

Robot control and kinematic analysis with 6DoF manipulator using direct kinematic method

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ABSTRACT

The robots play important role in all parts of our life. Hence, the modeling of the robot is essential to develop the performance specification. Robot model of six degree of freedom (6DoF) manipulator implemented numerically using model-based technique. The kinematic analysis and simulation were studied with Inverse kinematics of the robot manipulator through Denevit and Hartenberg method. Matrix transformation method is used in this work in order to separate joint variables from kinematic equations. The finding of the desired configuration is obtained precisely in all motion trajectory along the end-effector path. MATLAB/SIMULINK with R2018b is used for the implementation of the model-based robot system. Simulation results showed that the robot links follow their references smoothly and precisely and ensure the effectiveness of direct kinematic algorithm in the analysis and control of the robotic field.

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1. INTRODUCTION

The robotic aspects have many applications in the industry and the life such as painting pick and place operations, welding, grasping, assembly, material removal, medical operation and more. These tasks is described according to the end effector function, which should be controlled efficiently [1]. The 6DoF is required to explain the operation of an object in the three dimensional (3D), three for orientation and three for position [2]. The good performance specifications of the robots like produce much quantity compared to human being with elimination of the dangerous, don't need any practice or experience to perform the job, high precision, works in any invireronment to improve the hard life [3]. High degree of accuracy of system implementation is very interested and needed in any robotic field operation with efficient control technique [4]. The parallel manipulators with model-based controllers studied in [5]. The ability to carry out laborious tasks that involve interactions with various external forces [6]. The joint flexibility in controller design of industrial manipulator study to check the significant performance degradation in [7]. Kinematic analysis of flexible-joint parallel 3-RRR manipulator is performed in [8]. The states of the system according to generate the effects of the impact on the manipulator motion investigated in [9]. In [10], the authors studied the artificial neuro-fuzzy inference system technique in the 2DoF robot with sliding mode control a fuzzy tracking controller for balancing and velocity control of a two-wheeled inverted pendulum (TWIP) mobile robot based on its Takagi-Sugino (T-S) fuzzy model, fuzzy Lyapunov function and non-parallel distributed compensation (non-PDC) control law [11].

The Jacobean matrix or the design matrix need to be carefully considered in linear analysis and the error modeling [12]. In the robotic, the kinematic analysis is the first step in designing of the manipulator to obtain information on the position of the mechanical system components which is important for dynamic and control analysis [13]. Analysis of location of in parallel manipulators proposed based on the static characteristics and the kinematic function in parallel manipulators [14]. The proposed control algorithm allows greater flexibility in controlling the four robotic arms instead of using a scheme to control each part separately.

2. MATERIALS AND METHODS

The material and methods focused on design, modeling and control of robotic manipulators dedicated to perform different kinds of functions in industrial applications [15]. The Denavit-Hartenberg (DH) parameter is addressed as one of the direct kinematic solution methods. The homogeneous transformation has the form in (1) [16].

$$A_i = Rot_{z, \theta_i} Trans_{z, d_i} Trans_{x, \alpha_i} Rot_{x, \alpha_i} \quad (1)$$

In this context, the axis of the new frame $o_1x_1y_1z_1$ is projected onto the original frame $o_0x_0y_0z_0$ as in (2)

$$Rot^1_0 = \begin{bmatrix} x_1 \cdot x_0 & y_1 \cdot x_0 & z_1 \cdot x_0 \\ x_1 \cdot y_0 & y_1 \cdot y_0 & z_1 \cdot y_0 \\ x_1 \cdot z_0 & y_1 \cdot z_0 & z_1 \cdot z_0 \end{bmatrix} \quad (2)$$

Due to DH, each link is labeled from 0 to n as in (3).

$$link = \begin{cases} 0 & \text{fixed base} \\ n & \text{End effector} \end{cases} \quad (3)$$

The i th joint position is combined with Q_i . Normally, the radian and the meter are considered as measurement units for the revolute (R) joints position and for prismatic (P) joints respectively. Figure 1 shows the coordinate system on each joint.

