Inverse Kinematics Solution of a 6-DOF Industrial Robot

Kshitish K. Dash, B. B. Choudhury and S. K. Senapati

Abstract A vital part of many industrial robot manipulators is to reach required position and orientation of end effectors so as to complete the pre-defined task. To get this, one should have knowledge of kinematics, i.e. inverse kinematics (IK). Though inverse kinematics never gives a closed form solution, it is too difficult to solve such problem of an industrial robot. There are so many analytical and other simulation methods which are adopted to solve this IK problem for our 6-DOF industrial pick and place robot. In this paper, artificial neural networks (ANN) are used and simulated by using MATLAB.

Keywords Industrial robot · Inverse kinematics · ANN

1 Introduction

Kinematics of robot indicates the analytic behaviour of the movement of robot manipulator. By taking appropriate kinematics models of an industrial robot, the kinematic behaviour, i.e. inverse kinematics and forward kinematics, can be analysed. These two spaces utilized as a part of kinematics demonstrating are known as Cartesian space and Quaternion space. The alteration among two Cartesian coordinate takes place in form of rotation and a translation as soon in Fig. 1. So many methods are adopted to solve forward kinematics and inverse kinematics problems of an industrial pick and place robot. out of different method Jacobian matrix and Denvit-Hertenberg theory is useful for analytic solution of straight forward kinematics and Screw theory is useful for inverse kinematic solution.

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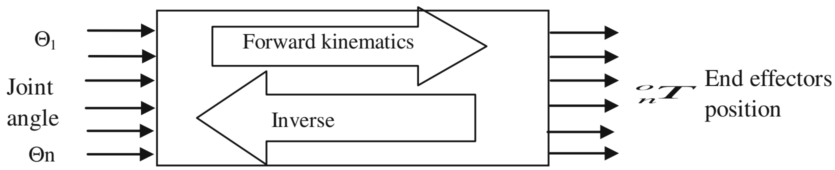


Fig. 1 Schematic portrayal of inverse and forward kinematics

Denavit–Hartenberg (D-H) gives common alteration between two joints, and it requires four parameters. The parameters used here are known as the D-H parameters. The kinematics of robot ordered in form of forward kinematics and inverse kinematics. Forward kinematics issue is simple, and also, there is no complication deriving the equations. Therefore, there is dependably a forward kinematics arrangement of a controller. Inverse kinematics is a considerably more troublesome issue than forward kinematics. The solution of the backwards kinematics issue is computationally extensive where some have solution, some have no solution, some have redundancy problem takes quite a while in the continuous control of controllers.

2 Literature Review

Li et al. [1] studied 6-R robot for virtual reality and analysed the virtual reality. The simulation is done by using EON software. The inverse kinematics of this robot is simulating by MATLAB, and the result is validating for the virtual reality using both the software. Lazar et al. [2] developed a robot manipulator control by using visual serving. The paper describes how integrating reference and image prediction novel architecture are used for the prediction camera velocity and time variation consider by interaction matrix. A simulation is done to improve its efficiency for a 6-DOF manipulator. Chen et al. [3] developed a paper to increase the inverse kinematics behaviour of a 6-DOF robot. The two coordinates are considered here as reference coordinate and tool coordinate. The screw motion calculated for each link based on reference coordinate. At last, a new algorithm is used to improve the efficiency of inverse kinematics. Duka [4] developed a paper inverse kinematics and forward kinematics of articulated robot. D-H theory is adopted to solve 4-axis articulated robot problem and considering the corresponding data inverse kinematics value also calculated. A comparison takes place between experimental data with calculated data for 4-axis articulated manipulator. Adrin et al. [5] developed a paper ANFIS-based inverse kinematics solution. They have discussed a 3-DOF planer manipulator which is considered to get effectiveness of this approach. The data obtained from forward kinematics is transfer for inverse kinematics and accepted the accuracy of the different joint angles. Dash et al. [6] developed a paper inverse kinematics of industrial using ANN. The end effectors' position is calculated by considering different joint angle. The multilayer neural network is used to train the data, and the analytical data is validate with ANN trained value. Chandra and Rolland [7] present 3RPR planer parallel manipulator where simulated annealing and relay collaborative met heuristics. The given method gave promise results. Henten et al. [8] devolved autonomous robot for harvesting. In this paper, the 3D image system implemented for controlling and to avoid collision-free motion during harvesting and 7-DOF manipulator was used to make more comfortable harvesting. Husty et al. [9] taken new algorithm to solve IK of 6-R manipulator. Here kinematics image considers to identify the displacement of each point, and the solution is made in two phase. In first phase, two joint angle value calculated algorithm by using and other four calculated by inverse kinematics equation. Srinivas et al. [10] accepting end-focuses for all segments of a multi-segment trunk are known and subtle elements are applying single-segment converse kinematics to each segment of the multi-segment trunk by adjusting for coming about changes in introduction. At last, an approach which registers per-area end-focuses given just a last segment endpoint gives an entire answer for the multi-segment converse kinematics issue. Iliukhina et al. [11] devolved modelling 5-DOF manipulator where the piece of research went for making mechanical controller controlled by methods for brain–computer interface for enhancing family unit confidence of people with incapacities and growing the extent of their movement. The mechanical controller gives plausibility of self-satisfaction in fundamental family works, and it shows a numerical model of the kinematics of the automated controller. Khuntia et al. [12] modelled a heuristics allocation of multitask robot. Here it has been created thinking about the earth, the framework parameters and the robots' capacities. An answer calculation has been created and executed to acquire the outcomes.

