Modelling and Control of 6- Degrees of Freedom movement Using Fuzzy Logic

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ABSTRACT: After the 20th century, the automotive industry is experiencing significant growth. This paper presents the design of a robotic arm capable of emulating the dexterity of the human hand, facilitating object manipulation in laboratory, industrial, or hazardous environments with 6 degrees of freedom (6-DOF). To analyse torque characteristics, a humanoid robot arm model is employed, simulating tasks such as lifting and transferring the objects. Current robotic hands often lack full hand functionality, limiting their use in environments tailored for human interaction. Acquiring high reliability trajectory tracking remains a formidable obitual in the field of industrial robot control, primarily due to nonlinearities and input couplings inherent in robot arm dynamics. In this we are focuses on the modelling and control of a 6-degree of freedom (DOF) robot arm, progressing through five key developmental stages. Initially, a comprehensive computer-aided design (CAD) model of the 6-DOF robot arm is developed. Subsequently, the CAD model is translated into a physical model using Sim Mechanics Link. The core of the paper involves applying a Neuro-Fuzzy Controller to the robot arm, known for its adaptability in handling complex and nonlinear systems. The controller implementation, simulations are conducted using MATLAB/Simulink, a robust platform for dynamic system analysis. The performance evaluation compares the Neuro-Fuzzy controller against a linear controller across key metrics: rise time, percentage overshoot, settling time, and steady-state errors. The findings indicate that the Neuro-Fuzzy controller outperforms the linear controller significantly in all measured characteristics. This underscores its suitability for enhancing trajectory tracking precision in industrial robotic applications.

Keywords: MATLAB, CAD Model, SolidWorks software

INTRODUCTION

The rapid development and wider application of automatic control in recent years can be attributed to several factors. One significant reason is the increasing complexity of modern industrial plants. These plants often require intricate control systems to manage various processes efficiently and effectively. Moreover, there is a growing demand for higher quality products, which imposes stringent constraints on manufacturing processes. To meet these demands, controllers with advanced capabilities are necessary. One such desirable capability in controllers is learning capability. A controller that can learn from its interactions with the plant or process can adapt and optimize its performance over time. This adaptability is crucial in dynamic environments where conditions may change unpredictably. Industrial robots exemplify this technological advancement in factory equipment. They are characterized by their high reliability, dependability, and advanced capabilities. Every industrial robot consists of two fundamental components: the manipulator arm, which performs the physical tasks, and the controller, which governs the robot's movements and actions (Jafar Tavoosi et al., 2011).

The primary challenge in controlling robots lies in achieving precise trajectory following for the manipulator. A robot manipulator with N degrees of freedom (DOF) is typically described by N nonlinear, dynamic, and coupled differential equations. These equations govern the motion and interaction of each joint in the robot, making the mathematical modelling complex and challenging (Srinivasan Alavandar et al., 2008). To address the complexity and facilitate efficient robot design at reduced costs and shorter development times, alternative approaches have been adopted. One significant approach involves the use of various software tools designed to aid engineers in the development and simulation of robot systems. These software packages enable engineers to design, simulate, and validate robot movements and behaviours in a virtual environment before physical implementation.

Currently, there exist advanced software tools capable of designing and simulating real-world robots in three dimensions (3D). These tools allow engineers to visualize the robot's structure, simulate its movements, and analyse its performance under different conditions. This virtual prototyping capability significantly accelerates the design process, minimizes errors, and reduces the need for costly physical prototypes (Tingjun Wang et al., 2009).

I. RELATED WORKS

CAD Model:

CAD stands for Computer-Aided Design. It refers to the use of computer technology to assist in the creation, modification, analysis, or optimization of designs, typically for engineering and manufacturing applications. CAD software allows designers and engineers to create detailed 2D or 3D models of products or structures, simulate their performance under various conditions, and generate technical documentation necessary for manufacturing.