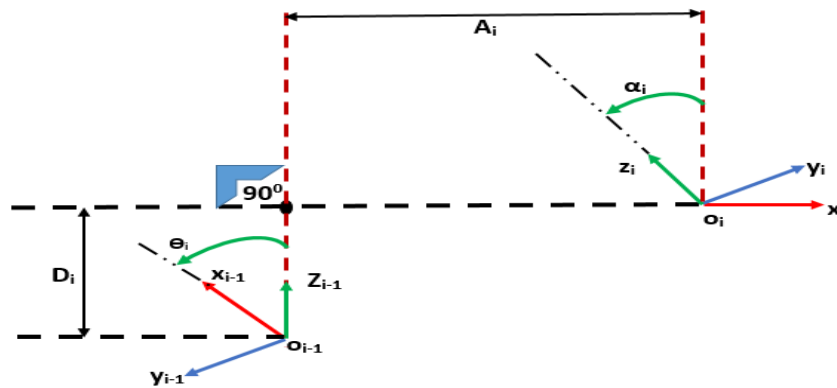


Figure 1. Description of link mechanism and parameters

The coordinate system of $X_0Y_0Z_0$ is considered as the reference system [17]. In Figure 1, the joints i and $(i+1)$ is connected to each other tightly. Hence, both size and shape described sufficiently. Where A_i , α_i is the distance between the common normal of both axes and the twist angle of both joint respectively. For RPR (revolute-prismatic-revolute) motion, the relative displacement can be described in terms of θ_i and D_i parameters. Where θ_i and D_i are the joint angle and its rotation about the joint axis and link offset or initial position of the robot respectively [18]. The offset value in this work as in (4). The DH parameters in simulation work for each joint of the Figure 1 are listed in Table 1.

$$\text{offset} = [0 \quad 1.5708 \quad 1.5708 \quad 0 \quad 0 \quad 0] \quad (4)$$

Table 1. DH parameters for the joints

links	α (angles)	A_i (dist)	D_i (dist)
1	-1.5708	0	-240.0
2	3.1416	540.0	0
3	-1.5708	0	0
4	1.5708	0	-415.0
5	-1.5708	0	0
6	0	0	-171.5

3. CONTROL TECHNIQUE

The control techniques of the proposed algorithm is Jacobean-based position control. This will express the manipulator joint angles mentioned before to eliminate the steady state error between the references positions the end effector of each motion. The MATLAB/SIMULINK model of the 6DoF robotic is shown in Figure 2. The 6DoF robot implemented in the laboratory is shown in Figure 3 and the practical results will be included in the second part of this paper.

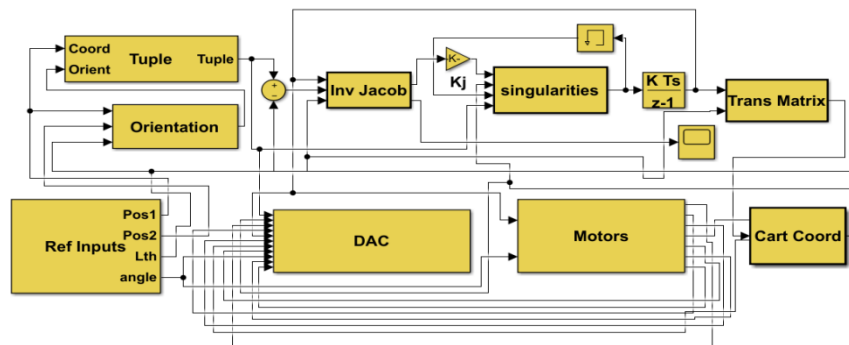


Figure 2. Simulink model of the proposed work



Figure 3. Set up of the 6DoF robot

Integral part controller in a part in Figure 2 after singularities block to eliminate steady state error (SSE) and highly precision value of (θ) [19]. The D_i distance can be measured as in (5).

$$D = L - \sqrt{[(R(1) - F(1))^2 + (R(2) - F(2))^2 + (R(3) - F(3))^2]} \quad (5)$$

This will be expressed as a part of orientation process.

where F, R, L is the fulcrum, reference points of (z,y,z) and the length of the instrument respectively. The two dimensional distance in (5) will as in (6).

$$D_{xy} = \sqrt{[(R(1) - F(1))^2 + (R(2) - F(2))^2]} \quad (6)$$

To derive Euler which will depend on the rotation around xyz axes as in Figure 4.

