FUZZY AND ANFIS BASED TEMPERATURE CONTROL OF WATER BATH SYSTEM

DISSERTATION REPORT

Submitted in partial fulfilment of the requirements for the award of the degree of

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IN

CONTROL AND INSTRUMENTATION

Submitted by:

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CERTIFICATE

This to certify that the dissertation titled, **"Fuzzy and ANFIS based temperature control of water bath system"** submitted in partial fulfilment of the requirement for the award of the degree of Master of Engineering in Control and Instrumentation by **Deepti Singh (02/ME/C&I/PT/09**) is a bonafide record of the candidate's own work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the report has not been submitted to any other University/institute for the award of any Degree or diploma.

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ABSTRACT

Conventional controller’s usually required a prior knowledge of mathematical modelling of the process. The inaccuracy of mathematical modelling degrades the performance of the process, especially for non-linear and complex control problem. The process used is Water-Bath system, which is most widely used and nonlinear to some extent. For Water-Bath system, it is necessary to attain desired temperature within a specified period of time to avoid the overshoot and absolute error, with better temperature tracking capability, else the process is disturbed.

To overcome above difficulties intelligent controllers, Fuzzy Logic (FL) and Adaptive Neuro-Fuzzy Inference System (ANFIS), are proposed. The Fuzzy controller is designed to work with knowledge in the form of linguistic control rules. But the translation of these linguistic rules into the framework of fuzzy set theory depends on the choice of certain parameters, for which no formal method is known. To design ANFIS, Fuzzy-Inference-System is combined with learning capability of Neural-Network. It is analyzed that ANFIS is best suitable for adaptive temperature control of above system. As compared FLC, ANFIS produces a stable control signal. It has much better temperature tracking capability with almost zero overshoot and minimum absolute error.

The system has been simulated in MATLAB and the results have been attached. The results obtained by using the Fuzzy Logic Controller has been studied and compared.

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Fuzzy logic is a technique that attempts to systematically and mathematically emulate human reasoning and decision-making. Fuzzy logic allows engineers to exploit their empirical knowledge and heuristics represented in the “if/then” rules and transfer it to a function block. Fuzzy logic thus Provides engineers with a clear and intuitive way to implement control systems, decision-making and diagnostic systems in various branches of industry. Fuzzy logic algorithms can be used for advanced applications in industrial automation such as:

(a) Intelligent control systems
Fuzzy control solutions are especially useful for complex systems where standard means such as PID control fails. Fuzzy logic can be an advantage in cases where an explicit Analytical-process model is not available or is too complex. Another advantage of fuzzy logic is that it can be easily combined with conventional controllers and substantially enhance their functionality. For example, fuzzy rules interpolate between a series of locally linear controllers and schedule gains of a PID controller based on changing operating conditions. So fuzzy rules do not have to necessarily replace conventional control methods, but rather extend their capabilities.

(b) Process diagnostics, fault detection
If an analytical process model is not available or is too complex to be run in real-time, empirical knowledge can be used to classify process conditions and early detect faults.

(c) Decision-making and expert systems
Fuzzy rules can emulate an experienced human operator in real time, e.g. select appropriate ingredients, components or machines according to specific situations in the manufacturing process.

1.2 Literature review

Most of the present day systems are large and may be considered to be complex in nature. Electrical power, chemical, water treatment and similar large-scale industrial plants are all complex in nature. Complex systems may be linear or nonlinear, continuous or discrete, time varying or time invariant, static or dynamic, short term or long term, central or distributed, predictable or unpredictable, ill or well defined. Also, system outputs may be measurable or immeasurable [1]. They may consist of many interconnected systems, sub-processes or components. The processes involved in the complex systems may possess widely varying properties. In large scale systems, every part performs a desired function and the overall system works satisfactorily only if all the different parts work in tandem for what they are designed for. Modelling of complex systems is of fundamental importance in almost all fields [2]. This is because models facilitate better understanding of the system and so help in system analysis. So prediction and simulation of the system's behaviour are then possible. System model also helps to design new processes and analyze the existing ones. The design, optimization and supervision of controllers, fault detection and faulty component diagnosis are all based on the system mode [3]l. This is because for the improvement of the system's performance, it is required to model the system correctly so that the model parameters can be tuned to get the required system response. It is because of this fact that in the last few decades, modelling of large scale, complex [4] systems has been a special topic of interest among the researchers of various disciplines worldwide. Most of the real world systems are ill defined in nature and hence difficult to model. Generally the performance of the system is dependent on the accuracy of the model [5]. Therefore it is of utmost importance to build a model which correctly reflects the behaviour of the system under consideration [6]. The functioning of complex large-scale systems also involves numerous trade off problems like cost and accuracy [7]. Hence, there is a strong demand for developing advanced methods of system modelling and identification techniques [8].

The conventional methods that have been used for system modelling rely heavily on the mathematical tools which require precise knowledge about the involved physical processes [9]. In systems where the mathematical model is not available, it is not possible to use the conventional methods for its analysis [10]. In such cases, soft computing based modelling approaches provide a viable alternative for identification of the system from the available data [11]. The concept of soft computing began to materialize near about the time when Lotfi Zadeh was working on soft analysis of data and fuzzy logic [12]. This gave birth to the intelligent systems. Nearly four decades later, the intelligent system became a reality [13]. However, initially the technology needed for building systems that possess Artificial intelligence (AI) was not available. Instead only predicate logic and symbol manipulation techniques formed the core of the traditional AI [14I. These techniques could not be used for building machines which could be called intelligent from the point of view of real world application. But today the requisite hardware, software and sensor technology are available for building intelligent systems. In addition to these, computational tools are available now which are far more effective for conception and design of intelligent systems [15]. These tools are derived from a collection of methodologies called soft computing [16]. Unlike hard computing the essence of soft computing is aimed at accommodating the prevalent imprecision of the real world [17]. Therefore soft computing helps in exploiting the tolerance for imprecision, uncertainty and partial truth so that tractability, robustness, low solution cost and better rapport with reality can be achieved [18]. Hence the human mind can be considered to be a role model for soft computing. Rather than a single technique, soft computing may be considered to be comprising of different methodologies with Neuro-computing (NC), the Fuzzy logic (FL) and the Genetic algorithm (GA) as the principal partners [19]. Therefore in soft computing based system identification, instead of a single standard method, a collection of techniques has been put forward as possible solutions to the identification problem. They can be broadly grouped as neural network based algorithm, fuzzy logic based algorithm and the genetic algorithm [20]. The neural network has the inherent advantage of being able to adapt itself and also in its learning capabilities [21].

Temperature control is an important factor in many process control system. Water-Bath temperature control is one of the most important and widely used applications of non-linear control system in process control industry and its application, in the production of a variety of drinks products such as chocolate drink, strawberry milk products etc [22]. The process industries which use Water-Bath temperature control are Nestle, Yeoh Hiop Seng, F&N, etc. If the temperature is out of the given range, the final product is badly affected. Therefore, it is necessary to reach at desired temperature points quickly within specified time period and to avoid large overshoot. Since the process-control systems are often non-linear and tend to change in an unpredictable way, they are not easy to control accurately [23]. Temperature is basic physical quantity, when is measured and controlled.

Similarly, the salient feature that is associated with the fuzzy logic is the distinct ability to take into account the prevailing uncertainty and imprecision of real systems with the help of the fuzzy if-then rules[24]. In order to exploit the advantage of the self adaptability and learning capability of the neural network and the capability of the fuzzy system to take into account of the prevailing uncertainty and imprecision of real systems with the help of the fuzzy if-then rules, an integrated forecasting approach comprising of both the fuzzy logic and the neural network has been considered [25]. This hybrid system is called the Adaptive network based fuzzy inference system (ANFIS) [26]. Here the fuzzy system with its expert knowledge stands as a front end pre-processor for the neural network input and output layers. Based on the historical data, the neural network learning algorithms are used to determine the parameters of the expert knowledge based fuzzy system [27]. The use of this hybrid system ANFIS helps to complement the weakness of the respective systems [28].

1.3 Project Objective

Water-Bath temperature control is one of the most important and widely used applications of non-linear control system in process control industry The main objective of this project is to develop a fuzzy logic based controller for Water-Bath system, it is necessary to attain desired temperature within a specified period of time to avoid the overshoot and absolute error, with better temperature tracking capability, else the process is disturbed. To overcome above difficulties intelligent controllers, Fuzzy Logic (FL) and Adaptive Neuro-Fuzzy Inference System (ANFIS) based temperature control of water bath system is simulated for different membership functions such as Gaussian, Trapezoidal, G-bell and Triangular. These membership functions are used to compare the result. MATLAB software is used for the purpose.

CHAPTER 2

FUZZY CONTROL

2.1 Fuzzy Logic

The pivotal contribution of fuzzy logic is a methodology for computing with words which can deal with imprecision and granularity. The human brain can interpret and process imprecise and incomplete sensor information which is received from the perceptive organs. Analogously the fuzzy set theory can also provide a systematic approach to deal with such information linguistically. It can also perform Numerical computation by using membership function for the stipulated linguistic labels. The Fuzzy inference system (FIS) is based on the concepts of fuzzy set theory, fuzzy if-then rules and fuzzy reasoning. The framing of the fuzzy if-then rules forms the key component in FIS. FIS is a very popular technique and has been widely applied in different fields like data classification, automatic control, expert system, decision making, robotics, time series analysis, pattern classification, system Identification etc. The basic structure of a fuzzy inference system consists of three principal components viz a rule base comprising of the selected fuzzy rules, a database defining the membership functions of the fuzzy rules, and a reasoning mechanism which performs a fuzzy reasoning inference with respect to the rules so as to derive a reasonable output or conclusion.

2.2 Analysis with Fuzzy Inference System

For the analysis of a fuzzy system whose inputs and outputs are described by linguistic variables, the following steps have to be carried out:

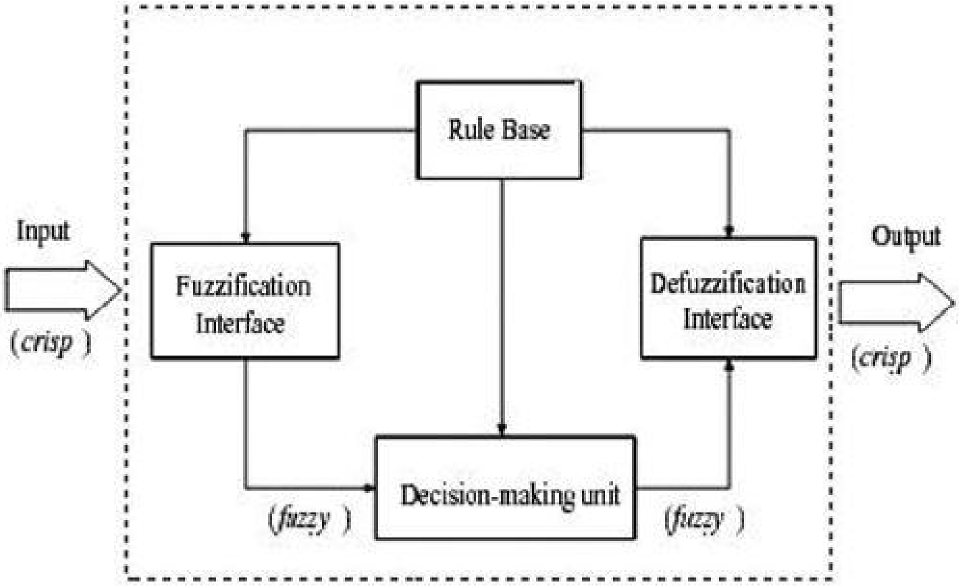

Fig 2.1 Fuzzy Logic System

• **Fuzzification**:-The linguistic variables of the fuzzy rules are expressed in the form of fuzzy sets where these variables are defined in terms of degree of their associated membership functions. This method of calculating the degree of belongingness of the crisp input in the fuzzy set is called the fuzzification.The membership functions may be triangular, trapezoidal, Gaussian or bell shaped. As the information about the degree of the membership is used for further processing, considerable amount of information may be lost during the course of fuzzification. This is because the procedure can be seen as a nonlinear transformation of the inputs. For example in the case of triangular or trapezoidal membership functions information is lost in the regions of membership functions where the slope is zero, as at these points the membership functions are not differentiable. Therefore fuzzy systems having triangular or trapezoidal membership function can encounter problems of learning from data. Smoother membership functions like Gaussian or bell function may be used to overcome this difficulty.

