MODELING AND CONTROL OF 6-DOF OF INDUSTRIAL ROBOT BY USING NEURO-FUZZY CONTROLLER

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ABSTRACT

High accuracy trajectory tracking is a very challenging topic in industrial robot control. This is due to the nonlinearities and input couplings present in the dynamics of the robot arm. This project report is concerned with the problems of modeling and control of a 6 degree of freedom (DOF) robot arm. This research undertook the following five developmental stages; firstly, the complete computer-aided design (CAD) model of a 6 DOF of robot arm is to be developed. In the second stage, the CAD model is to be converted into physical modeling by using SimMechanics Link. Then, the Neuro-Fuzzy Controller is applied to the robot arm. In the fourth stage, the research intends to perform the simulation. This is done through the simulation on the digital computer using MATLAB/SIMULINK as the platform. Lastly, the performance of Neuro-Fuzzy controller is to be compared with a linear controller. In summary, this project shows that Neuro-Fuzzy controller is far better than the linear controller in terms of four major characteristic which is the rise time, percentage overshoot, settling time and finally steady-state error.

ABSTRAK

Penjejak trajektori yang berketepatan tinggi merupakan satu topik yang mencabar dalam kawalan robot industri. Ini adalah disebabkan oleh ketaklelurusan dan gandingan masukan yang wujud di dalam dinamik lengan robot. Laporan projek ini membincangkan mengenai masalah dalam permodelan dan kawalan lengan robot yang mempunyai 6 darjah kebebasan. Kajian ini melibatkan lima peringkat seperti berikut; Pertama, pembangunan model *computer-aided design (CAD)* 6 DOF lengan robots yang lengkap. Di peringkat kedua, model *CAD* akan diubah ke model fizikal menggunakan *SimMechanics Link.* Kemudian, kawalan *Neuro-Fuzzy* diguna pakai dalam lengan robot ini. Peringkat kelima adalah membuat penyelakuan. Simulasi atau penyelakuan ini dijalankan menggunakan komputer digital dengan bantuan perisisan MATLAB/SIMULINK. Akhir sekali, keupayaan di antara kawalan *Neuro-Fuzzy* dengan kawalan lelurus dibandingkan. Sebagai kesimpulan, projek ini menunjukkan bahawa kawalan Neuro-Fuzzy adalah jauh lebih baik daripada kawalan lelurus dari segi empat ciri utama iaitu; masa naik, peratusan terlajak, masa menetap dan akhirnya ralat ketika keadaan mantap.

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LIST OF ABBREVIATIONS

3D	Three Dimensions
ANFIS	Adaptive Neural-Fuzzy Inference System
CAD	Computer-Aided Design
DOF	Degree of Freedom
FIS	Fuzzy Inference System
MF	Membership Function
PID	Proportional, Integral and Derivative
XML	Extensible Markup Language
trimf	triangular-shaped membership function

CHAPTER 1

INTRODUCTION

1.1 Research Background

The wider application of automatic control has developed rapidly in recent years. The reason for this is the complexity of modem plant and the constraints imposed by the increasing demand for higher quality products. Hence the design of a controller which possesses learning capability becomes highly desirable. Robots are highly reliable, dependable and technologically advanced factory equipment. All industrial robots have two physically separate basic elements which are the manipulator arm and the controller (JafarTavoosi et al., 2011).

The essential problem in controlling robots is to make the manipulator follow a desired trajectory. In general an N-degree of freedom (DOF) rigid robot manipulator is characterized by N nonlinear, dynamic, coupled differential equations (SrinivisanAlavandar et al., 2008). Due to the complexity of mathematical modeling of robot system, another approach was used to enable efficient robots to be designed in the shortest time possible at a lower cost, various software have been developed to help engineers in their task development. Currently there are software that enables the design and simulation of a real world robot into three dimensions (3D) (Tingjun WANG et al., 2009).

Nowadays, robots are used in applications that require precise techniques such as in surgical operations. To achieve this target, high precision robots need to be employed and modern controller such as intelligent controller is frequently used. Yusuf SAHIN et al., (2010) used Neuro-Fuzzy controller for 3-DOF SCARA Robot, they used three adaptive networks based fuzzy logic controllers for the control strategy as Neuro-Fuzzy controllers but the third controller for wrist of robot was ineffective to track the desired circular tool trajectory. These controllers were designed by training and checking the data sets obtained from PID control of SCARA robot. In this paper, Neuro-Fuzzy controller will be used for the control of 6-DOF robot arm CAD model.

1.2 Problem Statement

The problem statements of this project are as follow:

i. Robot is a complex system. The modeling in mathematical form shows a higher order and long equations need to be derived. Therefore another approach can be used by using CAD model.
ii. Linear controller needs to be linearized before use in robot system, furthermore the uncertainties of parameters does not included in the controller. Non-linear controller will be used to counter this problem.
iii. Transient response and steady-state response of non-linear controller can be improved by using the hybrid controller of two non-linear controllers which are the fuzzy and neural-network controller.

1.3 Aims and Objectives

Modeling and control of six (6) degree of freedom of industrial robotics by using Neuro-Fuzzy controller are the aims of the research. The model should be based on a CAD model, and using Neuro-Fuzzy controller that should able to control the angle of robot arm joint with high stability and efficiency. To achieve these aims, the objectives of this research are formulated as follow:

i. To design a robot arm model based on CAD model.
ii. To develop a Neuro-Fuzzy controller for the robot arm system.
iii. To evaluate the proposed controller performance through simulation study.
iv. To compare the proposed controller performance with conventional controller.

1.4 Scope of Project

This model and controller is mainly for six (6) degree of freedom of industrial robots by using CAD design. Controller development will be based on Artificial Intelligence such as Neuro-Fuzzy controller. Matlab/Simulink and SolidWorks will be used as simulation platform.

1.5 Project Report Outline

This thesis consists of five chapters. Chapter 2 deals with the brief review of the CAD model of robot arm. Then Neuro-Fuzzy controller will be presented from previous journal and finally a brief review of the 6-DOF industrial robot arm.

Chapter 3 presents the methodology that shows the steps taken in completing the project in the forms of flow charts. , CAD model design and Neuro Fuzzy controller development are going to be presented in this chapter.

Chapter 4 discusses the results and analysis of this project. The CAD model and physical model will be presented. The performance of the Neuro-Fuzzy controller is evaluated by the simulation study using Matlab/Simulink. For the comparison purposes, the simulation study of PID controller is also presented.

Chapter 5 summarizes the work undertaken. Recommendations for future work of this project are presented at the end of the chapter.

1.6 Project Planning

The Research Gantt Chart for this project can be summarized as in Table 1.1.

Table 1.1 Research GanttChart

	Month / Task	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
1	Literature Review												
2	CAD Model Development												
3	Sim-Mechanics Simulink												
4	Controller Design												
5	Simulation Study												
6	Comparison between Controller												
7	Preparing Proceeding Paper and Journal Writing												
8	Thesis Writing, Submission and Viva												
9	Thesis Correction and Final Submission												

CHAPTER 2

BRIEF REVIEW

2.1 CAD Model

Computer-aided design (CAD) is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.