CAD software is widely used across industries such as automotive, aerospace, architecture, electronics, and consumer goods manufacturing. It has revolutionized the design process by replacing traditional drafting methods with digital tools that offer greater efficiency, precision, and versatility.

Neuro-Fuzzy Controller:

i) **ANFIS for Inverse Kinematics (Alavandar et al., 2008)**: Alavandar et al. applied ANFIS to solve the inverse kinematics problem of a 3-degree-of-freedom (DOF) planar robot. ANFIS was successful in identifying and controlling both 2-DOF and 3-DOF manipulators. The trained ANFIS model provided fast and acceptable solutions for the inverse kinematics, which is crucial for accurately positioning the robot end-effector.

ii) **ANFIS-Based Computed Torque Controller (Ouamri et al., 2012)**: Ouamri et al. introduced an ANFIS-based Computed Torque (PD) controller for the dynamic model of a Puma 600 robot arm. They demonstrated that the ANFIS controller outperformed a traditional fuzzy controller in terms of robustness (ability to adjust to varying PD gains) and tracking precision/stability. This highlights ANFIS's capability in dynamic control applications, where precise and adaptive control is essential.

iii) **Neuro-Fuzzy Controllers and Learning**: Neuro-fuzzy controllers can learn static input-output characteristics given appropriate training data. They can mimic existing controllers' control surfaces if provided with input-output data from those controllers. This adaptability is similar to neural networks, where learning from data allows for the of effective control strategies.

iv) **Fuzzy Logic Toolbox and ANFIS Functionality**: The Fuzzy Logic Toolbox provides tools like the **anfis** function, which adjusts membership function parameters to optimize the fuzzy inference system's performance based on input/output data. The **anfis** function can be utilized through command-line interfaces or GUIs like the ANFIS Editor.

6-DOF Industrial Robot

A 6-degree-of-freedom (6-DOF) industrial robot refers to a robotic arm capable of movement in six different directions or axes. Each degree of freedom corresponds to a specific way in which the arm can move, allowing for complex positioning and manipulation tasks. Here's a breakdown of what each degree of freedom typically represents in such robots:

1. **Base Rotation (Axis 1)**: This degree of freedom allows the entire robot arm to rotate around a vertical axis. It provides the initial orientation of the robot relative to its base.
2. **Shoulder Rotation (Axis 2)**: Following the base rotation, this joint allows the arm to rotate horizontally. It typically connects the base to the lower arm segment.
3. **Elbow Rotation (Axis 3)**: This joint allows the lower arm segment to rotate vertically, adjusting the height and reach of the arm.
4. **Wrist Pitch (Axis 4)**: The first wrist joint allows the wrist to tilt up and down, adjusting the angle of the end-effector relative to the arm.
5. **Wrist Roll (Axis 5)**: The second wrist joint permits the wrist to rotate around its own axis, enabling the end-effector to be oriented horizontally.
6. **Wrist Yaw (Axis 6)**: The final wrist joint allows the end-effector to rotate side to side, adding flexibility in positioning the end-effector.

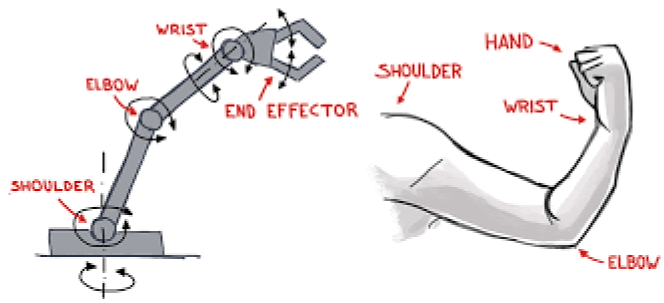
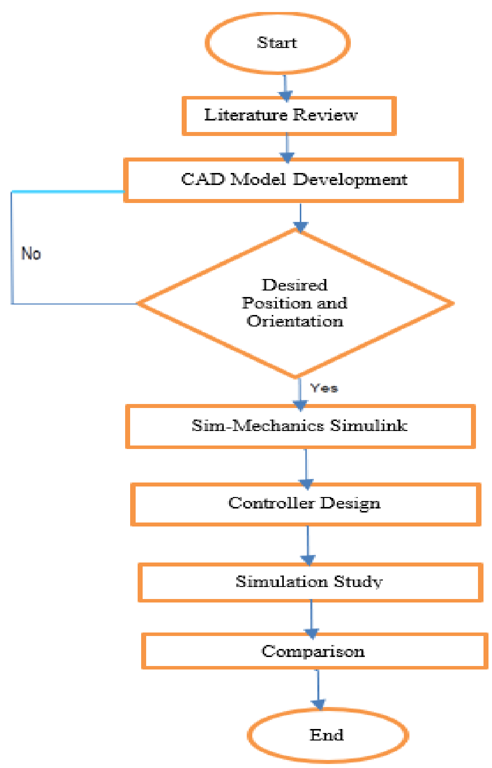