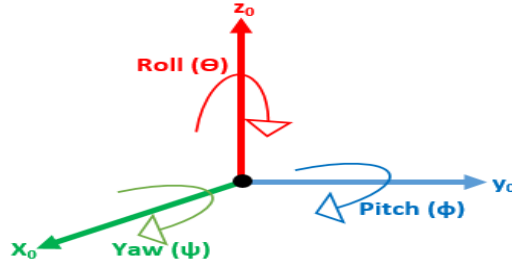


Figure 4. Euler ZYZ angle orientation

$$z_1 = \tan^{-1}[(R(2) - F(2))/(R(1) - F(1))] \quad (7)$$

$$y_2 = \tan^{-1}[(D_{xy} / R(3) - F(3))] \quad (8)$$

$$z_3 = 0 \quad (9)$$

The above expressions of zyz Euler angles function is approved in Figure 5. The Euler angles gives local parametrization of the plant.

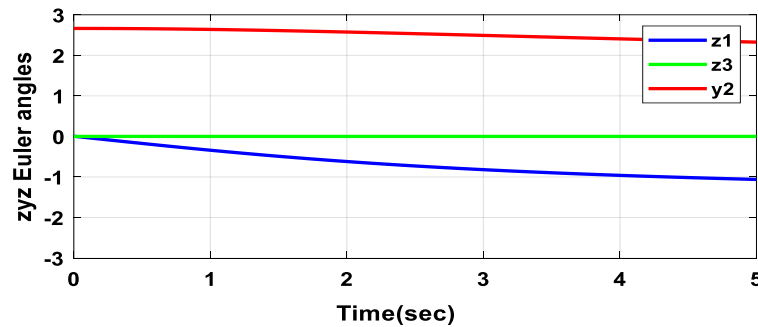


Figure 5. Euler angles

4. KINENAMATIC ROBOT

In the robotic science, the kinematics can be considered as a branch of mechanics of bodies' motion of the system without considering the force to investigate the relationship between the position links, orientation and acceleration. The end-effector position of each leg is generated by a simple trajectory generator with half rectified sine wave pattern. Furthermore, to move each robot's leg, it is proposed to use geometric-based inverse kinematic [20]. Robot kinematics reveals physical system locations and structure of the robot to the study movement of multi DoF kinematic chains. The robotic kinematic analysis is divided into, forward kinematic and inverse kinematic as can be shown in Figure 6.

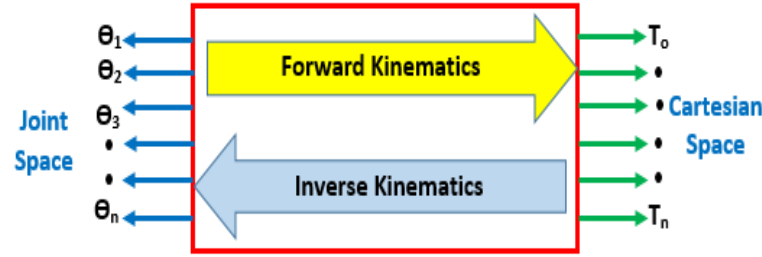


Figure 6. The forward and inverse kinematics [21]

According to the inverse kinematic approach used in this work, the angle of each joint need to be obtain [22]. The direct kinematic model is used and the procedure to find the kinematics in illustrated as in (10).

$$Q_i = Q_i + offset(i) \quad (10)$$

The constrains is included in the singularities block implies the difference between the real tuple position and the reference tuple should not exceed 0.6. The Homogeneous Transformation Matrix is obtained according to [23, 24] is shown in (11).

$$T^{i-1}_i = \begin{bmatrix} \cos \theta_i & -\cos \alpha_i \sin \theta_i & \sin \alpha_i \sin \theta_i & A_i \cos \theta_i \\ \sin \theta_i & \cos \alpha_i \cos \theta_i & -\sin \alpha_i \cos \theta_i & A_i \sin \theta_i \\ 0 & \sin \alpha_i & \cos \alpha_i & D_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (11)$$