Hee-Chan Song et al., (2012) introduced the method for tool path generation based on the matching between the tool path from the CAD model and the teaching points were proposed to compensate the position and orientation errors of the work piece when it is placed in a jig. Rosidah Sam et al., (2012) used SolidWorks Motion which is 3D CAD software that was used to successfully design a Cartesian robot, articulated robot arms, conveyors and products that which are parts of an automated pick and place robotic system.

2.2 Neuro-Fuzzy Controller

Srinivasan Alavandar et al., (2008) used ANFIS to Inverse Kinematics Solution of 3 DOF Planar Robot. In this paper, they illustrated that the ANFIS was able to identify and control of the 2-DOF and 3-DOF robot manipulator and trained ANFIS can be utilized to provide fast and acceptable solutions of the inverse kinematics of robots.

Ouamri Bachir et al., (2012) introduced an Adaptive Neuro-Fuzzy Inference System (ANFIS) based Computed Torque (PD) controller that were applied to the dynamic model of puma 600 robot arm presented. In this article they showed that the ANFIS controller is better compared to fuzzy controller in robustness (adjustment of the rate of variations of the PD gains) and in tracking precision and stability.

Neuro-fuzzy controller can basically learn any static input-output characteristics if the training data is available. This means that the learning algorithm can produce a neuro-fuzzy controller which can copy the control surface of an existing controller if the input-output data from the controller is known, as discussed by Gurpreet S. Sandhu et al., (1997).

The neuro-adaptive learning method works similarly to that of neural networks. Neuro-adaptive learning techniques provide a method for the fuzzy modeling procedure to learn information about a data set. Fuzzy Logic Toolbox software computes the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. The Fuzzy Logic Toolbox function that accomplishes this membership function parameter adjustment is called anfis. The anfis function can be accessed either from the command line or through the ANFIS Editor GUI. Because the functionality of the command line function anfis and the ANFIS Editor GUI is similar, they are used somewhat interchangeably in this discussion, except when specifically describing the GUI.

2.3 6-DOF Industrial Robot

An industrial robot is defined by (ISO Standard 8373:1994, Manipulating Industrial Robots – Vocabulary) as an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes. The field of robotics may be more practically defined as the study, design and use of robot systems for manufacturing (a top-level definition relying on the prior definition of robot).

Typical applications of robots include welding, painting, assembly, pick and place (such as packaging, palletizing and SMT), product inspection, and testing; all accomplished with high endurance, speed, and precision. For 6-DOF Industrial Robot there are six joints (six axes) that can be controlled separately for each part.

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

The steps in flow chart for completing this project are shown in Figure 3.1 and the explanations of each step are as follow:

i. Begin with literature review to study previous paper and come up with problem statement.
ii. Secondly, design the CAD model until the desired position and orientation are achieved.
iii. Then the CAD model is converted to physical model by using Sim-Mechanics Simulink.
iv. In the fourth stage, Neuro Fuzzy controller is developed.
v. Next, observation of result is done through simulation study
vi. Finally, the comparison between Neuro-Fuzzy controller and linear controller is to be made.

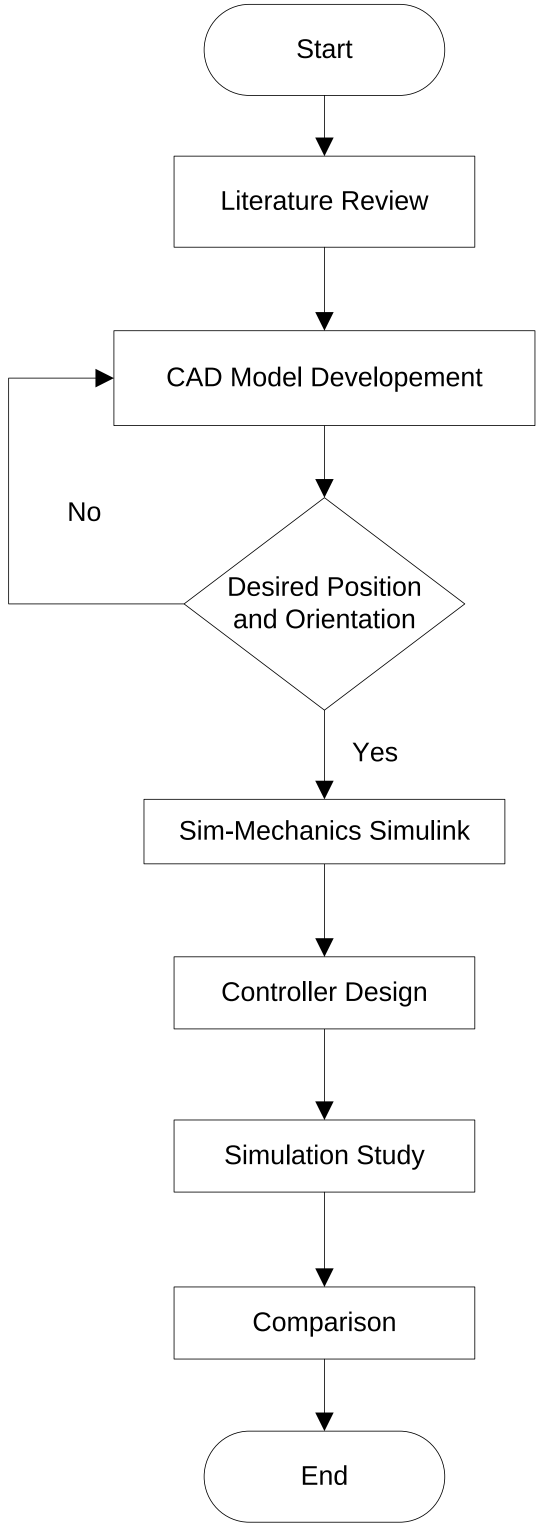

Figure 3.1 Project’s Flow Chart

3.2 CAD Model Design

The CAD model is design by using SolidWorks, the assemblies' window of SolidWorks can be referred to Figure 3.2. The purpose of creating CAD model in assemblies' window is to make sure the position and orientation of each part is correct.