Figure 1: Comparison of 6-DOF Robot with Human Hand

ALGORITHM



Neuro Fuzzy Controller Development

ANFIS Structure and Operation

- **Input/Output Mapping**: ANFIS is designed to model the input-output relationship based on given datasets. It learns to approximate this relationship using fuzzy logic principles.
- **Membership Functions and Parameters**: ANFIS constructs a fuzzy inference system (FIS) that includes membership functions for inputs and outputs. These membership functions have associated parameters that determine their shape and characteristics.
- **Parameter Adjustment**: The key task of ANFIS is to adjust these membership function parameters based on the input-output data. This adjustment process optimizes the FIS to minimize the error between actual outputs and desired outputs.

  The adjustment is facilitated using a gradient vector, which measures how well the current FIS configuration models the data.

- **Optimization Techniques**: ANFIS employs optimization routines to adjust the parameters of the membership functions. These routines aim to minimize an error measure, typically defined as the sum of squared differences between actual and desired outputs.

  Two common methods used in ANFIS for parameter estimation are:

  a) Backpropagation: Adapted from neural network training techniques, backpropagation adjusts the membership function parameters based on the gradient of the error function with respect to these parameters.

  b) Least Squares Estimation: This method fits a model to the data by minimizing the sum of the squared differences between observed and predicted values. ANFIS can use either of these methods independently or in combination, depending on the specific implementation and optimization goals.

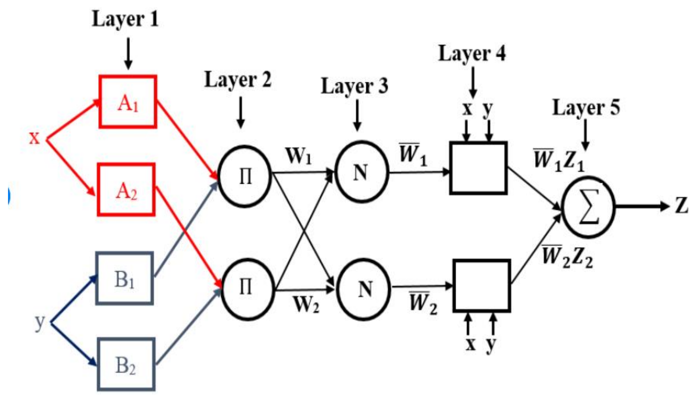


Figure 2: Equivalent ANFIS Structure

CAD Model Assemblies: Figure 3 shows the isometric angle for 6-DOF of industrial robot arm, the design has been done by using SolidWorks software.

