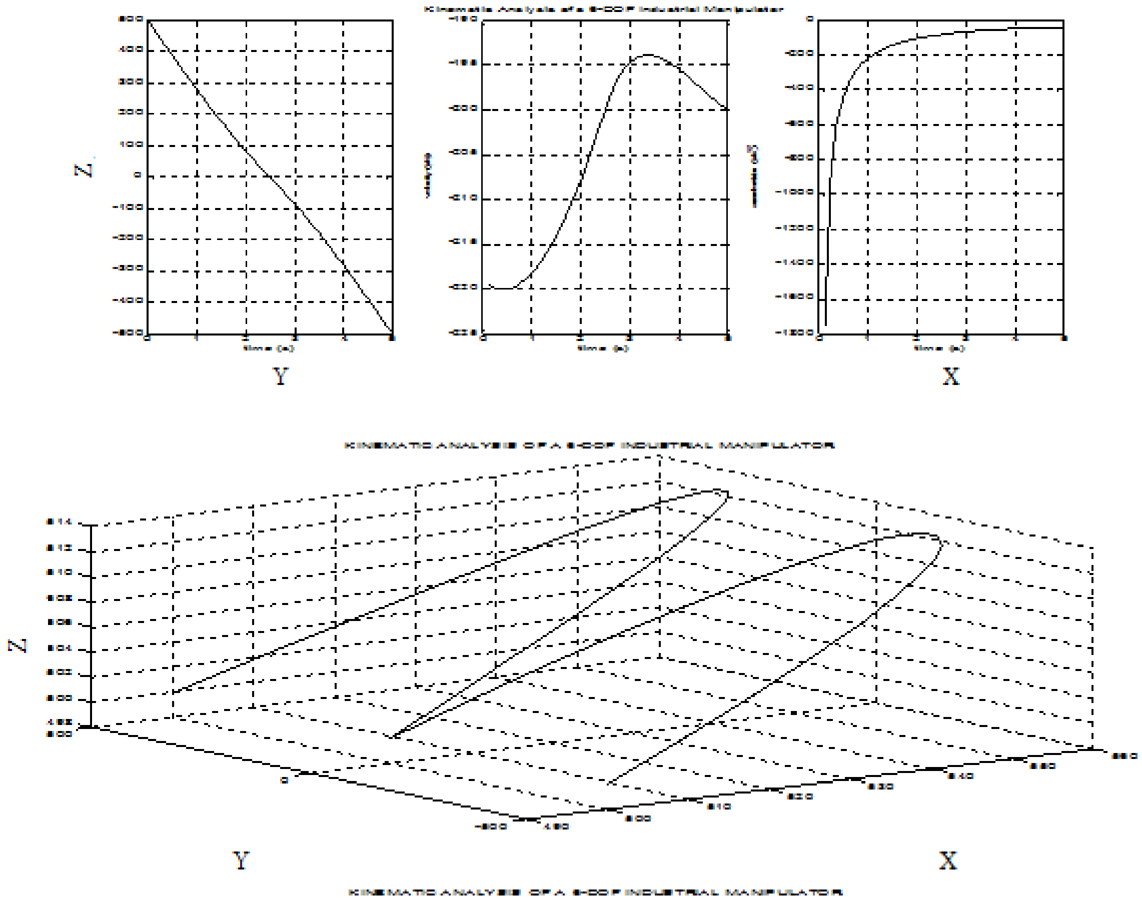

Figure 2: Kinematic analysis – motion of the end effector of a 6-DOF Industrial Manipulator

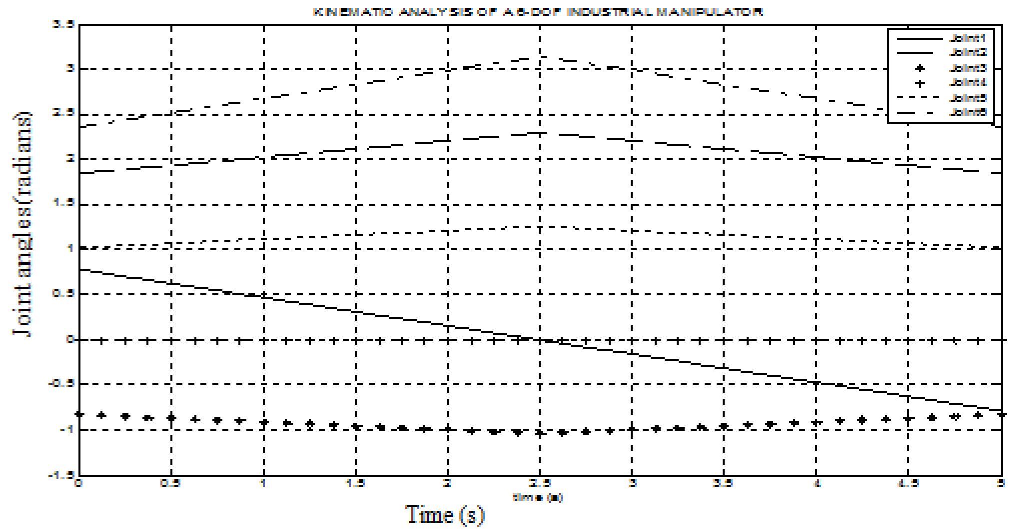

Figure 3: Plot of joints motion of a 6-DOF manipulator

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Author Profile

Umar Abubakar received the B.Tech. in Mechanical Engineering from the Federal University of Technology Minna-Nigeria in November 2004. He is gainfully employed at the Nigerian Institute for Oil palm Research where he is engaged in Agricultural research into the post-harvest and processing technologies of the mandate crops of the institute and also into improved manufacturing technologies. He is currently pursuing a Masters degree at the Tianjin University of Technology and Education in the Peoples Republic of China.