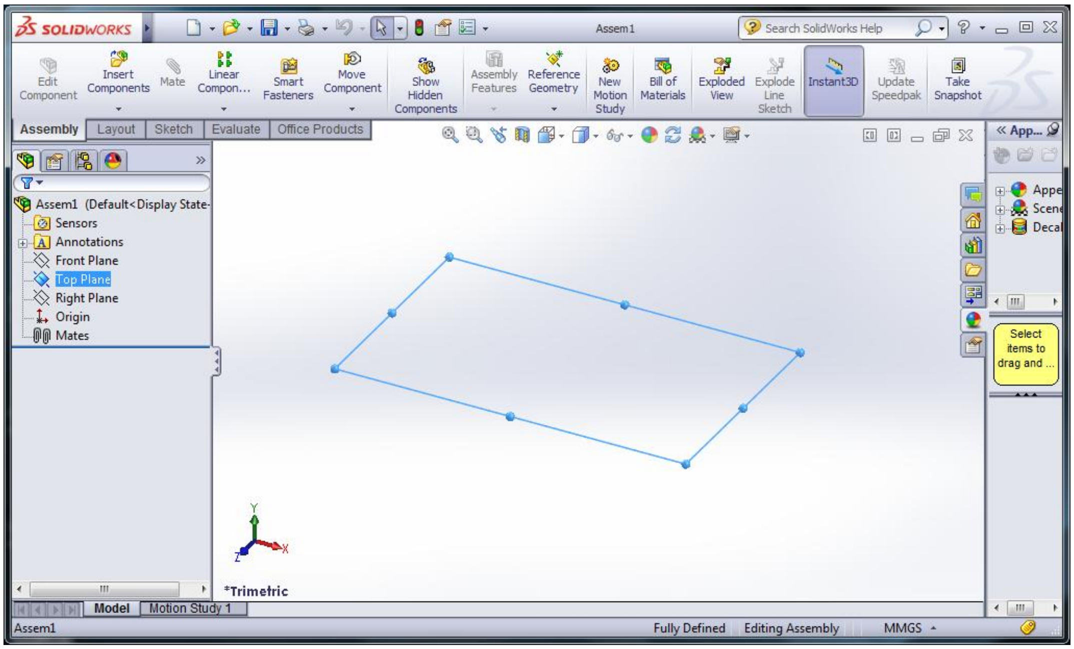

Figure 3.2 Assemblies' Window of SolidWorks

After the design of CAD model in SolidWorks assembly is completed, SimMechanics Link is used to provide a bridge between CAD systems and SimMechanics. The SolidWorks plug in from SimMechanics Link converts a SolidWorks assembly (CAD model) into an XML and associated graphic files that can be imported as a SimMechanics model. The import stage is shown in Figure 3.3.

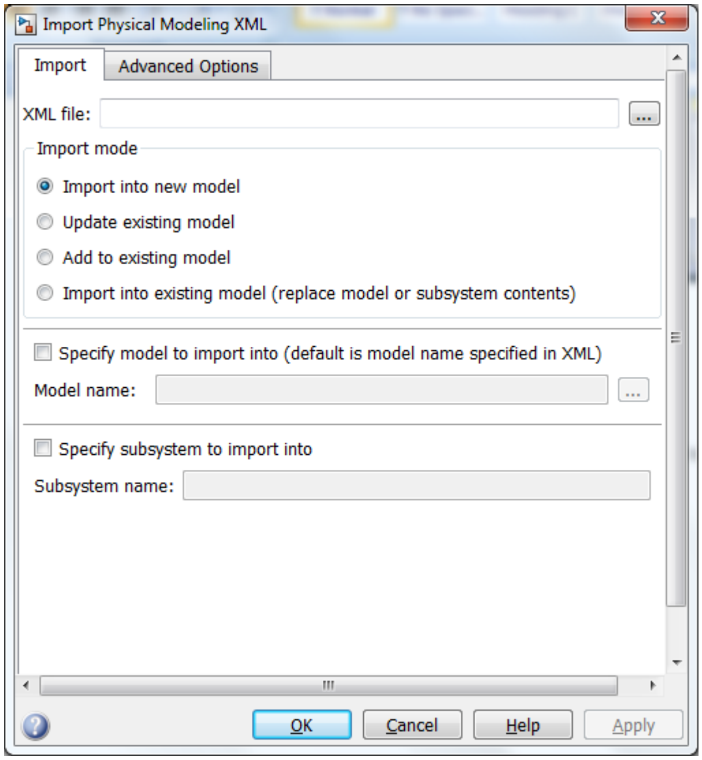

Figure 3.3 Import Physical Modeling

3.3 Neuro Fuzzy Controller Development

The adaptive neural fuzzy inference system (ANFIS) method is chosen to design the Neuro-Fuzzy Controller. Figure 3.4 show ANFIS equivalent structure (Dong Wenhan et al., 2010). The acronym ANFIS derives its name from adaptive neuro-fuzzy inference system. Using a given input/output data set, the toolbox function anfis constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a backpropagation algorithm alone or in combination with a least squares type of method. This adjustment allows fuzzy systems to learn from the data they are modeling.

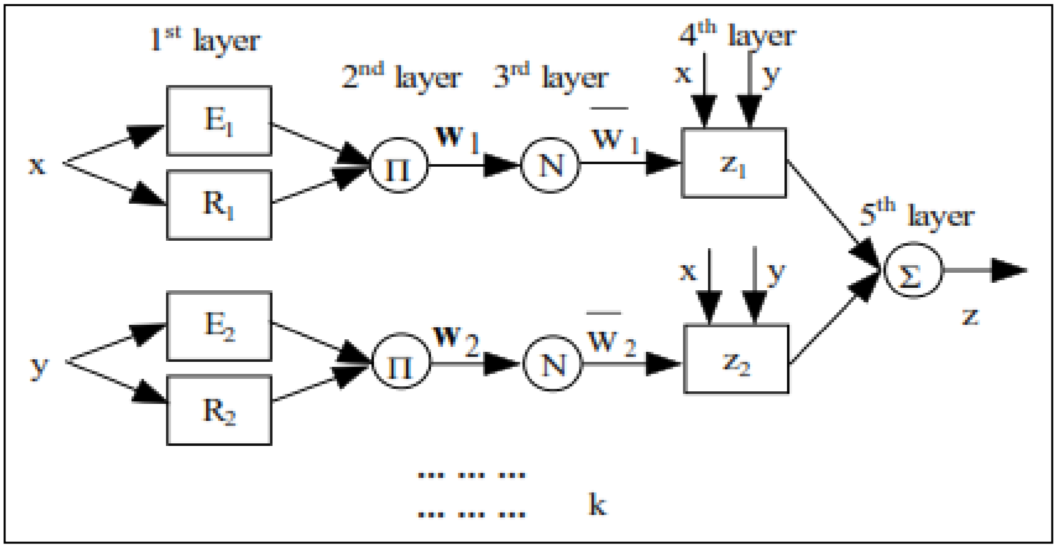

Figure 3.4 ANFIS Equivalent Structure

A network-type structure similar to that of a neural network, which maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs, can be used to interpret the input/output map.

The parameters associated with the membership functions changes through the learning process. The computation of these parameters (or their adjustment) is facilitated by a gradient vector. This gradient vector provides a measure of how well the fuzzy inference system is modeling the input/output data for a given set of parameters. When the gradient vector is obtained, any of several optimization routines can be applied in order to adjust the parameters to reduce some error measure. This error measure is usually defined by the sum of the squared difference between actual and desired outputs. anfis uses either back propagation or a combination of least squares estimation and backpropagation for membership function parameter estimation.

