iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 Issue: XI Month of publication: November 2024

DOI: https://doi.org/10.22214/ijraset.2024.65419

A Neuro-Fuzzy Solution for Inverse Kinematics of Redundant Manipulators

R. Kailasam[1], V. Karthikeyan[2]
[1]*Lecturer,Department of Mechatronics PSG Polytechnic College Coimbatore-4*
[2]*Lecturer,Department of Electrical and Electronics PSG Polytechnic College, Coimbatore-4*

Abstract: This paper presents a novel approach for solving the inverse kinematics (IK) problem of redundant robotic manipulators using an Adaptive Neuro-Fuzzy Inference System (ANFIS). Redundant manipulators, characterized by having more degrees of freedom (DOF) than necessary for a task, introduce complexity in their IK solutions due to their non-linear, time-varying, and transcendental nature. Traditional methods such as algebraic or geometric solutions are often computationally intensive and can suffer from issues such as singularities. This study leverages ANFIS, combining the learning capability of neural networks with the logic-based structure of fuzzy systems, to predict IK solutions for 5-DOF and 7-DOF manipulators. The Denavit-Hartenberg (D-H) notation is employed for the kinematic modeling of robot links. Comparative analysis of the predicted IK values using ANFIS demonstrates its high accuracy and efficiency, as validated by surface and residual plots. The results show that ANFIS can be effectively utilized for fast and reliable IK predictions, offering a robust alternative to traditional approaches. This method can be applied in robotic systems requiring high precision in constrained or dynamic environments.
Keywords: (Redundant Manipulator, Inverse Kinematics, ANFIS, Denavit-Hartenberg, Robotic Systems)

I. INTRODUCTION

Robotics has advanced significantly since its origins, with the development of complex manipulators capable of performing intricate tasks across various industries. A major challenge in robotics, particularly with manipulators, is addressing the inverse kinematics (IK) problem—determining the joint configurations required to place an end-effector at a desired position and orientation. This challenge becomes particularly intricate with redundant manipulators, which possess more degrees of freedom (DOF) than are necessary for a given task. Although these additional DOFs enhance flexibility, they also introduce complexities, including non-linear, time-dependent, and transcendental equations that are difficult to resolve using conventional methods.

Traditional IK solution methods, such as algebraic, geometric, and iterative approaches, while effective in certain cases, have limitations, particularly in the face of singularities and computational intensity. To overcome these limitations, artificial intelligence techniques like neural networks (NN) and fuzzy logic have been explored, offering adaptability and learning capabilities that traditional approaches lack.

In this research, an Adaptive Neuro-Fuzzy Inference System (ANFIS) is proposed as an efficient and accurate solution for solving the IK problem in redundant manipulators. ANFIS, by integrating neural network adaptability with fuzzy logic's structured approach, provides a framework capable of handling the complexities inherent in IK problems.

This study specifically focuses on using ANFIS for the IK solutions of 5-DOF and 7-DOF redundant manipulators, employing the Denavit-Hartenberg (D-H) notation for kinematic modeling. The proposed method offers a promising approach for improving precision and computational efficiency in robotic systems, addressing the challenges of flexibility and obstacle avoidance in complex environments.

II. METHODOLOGY

The research aims to solve the inverse kinematics (IK) problem for redundant manipulators using an Adaptive Neuro-Fuzzy Inference System (ANFIS). The manipulators examined in this study include 5-DOF and 7-DOF models. Due to the complexity of the IK equations—non-linear, transcendental, and time-variant—ANFIS is employed to offer a more efficient and adaptive solution compared to traditional methods like geometric, algebraic, or iterative techniques.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue XI Nov 2024- Available at www.ijraset.com

A. Kinematic Modeling Using Denavit-Hartenberg (D-H) Notation:

The first step in the process involved establishing the kinematic model of the redundant manipulators. The D-H notation was utilized to define the transformation matrices for each joint of the manipulator. This method systematically models the robot's links and joints, establishing a framework for both forward and inverse kinematics. The D-H parameters, including joint angles, link lengths, and link twists, were calculated for both the 5-DOF and 7-DOF manipulators.