• **Aggregation**:-After the degree of each linguistic statement is evaluated, they are combined by logical operators such as AND and OR. Max and Min operators are used for classification task. For the purpose of approximation and identification the product and algebraic product operators are better suited due to their smoothness and Differentiability. Similarly the bounded sum and difference operators offer several advantages to some neuro-fuzzy learning schemes.

• **Activation**:-Here the degree of rule fulfilment is used to calculate the output activations of the rules.

• **Accumulation**:-In this step the output activations of all the rules are joined together to give rise to the fuzzy output of the system.

• **Defuzzification** :-If a crisp value of the system is required, the final fuzzy output has to be defuzzified.This can be done by different methods like center of gravity, bisector of area, mean of maximum (mom), smallest (absolute) of maximum (som) and largest (absolute) of maximum (lom).

2.3 Types of Fuzzy System.

There are two major types of control rules in fuzzy control:

1) Mamdani System – This method is widely accepted for capturing expert knowledge. It
Allows us to describe the expertise in more intuitive, more human-like manner. However,
Mamdani-type FIS entails a substantial computational burden.

2) Takagi- Sugeno - This method is computationally efficient and works well with Optimization and adaptive techniques, which makes it very attractive in control problems,
Particularly for dynamic non-linear systems. These adaptive techniques can be used to
Customize the membership functions so that fuzzy system best models the data.
The most fundamental difference between Mamdani-type FIS and Sugeno-type FIS is the way the crisp output is generated from the fuzzy inputs. While Mamdani-type FIS uses the technique of defuzzification of a fuzzy output, Sugeno-type FIS uses weighted average to compute the crisp output. The expressive power and interpretability of Mamdani output is lost in the Sugeno FIS since the consequents of the rules are not fuzzy [2]. But Sugeno has better processing time since the weighted average replace the time consuming defuzzification process. Due to the interpretable and intuitive nature of the rule base, Mamdani-type FIS is widely used in particular for decision support application. Other differences are that Mamdani FIS has output membership functions whereas Sugeno FIS has no output membership functions. Mamdani FIS is less flexible in system design in comparison to Sugeno FIS as later can be integrated with ANFIS tool to optimize the outputs.

2.4 FUZZY RULE BASE

The fuzzy rules represent the level of knowledge and abilities of human who adjusts the system for minimum error and fast response. The objective of the fuzzy controller will depend only on the rule base and this is composed of IF- Clause and THEN-clause. For optimum response of the system is possible with effective rule base. Here, the final modified rule base as shown in the Figures which consists of 49 rules. The rules are framed based on the frequent checking of the output response.

2.5 DEFUZZIFICATION

The process of conversion of fuzzy set in to a real number is called defuzzification. Several methods have been developed to generate real values as outputs. In this application, we employed triangular and trapezoidal fuzzification techniques and with various defuzzification methods.

The defuzzification methods are given below;
1. Centroid

2. Bisector of area
3. MOM (Middle of Maximum)
4. SOM (Smallest of Maximum)

The selection of defuzzification method depends on the context of decision for calculating with the fuzzy logic controller. For quantitative decisions like prioritization etc., we prefer the centroid defuzzification method. For qualitative analysis like evaluation of single variable worthiness, then we prefer MOM. Important consideration in defuzzification method is continuity of the output.
For example, a fuzzy system consists of effective rule base with overlapping membership functions then if a small change in the input value never create an abrupt change in the output. So,this is the reason for selecting the membership functions overlapped each other. First, we considered the centroid which is continuous because, assume it consists the overlapping output membership functions. So, it does not jump to a abrupt value as a output if any small change in the input. In case of MOM is discontinuous, then if any small arbitrary change causes abrupt change in the output. Especially, the centroid defuzzification method results a continuous controller characteristics, in between the intervals of input values some of the values are active simultaneously. So, with this result achieved by averaging methods of defuzzification. From this application, we can conclude that the assessment of centroid defuzzification results very high computational effort and we can employ to closed loop and decision making applications. In case of bisector, MOM and SOM are having low computational effort and not suitable for closed loop systems. The various defuzzification methods are applied to this application and results are shown in the results section.

2.6 Advantages of Fuzzy Logic Controller

The advantages provided by a FLC are listed below:

(a) It is simple to design.
(b) It provides a hint of human intelligence to the controller.
(c) It is cost effective.
(d) No mathematical modelling of the system is required.
(e) Linguistic variables are used instead of numerical ones.
(f) Non-linearity of the system can be handled easily.
(g) System response is fast.
(h) Reliability of the system is increased.
(i) High degree of precision is achieved.

These advantages allow fuzzy controllers can be used in systems where description of the
Process and identification of the process parameters with precision is highly difficult.
Hence it provides a fuzzy characteristic to the control mechanism.

2.7 Fuzzy sets

A fuzzy set is a set with a smooth boundary. Fuzzy set theory generalizes classical set theory to allow partial membership the best way to introduce fuzzy sets is to start with limitation of classical sets. The degree of membership in a set is expressed by a

number between 0and 1; 0 means entirely not in the set. 1 means completely in the set, and a number in between means partially in the set.
A fuzzy set is thus defined by a function that maps objects in a domain of concern to their membership value in the set. Such a function is called the membership function. The domain of the membership function. Which is the domain of concern from which elements of the set are drawn is called the universe of discourse.

CHAPTER 3

WATER BATH TEMPERATURE CONTROL USING FUZZY LOGIC.

3.1 Water bath Temperature Control using Fuzzy Logic Control

Fuzzy logic is more effective in feedback control system and easier to implement. Since Water-Bath temperature control system shows highly non linearity to some extent, hence fuzzy inference system is highly efficient method for proposed problem. Fuzzy control system divides into the single variable fuzzy control system and the multi-variables Fuzzy control system.
Problem statement: In this demonstration, we shall design a fuzzy logic controller for the temperature control of a water bath. The plant to be controlled is described by:

$$y(k+1)= \alpha(T)y(k) + \frac{b(T)u(k)}{1+\exp(0.5y(k) - Y)} + (1-\alpha(T))Y_0$$

Where;

$$\alpha(T) = \exp(-\alpha T)$$

and

$$b(T) = \frac{\beta(1- \exp(-\alpha T))}{\alpha}$$

The parameters of the plant are sets as $\alpha= 1x10^{-4}$, $\beta=8.7x10^{-3,}$ Y=40 and $Y_0 = 25^0$ C. The plant input u (k) is limited to between 0 and 5 volts. The sampling period, T, is set as 25 seconds. The goal is to design a fuzzy controller what will control the water temperature to follow a reference profile as closely as possible. This reference profile is 35^0 C for 0≤t≤120 minutes and 80^0 C for 120≤t≤180 minutes.

The input variables for this controller are chosen as e (k), de (k) where e (k) is the performance error indicating the error between the desire output and the actually output. The de (k) is the change of the error. The output of the controller is the voltage that limited to between 0 to 5 volts.

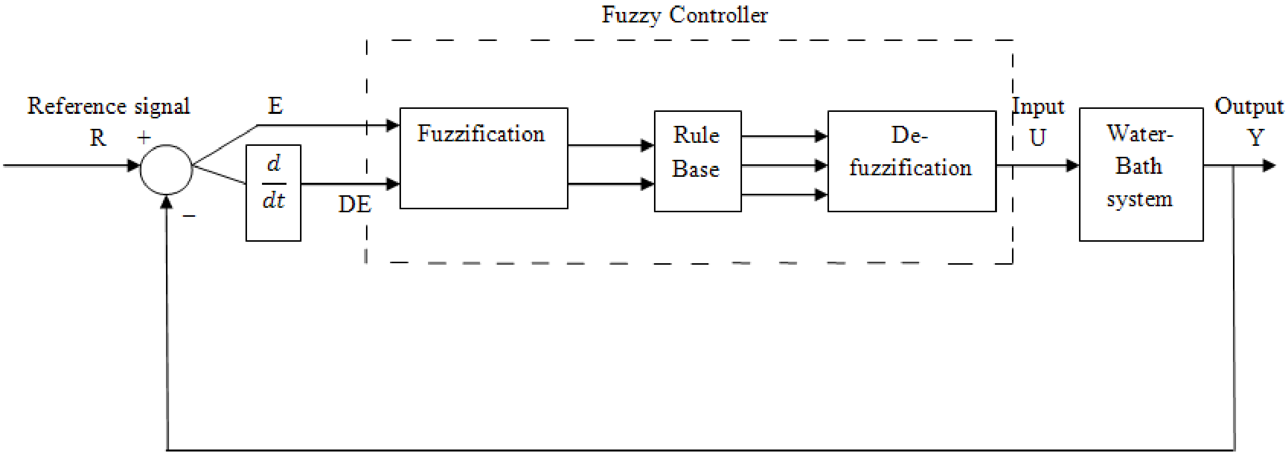

Fig 3.1 Fuzzy Control Model for Water-Bath system

The system used two input variables error _E_ change of error _DE_ and one output variable_U_. The computational structure of fuzzy logic control scheme is composed of fuzzification, inference engine and defuzzification.The input to the fuzzy controller is error E_k_ and the change in error DE_k_ is computed from the reference output U_k_ based on error and change in error as shown in Fig. 3.1 using FIS Editor.

3.2 Gaussian Membership Function

Gaussmf

Gaussian curve built-in membership function

Syntax

y = gaussmf (x, [sig c])

Description

The symmetric gaussian function depends on two parameters   and c as given by

$$f(x;\sigma,c) = \frac{-(x-c)^2}{2\sigma^2}$$

Where c and σ denote the centre and width of the function. we can control the shape of the function by adjusting the parameter σ A small σ will generate a “thin” membership function while big σ will lead to a “flat” membership function.

The parameter for gaussmf represents the parameters and c listed in order in the vector [sig c].