ANFIS editor in Matlab is used to design the controller, Figure 3.5 shows the ANFIS editor's window and the training data set that contains desired input/output data of the system to be modeled will be added in the ANFIS editor's window

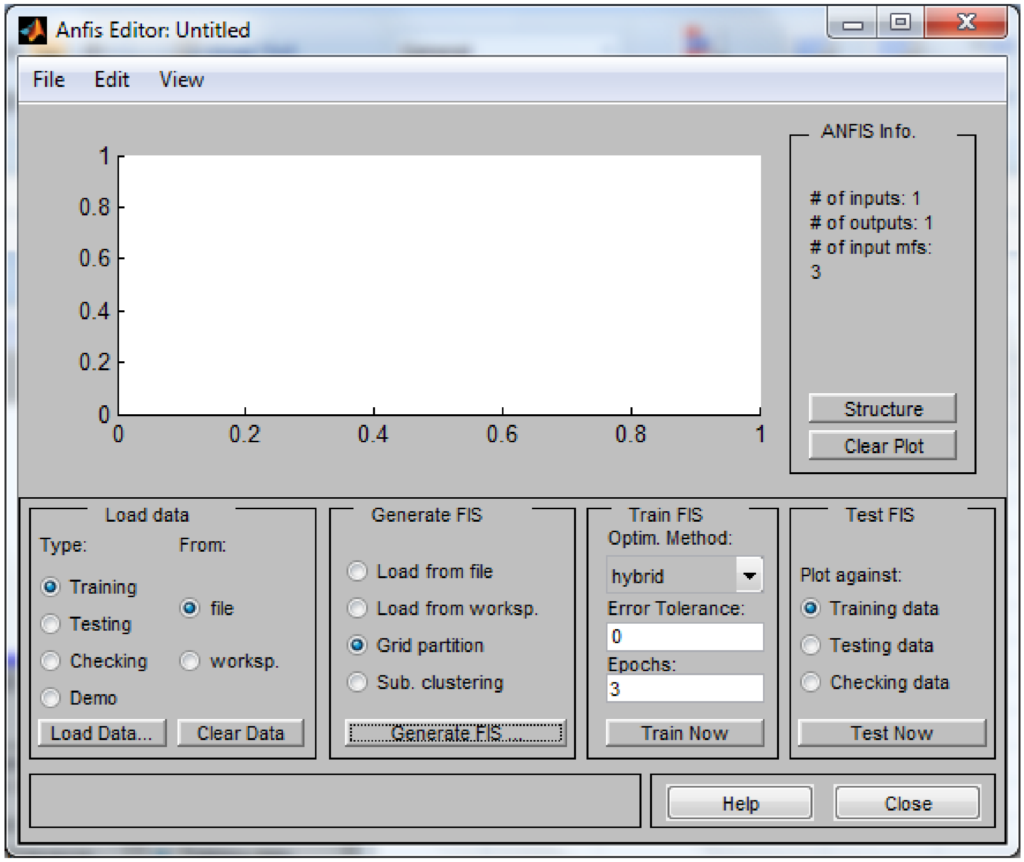

Figure 3.5 Training Data's Window for FIS Training

Then the FIS file will be generated depending on how many Membership Function (MF) and type of MF. Next the FIS is trained with number of epoch and training error can be seen. Finally the trained FIS will be tested against the training data that contains desired input/output data of the system to be modeled.

Model validation is the process by which the input vectors from input/output data sets on which the FIS was not trained, are presented to the trained FIS model, to see how well the FIS model predicts the corresponding data set output values.

One problem with model validation for models constructed using adaptive techniques is selecting a data set that is both representative of the data the trained model is intended to emulate, yet sufficiently distinct from the training data set so as not to render the validation process trivial

CHAPTER 4

RESULT AND ANALYSIS

4.1 CAD Model Assemblies

Figure 4.1 shows the isometric angle for 6-DOF of industrial robot arm, the design has been done by using SolidWorks software.

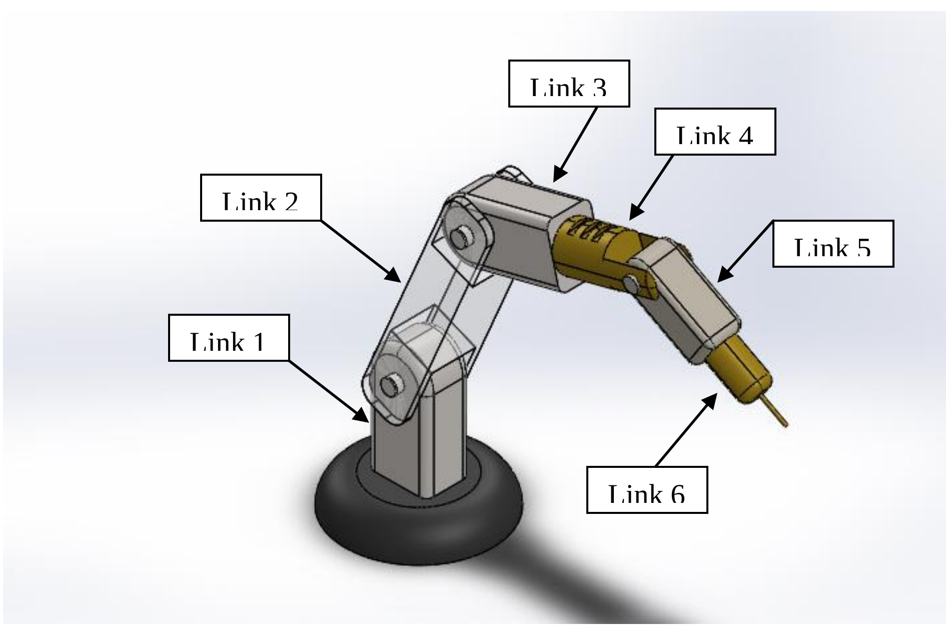

Figure 4.1 6-DOF of Industrial Robot Arm in Solidworks

4.2 Physical Model

Figure 4.2 shows the isometric angle for 6-DOF of industrial robot arm that was converted and imported to Matlab/Simulink file by using SimMechanics Link.