3 Inverse Kinematics

Backward kinematics is the inverse of forward kinematics. The position of end effectors calculated, after determining all joint angle position. The inverse kinematics solves the problem like end effectors position, what are the relating joint positions. In contrast with the forward kinematics issue, the arrangement of the converse issue is not generally conjugal. The end effectors position can be reached in several configurations according to position vectors. Our main aim is to solve 6-DOF industrial robot using artificial neural networks (ANN) and simulated the solution by using MATLAB.

The inverse kinematics model is shown in Fig. 2 whose angle can be calculated like $\theta_1, \theta_2, \theta_3 \ldots = f - (p)$. The arrangement is figured in two stages, first uses an area vector from the wrist to the wrist. The vector takes into consideration the arrangement of the initial three primaries DOF that finish the worldwide movement.

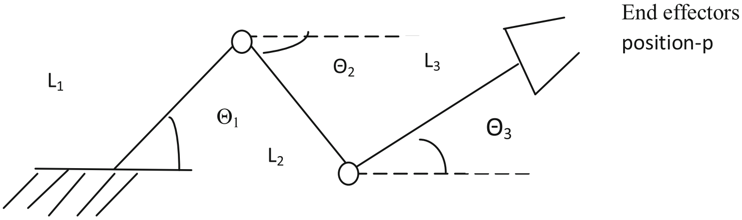


Fig. 2 Structure of 3-R arm

The last 3-DOF is discovered utilizing the computed estimations of the first 3-DOF and the introduction matrices T4, T5 and T6. The modelling is done here using D-H method for forward kinematics, and the values are obtained for end effectors with various corresponding joint angle position.

$$T = A_1 A_2 A_3 A_4 A_5 A_6 \tag{1}$$

where T is the target position Θ_i is the joint variable.

4 Denavit–Hartenberg Theory

D-H parameters are one of the most useful theories to take care of forward kinematics issue of automated arms. The D-H formalization takes place by using only four parameters to describe the spatial relationship between successive link coordinate frames as shown in Fig. 3. The 6-DOF robot solution made by introducing two constraints to the placement of those frames: The axis x_i is perpendicular to the axis $z_{i-1,}$ and the axis x_i intersects the axis z_{i-1}.

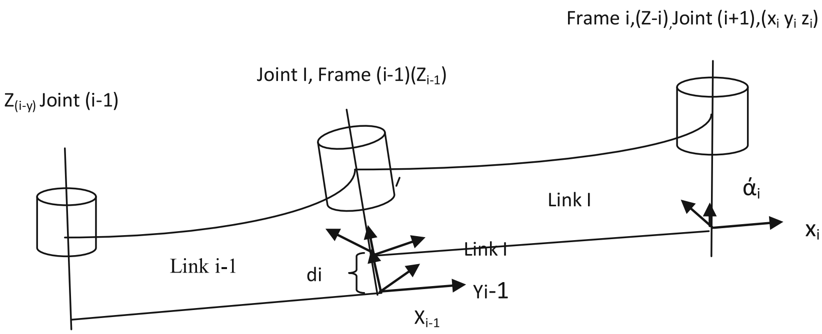
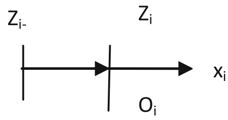


Fig. 3 D-H architecture

Fig. 4 D-H architecture for two axis



Frame i is rigidly attached to link joint i + 1. The frame is assign as D-H convention, i.e. D-H_1 x_i perpendicular to z_{i-1}, D-H_2 x_i intersects the axis z_{i-1}

Assign Z-axis as axis of motion. If Z_i and Z_{i-1} don't intersect and not parallel each other then x_i act along the common normal from origin O_i which is the meeting point between Z_i and the general normal line.