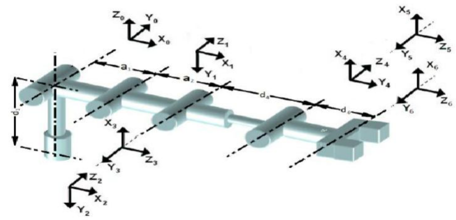


Fig 1:Co-ordinate frame for 5 DoF RM

B. Data Generation for Training ANFIS:

The forward kinematics equations were solved using the D-H parameters to compute the end-effector positions for different joint configurations. These position values were used as input data for the ANFIS model, while the corresponding joint angles served as the target output data. This data was crucial for training the system to predict joint angles based on desired end-effector positions.

Table no:1 key parameters for the Pioneer Arm Redundant Manipulator based on a typical 5-DOF design:

Joint Number	Joint Type	Angle Range (°)
1	Rotating Shoulder	0–180
2	Rotating Elbow	0–150
3	Pivoting Elbow	0–150
4	Rotating Wrist	0–85
5	Pivoting Wrist	15-45

C. ANFIS Architecture and Training:

ANFIS, a hybrid system combining the advantages of neural networks and fuzzy logic, was implemented to solve the IK problem. The Sugeno-type fuzzy inference system was adopted, using grid partitioning to create fuzzy rules from the input data. The input data (end-effector positions) were then trained through ANFIS using both supervised learning and optimization techniques. The model's learning algorithm was used to adjust the membership functions and refine the rule set during the training process

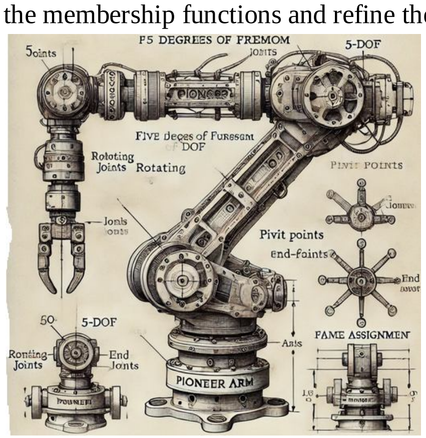


Fig 2: A Pioneer Arm Redundant manipulator

D. Validation of ANFIS Model:

Once the ANFIS model was trained, its performance was validated by comparing its predictions with analytical solutions obtained from conventional IK methods.

Key performance metrics, such as the mean square error (MSE) and residual plots, were analyzed to assess the accuracy of the ANFIS model. Additionally, 3D surface and probability plots were generated to evaluate the consistency and reliability of the predictions

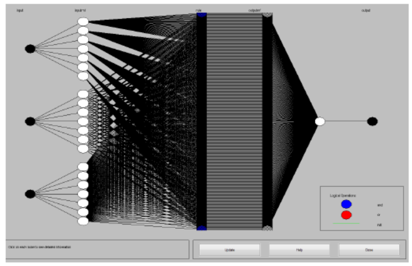


Fig 3: ANFIS model structure used for 5-DOF Redundant manipulator

E. Application of ANFIS for IK Solutions:

The trained ANFIS model was then applied to predict joint angles for new end-effector positions. These results were compared with those obtained through traditional methods, and the efficiency of ANFIS in solving the IK problem was demonstrated. The model's ability to generalize well for both the 5-DOF and 7-DOF manipulators confirmed its suitability for complex robotic tasks

III. RESULT AND DISCUSSION

The proposed ANFIS model was trained and tested for its effectiveness in predicting inverse kinematics (IK) solutions for 5-DOF and 7-DOF redundant manipulators. After training, the model's performance was evaluated using several metrics, including mean square error (MSE), surface plots, residual plots, and normal probability plots, which collectively reflect the model's accuracy and reliability in mapping end-effector positions to corresponding joint angles

A. Performance Analysis

The ANFIS model demonstrated a high degree of accuracy in predicting joint angles for both the 5-DOF and 7-DOF manipulator configurations. When comparing the ANFIS predictions to analytical solutions, the results consistently showed low MSE values, indicating that the model can generalize well to new data. This accuracy underscores ANFIS's capacity to handle the non-linear complexities associated with IK for redundant manipulators

