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A Comparative Study of Prediction of Inverse Kinematics Solution of 2-DOF, 3-DOF and 5-DOF Redundant Manipulators by ANFIS

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Abstract - In this paper, a method for solving forward and inverse kinematics of redundant manipulator is proposed. Obtaining the joint variables of these manipulators from a desired position of the robot end-effector called as inverse kinematics (IK), is one of the most important problems in robot kinematics and control. The difficulties in solving the IK equations of these redundant robot manipulator arises due to the presence of uncertain, time varying and non-linear equations having transcendental functions. The ability of ANFIS (Adaptive Neuro-Fuzzy Inference System) is used in this paper, to predict the IKs solution of this manipulator. A single-output Sugeno-type FIS (Fuzzy Inference System) using grid partitioning has been modelled in this work. The Denavit-Harbenterg (D-H) notation is used to model robot links and solve the transformation matrices of each joint. The forward kinematics and inverse kinematics for a 2-DOF, 3-DOF and 5-DOF robot manipulator are analysed symmetrically to shows the effectiveness of this approach. The Efficiency of ANFIS can be concluded by observing the surface plot, residual plot and normal probability plot of generated data.

Keywords - *2-DOF, 3-DOF and 5-DOF Robot Manipulator, Inverse kinematics; ANFIS; Denavit Harbenterg (D-H) notation.*

1. Introduction

Generating the desired space variables from the joint space variables is called forward kinematics but to obtain the joint space variables from Cartesian space is inverse kinematics. To obtain the inverse kinematics solution has been one of the major problems in robot kinematics and control. With higher degree of freedom (DOF), the manipulator becomes redundant which leads to difficulties in solving the IK problems. In spite of difficulties in solving the IK of complex robot, researchers used traditional method like algebraic [1], geometric [2] and iterative [3].But these methods are time consuming and produce highly complex equations for high degree of freedom manipulator. An analytical solution for a 5-DOF manipulator to follow a given trajectory while keeping the orientation of one axis in the end-effector frame by considering the singular position problem was carried out by the authors. [4].

A complete analytical inverse kinematics (IK) model has been developed [5], which is able to control the P2Arm to any given position and orientation, in its reachable space. An application has been adopted [6] of ANN to the solution of the IK problem for serial robot manipulators. In his study, two networks were trained and compared to examine the effect of the Jacobian matrix to the efficiency of the inverse kinematics solution. ANFIS can be employed to model nonlinear functions as it use the hybrid learning algorithm that combines least square method with gradient descent method to adjust the parameter of membership function [7]. It is noted that ANFIS is suitable for solving complex, non-linear mathematical equation for control of higher DOF robot manipulator. In this paper, ANFIS is implemented to analyze the kinematics solution of 2-DOF, 3-DOF and 5-DOF robot manipulator.

2. ANFIS Architecture

ANFIS stands for adaptive neuro-fuzzy inference system developed by Roger Jang [7]. It is a feed forward adaptive

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neural network which implies a fuzzy inference system through its structure and neurons. He reported that the ANFIS architecture can be employed to model nonlinear functions, identify nonlinear components on-line in a control system, and predict a chaotic time series. It is a hybrid neuro-fuzzy technique that brings learning capabilities of neural networks to fuzzy inference systems. It is a part of the fuzzy logic toolbox in MATLAB R2008a software of Math Work Inc [8]. The fuzzy inference system (FIS) is a popular computing frame work based on the concepts of fuzzy set theory, fuzzy if-then rule, and fuzzy reasoning. It has found successful application in a wide variety of fields, such as automatic control, data classification, decision analysis, expert system, time series prediction, robotics, and pattern recognition. The basic structure of a FIS consists of 3 conceptual components: a rule base, which contains a selection of fuzzy rules: a database, which define the membership function used in fuzzy rules; a reasoning mechanism, which performs the inference procedure upon the rules and given facts to derive a reasonable output or conclusion. The basic FIS can take either fuzzy input or crisp inputs, but outputs it produces are almost always fuzzy sets. Sometime it is necessary to have a crisp output, especially in a situation where a FIS is used as a controller. Therefore, method of defuzzification is needed to extract a crisp value that best represent a fuzzy set. For solving the IK of 2-DOF, 3-DOF and 5-DOF redundant manipulator used in this work Sugeno fuzzy inference system is used, to obtain the fuzzy model. The Sugeno FIS was proposed by Takagi, Sugeno, and Kang [9, 10] in an effort to develop a systematic approach to generate fuzzy rules from a given input and output data set.