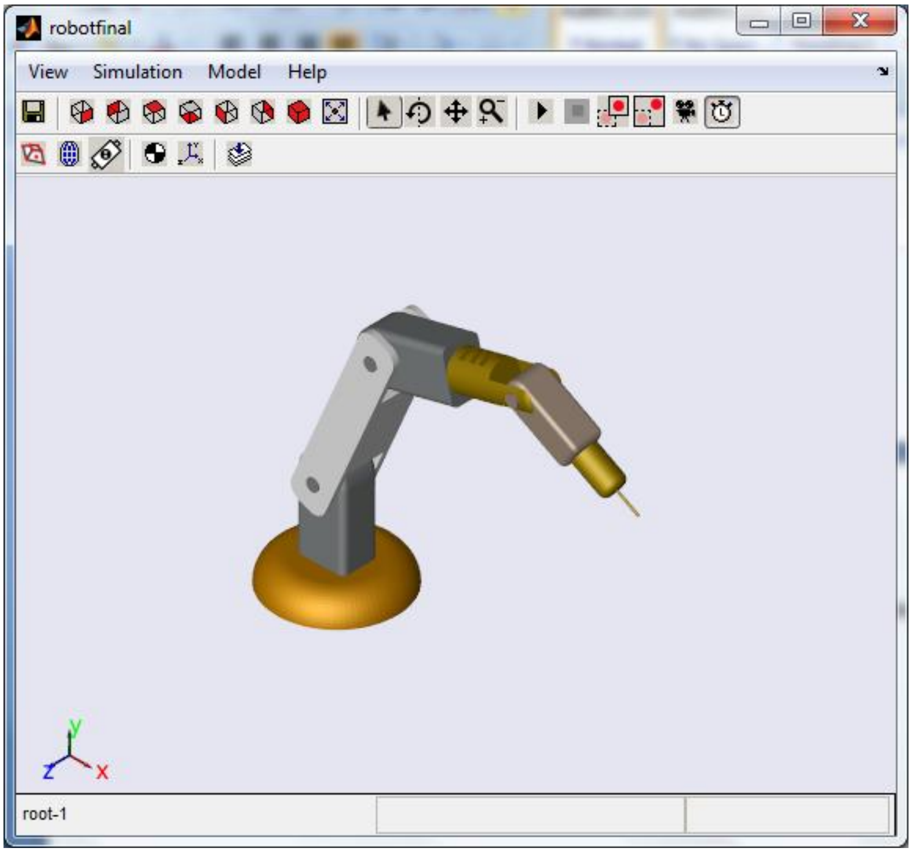

Figure 4.2 6-DOF of Industrial Robot Arm in Matlab/Simulink

Figure 4.3 shows the simulink block diagram that was imported from SolidWorks to Matlab/Simulink by using SimMechanics Link

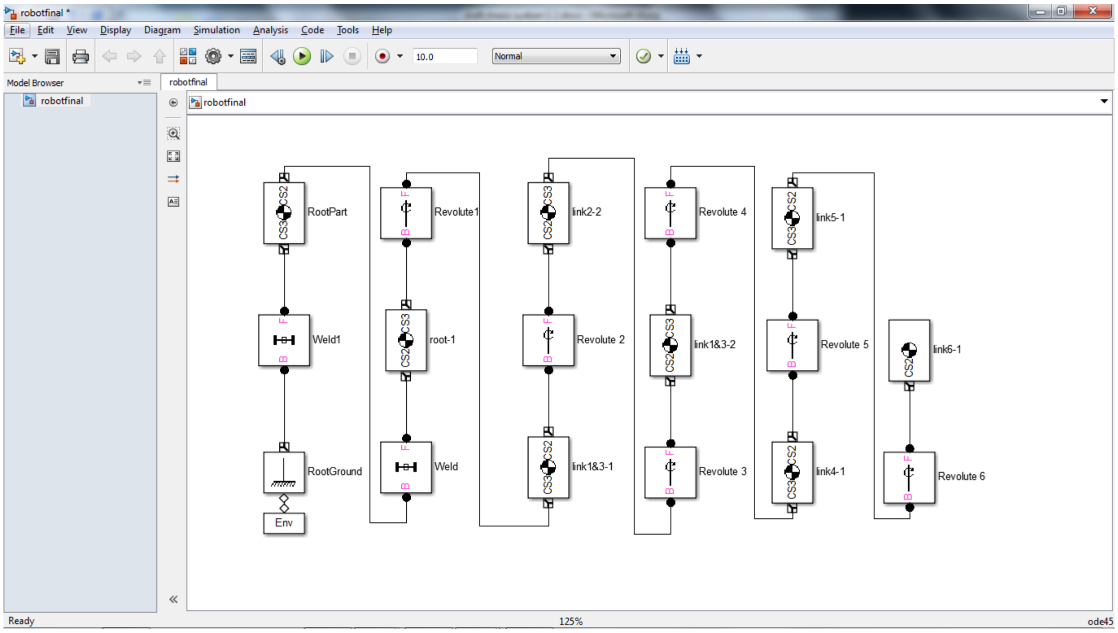

Figure 4.3 Simulink Block Diagram

4.3 Neuro-Fuzzy Controller

Joint 6 was chosen to represent the Neuro-Fuzzy controller development in this project. Figure 4.4 shows the training data set that contains desired input/output data of the system to be modeled.

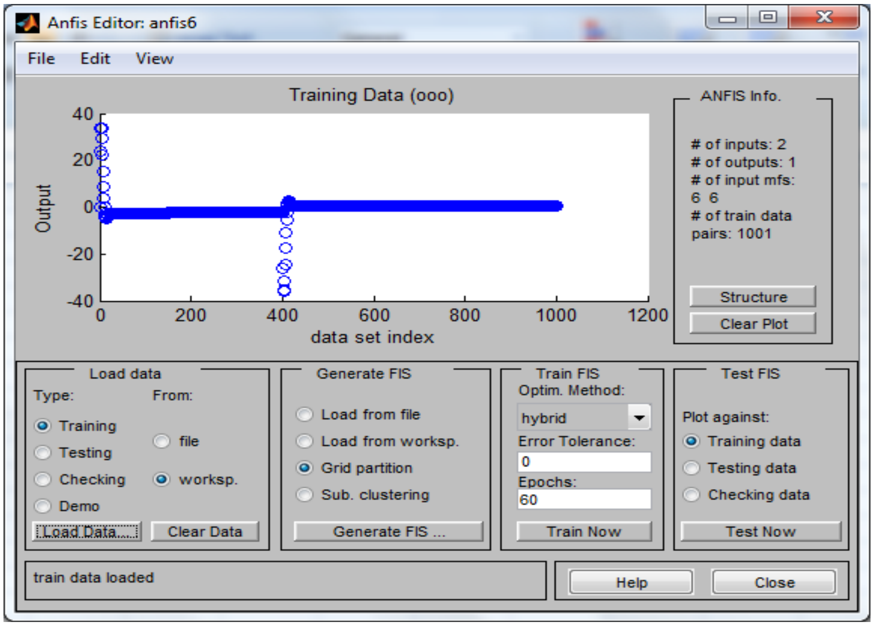

Figure 4.4 Training Data Set

Figure 4.5 show FIS generating where the number of MF for first input (error) and second input (change of error) is 6 and MF type is *trimf* and constant.

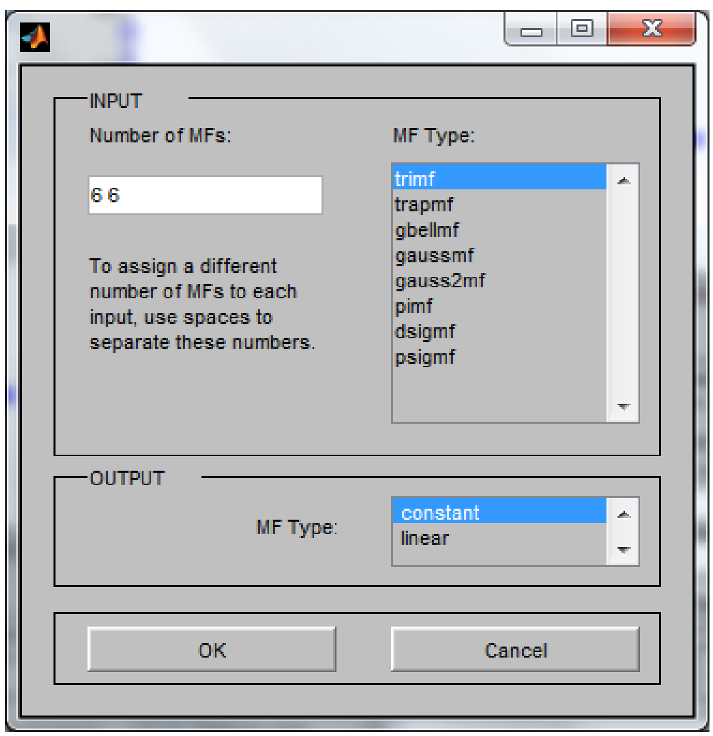

Figure 4.5 FIS Generate

Figure 4.6 shows the training error for 60 epochs where the error is 0.35243 compared to training data.