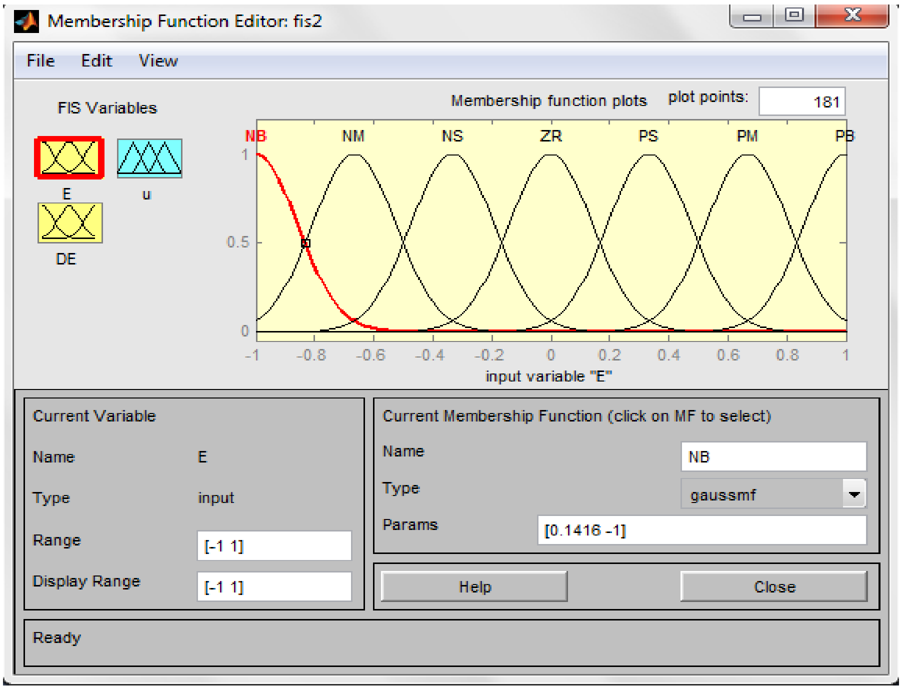

Fig.3.2 Input 1, Error (E)

In the figure 3.2 the first input variable to the Gaussian function is shown i.e. Error (E). The range is in between [-1 to 1].

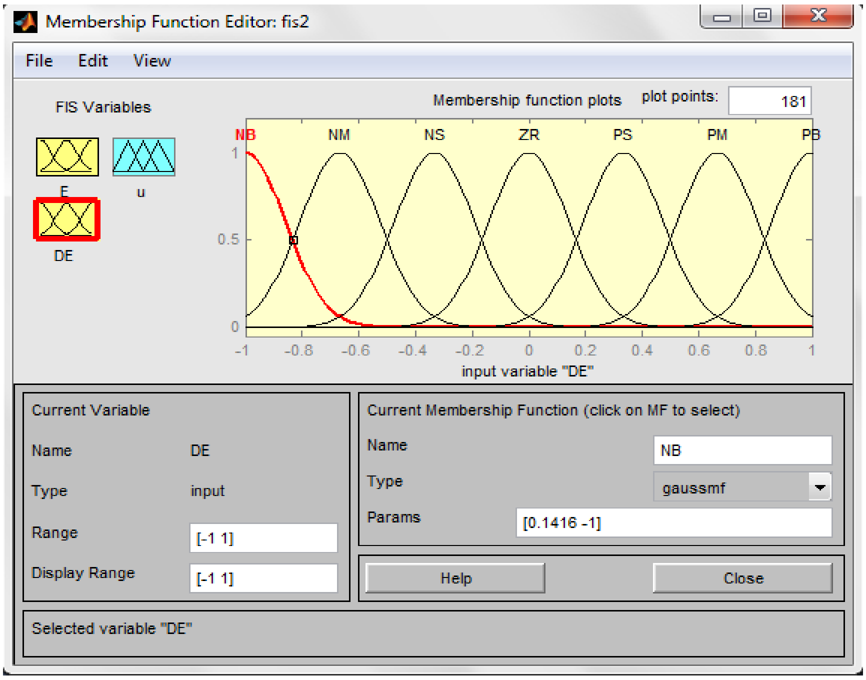

Fig.3.3 Input 2, Change in error (DE)

In the figure 3.3 the second input variable to the Gaussian function is shown i.e. Change in error (DE).The range is in between [-1 to 1].

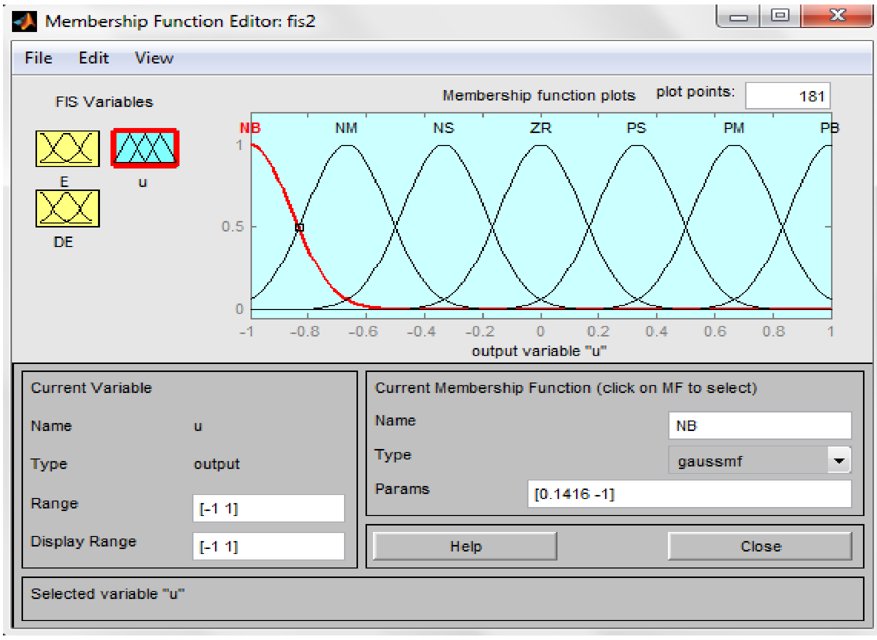

Fig.3.4 Output, control signal (u)

In the figure 3.4 the output variable to the Gaussian function is shown i.e. Control signal, (u).The range is in between [-1 to 1].

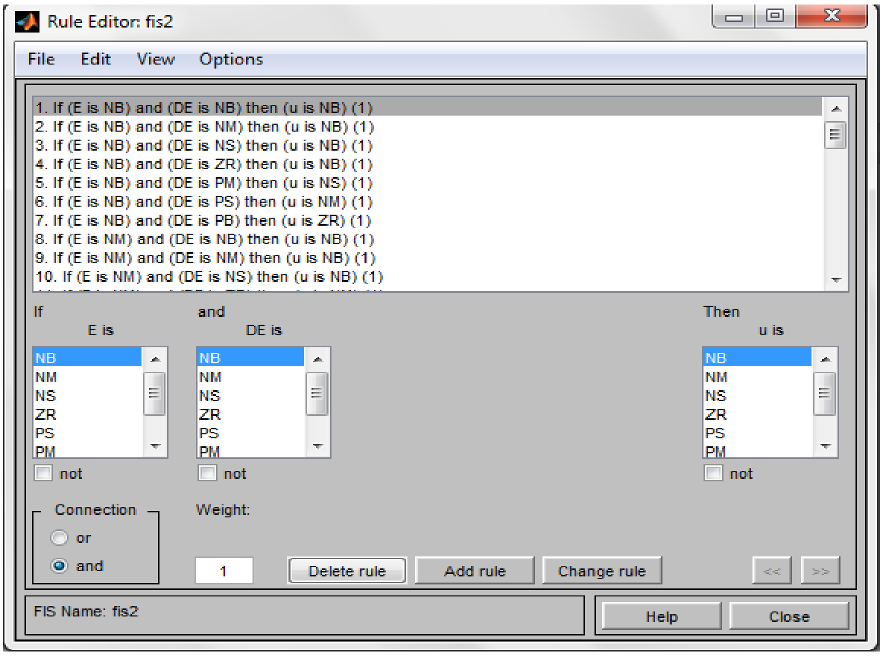

Fig.3.5 Rule base

In the figure 3.5, FIS rule editor shows the rules applied to the water bath temperature control system to attain the desired temperature i.e. Negative big(NB),Negative medium(NM),Negative,small(NS),Zero(ZR),Positivesmall(PS),Positive,medium(PM), Positive big (PB).

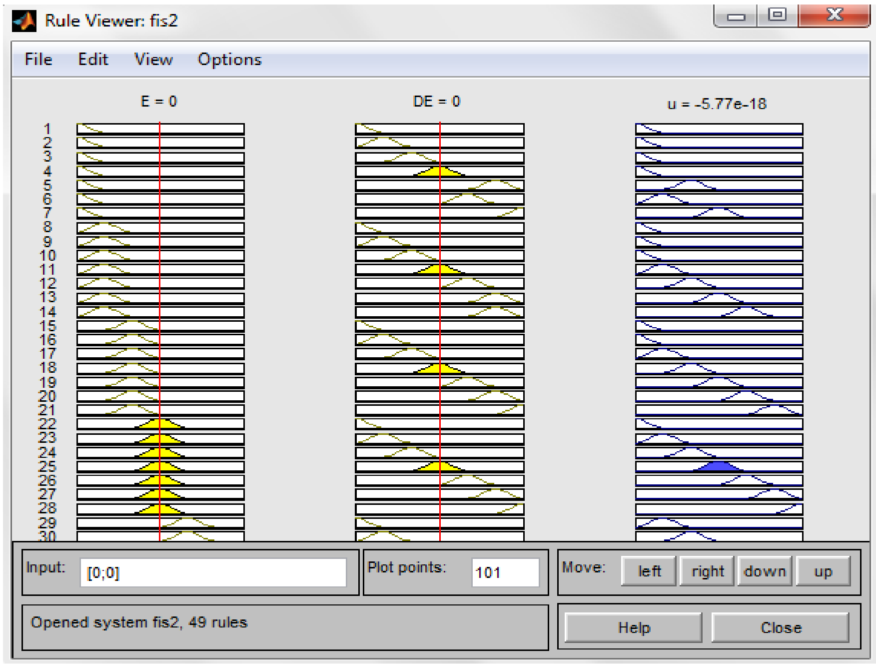

Fig.3.6 Rule Viewer

In the figure 3.6 rule viewer shows the defined rules in rule base i.e. E, DE and U. Error, change in error and control signal.

