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Kinematic Analysis Using Neuro-fuzzy Intelligent Technique for Robotic Manipulator

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Abstract

Inverse Kinematics of robotic manipulators is a complex task. This paper involves the forward and inverse kinematic analysis of three degree-of-freedom robotic manipulator. The inverse kinematic solutions have been achieved using a hybrid combination of Neural Networks and Fuzzy Logic Intelligent. The experimental validation has also been attempted on robotic manipulator to trace a desired trajectory. A comparison drawn on the methods applied shows that the results obtained for inverse kinematics are in reasonable agreement with one another.

Keywords: Inverse Kinematics; Degree of Freedom; ANFIS.

1. Introduction

The study of kinematics for any robotic manipulator can be broadly classified into two types, viz. forward kinematics and inverse kinematics. The forward kinematic problem is to find position and orientation of end-effector as a function of joint variables. The inverse kinematics problem is defined as the calculation of joint variables that would bring the end-effector in the specified position and orientation. As compared to forward kinematics, calculation of inverse kinematic solutions is a complex task since there is no possible unique solution due to non-linear and time-varying nature of its governing equation. Several authors have carried out their studies on multi-degree of freedom robots using either Artificial Neural Networks or Fuzzy Logic or their combination [1, 6, 7, 8, 9]. The kinematic analysis along with its software development has also been performed by authors in [2, 5].

In this paper, a neuro-fuzzy intelligent technique has been used to obtain inverse kinematic solutions of a three degree of freedom robotic manipulator moving in three dimensional spaces. The experimental validation of obtained results has also been attempted. This paper has been organized as follows: In section 2, ANFIS has been included. Section 3 includes kinematic analysis method used. Experimental analysis is given along with comparison in Section 4. Section 5 gives briefly the conclusion.

2. Anfis Method

J S R Jang [1] proposed an integrated system which is functionally equivalent to Sugeno fuzzy inference system, known as ANFIS (Adaptive Neuro-Fuzzy Inference System). It constructs a fuzzy inference system whose membership functions are tuned using either a back-propagation algorithm alone or in combination with a least squares type of method. The tuning or adjustment of membership functions allow the fuzzy systems to learn from the data they are modeling. The basic procedure followed by ANFIS starts with step (1) initializes fuzzy inference system; step (2) defines learning parameters such as number of membership functions and number of epochs; step (3) starts the learning process; and step (4) validates individual data set.

Here, ANFIS architecture of first order Sugeno Fuzzy Inference System has been taken. The fuzzification consists of generalized bell membership functions along with product inference rule while defuzzification is done using weighted average method. A number of epochs were used and results for 200 are reported since variations were acceptable. Here, the (x, y, z) coordinates of the end-effector are taken as the input data to ANFIS, while joint angles (θ_1, θ_2, θ_3) are taken as the output.

3. Kinematic Analysis

In this paper, the analytical method has been used for kinematic analysis carried out on a Quanser make Omni Bundle having three degree-of-freedom viz. θ_1, θ_2, θ_3, as shown in Figure 1. The robotic manipulator consists of sensors viz. potentiometers and encoders for positioning of the end-effector.

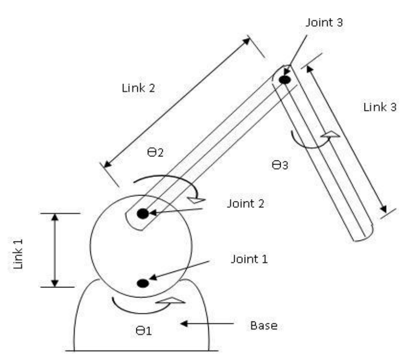


Figure 1: Schematic representation of robotic manipulator with total three degree-of-freedom.

3.1 Forward Kinematics

Denavit-Hartenberg parameters [3, 4] is used and given in Table 1. The forward kinematic equations obtained as three matrices multiplied as per the technique are as given below:

$$x = L_1 \cos\theta_1 \cos\theta_2 + L_2 \cos\theta_1 \cos\theta_2 \cos(\theta_3 - \tfrac{\pi}{2}) - L_2 \cos\theta_1 \sin\theta_2 \sin(\theta_3 - \tfrac{\pi}{2}) \quad (1)$$

$$y = L_1 \sin\theta_1 \cos\theta_2 + L_2 \sin\theta_1 \cos\theta_2 \cos(\theta_3 - \tfrac{\pi}{2}) - L_2 \sin\theta_1 \sin\theta_2 \sin(\theta_3 - \tfrac{\pi}{2}) \quad (2)$$

$$z = L_1 \sin\theta_2 - L_2 \sin\theta_2 \cos(\theta_3 - \tfrac{\pi}{2}) - L_2 \cos\theta_2 \sin(\theta_3 - \tfrac{\pi}{2}) \quad (3)$$

where, L_1, L_2 are link lengths and (θ_1, θ_2, θ_3) are respective joint angles and (x, y, z) are coordinates at any position of end effector.

