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ANALYSIS OF REDUNDANT MANIPULATOR USING ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

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Abstract

In this work a single-output suzeno-type FIS (fuzzy inference system) is modeled using grid segmentation. The Denavit–Hartenberg (D–H) representation is used to model the robot link and solve the transformation matrix of each joint. Forward kinematics and inverse kinematics are analyzed systematically for 5-DOF and 7-DOF manipulators. In this work ANFIS has been successfully used to predict IKs of 5-DOF and 7-DOF redundant manipulations. After comparing the outputs, it is concluded that the prediction capability of ANFIS is excellent because this approach provides a general framework for combining NN and fuzzy logic. The efficiency of ANFIS can be concluded by looking at the surface plot, residual plot and normal probability plot. This present study will provide valuable information for other modellers in using different non-linear models for predicting the IK of 5-DOF and 7-DOF redundant manipulations.

Keywords: *5-DOF and 7-DOF Redundant Robot Manipulator; Inverse kinematics; ANFIS; Denavit-Harbenterg (D-H) notation.*

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1. INTRODUCTION

A manipulator must have at least six degrees of freedom if it is required to achieve any random position and orientation in its operational location or workspace. Let's say there is an addition. Such manipulations must be composed of at least six joints for each degree of freedom required. Typically, in standard practice, three degrees of freedom are applied to the robotic arm to allow it to attain the desired position in its work space. The hand is then fitted with a wrist made of three joints to obtain the desired orientation. Such manipulations are called non-redundant. Although non-redundant manipulations are kinetically simple to design and solve, non-redundancy leads to two fundamental problems: singularity and the inability to avoid obstacles. The eccentricity of the robotic manipulator is present in both the hand and the wrist and can occur anywhere within the manipulator's scope. When passing through these singularities, the manipulator can lose some degree of freedom, resulting in uncontrollability in those directions [4]. Obstacle avoidance is another desirable feature for effectively planning motion trajectories, especially for manipulators designed to perform demanding tasks in compressed environments [5]. The two problems can be solved by adding degree of freedom to the manipulator [6]. These additional degrees of freedom can be added to the joints, effectively becoming singular in some positions such as the shoulder, elbow or wrist. And therefore help overcome eccentricities or avoidance of obstacles. So, a redundant manipulator must have at least one degree of freedom (DOF) higher than the number required for the normal free state. Redundant can also be defined as when a manipulator can reach a specified location with more than one linkage configuration; the manipulation is said to be redundant. From a general point of view, any robotic system in which the method of achieving a given task is not unique can be said to be redundant.

2. OBJECTIVE

The main objectives of this thesis can be summarized as follows:

- The difficulties in solving the inverse kinematics (IK) of the redundant manipulator increase as the IK equations possess an infinite number of solutions due to the uncertain, time-varying and non-linear nature of these equations having transcendental functions. So in this thesis, ANFIS is adopted for estimating the IK solution of a 7-DOF Redundant manipulator.
- The Denavit-Harbenterg (D-H) representation is used to model robot links and solve the transformation matrices of each joint.
- The solution of the IK of the redundant manipulator predicted by the ANFIS model is compared with the analytical value. It is found that the predicting ability of ANFIS is excellent as it is a combination of neural network (NN) and neuro-fuzzy (NF) techniques.
- The data predicted with ANFIS for 5-DOF and 7-DOF Redundant manipulators in this work depicts that the proposed method results in an acceptable error. Hence, ANFIS can provide fast and acceptable solutions to the inverse kinematics, thereby making ANFIS an alternate approach to mapping the inverse kinematic solutions.