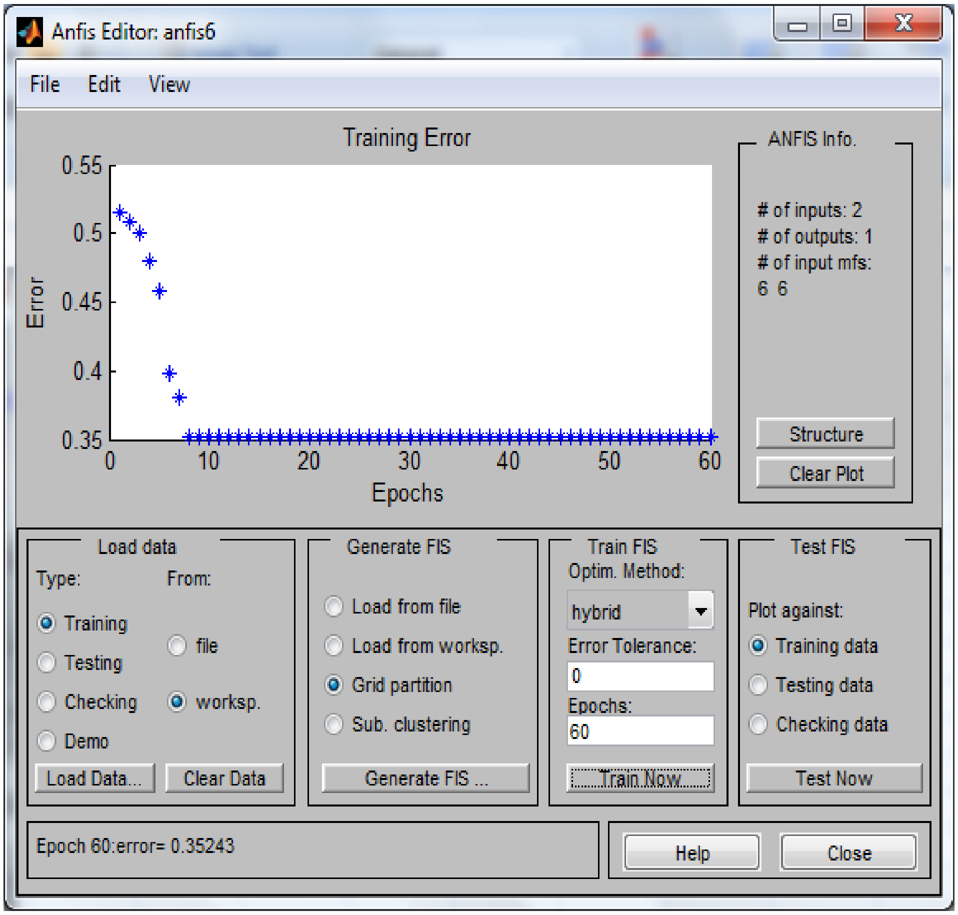

Figure 4.6 Training Error

Figure 4.7 shows the FIS testing against training data, red mark represent FIS output and blue mark represent training data.

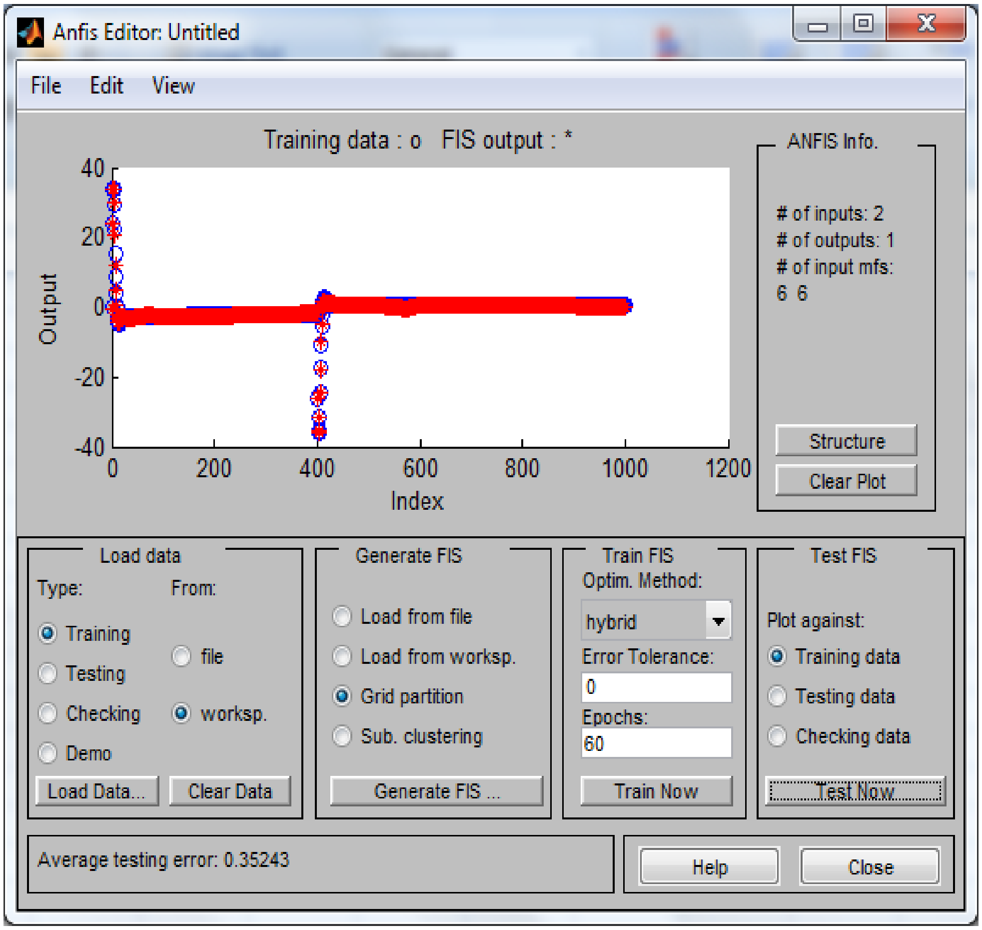

Figure 4.7 FIS Test

Figure 4.8 ANFIS model structures that have been generated.