Table 1: Denavit-Haretenberg parameters of robotic manipulator.

Links	ϴ [rad]	d [mm]	a [mm]	α [rad]	Link Movement
Link 1	ϴ1	0	0	-π/2	Clockwise/Anti-clockwise
Link 2	ϴ2	0	132	0	Front-Back
Link 3	ϴ3 – π/2	0	132	0	Up-Down

The results are obtained for three positions of triangle as given in Figure 2. The results are plotted in Figure 3.

3.2 Inverse Kinematics

For applying the ANFIS, the inverse kinematic equations have been used as given below:

$$\theta_1 = \tan^{-1}(y/x) \quad (4)$$

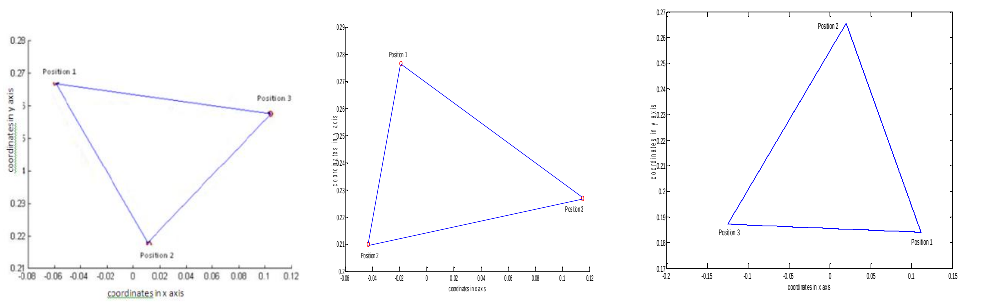
$$\theta_2 = \Phi - \gamma \quad (5)$$

$$\theta_3 = \frac{3\pi}{2} - \cos^{-1}\frac{(L_1^2 + L_2^2 - k^2)}{2L_1L_2} \quad (6)$$

where, $k = \sqrt{x^2 + y^2 + z^2}$, $\Phi = \cos^{-1}\frac{d}{k}, if\ z \le 0$ or $\Phi = -\cos^{-1}\frac{d}{k}, if\ z \ge 0$, $d = \sqrt{x^2 + y^2}$ and $\gamma = \sin^{-1}(\frac{L_2 \sin\frac{3\pi}{2} - \theta_3}{k})$. Using the above equations, the inverse kinematic solutions using ANFIS have been obtained for three positions of triangle given in Figure 2. The results have been plotted in Figure 3.

4. Experimental Analysis

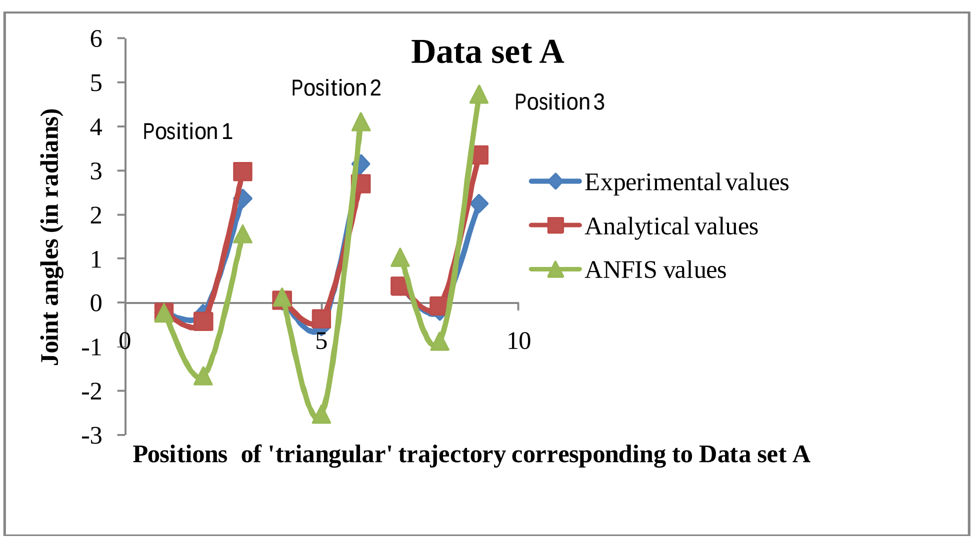
In this paper, ‘triangular’ trajectory has been traced with the help of used three degree-of-freedom robotic manipulator. Three data sets namely Data set A, Data set B and Data set C at three different positions (as shown in Figure 2 (a), (b), (c)) have been considered.