3. FORWARD KINEMATICS AND INVERSE KINEMATICS

In this section of the thesis the forward kinematics and the inverse kinematics of the 5- DOF and 7-DOF redundant manipulator is discussed. The Denavit-Hartenberg (D-H) notation for these two manipulators is discussed with steps used for deriving the forward kinematics is presented. Then this chapter is concluded with the solution of inverse kinematics for the 5-DOF redundant manipulator is given. The forward kinematics is concerned with the relationship between the individual joints of the robot manipulator and the position (x,y, and z) and orientation (ϕ) of the end-effector. Stated more formally, the forward kinematics is to determine the position and orientation of the end-effector, given the values for the joint variables (θ_i , a_i , d_i , α_i) of the robot. The joint variables are the angles between the links in the case of revolute or rotational joints, and the link extension in the case of prismatic or sliding joints. The forward kinematics is to be contrasted with the inverse kinematics, which will be studied in the next section of this chapter, and which is concerned with determining values for the joint variables that achieve a desired position and orientation for the end-effector of the robot. The above mention theory is explained diagrammatically in figure 1.

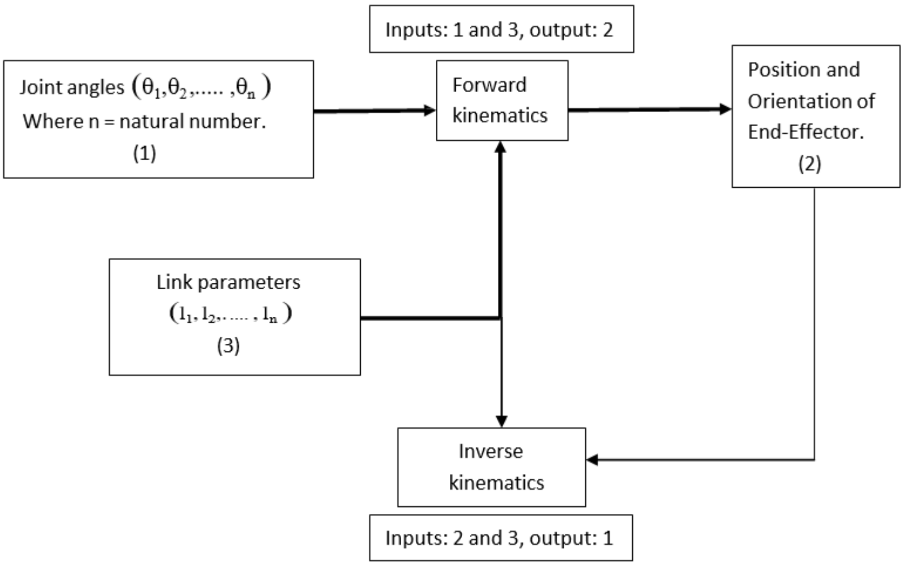