For the first three joints, the T in Cartesian relationship as in (12)

$$X_{cart}(i) = T(i,4), \quad i = 1, 2, 3 \quad (12)$$

For the next three iterations (i-4, 5, 6) the relationships will be as follows;

$$X_{cart}(4) = \tan^{-1}(T(2,3)/T(1,3)) \quad (13)$$

$$X_{cart}(5) = \tan^{-1}(\sqrt{T(1,3)^2 + T(2,3)^2} / T(3,3)) \quad (14)$$

$$X_{cart}(6) = \tan^{-1}(T(3,2) / -T(3,1)) \quad (15)$$

Conversion of the homogeneous transformation matrix (T) in a position XYZ and orientation Euler ZYZ is the final step as in (16),

$$R_{zyz} = R_{z, Roll} R_{y, Pitch} R_{z, Yaw} \quad (16)$$

$$R_{zyz} = \begin{bmatrix} C_\phi \cdot C_\theta C_\psi - S_\phi S_\psi & -C_\phi \cdot C_\theta S_\psi - S_\phi C_\psi & C_\phi \cdot S_\theta \\ S_\phi \cdot C_\theta C_\psi + C_\phi S_\psi & -S_\phi \cdot C_\theta S_\psi + C_\phi C_\psi & S_\phi \cdot S_\theta \\ -S_\theta C_\psi & S_\theta S_\psi & C_\theta \end{bmatrix}$$

Three rotations in this matrix, one about each principle axis. The commutation does not satisfied due to the matrix multiplication. First rotation will be around the x-axis, then the y-axis, and the z-axis.

5. RESULTS AND DISCUSSION

Robots can be mathematically modeled with computer programs where the results can be displayed visually, so it can be used to determine the input, gain, attenuate and error parameters of the control system [25]. The formulation of a tuple data is the first step and it is a vital block in this system. This block is able to generate the setup or reference position and orientation for the instrument tip. The comparison of the reference position and the End effector in the all six manipulated joints respectively. The first reference position is located at $X_{cart}(1)=T(1, 4)=(746)$ and the actual response (746) is follow the reference precisely with zero SSE as shown in Figure 7. The second reference position is located at $X_{cart}(2)=T(2, 4)=(-210.8^\circ)$ and the actual response (-209.6) is follow the reference precisely with a very small value of SSE as shown in Figure 8. The third reference position is located at $X_{cart}(3)=T(3, 4)=(-388^\circ)$ and the actual response (-388°) is follow the reference precisely with zero SSE as shown in Figure 9.

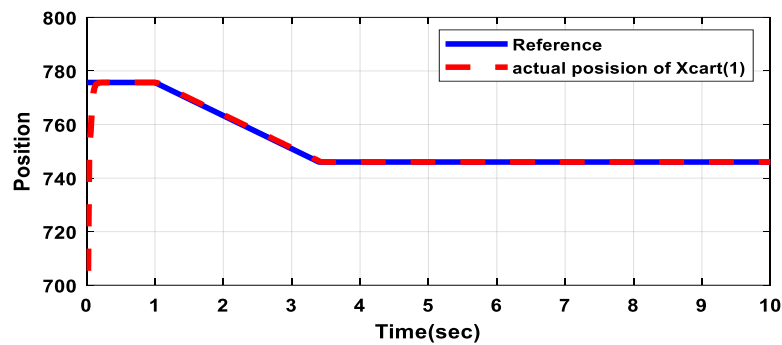


Figure 7. Reference and end effector of Xcart (1)

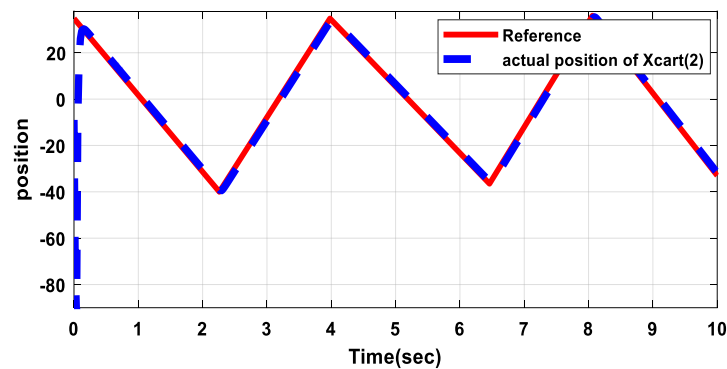


Figure 8. Reference and end effector of Xcart (2)