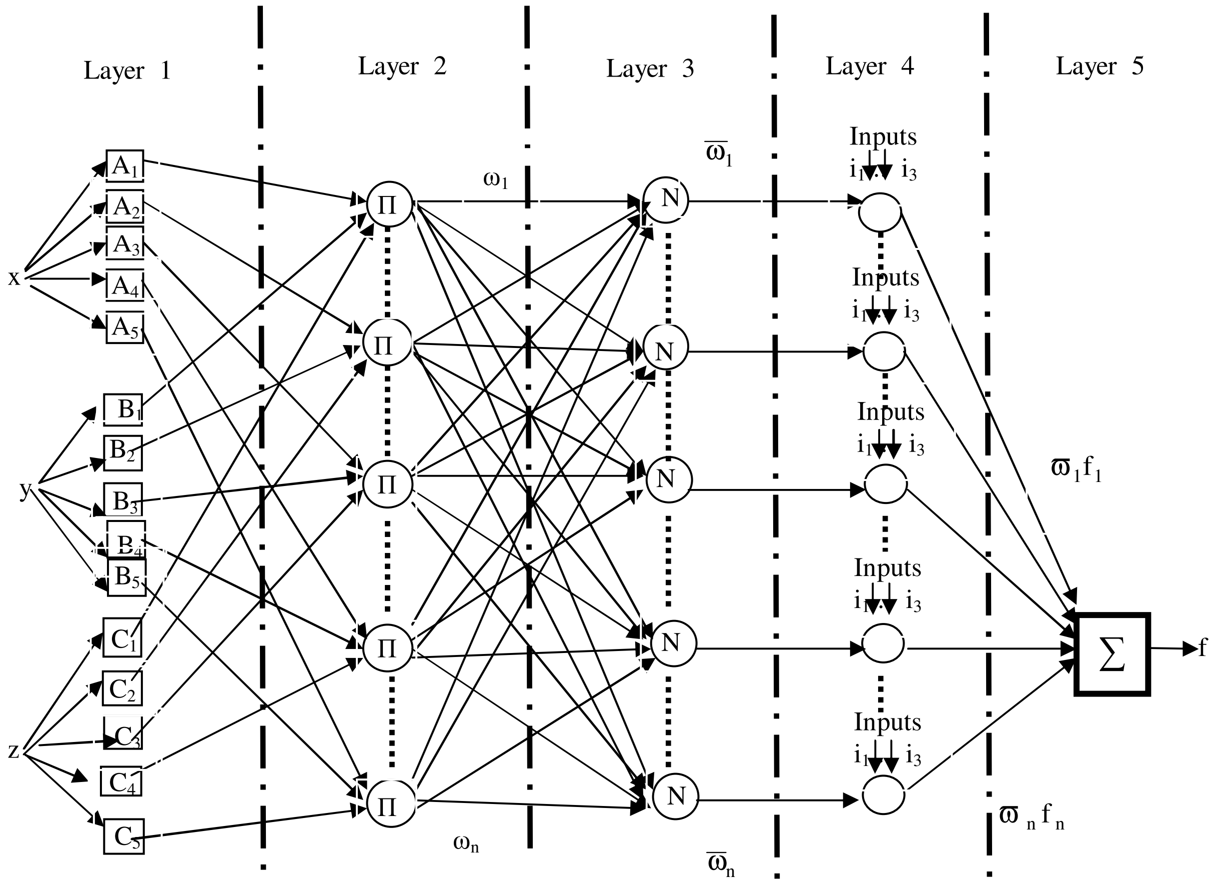

Fig. 1 Architecture of three inputs with five membership functions of the ANFIS model.