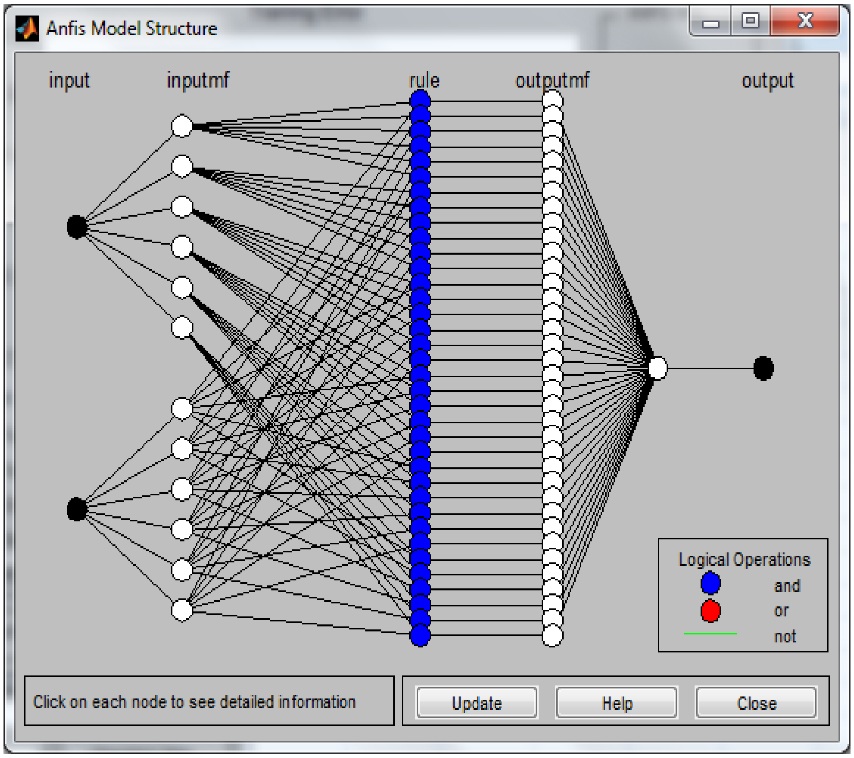

Figure 4.8 ANFIS Model Structure

Figure 4.9 shows the 36 rules viewer for ANFIS controller with two inputs and one output

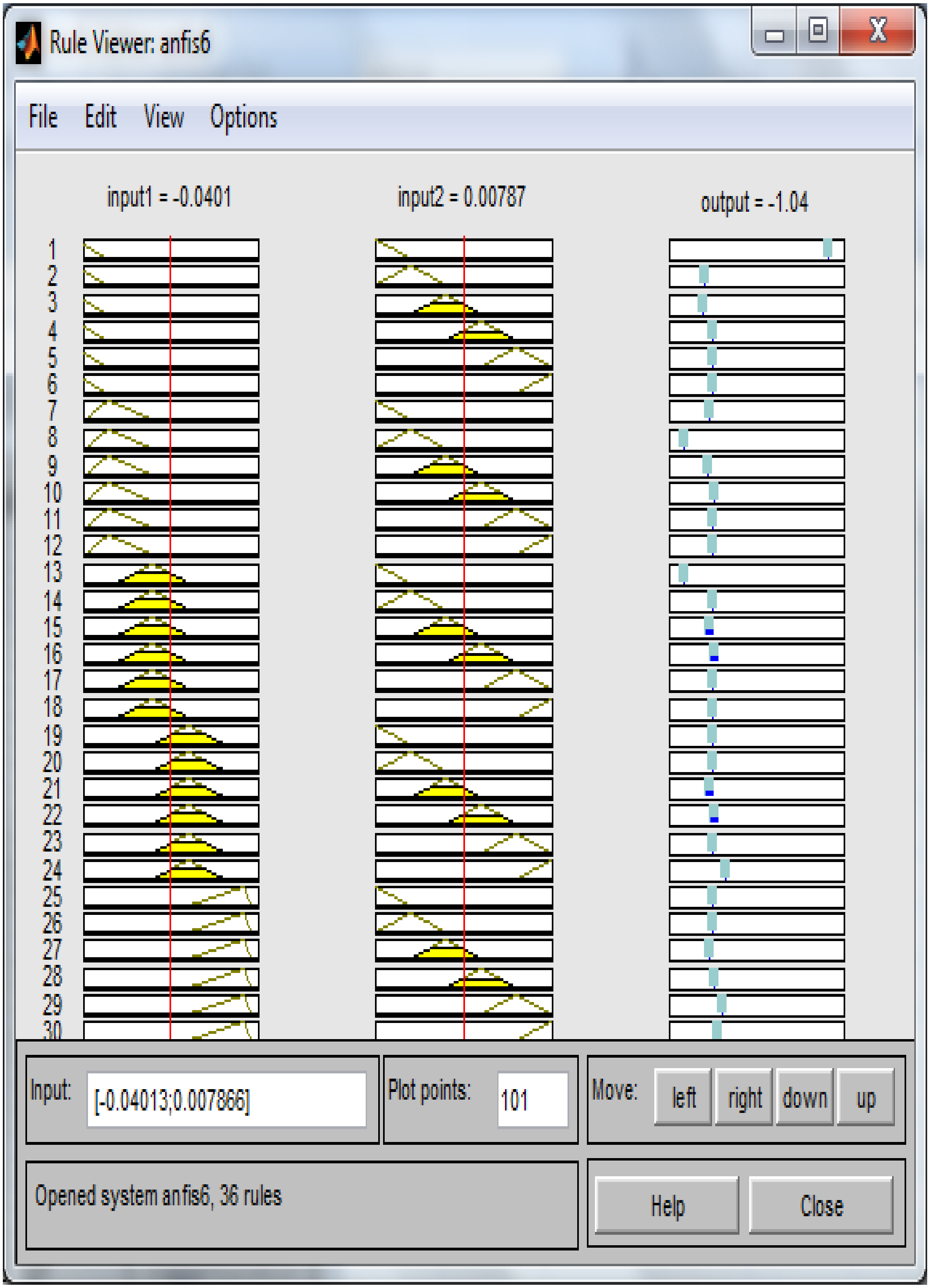

Figure 4.9 ANFIS Rules Viewer

Figure 4.10 shows the rules for ANFIS controller with two inputs and one output.