Figure 1. Forward and Inverse kinematics scheme

3.1 The forward kinematics of a 5-DOF and 7-DOF Redundant manipulator

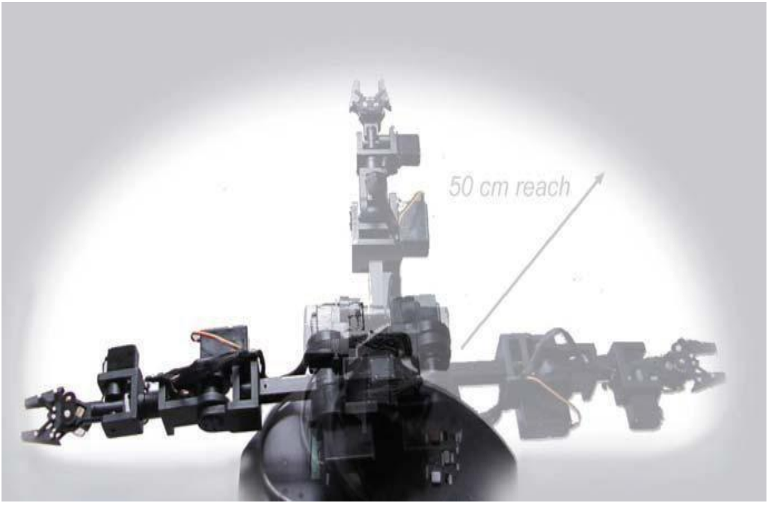

Figure 2. A Pioneer Arm Redundant manipulator

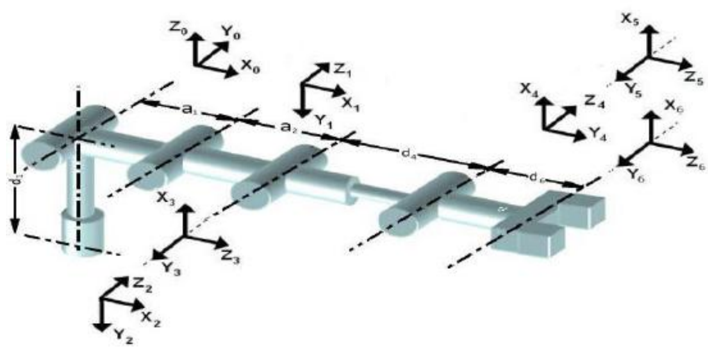

Figure 3.Coordinate frame for the 5-DOF Redundant manipulator

3.2 Work space for the 5-DOF Redundant manipulator

Considering all the D-H parameters, the x, y and z coordinates are calculated for 5-DOF Redundant manipulator End-effector using forward kinematics equation shown in equations 4-15. For solving the forward kinematics equations, the angles of rotation of the joints are taken as tabulated in Table 1. Figure 4 shows the workspace for 5-DOF Redundant manipulator.

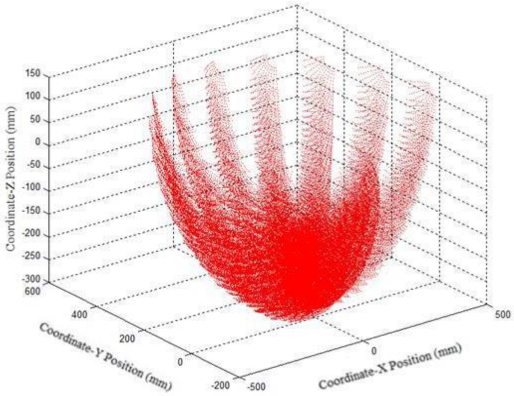

Figure 4. Work space for 5-DOF Redundant manipulator

3.3 Coordinate frame of a 7-DOF Redundant manipulator.

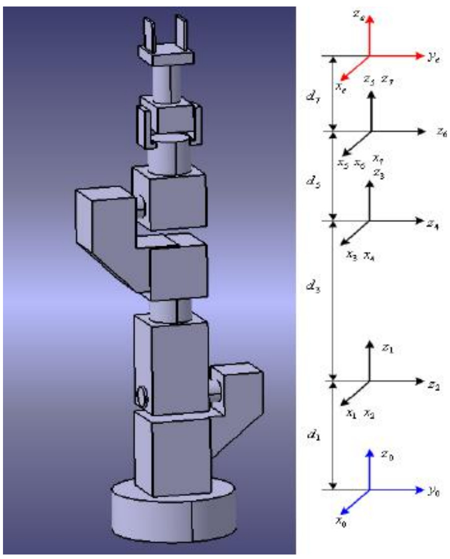

Figure 5. Coordinate frame for a 7-DOF Redundant manipulator

3.4 Work space for the 7-DOF Redundant manipulator

Considering all the D-H parameters, the x, y and z coordinates (i.e. End-effector coordinates) are calculated for 7-DOF Redundant manipulator using forward kinematics equation as shown in equations 17-28. For solving the forward kinematics equations, the angles of rotation of the joints are taken as tabulated in Table 2. Figure 6 shows the workspace for this manipulator.