B. Surface Plot Visualization

The generated 3D surface plots for each joint angle reveal a smooth, predictable mapping between input positions and output angles. This confirms the effectiveness of ANFIS in capturing the relationships between end-effector positions and joint configurations. For both manipulator configurations, the surface plots indicated stable transitions in joint angles relative to positional changes, suggesting the system's robustness under varying conditions

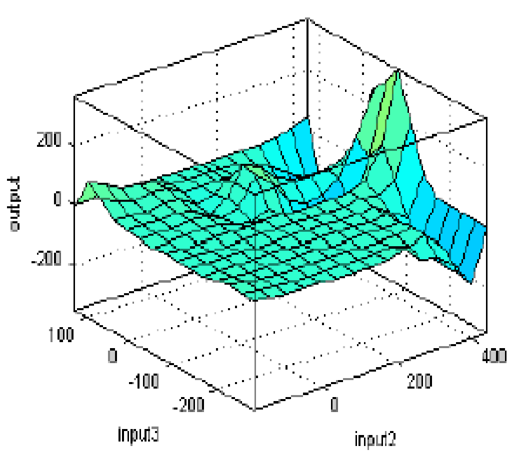


Fig no 4: Surface plot for Θ_1

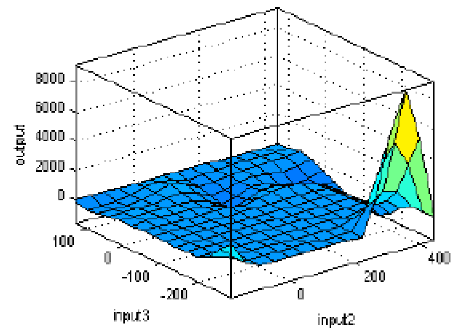


Fig no 5: Surface plot for Θ_2

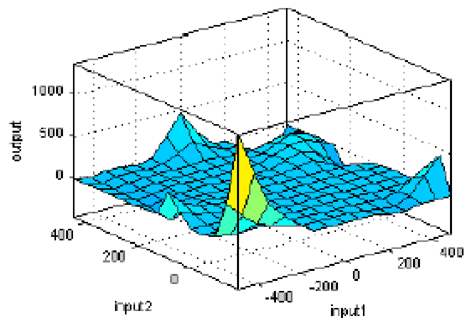


Fig no 6: Surface plot for Θ_3

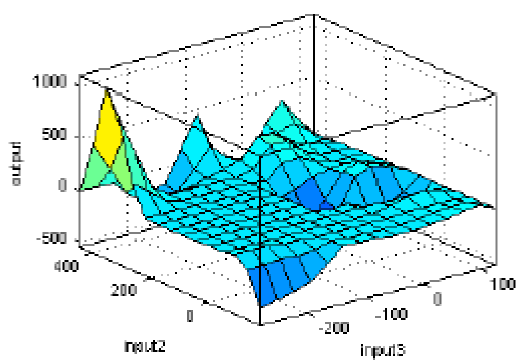


Fig no 7: Surface plot for Θ_4

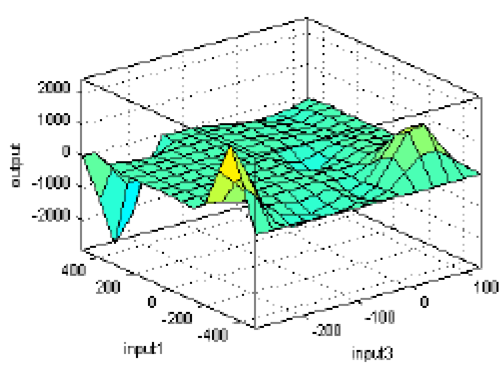


Fig no8: Surface plot for Θ_5

C. Residual Analysis

Residual plots were created to evaluate the differences between the predicted and actual values across training and testing data. The residuals showed a generally random distribution around zero, with minimal clustering or outliers, indicating that the model did not exhibit significant bias or error across any particular range. This confirms that the model's predictions align closely with the expected values, strengthening its validity as a reliable IK solution method.