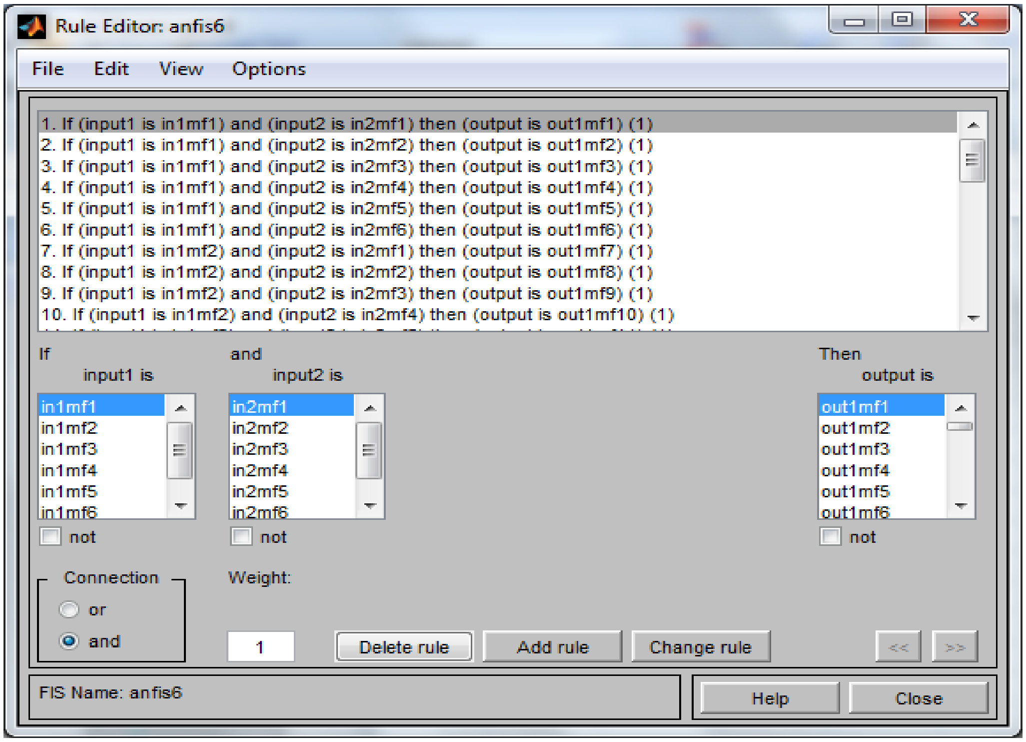

Figure 4.10 ANFIS Rules

Figure 4.11 shows the membership function for input one with range from -0.1605 until 0.08023.

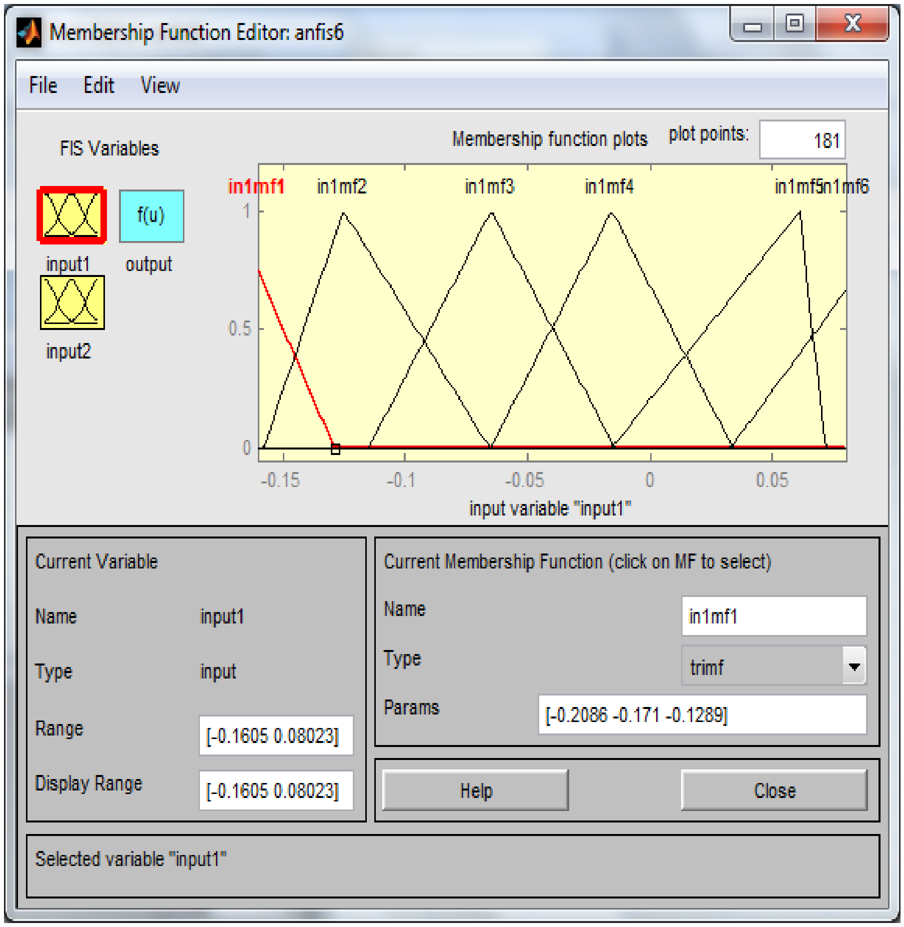

Figure 4.11 MF for Input One

Figure 4.12 shows the membership function for input two with range from -2.402 until 2.418.

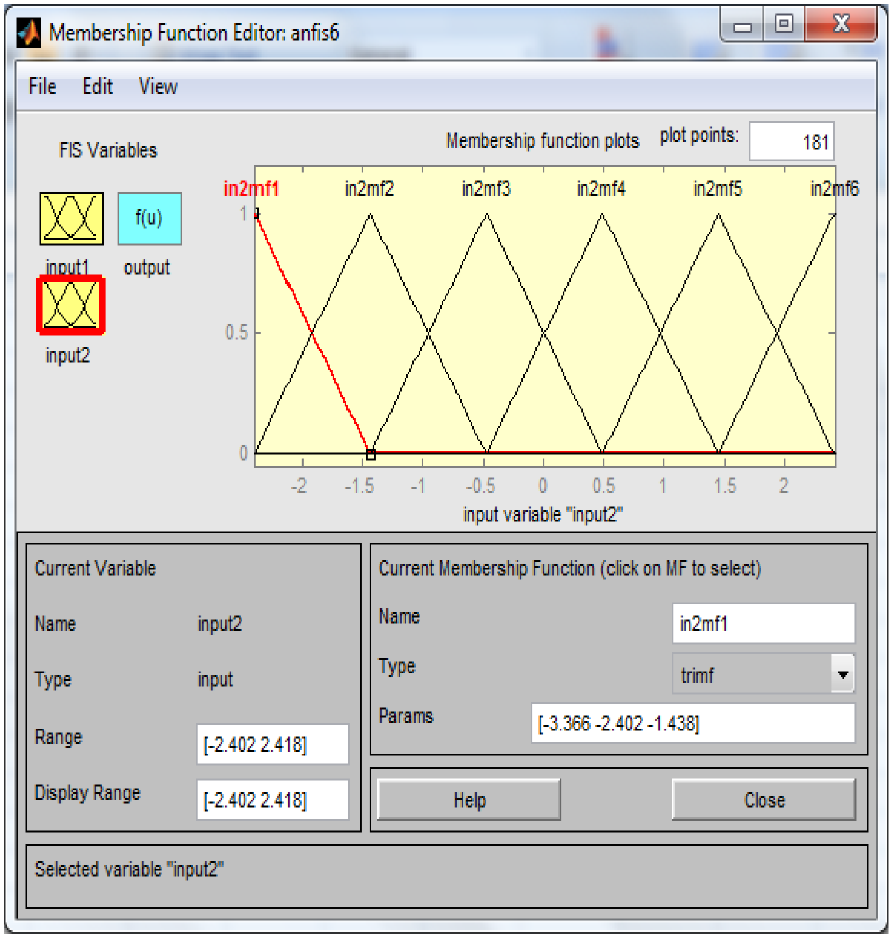

Figure 4.12 MF for Input Two

Figure 4.13 shows the membership function for output with range from -36.11 until 33.99.

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