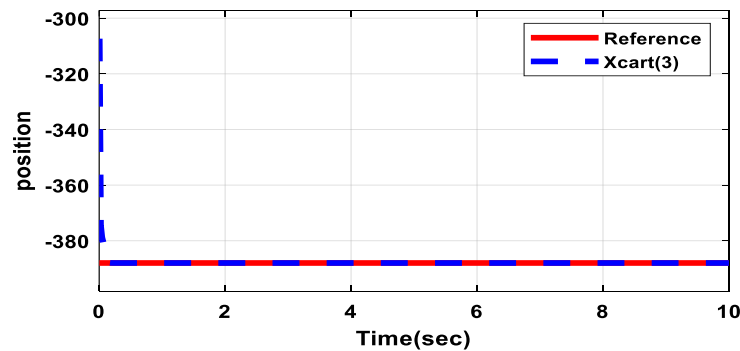


Figure 9. Reference and end effector of Xcart (3)

The fourth reference position is located at $X_{cart}(4) = (-1.061^\circ)$ and the actual response (-1.059°) is follow the reference precisely with a very small value of SSE as shown in Figure 10. The fifth reference position is located at $X_{cart}(5) = 2.326^\circ$ and the actual response (2.326°) is follow the reference precisely with zero SSE as shown in Figure 11. Finally, the reference position is located at $X_{cart}(6) = 0^\circ$ and the actual response ($-3.97e^{-70}$) is follow the reference precisely with a very small value of SSE as shown in Figure 12, In all above figures, X_{cart} defines the rotation and it is used to set the position in each case.

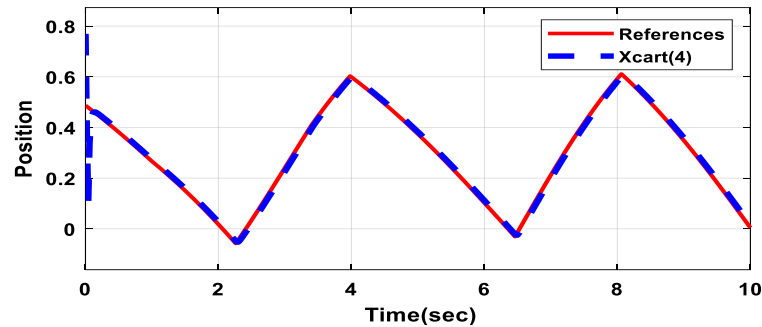


Figure 10. Reference and end effector of Xcart (4)

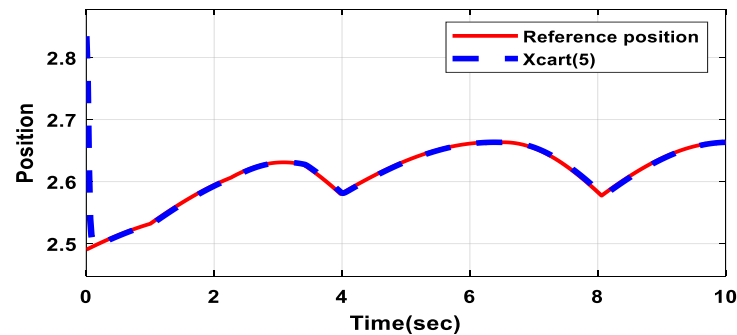


Figure 11. Reference and end effector of Xcart (5)

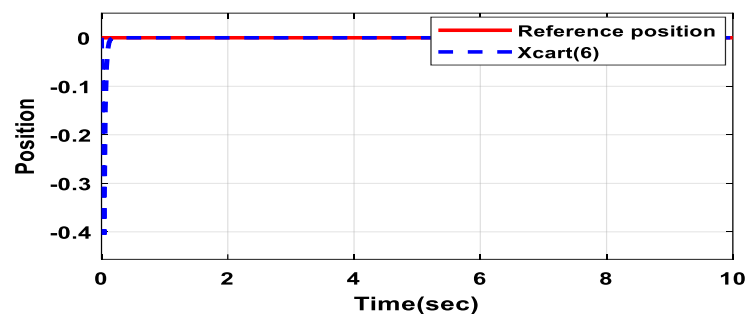


Figure 12. Reference and end effector of Xcart (6)

6. CONCLUSION

Robot control is very important in the intelligent control field. Control of series manipulators with flexible-joint drives analyzed in the presence of 5% modeling error and disturbances. Series manipulator subject to impact considered as a case study to specify the performance of the control method. The kinematic direct method is powerful method in the analysis of the robotic operation. The required joint positions for end effector placement reached precisely. DoF considered as the independent positions used to locate all mechanism parts of the robot. D-H method used for selecting reference frames of in robotic field. In another words, all of the objectives of the study have been achieved.

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