From Fig. 4 if Z_i and Z_{i-1} are parallel and do not intersect, then O_i can be consider anywhere along Z_{i-1} axis. The y_i value can be obtain by cross product of two axis when both Z_i and Z_{i-1} are intersect each other, Generally cross product that two axis each other. To get the above value from the frame i − 1 to frame i, some necessary steps to be followed then after we can get the equation like as stated below

$$T_i^{i-1} = T_z(d_i)T_z(\theta_i).T_x(a_i)T_x(\alpha_i) \tag{2}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} Cos\,\theta_i & -Sin\,\theta_i & 0 & 0 \\ Sin\,\theta_i & Cos\,\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & Cos\,\alpha_1 & -Sin\,\alpha_i & 0 \\ 0 & Sin\,\alpha_i & Cos\,\alpha_i & o \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} Cos\,\theta_i & -Cos\,\alpha_i Sin\,\theta_i & Sin\,\alpha_i Sin\,\theta_i & a_i Cos\,\theta_i \\ Sin\,\theta_i & Cos\,\alpha_i Cos\,\theta_i & -Sin\,\alpha_i Sos\theta_i & a_i Sin\,\theta_i \\ 0 & Sin\,\alpha & Cos\,\alpha_i & d_i 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

By considering 6-DOF architecture of Aristo as shown in Fig. 5, the parameters are calculated as stated Table 1. After getting parameter by using D-H principle, the joint angle for different position for inverse kinematics can be calculated.

Fig. 5 6-DOF robot position

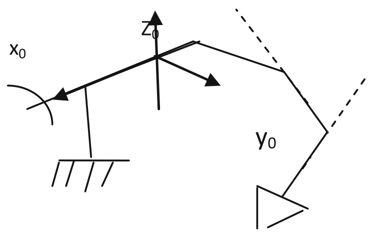


Table 1 D-H parameter value

DOF.	θi	A	ai	di
1	90	O	0	184
2	89.28	O	150	158
3	91.61	79.71	0	300
4	92.18	90	250	150
5	92.51	0	0	378.5
6	95.02	63.9	0	64.0

$$\theta_1 = \tan^- \left[\lambda q_y - d_2 q_x / \lambda q_x + d_2 q_y\right] \tag{3}$$

$$\theta_3 = \tan^- \left[\frac{q_x^2 + q_y^2 + q_z^2 - d_4^2 - a_2^2 - d_2^2}{\pm\sqrt{4d_4^2 a}^{\,2} - \left(q_x^2 + q_y^2 + q_z^2 - d_4^4 - a_2^2 - d_2^2\right)^2}\right] \tag{4}$$

$$\theta_2 = \tan^- \left[\frac{q_z(a_2 + d_4 s_3) - d_4 c_3(\pm\sqrt{q_x^2 + q_y^2 - d_z^2}}{q_z d_4 c_3 - (a + d_4 s_3)\left(\sqrt{q_x^2 + q_y^2 - d_2^2}\right)}\right] \tag{5}$$

$$\theta_4 = \tan^- \frac{C_1 a_y - S_1 q_x}{C_1 C_{23} q_x + S_1 C_{23} q_y - C_{23} q_z} \tag{6}$$

$$\theta_5 = \tan^- \left[\frac{(C_1 C_{23} C_4 - S_1 S_4) q_x + (S_1) C_{23} C_4 + C_1 S_4) q_Y - C_4 S1_{23} q_z}{C_1 S_{23} q_x + S_1 S_{23} q_y + C_{23} q_z}\right] \tag{7}$$

$$\theta_6 = \tan^- \left[\frac{-(S_1 C_4 + C_1 C_{23} S_4) nx + (-C_1 C_4 - S_1 C_{23} S_4) n_y + (S_4 s_{23}) n_z}{-(S_1 C_4 + C_1 C_{23} S_4) + C_1 C_4 - S_1 C_{23} S_4 + S_4 S_{23}}\right] \tag{8}$$

The above equation is used to calculate the joint angle value experimentally for different position of end effector.

5 Artificial Neural Network

The neural system design of this arrangement as appeared in Fig. 6 and the neurons are completely associated with this system. In this network, 18 nodes have been used to train the network. A sigmoid capacity is utilized as an exchange work among neurons, and there are three components of the system input. The initial three components speak to Cartesian position, and other six speak to the joint edge of various hubs. The showing informational index was set up keeping in mind that the end point position where ANN can be utilized for the inverse kinematics controller.