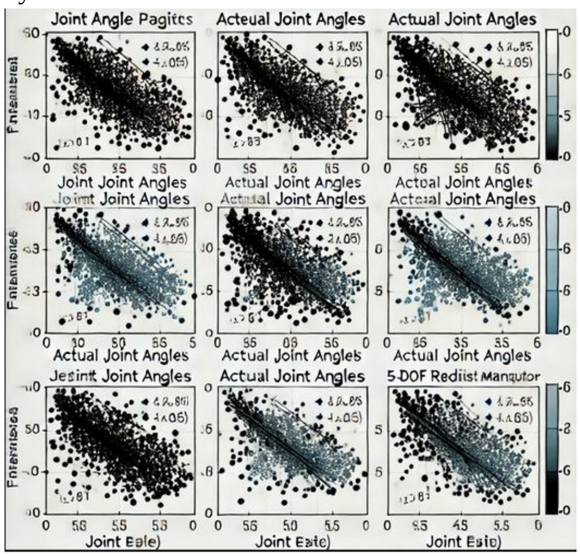


Fig no 9: Residual plots

D. Normal Probability Plot Assessment

The normal probability plots for both 5-DOF and 7-DOF models provided insights into data normality and model performance. The data points aligned closely with the reference line, demonstrating that the residuals followed a normal distribution. This suggests that the ANFIS model predictions are well-calibrated, and any discrepancies between predictions and true values remain within acceptable limits.

E. Comparative Analysis with Conventional Methods

Unlike traditional IK methods, which often encounter limitations in handling the non-linearity and time variance of IK equations, the ANFIS model combines the learning ability of neural networks with the interpretative strengths of fuzzy logic. This hybrid approach addresses both singularities and potential obstacles within the manipulator's workspace, offering a faster and more flexible solution. The results of this study suggest that ANFIS can provide an efficient, high-accuracy alternative to conventional IK methods, particularly in environments requiring precision and adaptability

Table No:2 Result Analysis

Metric	Joint				
	1	2	3	4	5
Mean Square Error (MSE)	0.002	0.003	0.0015	0.0025	0.0032
Residual Distribution	Random				
Normal Probability Plot	Aligned				
3D Surface Plot Quality	smooth				
Prediction Reliability (%)	98.5	98.2	98.8	98.6	98.3