For solving the inverse kinematics equation of 2-DOF, 3-DOF and 5-DOF Redundant manipulator, in this work, the grid partitioning option in the ANFIS toolbox is used. For each input, 5 membership function (Gaussian membership) are used along with 125(=5^3) fuzzy rules are applied for all three inputs. For the neuro-fuzzy model used in this work, 400, 512, 1024 data points respectively for 2-DOF, 3-DOF and 5-DOF are analytically obtained from MATLAB, of which 300, 416, 776 are used for training and the remaining 100, 96, 248 are used for testing (validating). The architecture of three inputs and 5

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membership function of ANFIS model is prescribed in Fig.1.

2.1 Work Space for 2-DOF, 3-DOF and 5-DOF Redundant Manipulator

Considering all the D-H parameters, the x, y and z coordinates are calculated for 2-DOF, 3-DOF and 5-DOF end-effector using forward kinematics. Fig.2 (a), Fig(2b) and Fig(2c), shows the workspace for all this manipulator which are obtained by plotting the x, y and z coordinates.

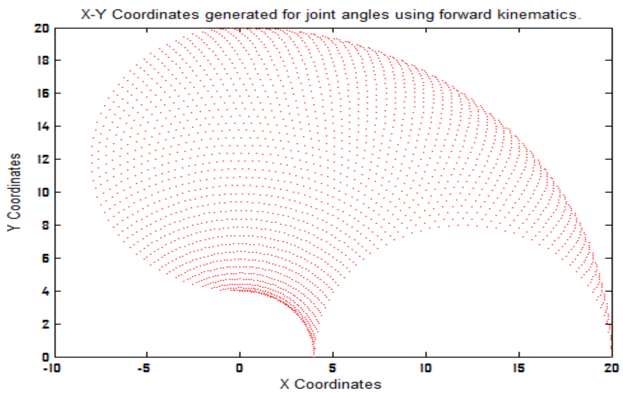

Fig. 2 (a). Workspace for 2-DOF

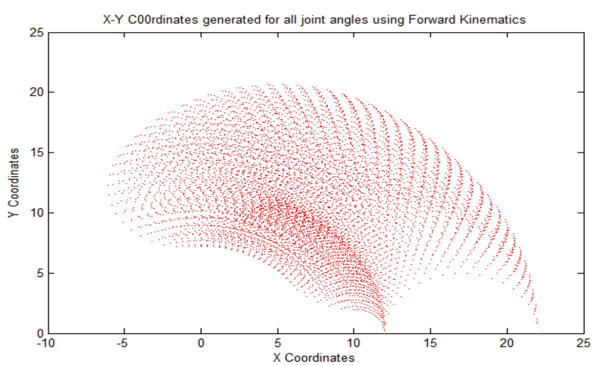

Fig. 2(b). Workspace for 3-DOF

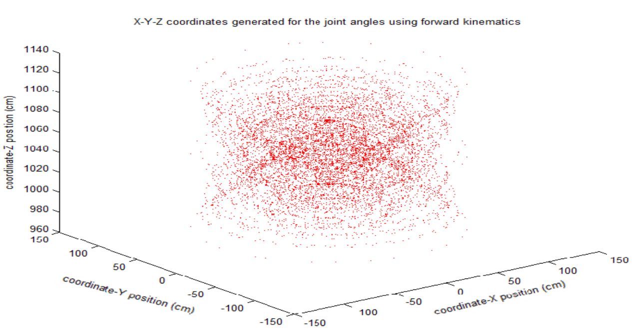

Fig. 2 (c). Workspace for 5-DOF

3. Results and Discussion

In this section of the paper surface plots, the residual plots and the normal probability plots for the 2-DOF, 3-DOF and 5-DOF redundant manipulator is carried out. The surface plots obtained for this type of manipulators explains the efficiency of the ANFIS methodology. The residual plots obtained by comparing the predicted data from the ANFIS and the analytical data show that, the data predicted using ANFIS methodology deviate very less from the analytical data.