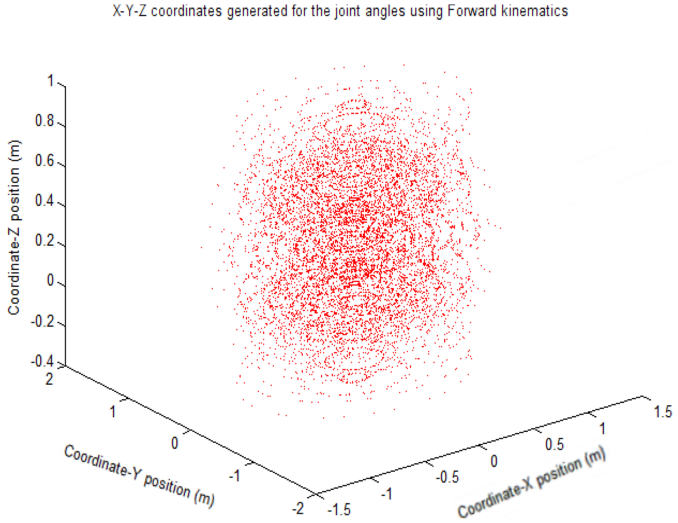

Figure 6. Work space for 7-DOF Redundant manipulator

4. RESULT AND DISCUSSION

In this section of the thesis the surface plots, the residual plots and the normal probability plots for the 5-DOF and 7-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. The last section of this chapter is concluded with obtaining the normal probability plots. The details of the plots are explaining in the following section.