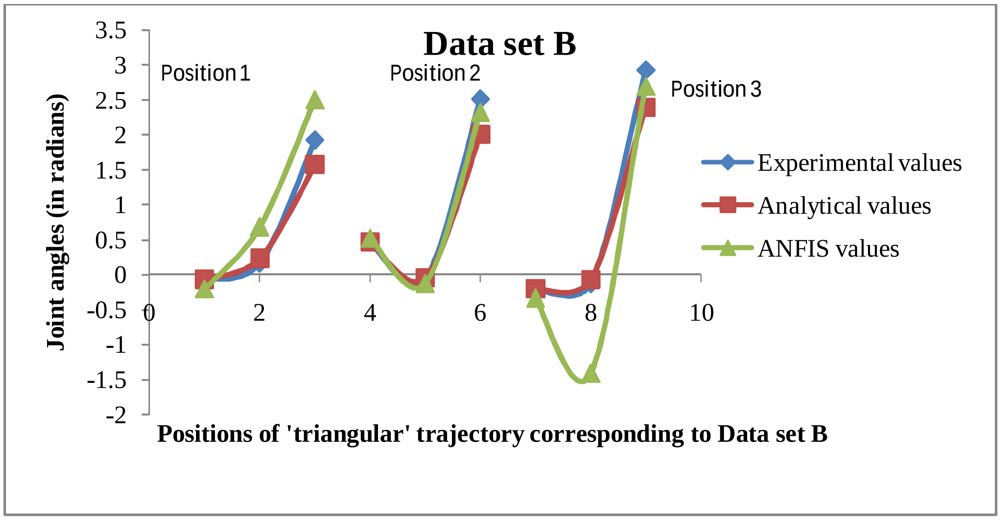
(a) Position A of triangle **(b)** Position B of triangle **(c)** Position C of triangle

Figure 2: ‘triangular’ trajectory traced with the help of robotic manipulator.

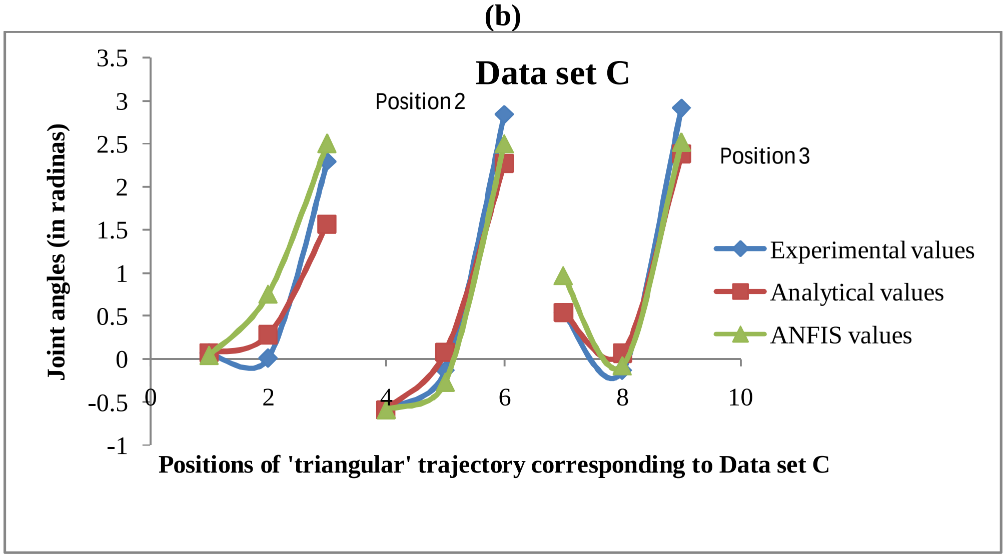
The experimental plots were obtained for the triangle as shown in Figure 2. These have been compared along with those obtained from analytical and ANFIS methods as shown in Figure 3 (a), (b) and (c). The comparison shows reasonable agreement in general though results differ for few positions.



(a)



(b)



(c)

Figure 3: Variation of joint angles (θ_1, θ_2, θ_3) of robotic manipulator.

5. Conclusion

This paper gives the results of forward and inverse kinematic analysis of three degree-of-freedom robotic manipulator moving in three dimensional spaces. Neuro-fuzzy intelligent technique viz. ANFIS has been used. An example of triangle in three positions has been used for comparisons. The comparison drawn on the methods show that the results obtained for inverse kinematics are in reasonable agreement with one another though for some positions, the results differ. Further work can include different trajectories.

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