3.1. 3-D Surface viewer Analysis

The 3-D surface plots, obtained for the 2-DOF, 3-DOF and 5-DOF Redundant manipulator are discussed. The surface plot dispaly both the connecting lines and faces of the surface in color. The surf command in MATLAB tool is use to create the 3-D surface plots of the matrix data. The surface plot explains the relation between the output and two inputs.

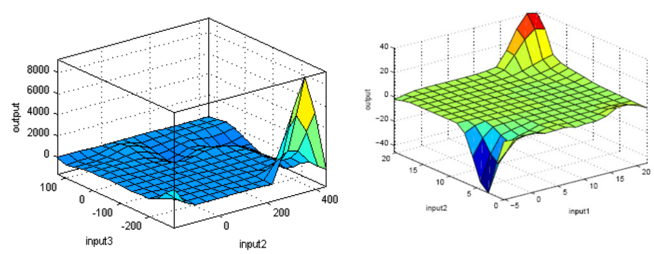

Fig. 3(a) 3-D Surface plots obtained for joint angles of 2-DOF Redundant manipulator.

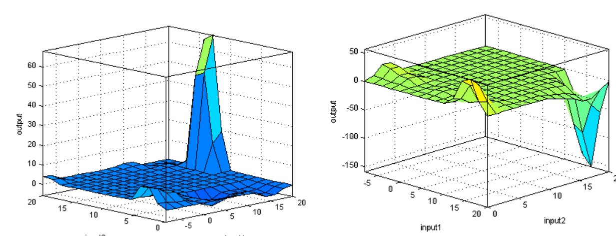

Fig.3 (b). 3-D Surface plots obtained for joint angles of 3-DOF Redundant manipulator.

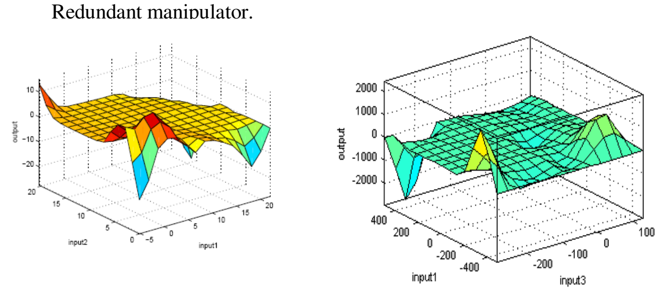

Fig.3 (c). 3-D Surface plots obtained for joint angles of 5-DOF Redundant manipulator.

3.2. Residual Plot Analysis

Residuals are the difference between the predicted output data from the model (ANFIS) and the actual values of joint angles. The residual plot is a graph that shows the residuals in the vertical axis and the independent variables in the horizontal axis. If the points in the residual plot are randomly dispersed around the horizontal axis, the prediction model is considered to be appropriate for the data i.e. there is no drift in the data. In this section the residual plots are obtained for training and testing data of few joint angles of 2-DOF, 3-DOF and 5-DOF Redundant manipulator. It depicts the distribution of residuals of all joint angles are in the positive and negative axis of the plot. The following Fig 4(a), 4(b) depicts the residual plot of training data of 5-DOF manipulator. Similarly we can also obtained the residual plots for training and testing data of all the manipulators.

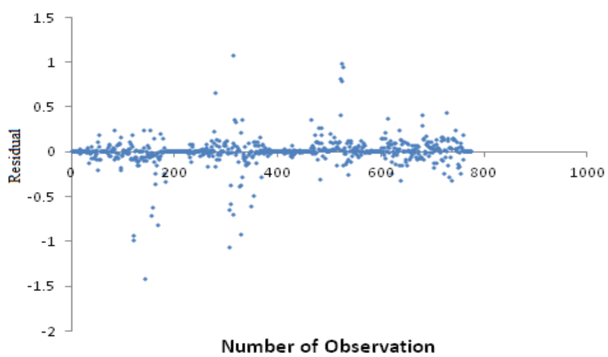

Fig. 4(a). Residual plot of training data for θ_1 of 5-DOF Redundant manipulator.