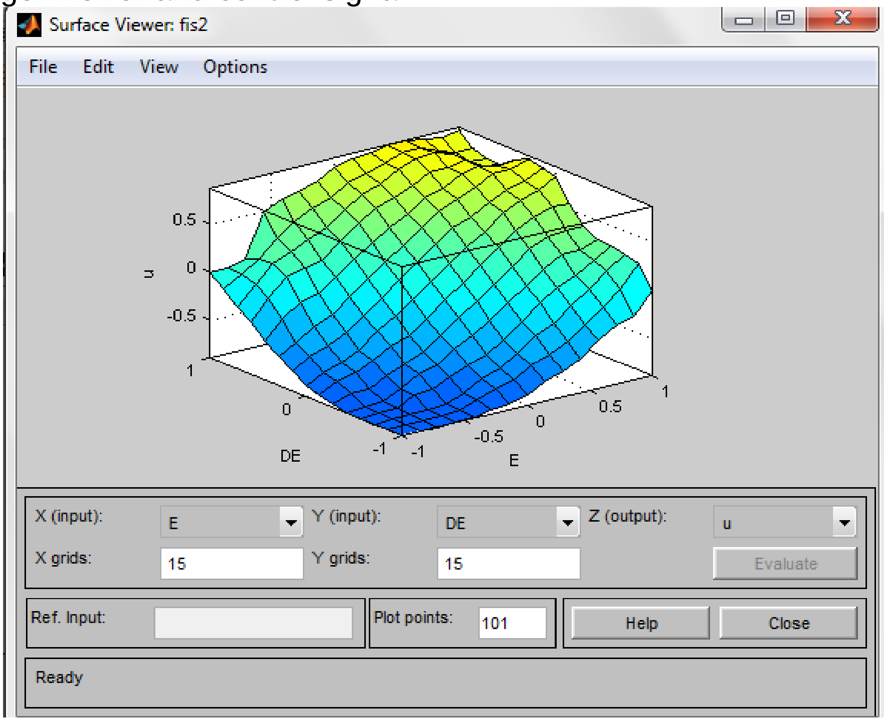

Fig.3.7 Surface Viewer

In the fig.3.7 surface viewer shows the view of error, change in error, and control signal i.e. (E, DE, U) in three dimensional view.

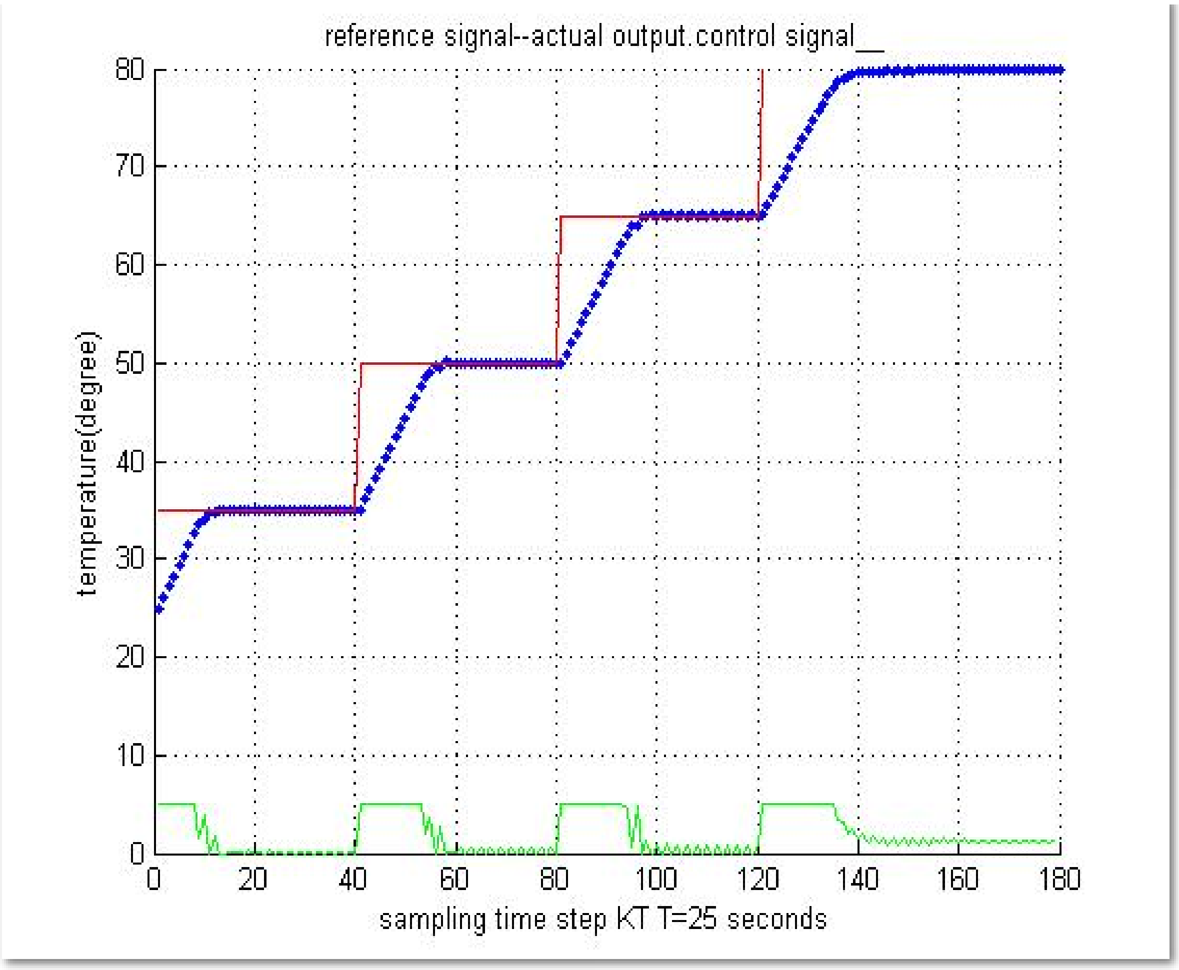

Fig.3.8 Controlled Output

Gaussian function

AES= sum (abs (ref-y))

=429.075

In the fig 3.8 the graph shows the reference signal (red line), actual output (blue line) and
Control signal (green line).The actual output is reach approximate to the reference signal. The output of the controller is the voltage that limited to between 0 to 5 volts. Sampling time t is for 25 seconds.
We can see that the Gaussian gives the good approximation of the fuzzy system and this will be compared with the other types of membership functions later.

3.3 Trapezoidal Membership Function

Trapmf
Trapezoidal-shaped built-in membership function

Syntax
y= trapmf (x, [a b c d])

Description
The trapezoidal cirve is a function of vector, and depends on four scalar parameters a,b,c and d, as given by

$$f(x;a,b,c,d) = \begin{bmatrix} 0, & x \le a \\ \frac{x-a}{b-a} & a \le x \le b \\ 1, & b \le x \le c \\ \frac{d-x}{d-c}, & c \le x \le d \\ 0, & d \le x \end{bmatrix}$$

or, more compactly ,by

$$f(x;a,b,c,d) = \max\left[\min\left[\frac{x-a}{b-a}, 1, \frac{d-x}{d-c} \right], o \cdot \right]$$

The parameters a and d locate the "feet" of the trapezoid and the parameters b and c locate the "shoulders".

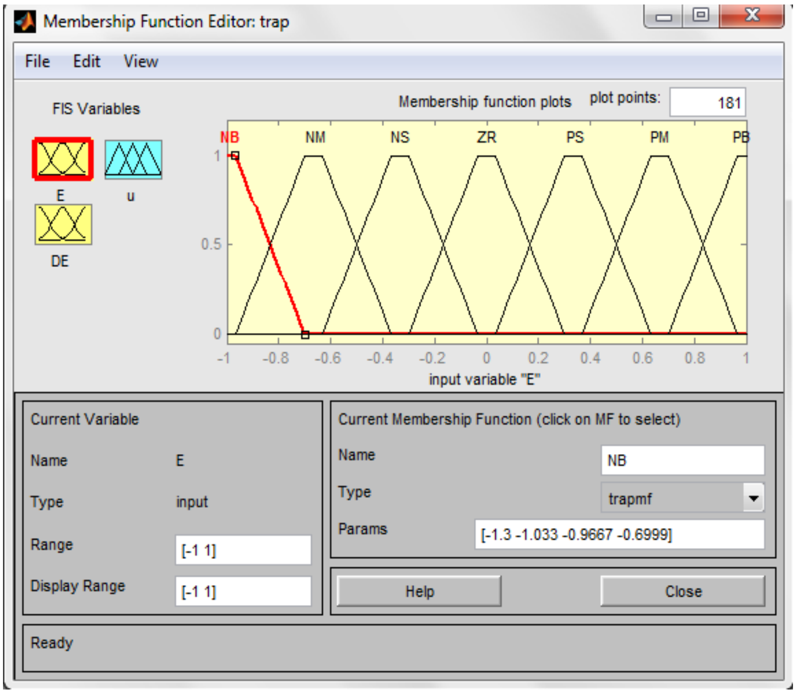

Fig.3.9 Input -1, 2 Error and change in error (E, DE)

In the figure 3.9 the first and second input variables to the Trapezoidal function are shown i.e. error (E) and change in error (DE). The range is in between [-1 to 1].

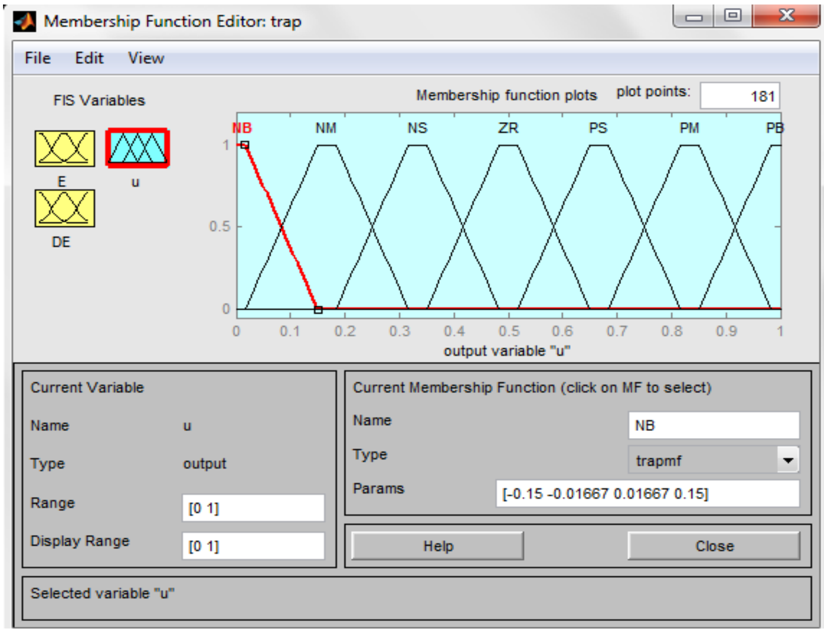

Fig.3.10 output, Control signal (u)

In the figure 3.10 it shows the output variable to the Trapezoidal function i.e. Control signal, (u) the range is in between [-1 to 1].