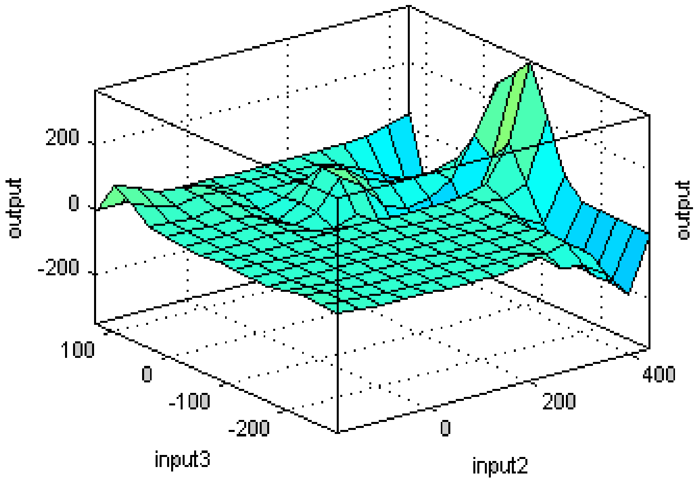

Figure 7. Surface plot for □1

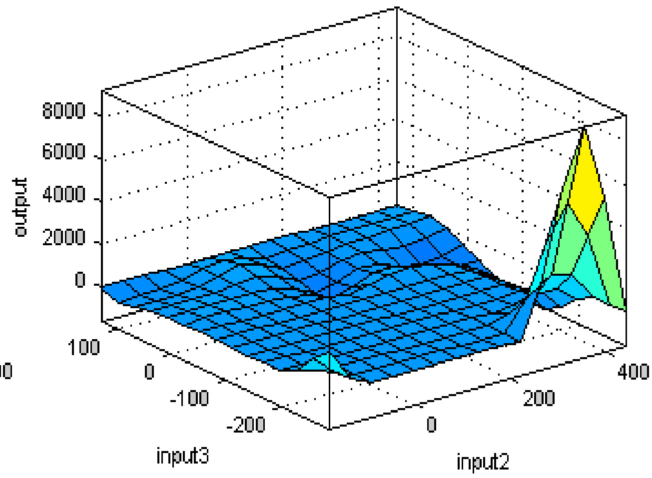

Figure 8. Surface plot for □2

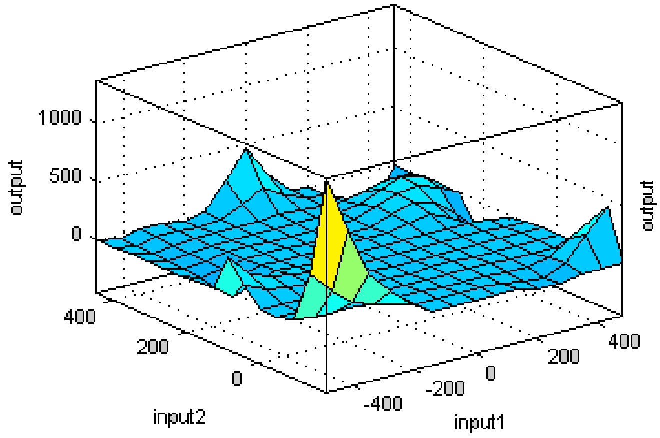

Figure 9. Surface plot for □3

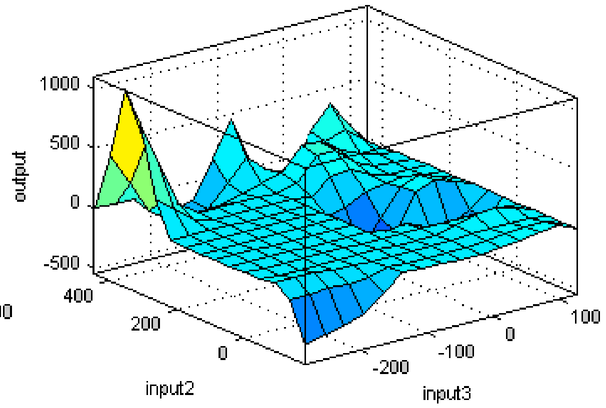

Figure 10. Surface plot for □4

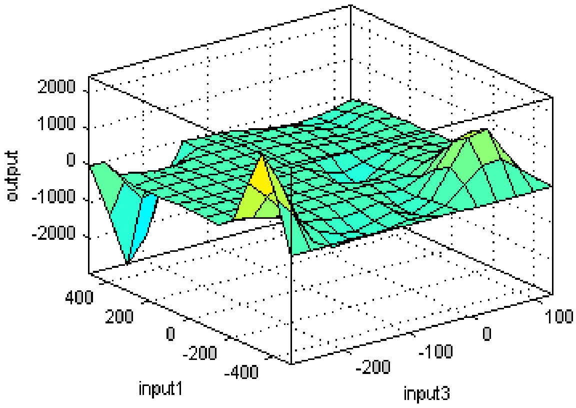

Figure 11. Surface plot for □5

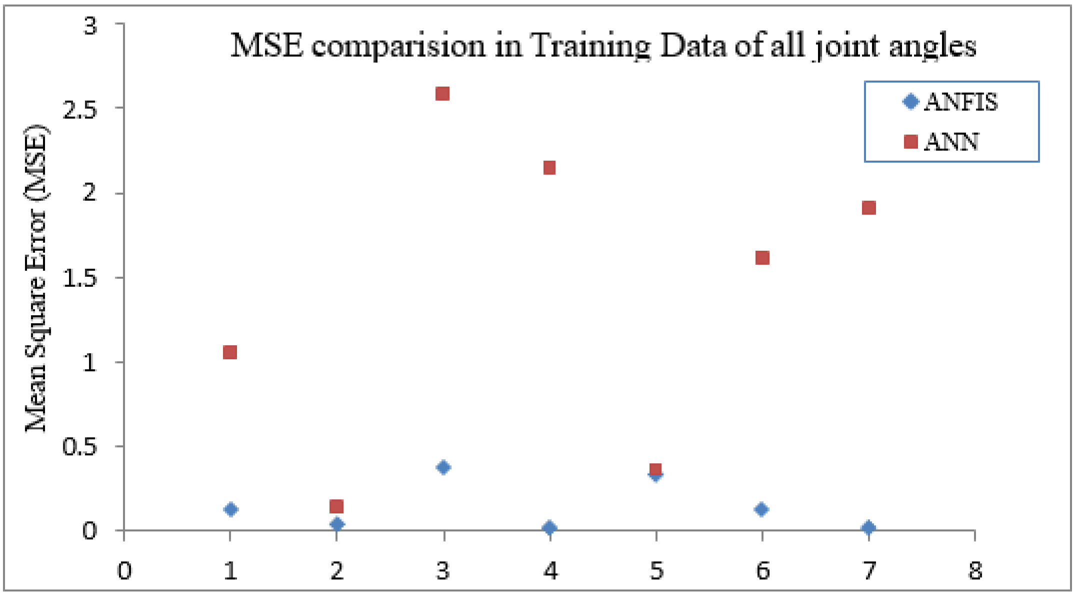

Figure 12. Comparison of Mean Square Error plot for Training data

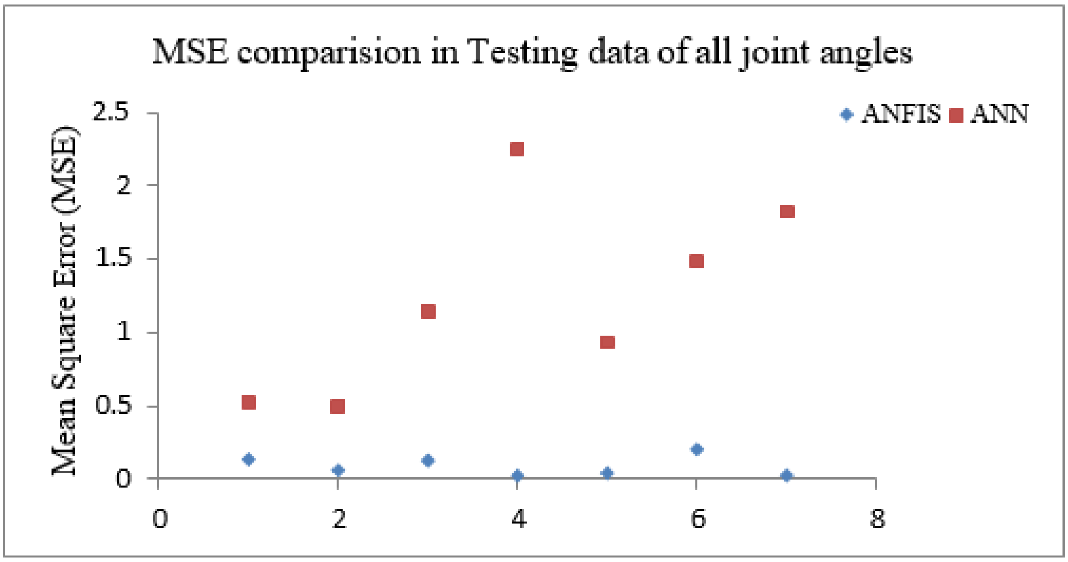

Figure 13. Comparison of Mean Square Error plot for Testing data.

By comparing the output from ANFIS and ANN model on the basis of global statistic i.e. MSE, MBE, and R2, it can be concludes that the ANFIS model is more flexible than the ANN model considered in this research, for prediction of IKs. As the ANFIS approach provides a general frame work for combination of NN and fuzzy logic. The efficiency of ANFIS over ANN can also be concluded by observing the graphs and tables which shows the comparison MSE, MBE, R2 for the two models. Based on comparison of the results of these two techniques, it is found that the proposed ANFIS model with Gaussian membership function is more efficient than the multilayer feed forward ANN using Levenberg-Marquardt (LM) algorithm for predicting the IK of the 7-DOF redundant manipulator

5. CONCLUSION

In this study, the inverse kinematics solution using ANFIS for a 5-DOF and 7-DOF Redundant manipulator is presented. The difference in joint angle deduced and predicted with ANFIS model for a 5-DOF and 7-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 five and seven joint positions for a 5-DOF and 7-DOF Redundant manipulator respectivly as output parameters in training and testing data of NF models. Also, 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 analytical inverse kinematics model derived always provide correct joint angles for moving the arm end-effector to any given reachable positions and orientations.

As the ANFIS approach provides a general frame work for combination of NN and fuzzy logic. The efficiency of ANFIS for predicting the IK of Redundant manipulator can be concluded by observing the 3-D surface viewer, residual and normal probability graphs. The normal probability plots of the model are also plotted. The normal probability plot of residuals of training and testing data obtained from ANFIS shows that the data set of ANFIS are approximately normally distributed.

The methods used for deriving the inverse kinematics model for the these manipulators 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 PArm more useful in application with unpredicted trajectory movement in unknown environment.

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