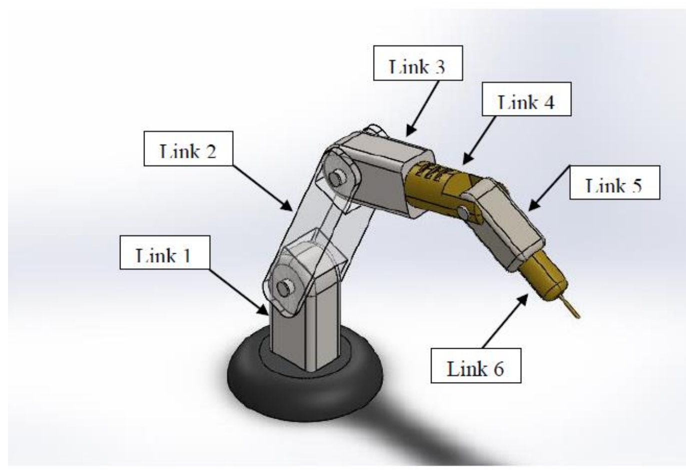


Figure 3: 6-DOF of Industrial Robot Arm in Solid works

Figure 4 shows the Simulink block diagram that was imported from SolidWorks to MATLAB/ Simulink by using Sim Mechanics Link.

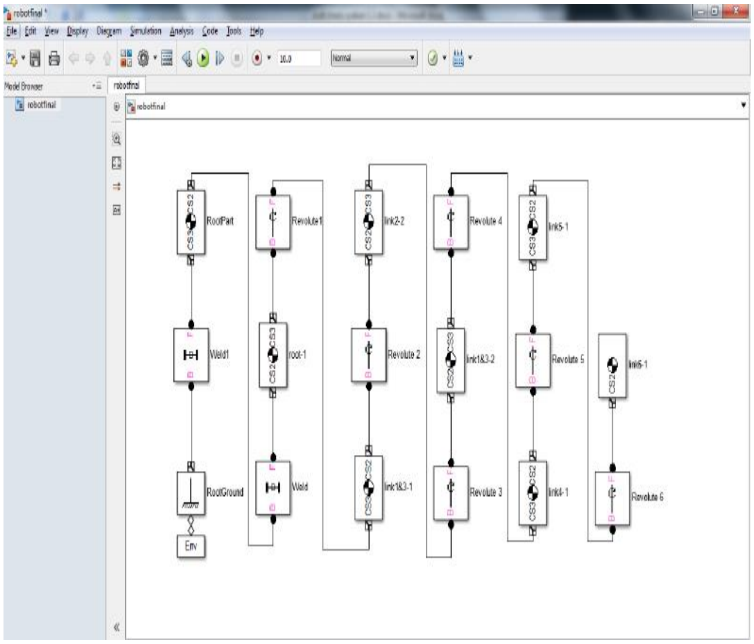


Figure 4: Simulink Block Diagram

Neuro-Fuzzy Controller: Joint 6 was chosen to represent the Neuro-Fuzzy controller development in this project. Figure 5 shows the training data set that contains desired input/output data of the system to be modelled.

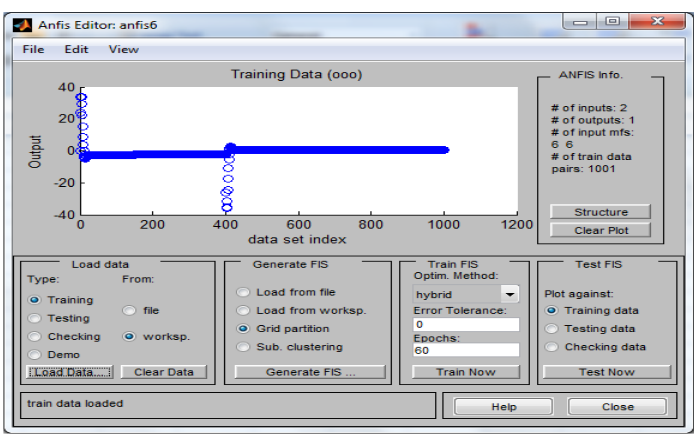


Figure 5 Training Data Set

Figure 6 ANFIS model structures that have been generated.