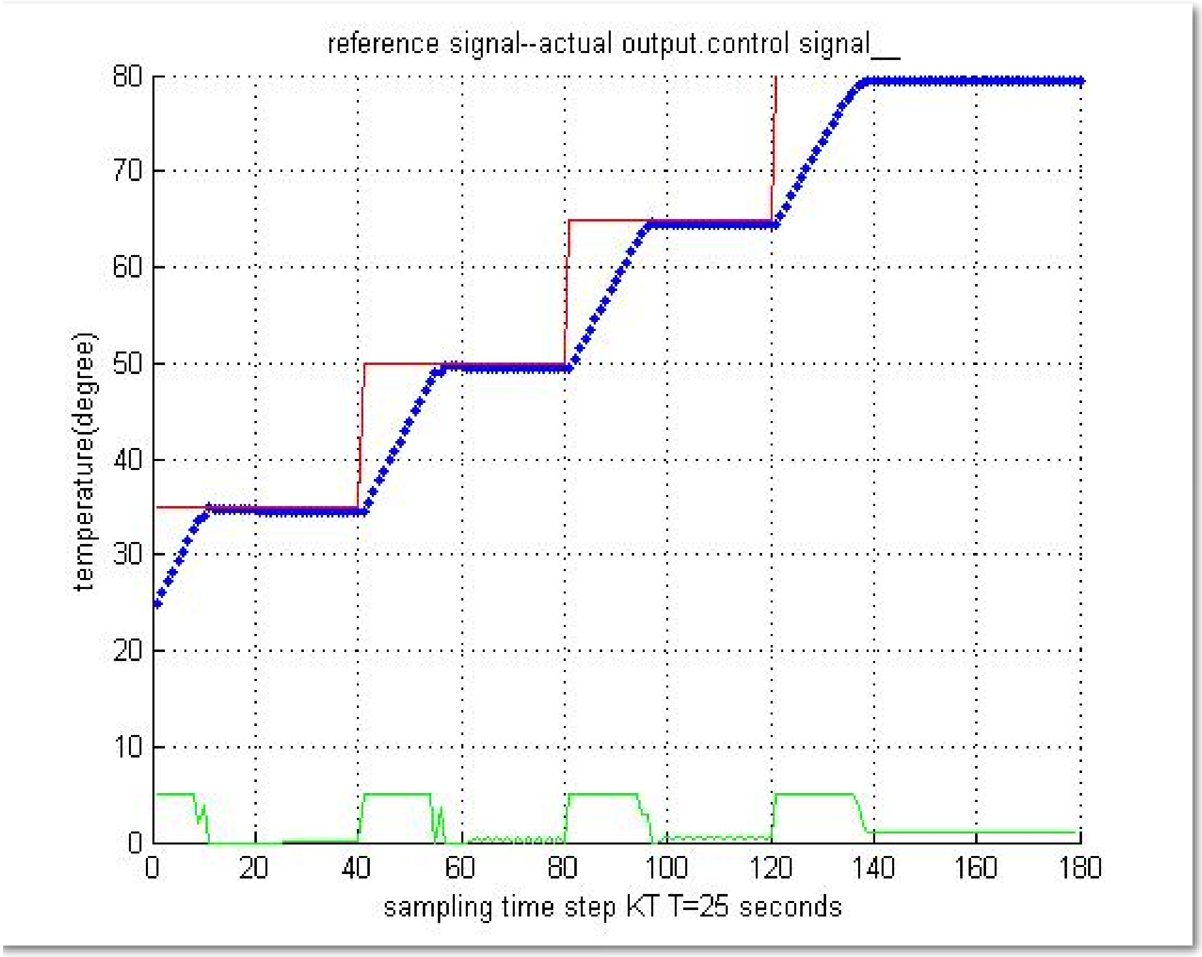

Fig.3.11 Controlled output

Trapezoidal function

AES= sum (abs (ref-y))

=501.7266

In the fig 3.11 the graph shows the reference signal (red line), actual output (blue line) and

Control signal (green line).The actual output is reach approximate to the reference signal. The output of the controller is the voltage that limited to between 0 to 5 volts. The absolute error sum for the trapezoidal function (501.72) is coming much larger than that for Gaussian membership function (429.07). Thus we can say that Gaussian membership function is better for fuzzy system than the trapezoidal function.

3.4 Gbell membership Function

Gbellmf

Generalized bell-shaped built-in membership function.

Syntax

y=gbellmf (x, params)

Description

The generalized bell shaped function depends on three parameters a, b, and c is given by

$$f(x;a,b,c)=\frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}}$$

Where the parameter b is usualldcsasy positive. The parameter c locates the centre of the curve. Enter the parameter vector prams, the second argument for gbellmf,as the vector whose entries are a,b,c, respectively

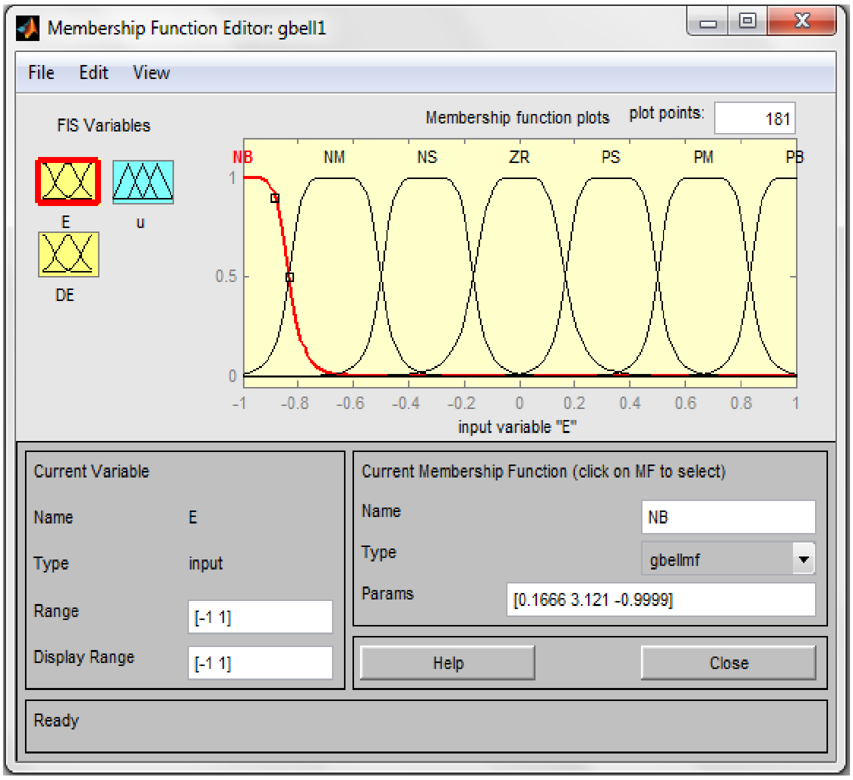

Fig.3.12 Input-1, 2 Error and change in error (E, DE)

In the figure3.12 the first and second input variables to the G bell function are shown i.e. error (E) and change in error (DE). The range is in between [-1 to 1].

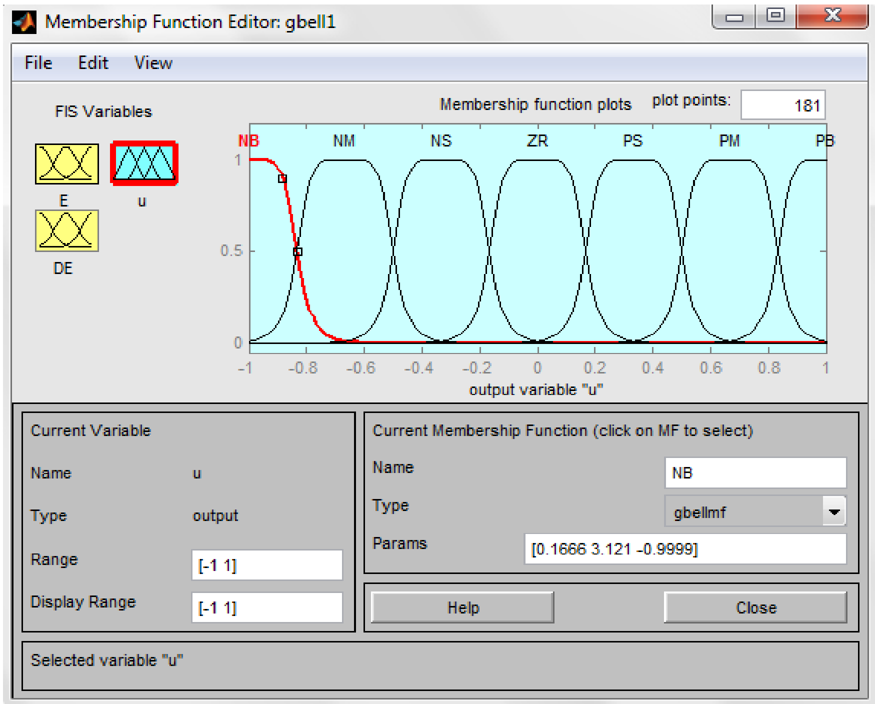

Fig.3.13 Output, Control signal (u)

In the fig 3.13 the output variable to the G bell function is shown i.e. Control signal, (u) .
The range is in between [-1 to 1].

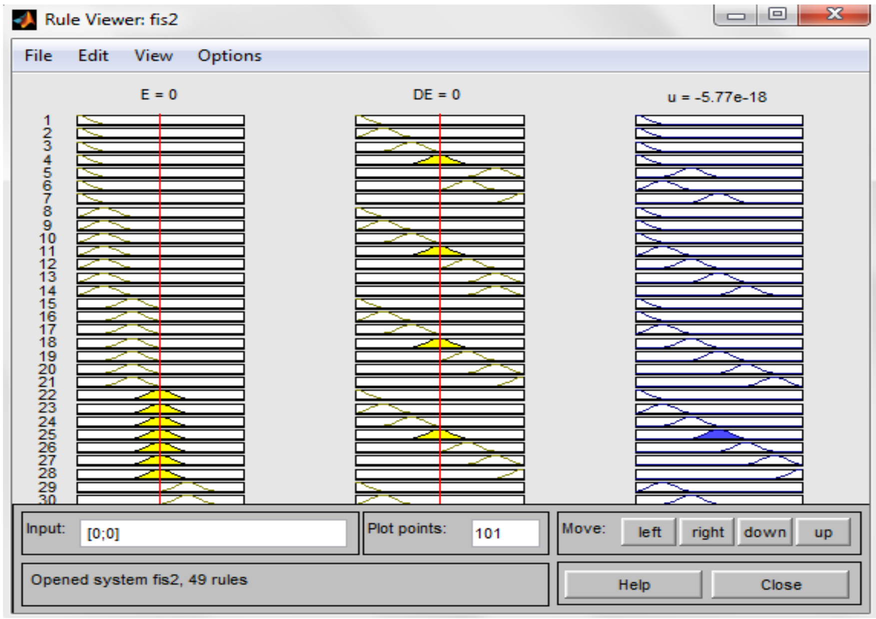

Fig.3.14 Rule Viewer

In the figure 3.14 the rule viewer shows the defined rules in rule base i.e. E, DE and U.
Error, change in error and control signal.