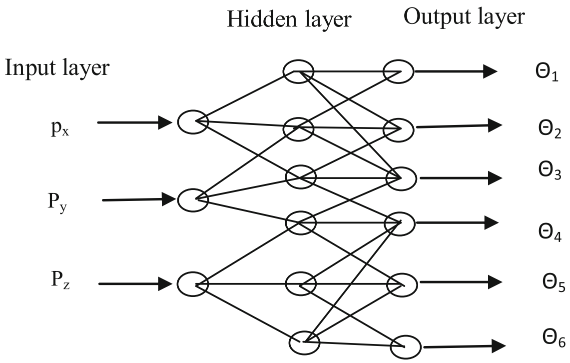


Fig. 6 Multilayer neural network

$$Ahi(t) = \sum_{k=1}^{i} WT_{ik}I_k + \sum_{k=1}^{m} Wh_{ik}f(Ah_k(t-1)); \tag{9}$$

The actuation work which is utilized as a part of concealed layer and the yield of the system is a weighted total of the shrouded unit output.

6 Results and Discussion

With reference to above equation and considering some equation from author [6], a number of joint angle value calculated which is shown below. From the table, it is observed that obtain joint angle value is varying within the maximum and minimum value of manipulator joint angle with a different position of end effector.

6.1 Experimental Data of Industrial Robot

See Table 2.

6.2 Specification of Industrial Robot

By taking number of experimental data, the neural network trained and obtained performance curve as shown in Fig. 7 (Tables 2 and 3).

Table 2 Joint angle and position of manipulator value

Θ_1	Θ_2	Θ_3	Θ_4	Θ_5	Θ_6	p_x	p_y	p_z
90	−89.98	90	0	90	0	0.30	378.88	393.84
89.85	−89.82	89.28	3.25	88.50	4.68	2.29	281.47	394.37
89.56	−89.78	91.61	5.25	85.00	7.84	2.56	380.14	394.74
89.20	−89.59	92.18	11.85	83.74	10.91	7.38	383.33	382.24
88.51	−89.22	92.51	17.17	79.71	15.46	8.11	390.57	375.52
86.45	−87.81	95.02	22.92	76.98	21.74	0.52	395.10	351.48
82.39	−85.56	95.44	26.56	63.93	24.37	29.85	414.98	336.66

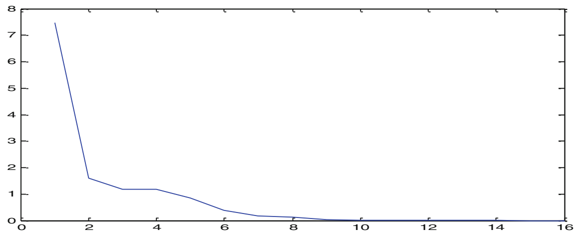


Fig. 7 Performance curve

Table 3 Joint angle specification

Minimum	Maximum	Home	Axis
−250°	90°	90°	Base
−90°	45°	90°	Shoulder
90°	−45°	−90°	Elbow
0°	340°	0°	Wrist
−90°	90°	90^0	Pitch
0°	340^0	0^0	Roll

The Levenberg–Marquardt (LM) algorithm is used to get the performance curve very fast. It is an iterative technique to get performance curve. The curve shows that the experimental value is nearly close to the theoretical value, and its errors are decrees with higher DOF.

The training rate is adapted for different epochs. Fig. 8 shows the change of the training rate decreasing with the number of epochs. By increasing the DOF, the joint angle value is closer with the train data.

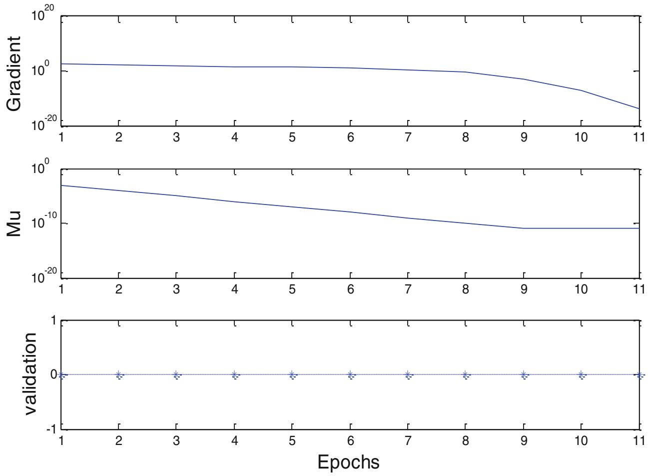


Fig. 8 Validation curve

7 Conclusion

From the analysis, it is observed that the calculated value of all joint angle of the industrial 6-DOF industrial robot is nearly equal to the experimental data. Out of different joint angle θ_1, θ_3, θ_4, θ_5 values are nearly equal to experimental data and θ_2, θ_6 values match 60% with experimental joint angle values. The trained value obtained by using neural network for the inverse kinematics gives approximate value after high training sample which is a big drawback of this paper.

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