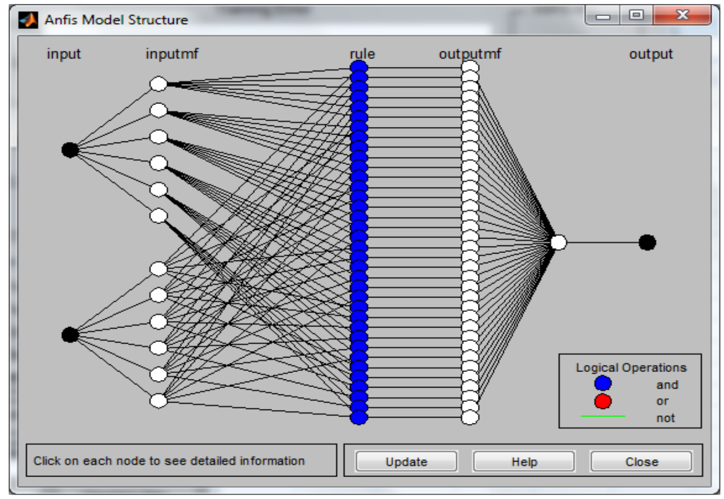


Figure 6 ANFIS Model Structure

Figure 7 shows the membership function for input one with range from -0.1605 until 0.08023.

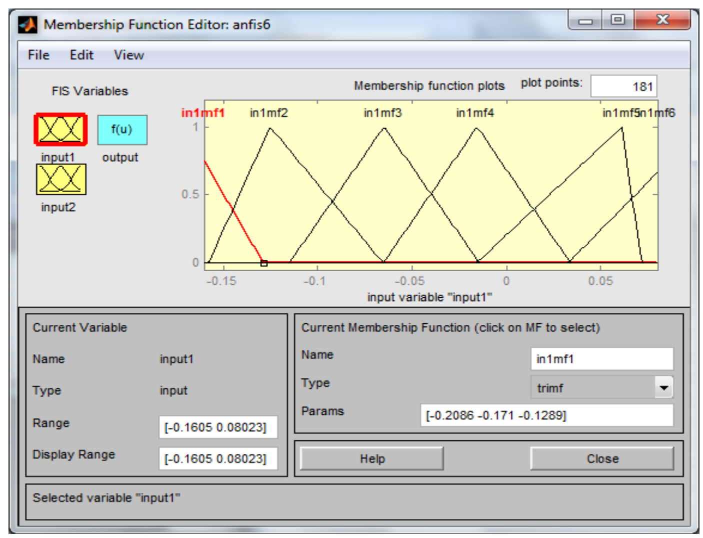


Figure 7 MF for Input One

Figure 8 shows the membership function for input two with range from -2.402 until 2.418**.**

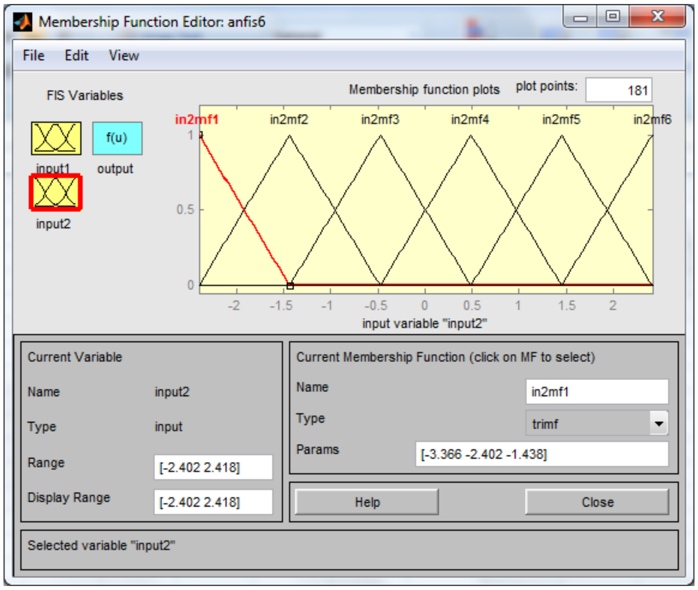


Figure 8 MF for Input Two

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