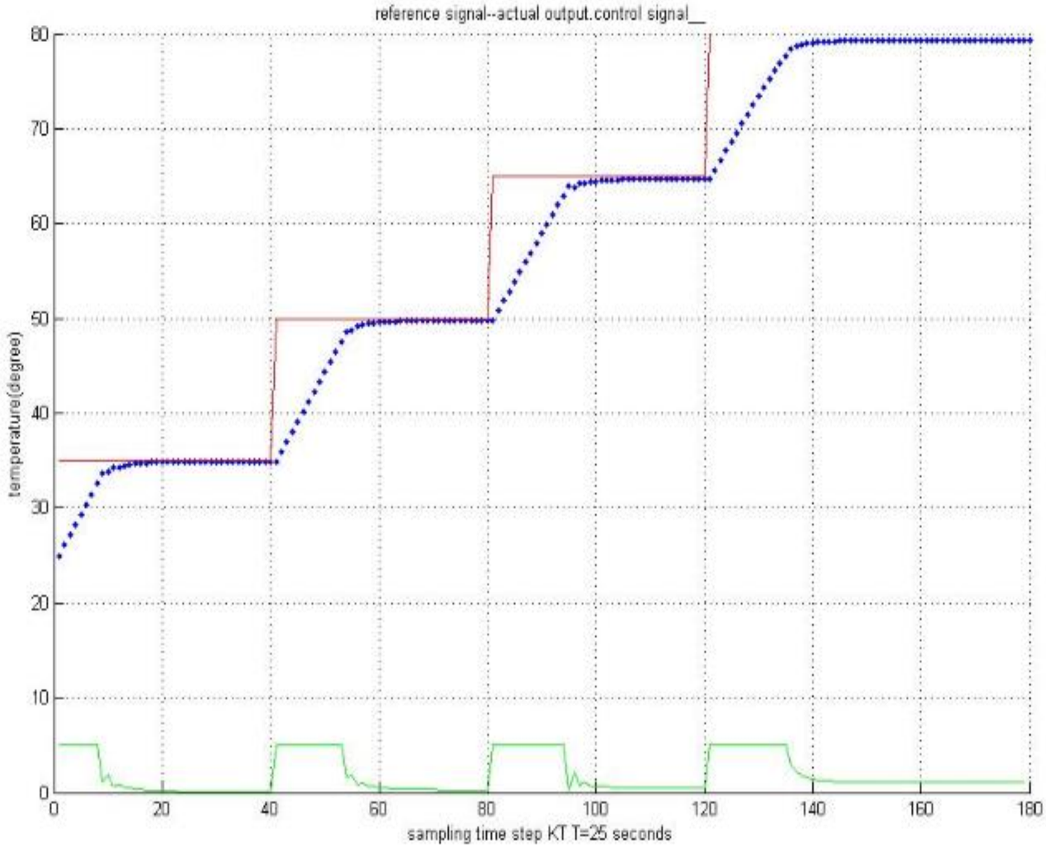

Fig.3.15 Controlled Output

G bell function

AES= sum (abs (ref-y))

=476.2639

In the fig 3.15 the graph shows the reference signal (red line), actual output (blue line) and
Control signal (green line).The actual output is reach approximate to the reference signal. The output of the controller is the voltage that limited to between 0 to 5 volts. The absolute error sum for the G bell function (476.26) is coming much smaller than trapezoidal function (501.72) but coming much larger than that for Gaussian membership function (429.07). Thus we can say that Gaussian membership function is better for fuzzy system than the trapezoidal function and G bell function.

3.5 Triangular Membership Function

Trimf
Triangular-shaped built-in membership function.

Syntax
y=trimf(x, params)
y=trimf(x, [a b c])

Description
The triangular curve is a function of vector, x, and depend on three scalar parameter a,b, and c, as given by

$$f(x;a,b,c)=\begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases}$$

or,more compactly, by

$$f(x;a,b,c)=\max\left(\min\left(\frac{x-a}{b-a},\frac{c-x}{c-b}\right),o\right)$$

The parameters a and c locates the “feet” of the triangle and the parameter b locates the peak.

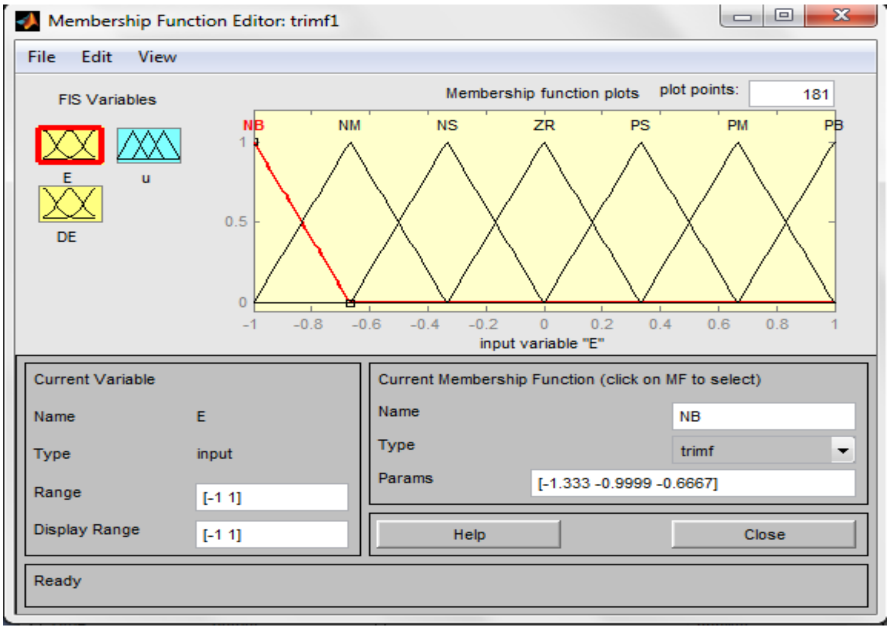

Fig.3.16 Input1, 2 Error and change in error (E, DE)

In the fig 3.16 the first and second input variables to the Triangular function are shown i.e. error (E) and change in error (DE). The range is in between [-1 to 1].

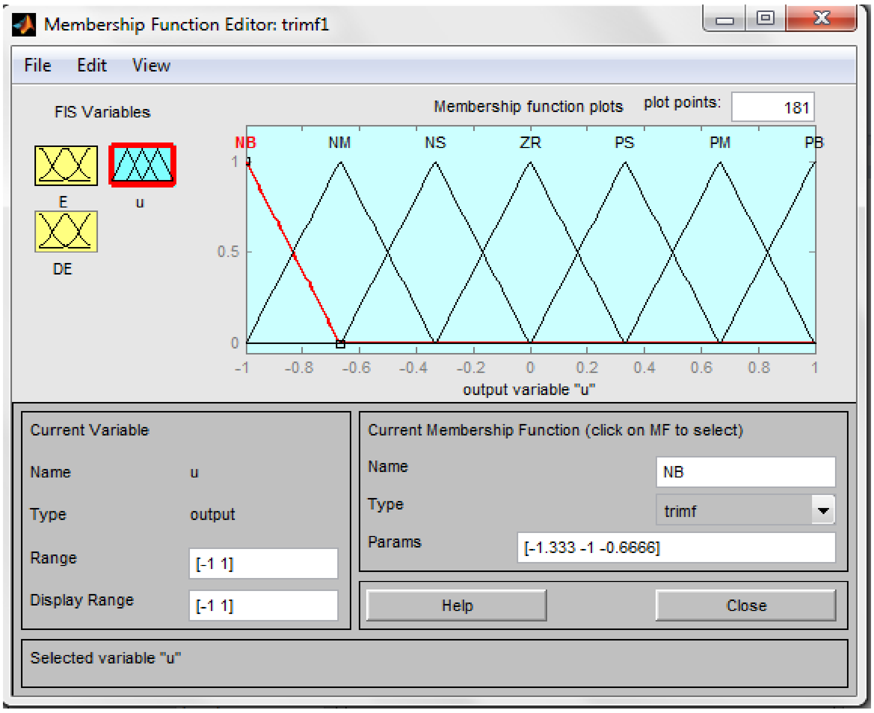

Fig.3.17 Output, Control signal (u)

In the fig 3.17 the output variable to the Triangular function are shown i.e. Control signal, (u) the range is in between [-1 to 1].

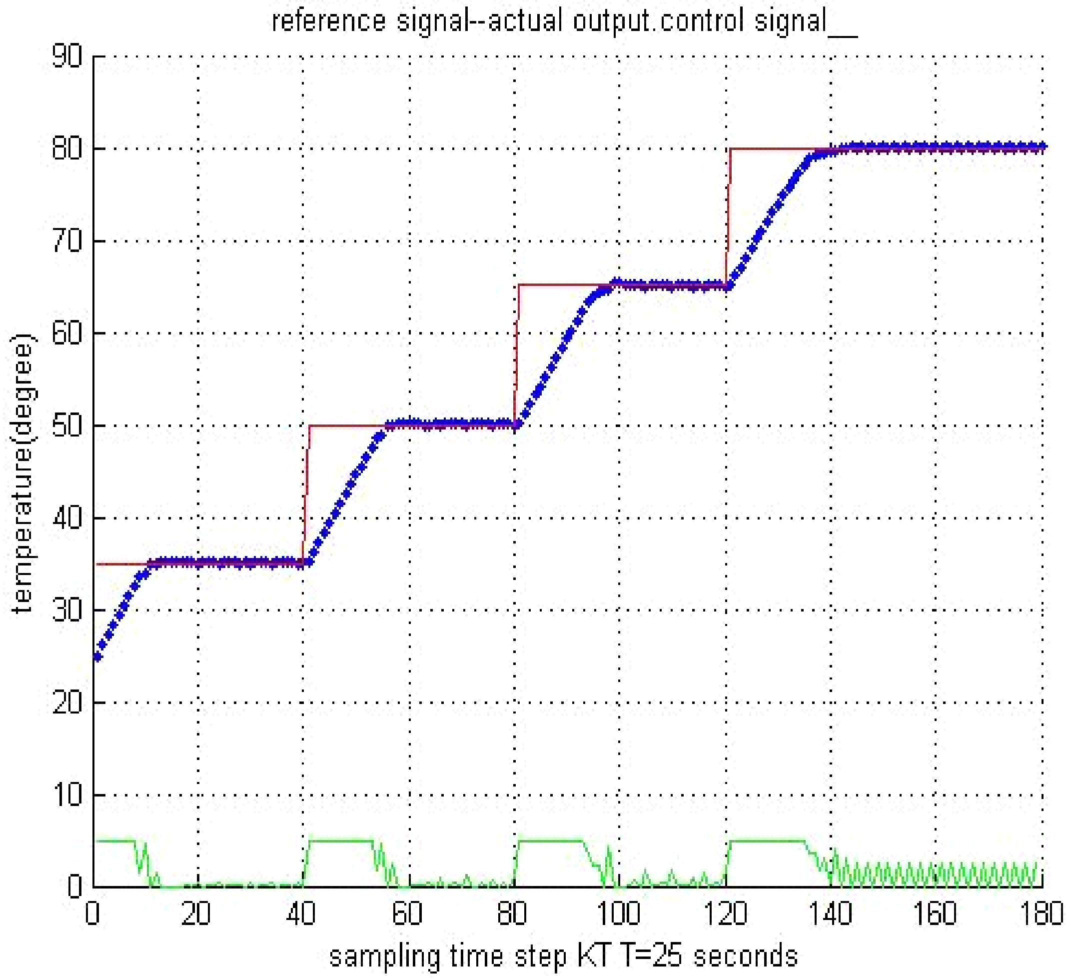

Fig.3.18 Controlled Output

Triangular function

AES= sum (abs (ref-y))

=430.7290

In the Fig 3.18 the graph shows the reference signal (red line), actual output (blue line) and
Control signal (green line).The actual output is reach approximate to the reference signal. The output of the controller is the voltage that limited to between 0 to 5 volts. The absolute error sum for the Triangular function (430.72) is coming much smaller than G bell function (476.26) and trapezoidal function (501.72) but coming much larger than that for Gaussian membership function (429.07). Thus we can say that Gaussian membership function is better for fuzzy system than the trapezoidal function and G bell function.

CHAPTER 4

Water bath temperature control using ANFIS

4.1 Adaptive Neuro-Fuzzy Inference System

ANFIS was 1st proposed by Roger Jang as a hybrid system between Fuzzy Inference System but with neural network architecture. A neuro-fuzzy system describes a fuzzy-rule based model using an NN-like structure (i.e. involving nodes and links). A neuro-fuzzy system differs from an NN in four major ways. First, the nodes and link in a neuro-fuzzy system usually are comprehensible because they each correspond to a specific component in fuzzy system. The connection between nodes in a neuro-fuzzy system reflects the rule structure of the system. the second layer node are connected to only two nodes from the first layer, each one of which describes a condition about an input variable. The nodes in the second layer thus perform the "AND" (conjunction) operator in fuzzy rules third, the nodes in different layer of neuro-fuzzy system typically perform different operations. Finally a neuro-fuzzy system typically has more layers than neural networks.

Some advantages of ANFIS are:
1) Refines fuzzy if-then rules to describe the behaviour of a Complex system.
2) Does not require prior human expertise.
3) Greater choice of membership functions to use.
4) Very fast convergence time

(a) The fuzzy inference system that we have considered is a model that maps

– Input characteristics to input membership functions,
– Input membership function to rules,
– Rules to a set of output characteristics,
– Output characteristics to output membership functions, and
– The output membership function to a single-valued output, or
– A decision associated with the output.

(b) We have only considered membership functions that have been fixed, and somewhat arbitrarily chosen.

(c)Also, we have only applied fuzzy inference to modelling systems whose rule structure is essentially predetermined by the user's interpretation of the characteristics of the variables in the model.

(d) In general the shape of the membership functions depends on parameters that can be adjusted to Change the shape of the membership function.

(e) The parameters can be automatically adjusted depending on the data that we try to model.

(f) Suppose we already have a collection of input/output data and would like to build a fuzzy inference Model/system that approximate the data.

(g)Such a model would consist of a number of membership functions and rules with adjustable Parameters similarly to that of neural networks.

(h) Rather than choosing the parameters associated with a given membership function arbitrarily, these parameters could be chosen so as to tailor the membership functions to the input/output data in order to account for these types of variations in the data values.

(i)The neuro-adaptive learning techniques provide a method for the fuzzy modelling procedure to learn information about a data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data.

(j)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 back propagation Algorithm alone, or in combination with a least squares type of method.

(k) This allows your fuzzy systems to learn from the data they are modelling.

(l) 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.

(m) The parameters associated with the membership functions will change through the learning process.

(n)The computation of these parameters (or their adjustment) is facilitated by a gradient vector, which provides a measure of how well the fuzzy inference system is modelling the input/output data for a given set of parameters.

(o) Once the gradient vector is obtained, any of several optimization routines could be applied in order to adjust the parameters so as to reduce some error measure (usually defined by the sum of the squared difference between actual and desired outputs).

(p) Anfis uses either back propagation or a combination of least squares estimation and back propagation for membership function parameter estimation.

The learning is required in order to fine-tune the parameters of the membership function as well as the parameters of defuzzification. For details of the ANFIS, One of the used of ANFIS in control system is to learn the universe of the plant, so that I can be used as a controller after training phase. Figure has shown the learning phase of ANFIS. As an example, we take the water bath temperature system as the target plant to be controlled. Notice that the learning of ANFIS is based on error back propagation as well.

Neural networks are computational models that consist of nodes that are connected by links. Each node performs a simple operation to compute its output from its input ,which is transmitted through links connected to other nodes .This relatively simple computational model is named as" neural network" because the system is analogous to that of neural system in human brains-nodes corresponding to neurons and links corresponding to synapses that transmit signals between neurons.

One of the major features of Neural Network (NN) is its learning capability.

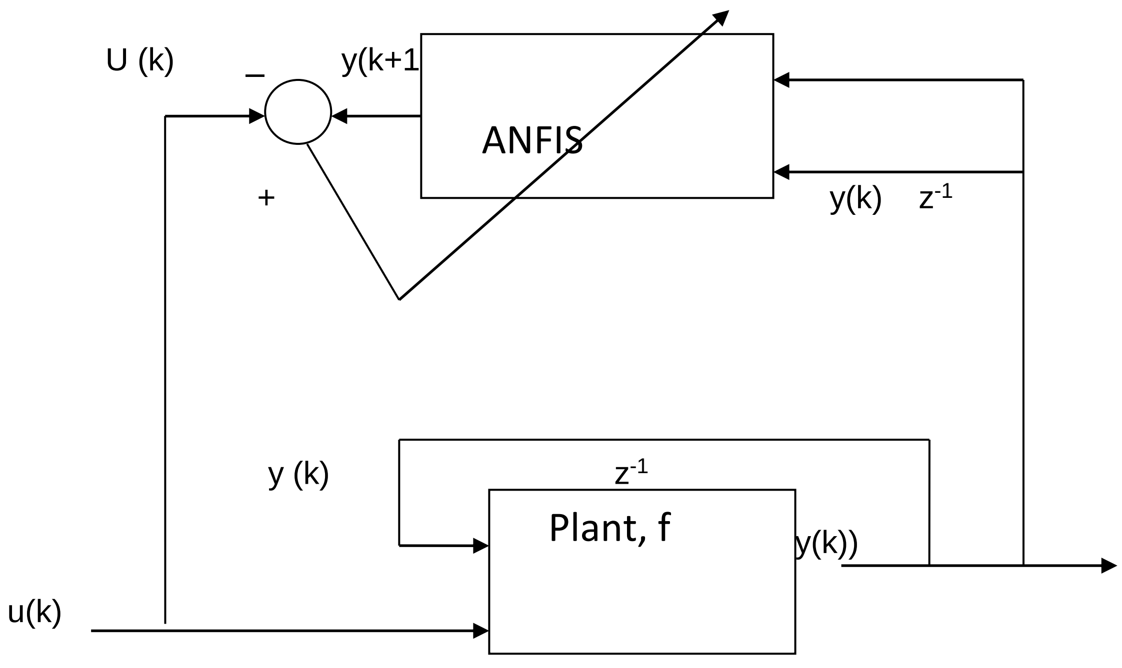

Fig.4.1 learning phase of ANFIS

After the learning phase is finished, the trained ANFIS is then to be used as a controller for the plant. The configuration of block to do this is shown in figure 4.2.

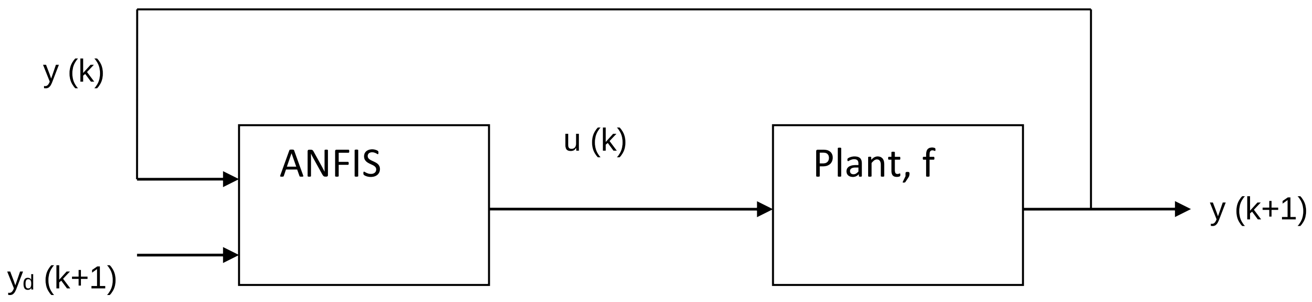

Figure.4.2 Controller for the plant

To design an ANFIS controller for the temperature control of a bath described in module
We shall implement the ANFIS controller using the direct inverse control strategy we first obtain the training data by imposing random input voltages to the water bath system and recording the corresponding temperature.

The ANFIS is then trained to identify the inverse model of the water bath system using the gathered training data to start the ANFIS training; we need an FIS matrix that specifies the structure and initial parameters of the FIS for learning. The user can use the command``genfis1'' to generate an FIS matrix from the training data using the grid-type partition according to the given number and types of membership functions.

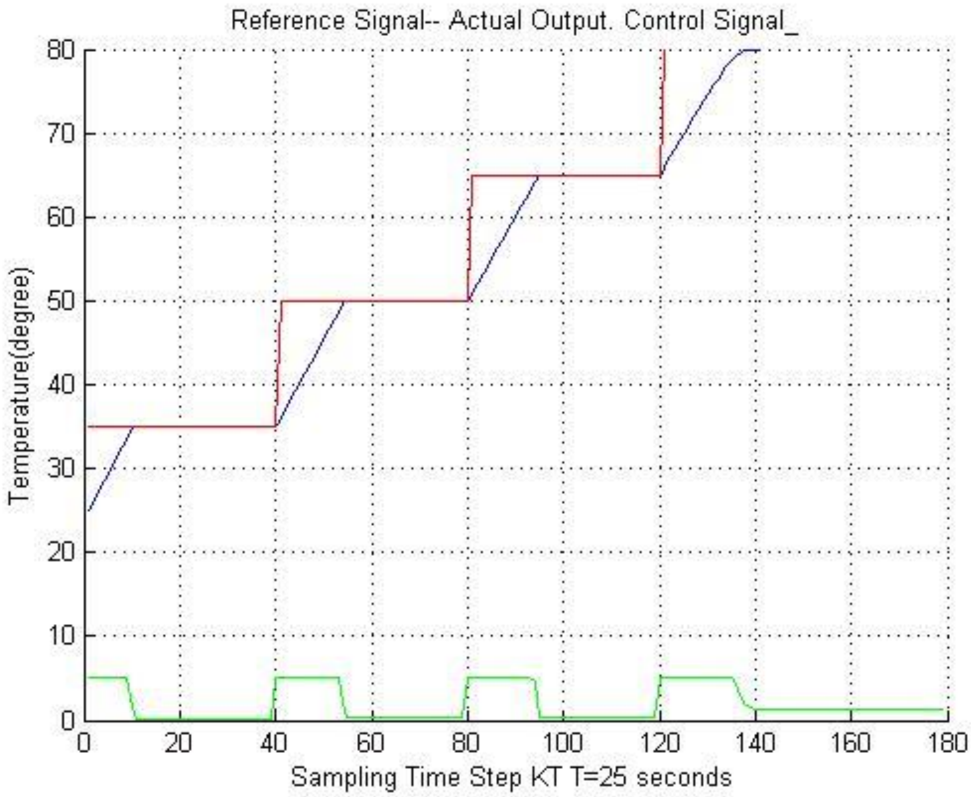

Figure.4.3 Controlled output (gaussmf)

ANFIS (gaussmf)

AES= sum (abs (ref-y))

=367.3556

The above graph shown in fig 4.3 shows the reference signal (red line), actual output (blue line) and Control signal (green line).The actual output is reach approximate to the reference signal. The output of the controller is the voltage that limited to between 0 to 5 volts
The absolute error sum for the Anfis gaussmf (367.3556) is coming much smaller than the b Triangular membership function (430.72), G bell membership function (476.26), trapezoidal membership function (501.72) and Gaussian membership function (429.07). Thus we can say that ANFIS is better than fuzzy system.

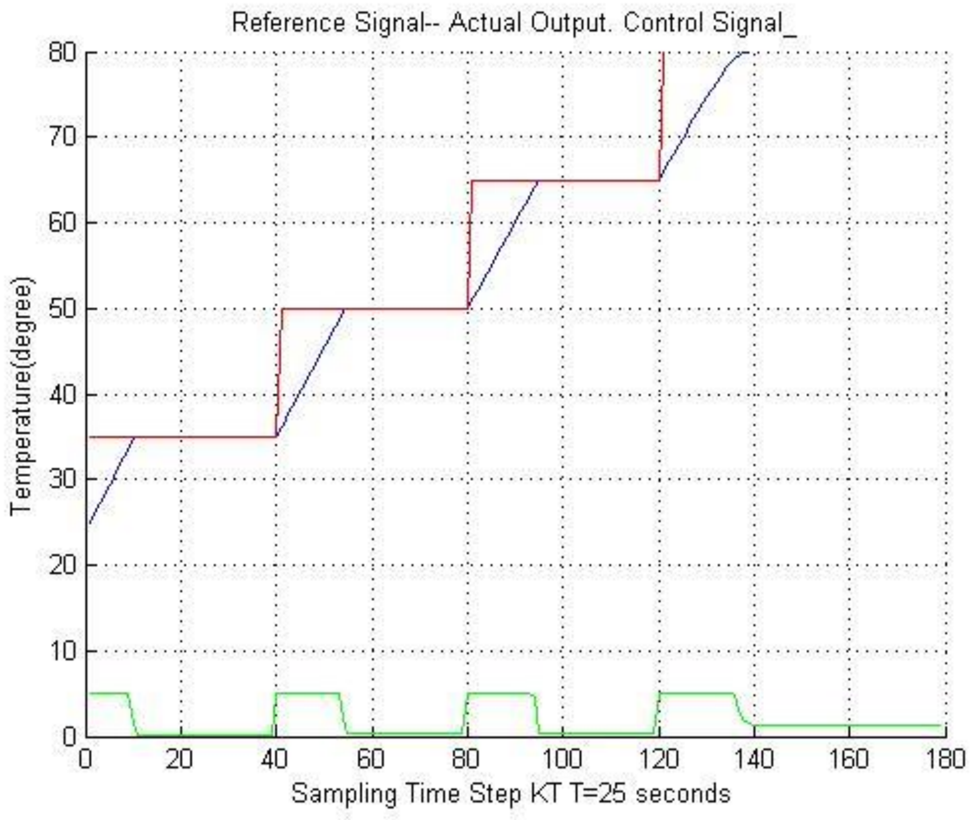

Figure.4.4 Controlled output (trapmf)

ANFIS (trapmf)

AES= sum (abs (ref-y))

=368.9700

The above graph shown in fig 4.4 shows the reference signal (red line), actual output (blue line) and Control signal (green line).The actual output is reach approximate to the reference signal. The output of the controller is the voltage that limited to between 0 to 5 volts

The absolute error sum for the Anfis trapmf (368.9700) is coming bit larger than the Gaussian membership function (367.3556) and smaller than Triangular membership function (430.72), G bell membership function (476.26), trapezoidal membership function (501.72) and Gaussian membership function (429.07). Thus we can say that ANFIS is better than fuzzy system

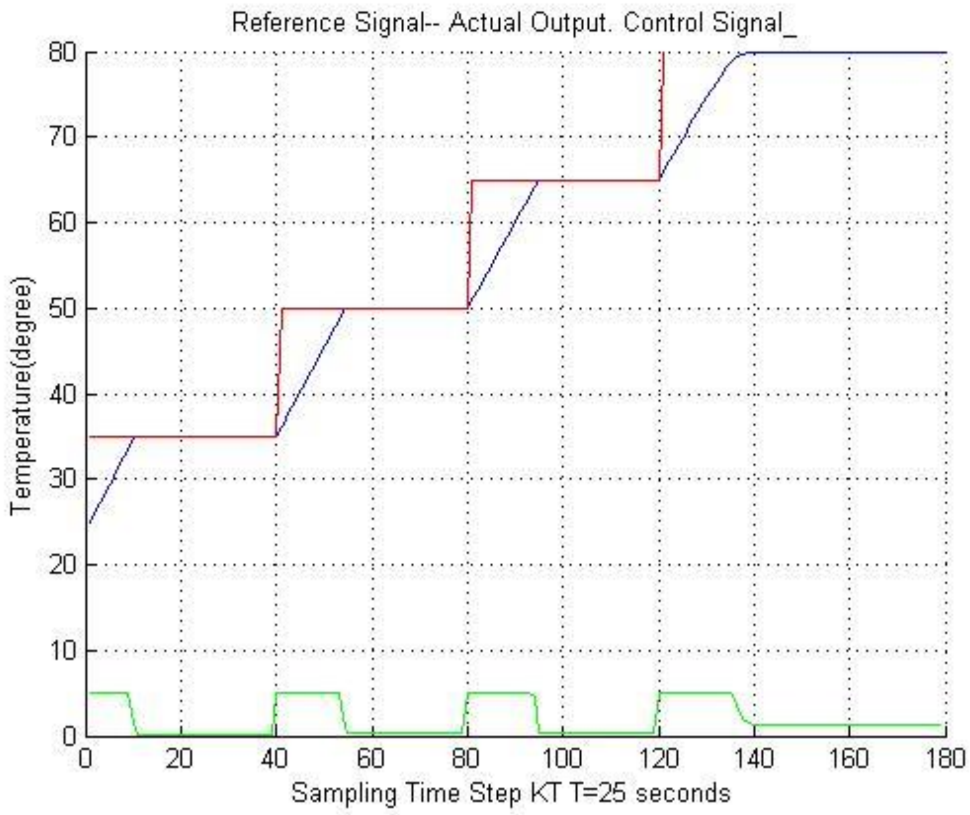

Figure.4.5 Controlled output (gbellmf)

ANFIS (gbellmf)

AES= sum (abs (ref-y))

=370.2979

The above graph shown in fig 4.5 shows the reference signal (red line), actual output (blue line) and Control signal (green line).The actual output is reach approximate to the reference signal. The output of the controller is the voltage that limited to between 0 to 5 volts

The absolute error sum for the Anfis gbellmf (370.9652) is coming bit larger than Gaussian membership function (367.3556),trapezoidal membership function(368.9700) and much smaller than the Triangular membership function (430.72), G bell membership function (476.26), trapezoidal membership function (501.72) and Gaussian membership function (429.07). Thus we can say that ANFIS is better than fuzzy system

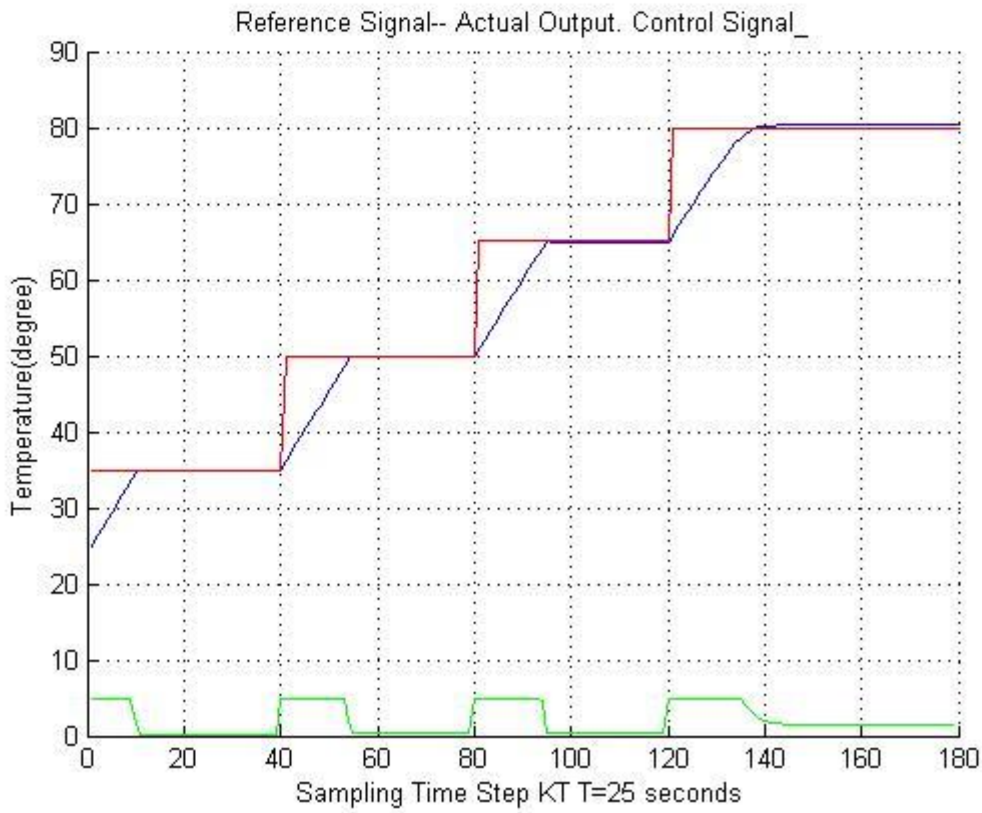

Figure.4.6 Controlled output (trimf)

ANFIS (trimf)

AES= sum (abs (ref-y))

=381.2979

The above graph shown in fig 4.6 shows the reference signal (red line), actual output (blue line) and Control signal (green line).The actual output is reach approximate to the reference signal. The output of the controller is the voltage that limited to between 0 to 5 volts

The absolute error sum for the Anfis trimf (381.9652) is coming much bit larger than the gbell membership function (370.9652) ,Gaussian membership function (367.3556),trapezoidal membership function(368.9700) ,Triangular membership function (430.72), G bell membership function (476.26), trapezoidal membership function (501.72) and Gaussian membership function (429.07). Thus we can say that ANFIS is better than fuzzy system.

CHAPTER 5

CONCLUSION AND FURTHER SCOPE OF WORK

The designed fuzzy controller has a good temperature capability, but that the control signal u (k) has a big change rate in the region of high temperature.

This shows that the designed fuzzy logic controller does not perform well. In order to quantify the tracking capability for comparison, we define a performance index AES= sum (abs (ref-y))

Where ref (k) is reference signal and y (k) is the actual output.

We observe temperature tracking capability with four different membership functions and found that Gaussian function has good temperature tracking capability in comparison with Triangular, Trapezoidal and G bell functions.

Further we observe that ANFIS controller has a perfect temperature tracking capability. It produces a stable control signal u (k) to the plant. The performance index is smaller than of fuzzy controller.

Further Scope:

A lot of research has been carried out in the region pertaining to fuzzy nonlinear control. Many different types of fuzzy membership function can be customized. Fuzzy logic is an innovative technology to design non-linear control problems and to design solutions for multi-parameter problems. Since it does not use mathematical model and instead uses man experience and experimental results. Human brain works with fuzzy patterns with ease, but computers fail to do so. Fuzzy logic tries to change that.

Different customized membership functions can be used to analyze the behaviour of the fuzzy control for different class of nonlinear systems. Analysis can also be done by increasing the number of rules for each customized membership function. This work can also be done using various techniques such as using Neural Networks (NN), Genetic Algorithm (GA) for obtaining better controlled output.

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