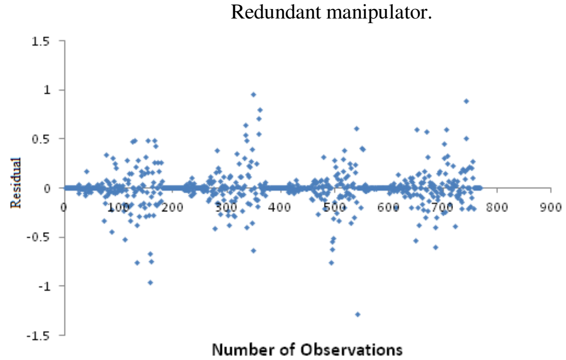

Fig. 4(b). Residual plot of training data for θ_4 of 5-DOF Redundant manipulator.

3.3. Normal Probability Plot Analysis.

The normal probability plot [11] is a graphical technique for assessing whether or not a data set is approximately normally distributed, if it is nearly straight, the data satisfy the nearly normal condition. The data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. It provides a good assessment of the adequacy of the normal model for a set of data. The following Fig 5(a), 5(b) depicts the Normal probability plot of training data of 5-DOF manipulator. Similarly we can also obtained the Normal probability plots for training and testing data of all the manipulators.

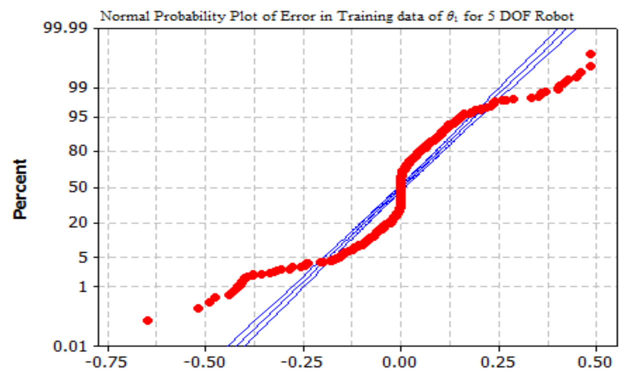

Fig. 5(a). Normal probability plot for residuals of Training data of θ_1

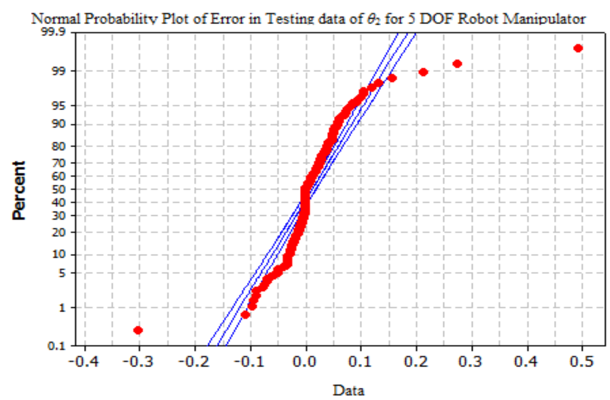

Fig. 5(b). Normal probability plot residuals of Testing data of θ_2

4. Conclusion

In this study, the inverse kinematics solution using ANFIS for a 2-DOF, 3-DOF and 5-DOF redundant manipulator is presented. The difference in joint angle deduced and predicted with ANFIS model for The difference in joint angle deduced and predicted with ANFIS model for a 2-DOF, 3-DOF and 5-DOF Redundant manipulator clearly depicts that the proposed method results with an acceptable error. The modelling efficiency of this technique was obtained by taking three end-effector coordinates as input parameters and 2,3,5 joint position for 2-DOF, 3-DOF and 5-DOF respectively. The ANFIS model used with a smaller number of iteration steps with the hybrid learning algorithm. Hence, the trained ANFIS model can be utilized to solve complex, nonlinear and discontinuous kinematics equation complex robot manipulator; thereby, making ANFIS an alternative approach to deal with inverse kinematics. The methods used in this work can be use for deriving the inverse kinematics model for the these manipulators and could be applied to other types of robotic arms, such as the EduBots developed by the Robotica Ltd, Pioneer 2 robotic arm (P2Arm), 5-DOF Lynx 6 Educational Robot arm. It can be concluded that the solution developed in this paper will make the complex manipulator more useful in application with unpredicted trajectory movement in unknown environment.

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