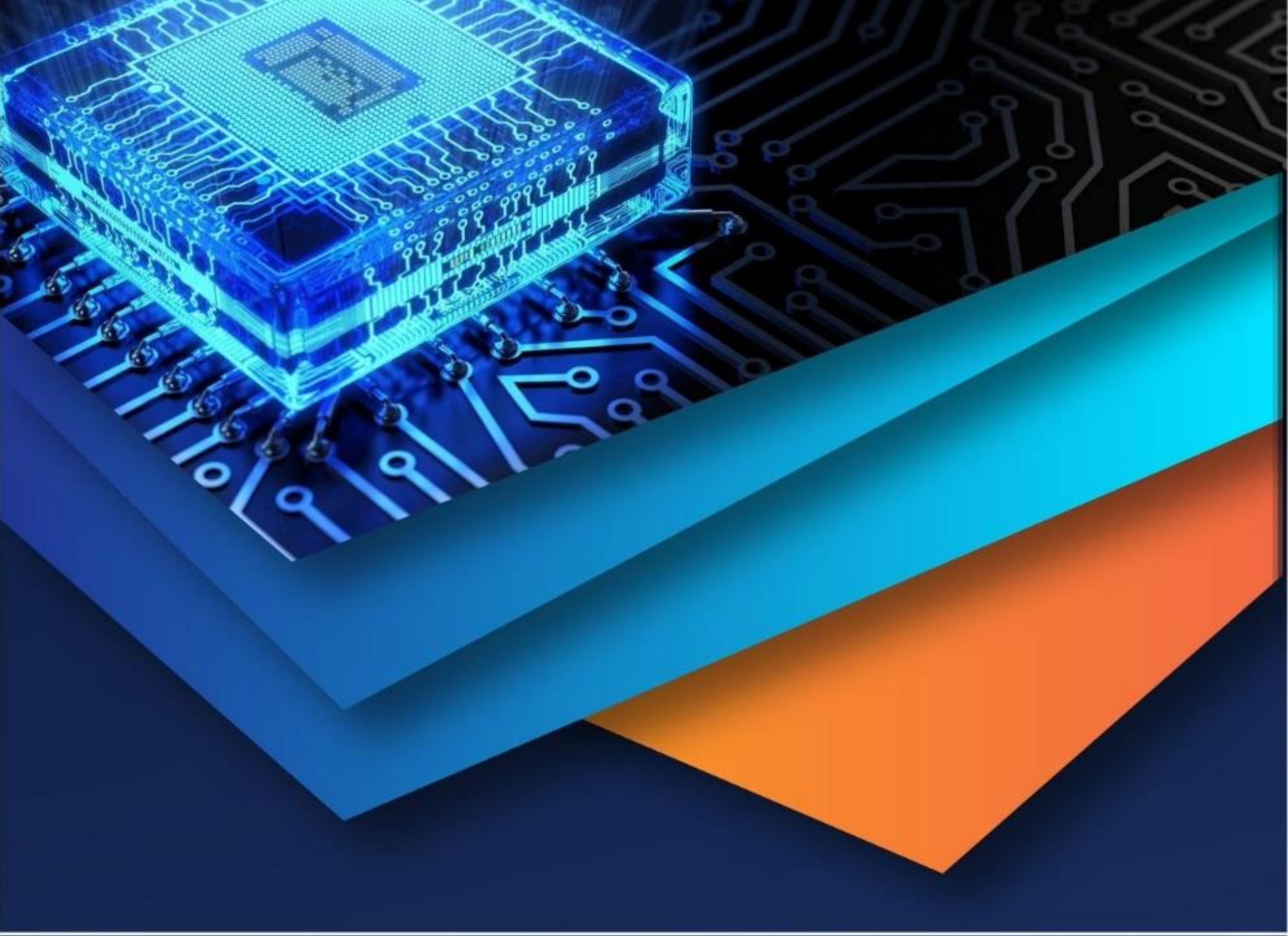
IV. CONCLUSION

This paper explores the use of Adaptive Neuro-Fuzzy Inference System (ANFIS) for solving inverse kinematics in 5-DOF and 7-DOF redundant manipulators. By utilizing three end-effector coordinates as input and five or seven joint positions as output during training and testing, the ANFIS model demonstrates satisfactory accuracy in predicting joint angles. The hybrid learning algorithm employed allows for efficient training with fewer iterations, enabling the model to handle complex and nonlinear kinematic equations effectively.

The study also highlights the model's reliability through 3-D surface plots and normal probability distributions of the residuals, confirming that the output is approximately normally distributed. The methodologies developed can be applied to various robotic arms, including those from Robotica Ltd. and the Lynx 6 Educational Robot arm. Overall, this work enhances the capabilities of robotic systems in executing unpredictable trajectories in unknown environments.

REFERENCES

[1] G Jang, J.S.R. (1993). "ANFIS: Adaptive-Network-Based Fuzzy Inference System." IEEE Transactions on Systems, Man, and Cybernetics, 23(3), 665-685
[2] Sciavicco, L., & Siciliano, B. (2000). Modelling and Control of Robot Manipulators. Springer Science & Business Media.
[3] Hasan, S., & Assadi, A.A. (2011). "Application of Artificial Neural Networks for Solving Inverse Kinematics of Robotic Arm." International Journal of Advanced Robotic Systems, 8(4), 28-35.
[4] Noori, R., et al. (2010). "Daily Prediction of Tehran's CO Concentration by Neural Network and Neuro-Fuzzy Models Using Predicted Meteorological Data." Journal of Hazardous Materials, 166(2-3), 1233-1240
[5] Wampler, C.W. (1986). "Manipulator Inverse Kinematic Solutions Based on Vector Formulations and Geometry-Based Computations." IEEE Transactions on Systems, Man, and Cybernetics, 16(1), 96-10



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY