MAJOR PROJECT

GUIDED BY
DR. PARMOD KUMAR
ON

PERFORMANCE OPTIMIZATION OF PID CONTROLLER USING FUZZY LOGIC

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CERTIFICATE

This is to certify that the major project entitled **"PERFORMANCE OPTIMIZATION OF PID CONTROLLER USING FUZZY LOGIC"**, submitted by Mr. Rajeev Agarwal in partial fulfillment of requirement for the award of degree of " Master of Engineering" in Control and instrumentation is bona fide record of project work carried out under my supervision and guidance . This work has not been submitted earlier in any University/ Institute , to best of my knowledge.

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RAJEEV AGARWAL

ABSTRACT

While Proportional integral derivative (PID) controller are widely used in industrial application particularly in control application such as set point regulation problem , where the control objective is to derive a process variable (e.g. motor shaft position, oven temperature ,steam turbine control etc.) to a commanded set point , they exhibit poor performance when applied to system containing unknown nonlinearities, such as dead zones, saturation and hysteresis .

In this project we propose a fuzzy logic based precompensation approach for PID controller.The performance of this fuzzy PID controller can be tested on a D.C servomotor position control under varying load condition, as suggested in this project it can be shown that this fuzzy precompensated PID controller has superior performance compared to conventional PID controller since it modify the command signal to compensate for the overshoots and undershoots present in the output response when there is variation in load . We implemented PID control scheme for the Temperature control of the tank using software written in Matlab.

LIST OF FIGURES

SYMBOL

A	A fuzzy set A where $A = \{(\mu_A(x), x / x \in U\}$
μ_A	Fuzzy membership function of A
$\mu_A(x)$	Membership grade of x in fuzzy set A
$y_m(k)$	command input
$y_p(k)$	plant output
e(k)	Tracking error between the command input $y_m(k)$ and the plant output $y_p(k)$
Δ e(k)	change in tracking error
$\gamma(k)$	compensations or correction term
F[e(k), Δ e(k)]	Is a nonlinear mapping of e(k) and Δ e(k) based on fuzzy logic.
e'(k)	is the precompensated tracking error
Δ e'(k)	is the change in precompensated error
U(k)	command applied input to the plant
α_i	$\mu\ l_1^{e}(c_e e(k)) \wedge \mu\ l_2^{\Delta e}(c_{\Delta e}\ \Delta e(k))$ where ^ represent the minimum operator and C_e scaling factor of error $C\Delta e$ scaling factor of change in error
C_F	scaling factor

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CHAPTETR-1

INTRODUCTION

1.1 Introduction

Many physical components used in control system such as gears and hydraulic servo valves, suffer from nonlinearities including saturation relays, hysteresis and dead zones. Such nonlinearities are often unknown and time varying. Friction which represents a common source of nonlinearities often varies with temperature and wear and tear may differ significantly between components that are mass produced. Standard proportional integral derivative (PID) controller while simple to implement and commonly used in practice suffer from poor performance when applied directly to system with significant nonlinearities. For example it is well known that PID controller suffer from stick slip limit cycle when applied to plants with stiction(e.g[1],[2]). The study of methods for dealing with unknown nonlinearities has therefore been of interest to control practitioners for some time.

Since the seminal work of zadeh introducing the concept of fuzzy sets, fuzzy logic controller have received considerable interest .fuzzy based method are useful when precise mathematical formulation are infeasible , moreover, fuzzy logic controllers often yield superior results to conventional control approaches[9]

In 1965, Professor L.A.Zadeh of the university of California, Berkeley, presented his paper outlining fuzzy theory. In about 1970, fuzzy theory begin to produce result in Japan , Europe and China .Fuzzy control found application in control system , information processing industries etc.

Fuzzy logic is very human concept, potentially applicable to a wide range of processes and tasks that require human intuition and experience. It provides a remarkable simple way to draw definite conclusion from vague, ambiguous or imprecise information. Fuzzy logic can be applied by means of software ,dedicated controllers or fuzzy microprocessors embedded in digital products.

While proportional Integral derivative(PID) controller which is simple to implement and are widely used in industrial application, they exhibit poor performance when applied to a system containing nonlinearities. Fuzzy logic based precompensator for PID controller has recently yield so much positive result that it is no doubt that it is the best solution for time varying, nonlinear, dynamic and ill understood process. They have superior performance compared to conventional PID control.

In the theory we try to study and implement of such type of fuzzy logic based PID controller.

1.2 Brief Review of Previous Work on Fuzzy Controllers:

Present scheme of fuzzy PID controller have evolved over the past two decades. Yasuda et al[12] has presented a comprehensive study in the paper entitled **"A PID controller for with overshoot suppression algorithm".** In this paper he described a method to suppress process overshoot using a fuzzy expert control technique embedded in a PID controller. Their implementations, although different from ours, is also based on the approach modifying the controller internal set so that plant output stays on a desired response curve with minimal overshoots.

Advanced control schemes for controlling system with nonsmooth nonlinearities includes sliding mode and variable structure model [2]-[4] and dithering [5]. Motivated by limitation in some of methods, such as chattering in sliding mode control. Recker et al [6] proposed an adaptive nonlinear control scheme for controlling system with deadzones. In[6] full state measurement were assured to be available. Recently, Tea & kokotovic[7] considered the more realistic situation where only a single output measurement is available. In practice, however the transit performance of the adaptive control scheme is limited.

Matsunaga and Kawaji[13] used a hybrid scheme for controlling a D.C. servomotor . in their scheme, the controller switches between a fuzzy controller and PD controller depending on whether the system is in transient or steady state respectively. Their motivation is also based on the desire to improve the performance of controllers under nonlinearities.

Since the seminal work of zadeh[g] introducing the concept of fuzzy sets, fuzzy logic controller have received considerable interest (e.g.[9]) fuzzy based methods are useful when precise mathematical formulation are in feasible moreover, fuzzy logic controllers often yield superior results to conventional control approaches[9]. Kemi et al [0], publish three research paper entitled **"A two layered fuzzy logic controller for system with dead zones",** in which they studied a fuzzy logic based controller applied to system with deadzones. Their scheme exhibits superior transient & steady state response compare to other scheme. Motivation by this kim et al [11] applied a pre compensator scheme based on [10] for PD controller, and demonstrated positive result using computer simulation models.

In this present work a attempt has been made to design, a fuzzy logic based pre compensation scheme for PID controller. A design philosophy reflected in this thesis is that fuzzy method can be used effectively to conventional control methods for performance improvement.

A. The basis for the design of the present fuzzy pre compensator in different from that of [11]. The scheme is [11] was based on graphically studying the source of steady state error arising from applying PD type scheme to deadzones. In this paper the scheme is based on trying to compensate for overshoot and undershoot in the transient response.

B. Our present pre compensator is designed specifically for PID controllers, which are widely used in practice ,our scheme is easy to implement in practice. Since an existing PID controller can use in conjunction with the fuzzy pre compensator method modification.

C. [11], provides only computer simulation examples to illustrate the behavior of the scheme. In this thesis result are include on performance of the control scheme from as experimental ------

The main objective of the work presented in this thesis:

1. To develop a model for pre compensated PID controller and proposed hardware for the same .
2. To suggest a approach for designing the parameter of fuzzy pre compensator and optimizing them.
3. To study and to compare the dynamic performance to fuzzy and PID control to other conventional PID controller.
4. To develop full software in matlab for fuzzy precompensator PID control scheme for the…..
5. Further work and loaded of possibility of further work that can be done related to fuzzy logic control.

1.3 Organization of the thesis:

The brief outline of the thesis is as follows

Chapter 1: Introduces the brief introduction about fuzzy pre compensated PID controller and attempt to present a brief critical study of the past work carried out in the area of the conventional and fuzzy PID controller.

Chapter 2: Deals with fuzzy logic control , designing of fuzzy knowledge based controller (FKBC), requirement and application of fuzzy basic control.

Chapter 3: Dynamic model of the fuzzy pre compensated PID controller has been developed. A comprehensive design procedure for optimizing the parameter of fuzzy pre compensated controller has been presented.

Chapter4: Software

Chapter 5: Being out the detailed conclusion simulation of the entire work. The dynamic performance of fuzzy optimized controller has been compared with that of the performance of previous controller. The scope of further work is the area of fuzzy logic based controller has been discussed.

CHAPTER- 2

CHAPTER -2

FUZZY LOGIC CONTROL

2.1 Introduction:

In 1965 , Professor L.A. Zadeh [8] of the university of California, Berkely presented his paper outlining fuzzy theory in which he introduced the concept of fuzzy set theory and operation, fuzzy logic based controller etc. In about 1970 , fuzzy logic theory began to produce result in Japan, Europe and China. Recently fuzzy logic has emerged as one of the active areas of research activity particularly in control application system, information processing ,processing industries beside other applications as well.

Fuzzy logic [22] is a very powerful method of reasoning when mathematical formulations are infeasible and input data are imprecise. These above problem are encounter in many control applications in which we know , how the system is behaving but find it difficult to express the derived behavior in terms of mathematical model are in analytical formula. In this case fuzzy logic is a powerful tool for designing the control system accurately. Fuzzy logic application mainly to control is being studied [23] throughout the world by control engineers. The result of these studies have shown that fuzzy logic is indeed a powerful control tool, when it comes to control system or process. Some studies have also shown that fuzzy logic performs better when compared to conventional control mechanism like PID.

Fuzzy logic is very like to human mind concept, potentially applicable to a wide range of processes and tasks that require human intuition and experience. It provides a remarkable simple way to draw definite conclusion from vague, ambiguous or imprecise information. Fuzzy logic can be applied by means of software, dedicated controllers or fuzzy microprocessors embedded in digital products.

Fuzzy logic based controller are most suitable for time varying, nonlinear, dynamic, and ill understood process. Many control system containing unknown nonlinearities such as dead zones, saturation and hysteresis in which conventional PID controller when applied exhibit poor performance. In that system fuzzy logic based PID controller can applied easily and study shows that their performance is superior than conventional PID controller. Fuzzy logic can be applied by means of software, dedicated controllers or fuzzy microprocessors embedded in digital products.

2.2 Principal of fuzzy logic control:

Fuzzy logic is not really “fuzzy”. A fuzzy controller has a set of rules that is used to calculate the final control action. Each rule is linguistic expression about the control action to be taken in response to a given set of process conditions. There are several types of rules, which each have the following general format.

IF (CONDITION) THEN ACTION

The condition may include ‘AND’ and ‘OR’ condition, e.g. If set point is positive big and error change is positive small than actuator output is negative big.

The step for designing a simple fuzzy logic control system are as follows:-

1. Identify the variables(Input, states, and output) of the plant.
2. Partition the universe of discourse or the interval spanned by each variable into a number of fuzzy subsets, assigning each a linguistic labels.(subset includes all the elements in the universe).
3. Assign or determine a membership function for each fuzzy subset.
4. Assign the fuzzy relationship between the ‘inputs’ or the ‘states’ fuzzy subsets on the one hand and the ‘output’ fuzzy subsets on the otherhand, thus forming the rule base.
5. Choose appropriate scaling factor for the input and variables in order to normalize the variable to the [0,1] or [-1,1] interval.
6. Fuzzily the inputs to the controller.
7. Use fuzzy appropriate reasoning to input the output contributed from each rule.
8. Aggregate the fuzzy outputs recommended by each rule.
9. Apply defuzzification to form a crisp output.

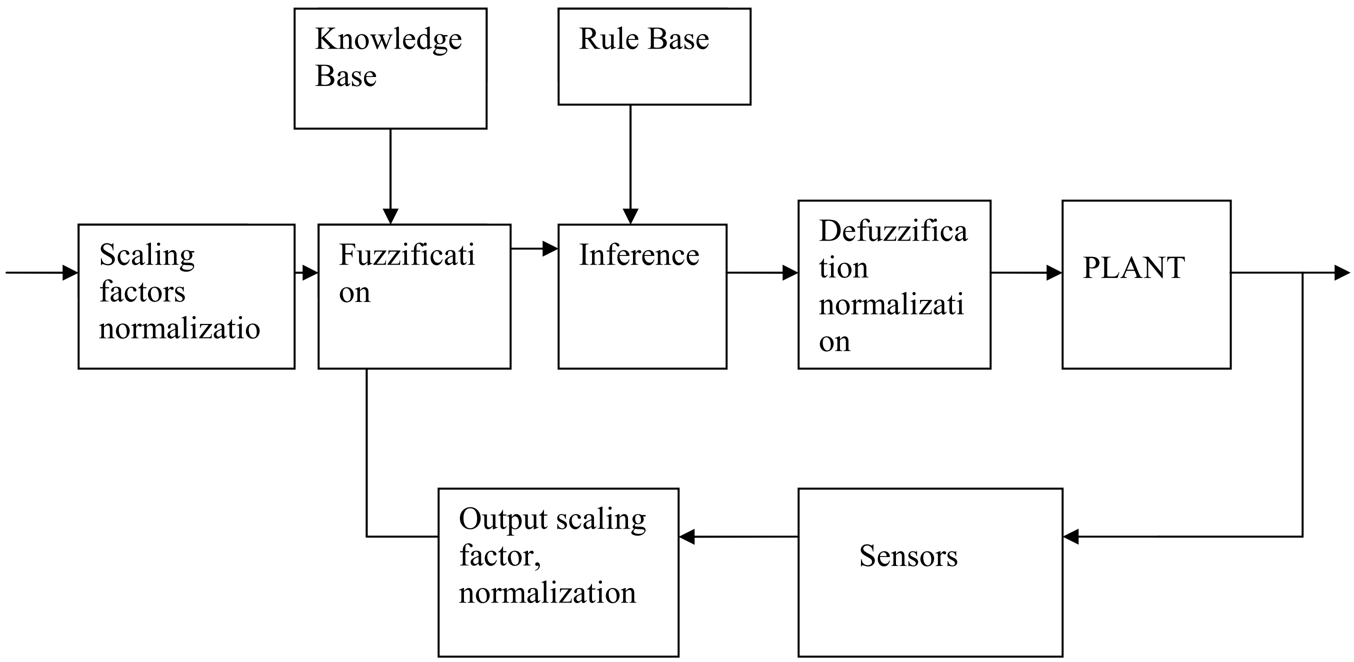

Fig 2.1 A simple fuzzy logic control system block diagram

BASIC FUZZY LOGIC DEFINATION:

The following are certain definition in relation to fuzzy logic system.

Fuzzy logic

A kind of logic or mathematical set theory, which uses graded or qualified statements (linguist hedges) rather than one's which is strictly true or false. The result of fuzzy reasoning are not as definite as those derived by strict logic, but they cover large field of disclosure.

Fuzzy sets

Sets that do not have crisply defined membership, but allows objects to have partial membership states (or grades) from 0 to 1, or the set, which intersects with its complement.

Linguistic variables

Ordinary language terms that are used to represent a particular fuzzy setin a given problem, such as 'large', 'medium', 'small' or 'okey'.

Ultra Fuzzy Set

Sets whose membership function is itself fuzzy set, so that an object in the set , rather than being given membership grade between 0 and 1, is assigned a range of possible membership grades-0.4 to 0.6 instead of 0.55.

Crisps

Antonym of fuzzy. Thus crisp set has precise boundaries and does not intersect with its complement.

Truth value (Grade)

The degree to which an attribute lies within a fuzzy set.

Membership Function

Truth value against sensor output for each fuzzy set, mapping that associates each member with its grade or membership. It is shown in following fig.

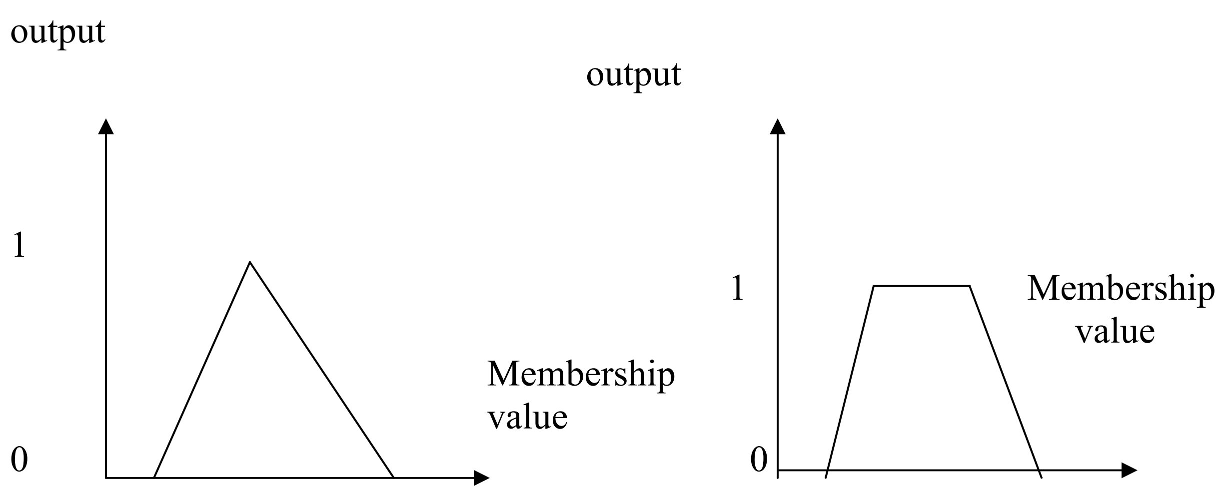

Fig 2.2 Membership function

Fuzzification

Finding the truth value and set for each sensor signal or where a particular input crosses the membership function. It is shown in fig 2.3

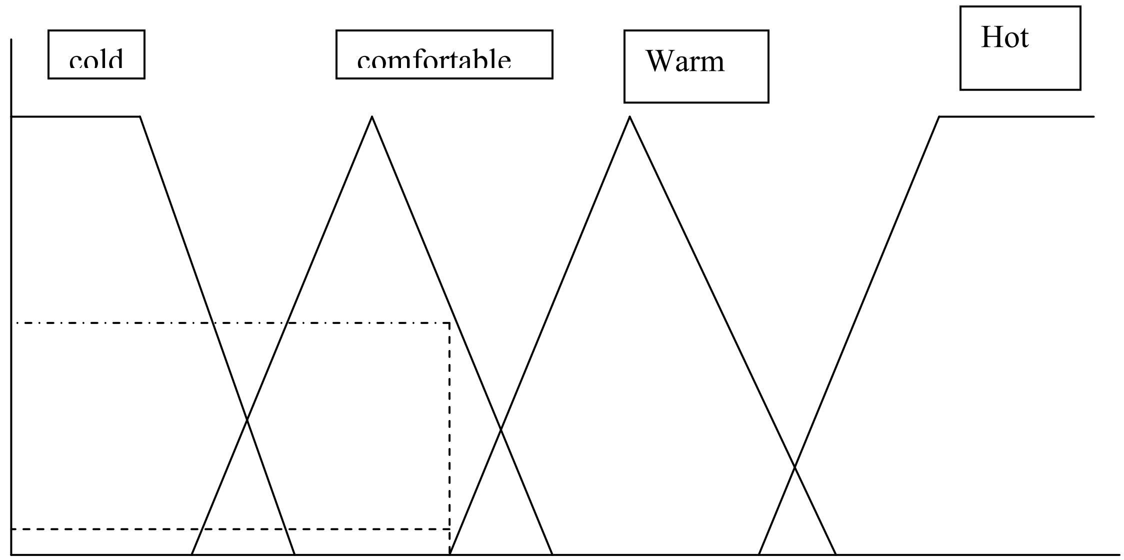

Fig 2.3 Fuzzification

Defuzzification

Converting the fuzzy outputs into single crisp value or given fuzzy set

Fuzzy system

A system who's variable ranges over states that are fuzzy sets.

Overlap

The degree to which domain of one fuzzy set overlaps with that of another.

Fuzzy control system

One based on fuzzy IF THEN rule for logic on utilizing sets for inputs and outputs.

Fuzzy Modifiers

Operations that changes to membership function of fuzzy set by spreading out the transition between the full membership by sharpening that transition or by moving the position of transition region.

2.3 Fuzzy Logic Controller Component Designing :

A fuzzy logic based controller is developed using the concept of prevailing conventional controllers. Consider of example of ordinary PID controller. The model describe its linear behavior.

$$U(C) = k\left[e(C) + (1/\gamma i)\int e(C)dt + \gamma d\,(de(C)/dt) \right] \qquad \text{-----------(2.1)}$$

Where U(C) is the control signal and e (C) is the error signal. PID controller can be understood very well about this linear equation. To obtain a good PID controller, it is also necessary to consider operation interfaces , operational issues like switching smoothly between manual and automatic operation, transients due to parameter changes, the effect of nonlinear actuators wind up of the integral term maximum and minimum selectors etc. An operational industrial PID controller consists of implementations of the above model and heuristic logic that takes care of these issues.

It can be concluded that practical solution to such mundane problems like PID control are not done by theory alone but heuristics play an important role. The discrete form of equation can be represented as

$$U(K) = U(k-1) + \Delta U(k) \quad \text{--------------------------------} \ (2.2)$$

Where

$$\Delta U(k) = F[e(k), \Delta e(k)] \quad \text{---------------------------------} (2.3)$$

Once the system behavior is thoroughly studied, comprehensive performance objectives of the controller can be speculated. Then the heuristic rule that describe that the help of intelligent trial and error science can formulate equation as well self institution learned from experience. This form the basis for the design of fuzzy logic based control.

2.4 Design Parameters for An Fuzzy logic Based Controller:

The principal design parameters for the fuzzy knowledge based controller as illustrated in fig are as following:-

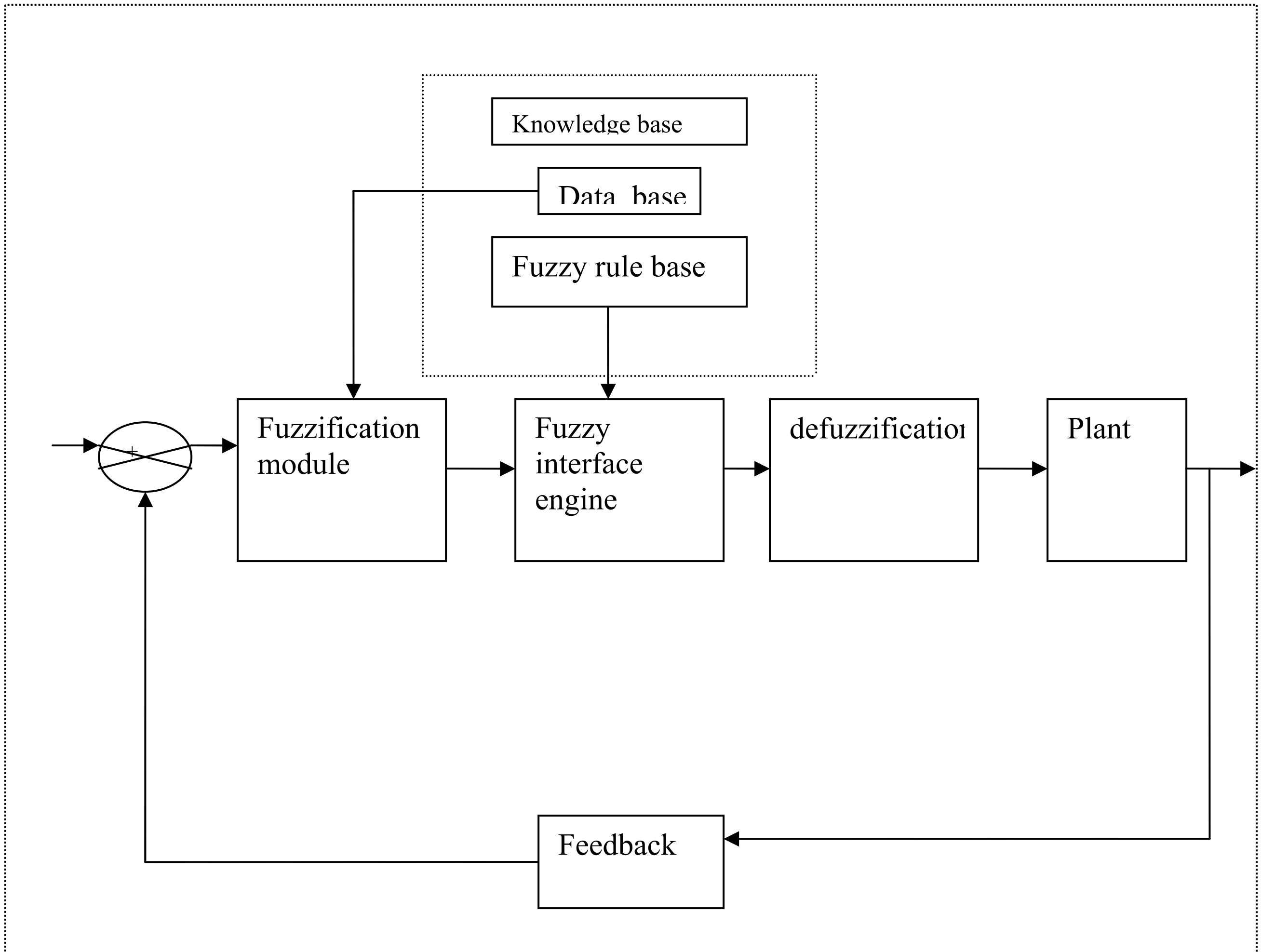

Fig 2.4 Fuzzy logic based controller

(1) **Fuzzification** strategies and implementation of a fuzzification operator (fuzzifier).

(2) Data base

a. Discretion/ normalization of universe of discourse.

b. Fuzzy partition of the input and output spaces.

c. Completeness of the partitions.

d. Choice of the membership function of a provisory fuzzy rate.

(3) Rule Base-

a. Choice of process state (input) variables and control (output) variables of fuzzy control rules.
b. Source and derivation of fuzzy control rules.
c. Type of fuzzy control rules.
d. Consistency interactivity ,completeness of fuzzy control rules.

(4) Decision making logic

a. Definition of a fuzzy implementation
b. Interpretation of the sentence connective and
c. Interpretation of the sentence connective or
d. Inference mechanism.

(5) Defuzzification strategies and the interpretations of and defuzzification operator (defuzzifier) .

2.5 Membership Function And Defuzzification Method :

Membership function :-

Membership function forms a crucial part in a fuzzy rule base model because they actually define the fuzziness of a control variable or a process variable. For example if 50 C represents hot for a particular membership function for a process, the same value may mean very hot for another function.

The next popular choices for the shape of the membership function are triangular, trapezoidal and bell shaped functions are:-

1. <u>Triangular Membership Function :-</u>

This is one of the most popular among the scientist in this field. Triangular function is the most economical one.

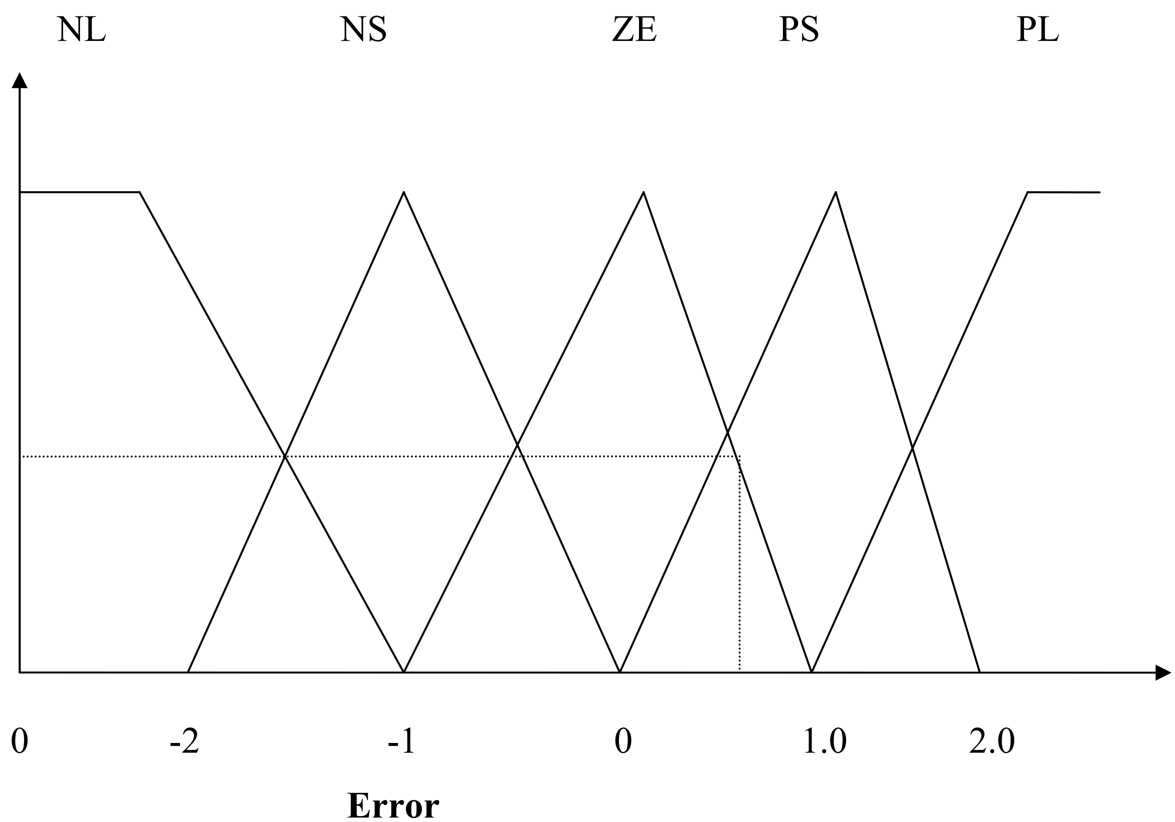

Fig 2.5 Triangular membership function

2. Trapezoidal Membership Function:-

As the name suggests, the shape of this class of membership function is that of a trapezoid and is shown in fig.

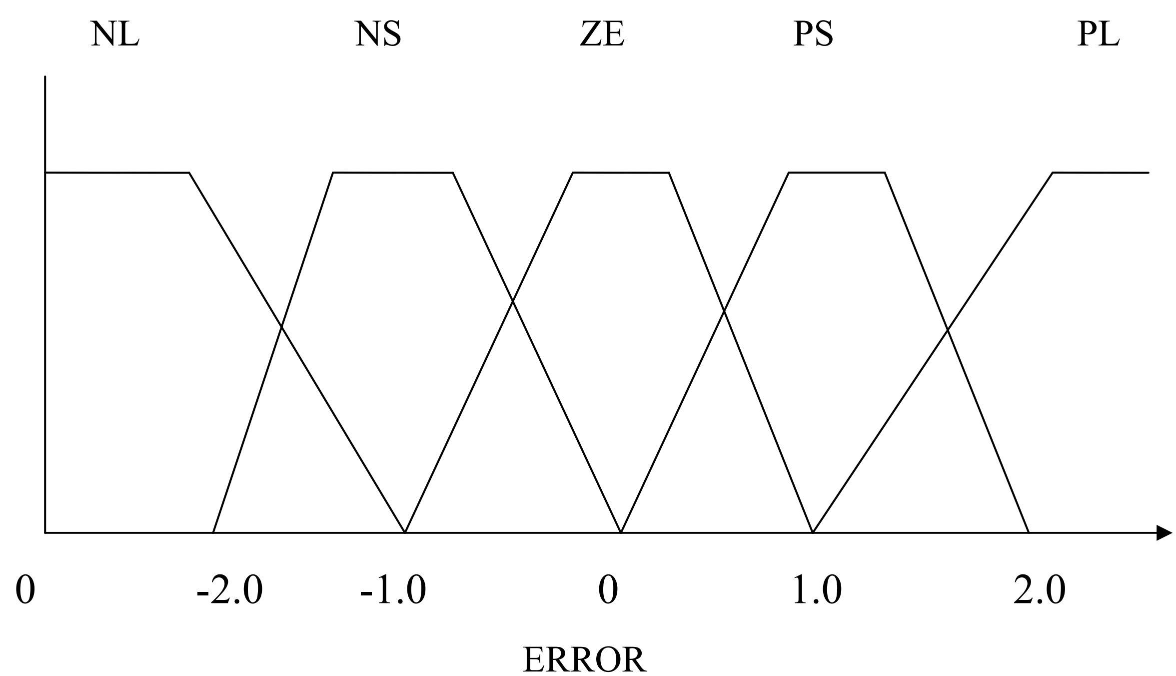

FIG 2.6 Trapezoidal Membership function

The maximum membership values of 1.0 occur over a scroll range about the central point of the function. Studies show in general that this function gives a better performance than triangular membership functions.

3. <u>Bell Shaped Functions:-</u>

   This choice has a advantage that the decided shape of the fuzzy set can be adapted by three parameters, c altos the pent of minimum fuzziness, a altos the spread and b the contrast, because the decision procedure is too time consuming in the continuous care the fuzzy output sets are calculated at finite quantized interval of the term set, one example for the membership function that can be used is given below:

$$Y = \frac{1}{(1 + (x-c)^2)}$$

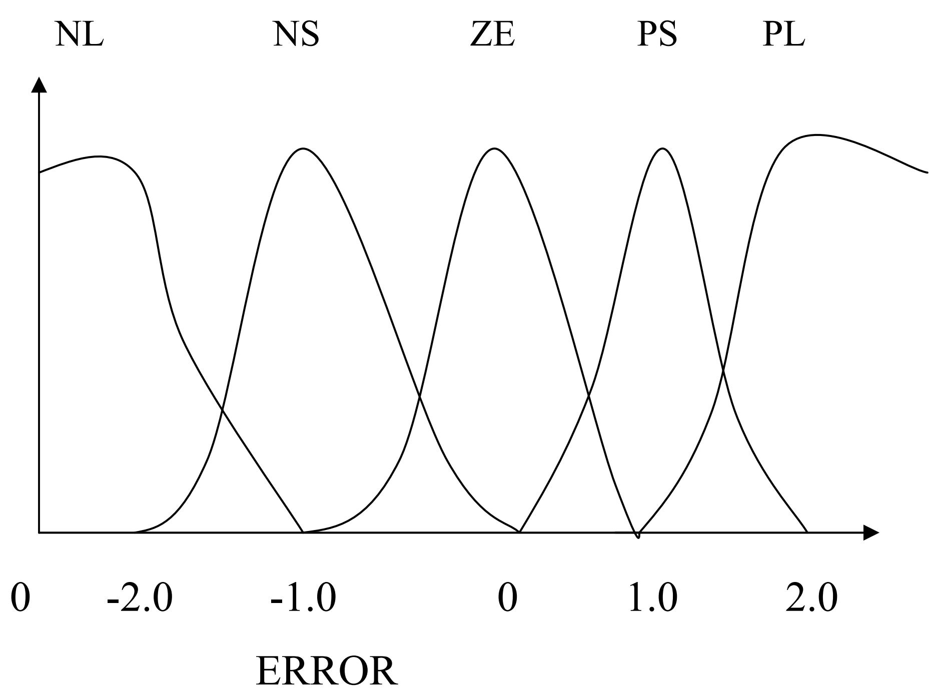

FIG 2.7 Bell shaped membership definition of error

1. Defuzzification Module:

The function of defuzzification module is as follows:

DM – F1: Performs the so called defuzzification which converts the set of modified control output into a single point wise value.

DM – F2: Performs an output renormalization, which maps the point wise value of the control on to its physical domain. DF –F2 is not needed if non – normalized domain is used.

CHOICE OF DEFUZZIFICATION PROCEDURE:

The most commonly used defuzzification methods [18] are:-

1. Centre of area/ Gravity defuzzification
2. Centre of sums defuzzification
3. Centre of largest area defuzzification
4. First of maxima defuzzification
5. Middle of maxima defuzzification
6. Height defuzzification

1. CENTRE OF AREA / GRAVITY

The centre of area method is the best known method of defuzzification. This method determines the centre of area below the combined membership function fig 2.8 shows this operation in a graphical way. It can be seen that this defuzzification method takes into account the area U(union of clipped or scaled control outputs) as a whole. Thus if the area of two clipped fuzzy sets constituting U overlap then the overlapping area is taken only once in the formula. This operation is computationally rather complex and therefore is quite slow inference cycle.

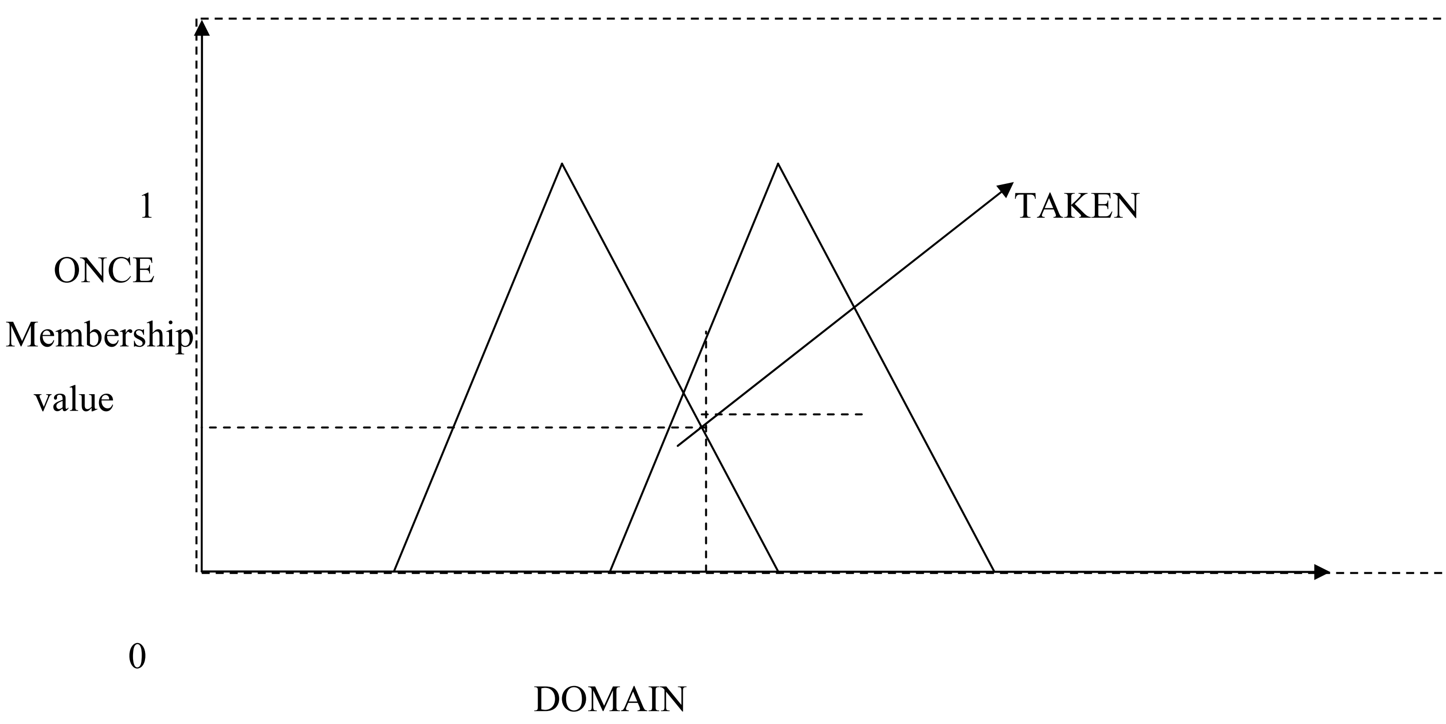

Fig 2.8 Representation of centre of Area /Gravity defuzzification

2. <u>CENTR OF SUMS</u>

A Similar but faster fuzzification method is centre of sums. The motivation for using this method is to avail the computation of U. The idea is to consider the contribution of the area of each CLU (kHz clipped fuzzy set) individually. Mathematically the centre of area /gravity method builds U by taking the union of all CLU. The centre of sums however takes the sum CLU. Thus overlapping areas, if such exists , are reflected more than once by this method. The faster algorithms for this defuzzification method are on reason why most FKBC use this method. This method is graphically shown in fig 2.9.

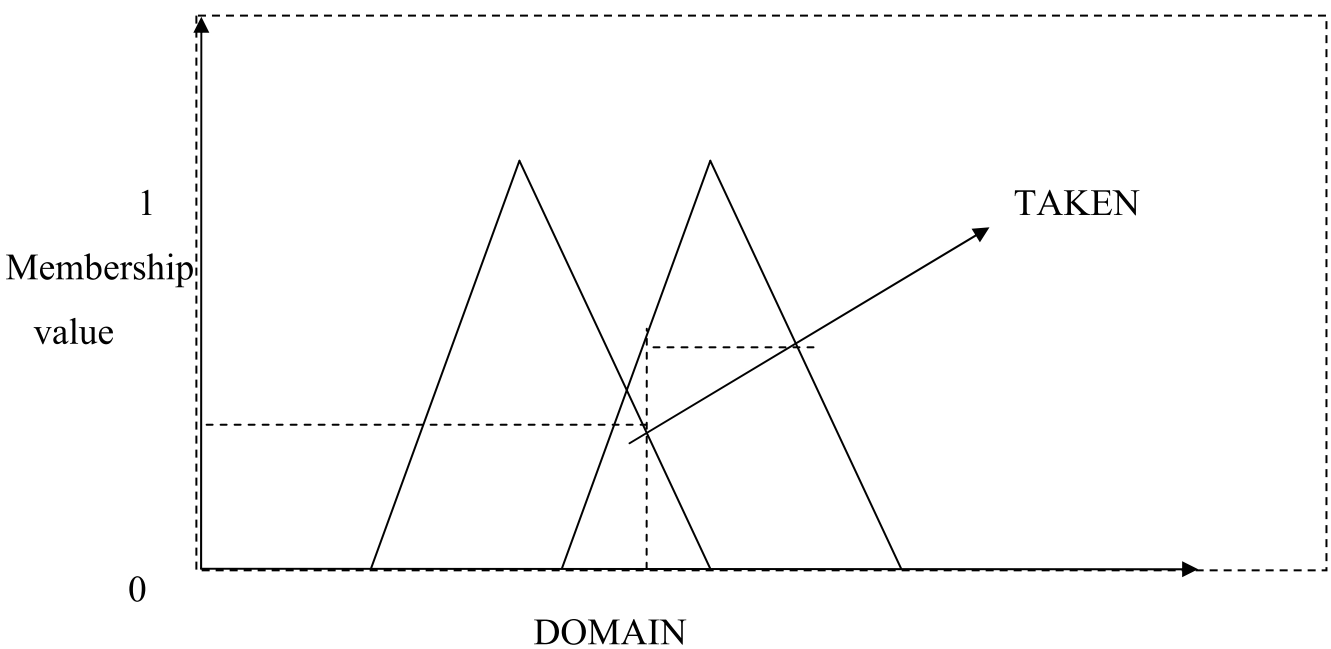

FIG 2.9 Representation of centre of sums defuzzification

3. <u>CENTRE OF LARGEST AREA</u>

The centre of largest area is used in the case when U is non convex, i.e. it consists of at least two convex fuzzy subsets. The method determines the convex fuzzy subset with the largest area and defines the crisp output value to be the centre of area of this particular fuzzy subset. Fig 2.10 illustrates this method.

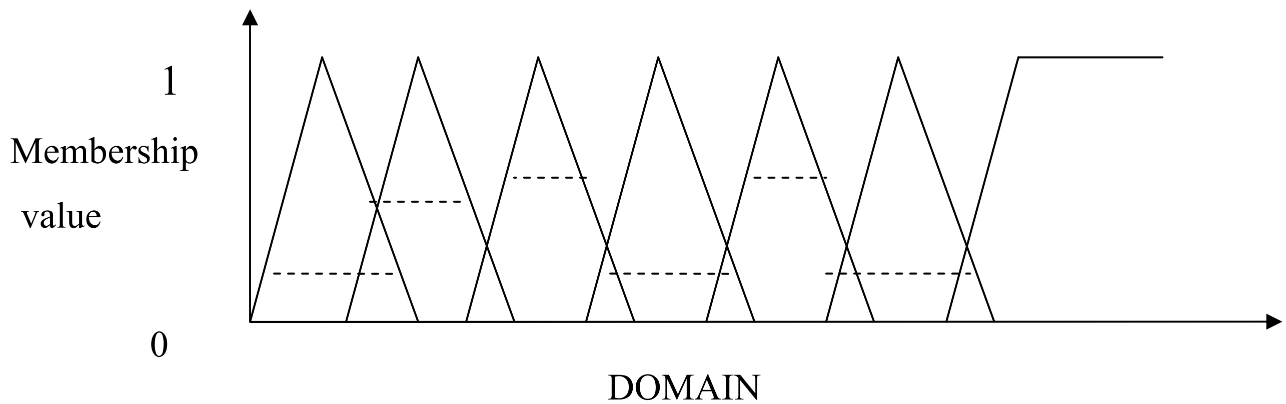

Fig 2.10 Graphical representation of centre of largest area defuzzification

4. **<u>FIRST OF MAXIMA</u>**

First of maxima uses U and takes the smallest value of the domain U with maximal membership degree in U, fig 2.11 illustrates this method.

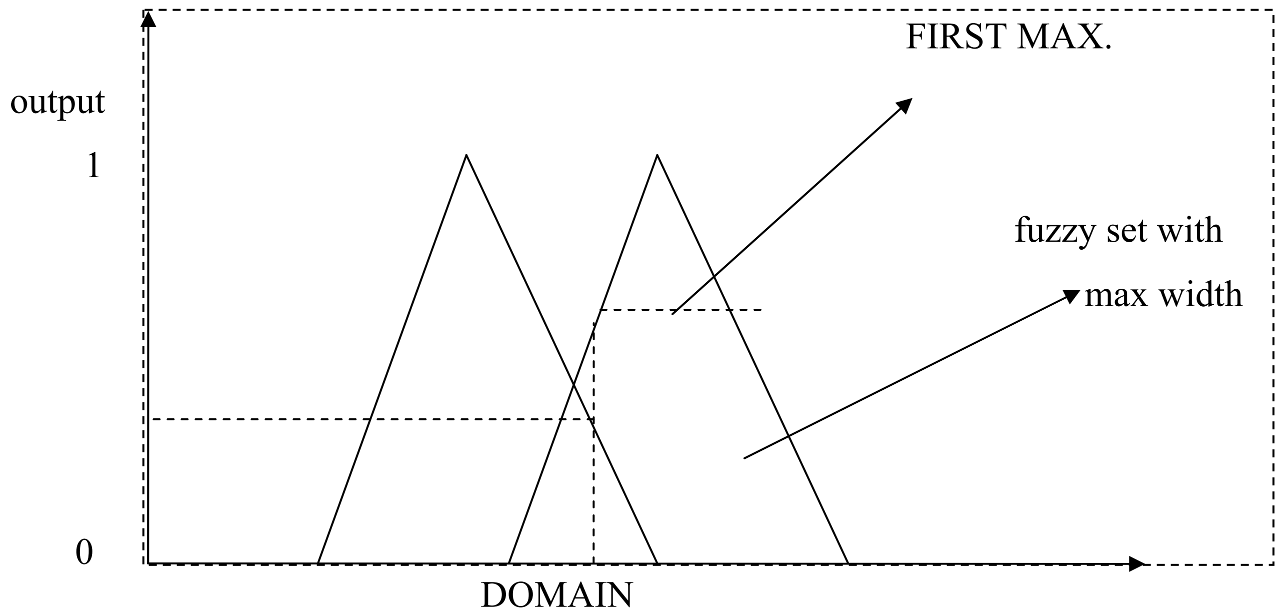

FIG 2.11 Representation of first maxima defuzzification

5. MIDDLE OF MAXIMA

Middle of maxima is very similar to first of maxima or last of maxima. Instead of determining U, to be the first or last from all values where U has maximal membership degree, this method takes the average of these two values. Fig 2.12 illustrates this method.

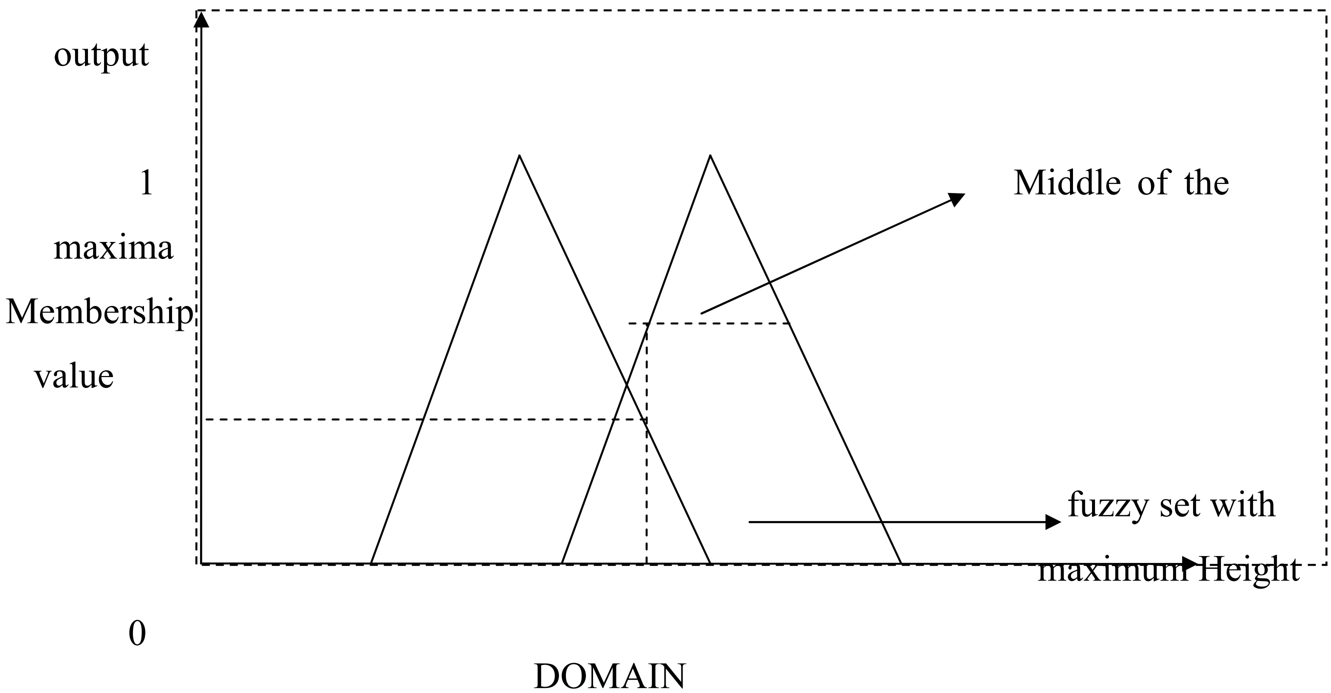

FIG 2.12 Representation of middle of maxima defuzzification

6. HEIGHT DEFUZZIFICATION

Height defuzzification is the method, which instead of using U uses the individual clipped or scaled control output. This method takes the peak value of each CLU and builds the weighted sum of these peak values. Thus neither the support nor the shape nor CLU plays the role in the computations of U. The height method is both a very simple and very quick method. Fig 2.13 illustrates this method.

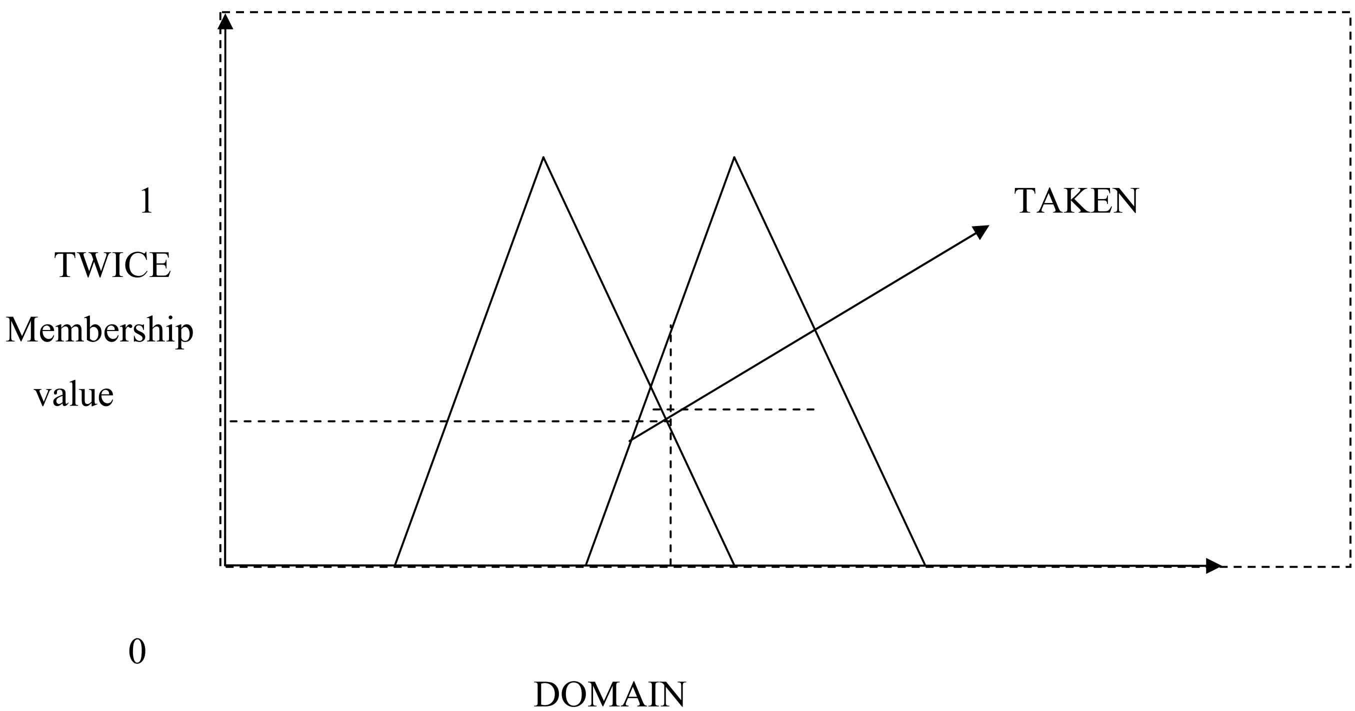

FIG 2.13 Representation of the height defuzzification

2.6 Requirements of fuzzy logic

Using fuzzy logic, system designer can realize lower development costs, superior features, and better end product can be brought to market faster and more cost effectively several factors that makes fuzzy logic more desirable to the system designer:-

1. Desirable and model solution to a problem without having to use complex mathematical models for system and development.
2. Optimize a known solution in order to obtain simpler and more effective implementations.
3. Simplifying the system during process there by decreasing development cost.
4. Make the system more descriptive. A system is more convenient to manage, maintain and upgrade, and easy to differentiate with less risk.
5. Having a higher fault tolerance and a better trade off between system robustness and system sensitivity.

APPLICATION OF FUZZY LOGIC:

Fuzzy logic is employed in the field of control system [16] e.g. factory automation, consumer products, medical and information technology, social science and biological science etc.

CONTROL SYSTEM AND FACTORY AUTOMATION :

It is employed in steam turbine control application to control turbine's action based on the two input variable vise, temperature and pressure, it is used in slitting bobbin windows , warp pieces of metals produced by making vertical cuts in rolled coins of iron, stainless steel and aluminum. It is also used in controlling chemical reactors.

CONSUMER PRODUCTS:

Fuzzy system are used in consumer product such as microwave, ovens, washing machine, vacuum cleaners, video cameras and conditioners. In fuzzy controlled washing machine has an infrared LED (light emitting diode) sensor, that emits light rays in the band of infra red which is out of range of human visibility, measures the turbidity of the exiting water. If the turbidity increases rapidly as a function of time than it is inferred that the clothes were soiled by mud (which washes off earlier). If the turbidity increases slowly, then it is inferred that the clothes were soiled by oil.

INFORMATION TECHNOLOGY:-

Fuzzy logic is used in neural network, to built compliers, for pattern recognition and data base searching.

SOCIAL SCIENCE AND BIOLOGICAL SCIENCE:-

Fuzzy logic application can use in the realm of 'humanistic system' such as linguistics, social sciences and biological sciences where hard mathematics does not seem effective.

SPACE APPLICATION:-

NASA has used fuzzy control in their various space programs. For example fuzzy control used in project for a controller for space shuttle proximity operation i.e. maneuvering around or keeping position with report to another object in space.

Also research done by NASA shows that fuzzy control can reduce both fuel and structural street in spacecraft maneuver. Compared to a conventional digital autopilot, fuzzy logic control uses 70 percent less fuel in altitude hold runs &40 percent less fuel in altitude maneuver.

In this way we can see that application flexibility combined with inherent simplicity and its wide range of capabilities give fuzzy logic technology great potential for growth.

CHAPTER- 3

CHAPTER- 3

Design of PID Controller using Fuzzy Logic

3.1 Introduction:

Study and research has proved that PID controller optimized with fuzzy logic have been widely used in control system which contain unknown nonlinearities such as dead zone, saturation, hysteresis because when conventional proportional Integral and Derivative controller (PID) is applied to above said system having non linearity exhibit poor performance .It is important to analyze the fuzzy based PID controller to answer some important questions.

Is there any merit using fuzzy logic based PID controller for nonlinear system compared to a conventional PID controller?

In the present work an attempt is made to design the nonlinear PID controller based on fuzzy logic for system containing nonlinearities.

The main objectives of the work presented in this chapter are as follows.

1. To develop a dynamic model and proposed modeling of water heating system to control the temperature of the tank.
2. To suggest a comprehensive design procedure for fuzzy logic based controller. It includes three steps.
    1. Fuzzification
    2. Decision making logic
    3. Defuzzification
3. To study the dynamic performance of nonlinear PID controller and to compare dynamic performance of the system with exiting controller.

3.2 Fuzzy based PID controller:

3.2.1 Control Structure:

Fig shown below shows the basic control structure. The structure consists of a conventional PID control structure together with our fuzzy controller.

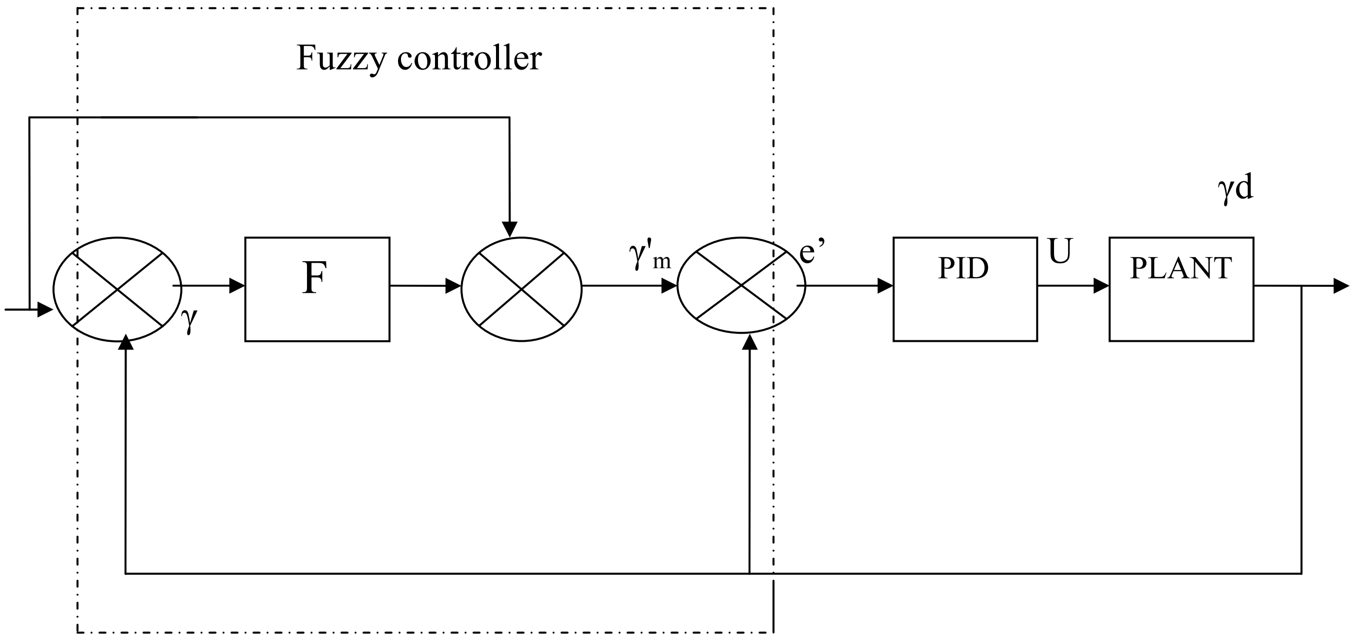

Fig 3.1 Basic Control Structure

The fuzzy based controller uses the command input y_m and the plant output y_p to generate a precompensated command signal y'_m described the following equations.

$$e(k) = y_{m(k)} - y_{p(k)}$$

$$\Delta e(k) = e(k) - e(k-1)$$

$$\gamma(k) = F[e(k), \Delta e(k)]$$

$$y'_{m(k)} = y_{m(k)} + \gamma(k)$$

in the above e(k) is the tracking error between the command input $y_{m(k)}$ and the plant output $y_{p(k).}$

$\Delta e(k)$ – is the change in the tracking error

$F[e(k), \Delta e(k)]$- is a nonlinear mapping of e(k) and $\Delta e(k)$ based on fuzzy logic

$\gamma(k)$ - $F[e(k), \Delta e(k)]$represents a compensations or correction term, so that compensated command signal $y'_{m(k)}$ is simple the sum of the external command signal $y_{m(k)}$ and $\gamma(k)$

F - Fuzzy controller

The correction term $\gamma(k)$ is based on the error e(k) and the change of error $\Delta e(k)$. The compensated command signal $y'_{m(k)}$ is applied to a conventional PID scheme as shown in above fig.

The equations of governing the PID controller as follows:

$$e'(k) = y'_{m(k)} - y_{p(k)}$$

$$\Delta e'(k) = e'(k) - e'(k-1)$$

$$U(k) = U(k-1) + k_p \Delta e'(k) + k_i\, e'(k) + k_d\, (\Delta e'(k)) - \Delta e'(k-1)$$

The quantity e'(k) – is the precompensated tracking error between the precompensated command input $y'_{m(k)}$ and the plant output $y_{p(k)}$

$\Delta e'(k)$- is the change in the precompensated tracking error

$U(k)$ - is the command applied input to the plant

The purpose of the fuzzy controller is to modify the command signal to compensate for the overshoot and undershoot present in the output response when the plant has the unknown nonlinearities. Such nonlinearities can result in significant overshoot and undershoot if a conventional PID control scheme is used.

3.2.2 Fuzzy Controller Design

We now describe the fuzzy logic based precompensator hence the term

$$\gamma(k) = F[e(k) , \Delta e(k)]$$

let $e(k)$ and $\Delta e(k)$ is the input to the map F , and $\gamma(k)$ is the output associated with the map F is a collection of linguistic values.

L={ZO,PS,PM,PB}

That represents the term set for the input and output variables of F. In our scheme we have four linguistic values. The meaning of each linguistic value is the term set that should clear from it's mnemonic, for example PM stands for positive medium , PB stands for positive big, PS stands for positive small and Z0 stands for zero.

$$\mu = \{ \mu_{zo}, \mu_{ps}, \mu_{pm}, \mu_{pb} \}$$

Each membership function is a map from read line to the interval [0,1] . fig 3.2 to fig 3.4 shows a plot of membership function.

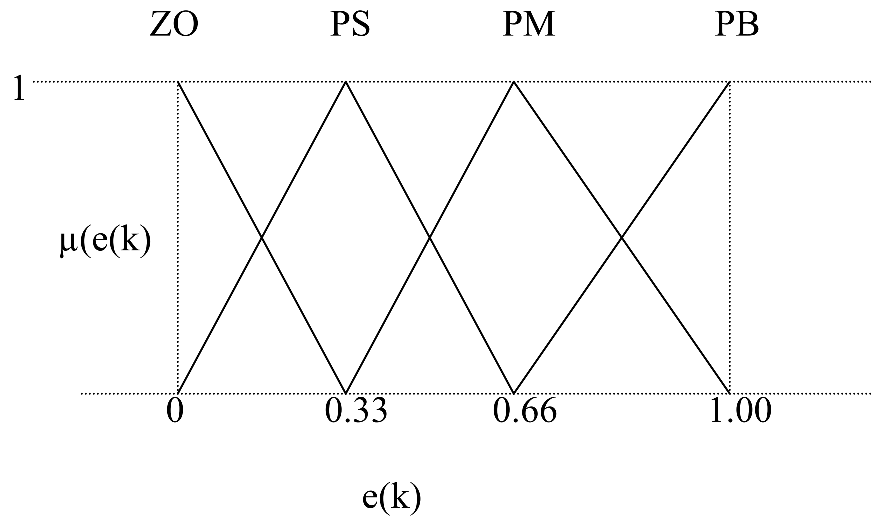

fig 3.2 Membership Function of e(k)

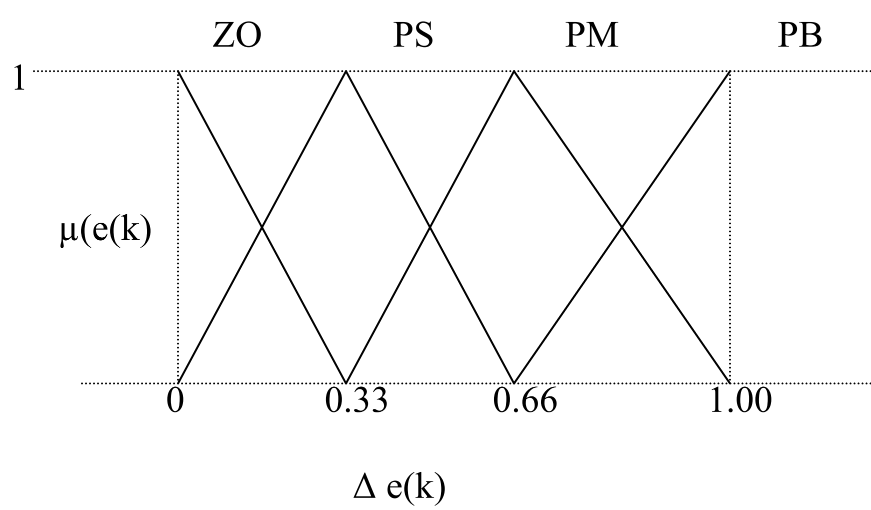

fig 3.3 Membership Function of Δ e(k)

The membership function we use are of triangular yype. The height of the membership function in this case is 1, which occurs at the points 0, 0.33,0.66, and 1 respectively.

Fig 3.4 shows the membership function of output γ(k).

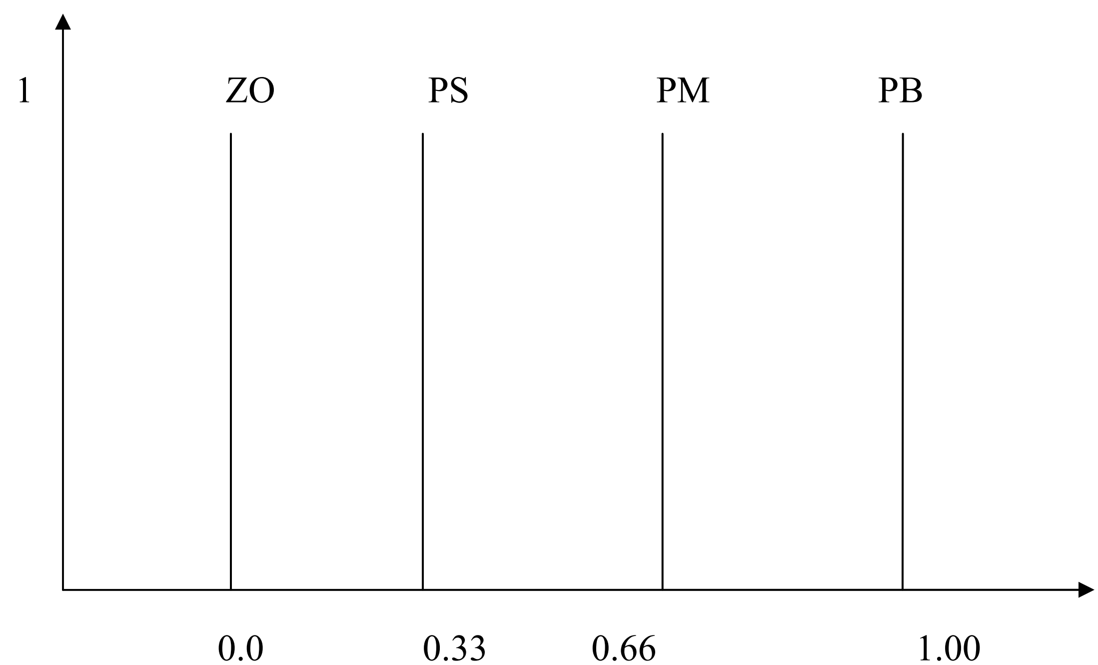

Fig3.4 Membership function of output γ(k).

The realization of the function F [e(k) , Δe(k)] based on standard fuzzy method consists of three stages.

1. **Fuzzification**
2. **Decision making logic**

3. **Defuzzification**

We will explain these three stages in detail one by one.

A. Fuzzification:

The process of fuzzification transforms the inputs e(k) and Δe(k) into the setting of linguistic value this consists of scaling of inputs e(k) and Δe(k) appropriately and converting into fuzzy sets. We use the symbol Ce for the scaling constant for the input e(k) and the symbol $C_{\Delta e}$ for the scaling constant for the input Δe(k) .

For each linguistic value l ϵ L we assign a pair or number $n_{e(l)}$ and $n_{\Delta e(l)}$ to the inputs e(k) and Δe(k) via the associated membership function.

$$n_{\mathbf{e(l)}} = \mu l\ (C, e(k))$$

$$n_{\Delta e(l)} = \mu l\ (C, \Delta e(k))$$

The number $n_{\mathbf{e(l)}}$ and $n_{\Delta e(l\ )}$, l ϵ L are used in the computations of F[e(k), Δe(k)] , which we will describe when discussing the defuzzification stage.

B. Decision Making Process:

Associated with the decision making process is a set of fuzzy rule R= $\{R_1,R_2,R_3, --------,R_r\}$, where r is the total no. of rules. Each R_i = 1,2,3,-----7is represented by a triplet $(l_1^e,l_1^{\Delta e},-----l_1^{\gamma})$ where $l_1^e,l_1^{\Delta e},-----l_1^{\gamma}$ ϵ L. The first two linguistic values are associated with the input variable e(k) and Δe(k), with the third linguistic value is associated with output.

The triplet (PS,PM,PB)rules are often written in the form ; if e(k) in l_e and Δe(k) in $l_{\Delta e}$ then the output is γ_l. An example of this is rule triplet (PS,PM,PB). The idea of the rule is that if e(k) is positive medium and Δe(k) is the positive medium than output is positive big.

The set of rules used in fuzzy controller is shown in the table shown in the fig.

		e(k)			
		ZO	PS	PM	PB
Δe(k)	ZO	ZO	PS	PM	PB
	PS	PS	PM	-	-
	PM	PM	PB	PB	-
	PB	PM	PB	-	-

Fig 3.5 FAM Table

The rules are derived from using a combination of experience, trials and error, and out knowledge of the response of the system. To explain how these rules are obtained consider for example the rule (PB, PS, NB) is the rule table. Suppose that the command signal is a constant y_m, the set point error e(k) is positive big (PB) and change of error Δe(k) is positive small (PS). This means that the output $y_{p(k)} = y_m - e(k)$ is decreasing i.e. heading is the direction of undershoot and change of error is slowly increasing. To compensate for this we increase the command signal. This corresponds to applying a correction term γ(k) that is positive medium.

Similarly consider that the rule (PM,PM,PB) in table 1. Correspondingly consider the case where e(k) is positive and Z0 is Δe(k). This means that the plant output $y_{p(k)}$ is below the command signal and is still decreasing (i.e. we are in the middle of an undershoot). To compensate for this , we need to increase the command signal by a positive around. This corresponds to applying positive values of γ(k). Hence the rule ‘ if error is positive positive medium and the change of error is positive medium , than output is positive big connection.

The other rule are obtained in a similar manner hence we have created IF-THEN-ELSE statement.

CREATING IF-THEN RULES

We can translate the FAM table entries into IF – THEN rules .

RULES:

1. If input e(k) is zero (Z0) and Δe(k) is zero (Z0) then output is zero (Z0).

2. If input e(k) is positive small (PS) and Δe(k) is zero (Z0) then output is positive small(PS).
3. If input e(k) is positive medium (PM) and Δe(k) is zero (Z0) then output is positive medium (PM).
4. If input e(k) is positive big (PB) and Δe(k) is zero (Z0) then output is positive big (PB).
5. If input e(k) is zero (Z0) and Δe(k) is positive small (PS) then output is positive small (PS).
6. If input e(k) is positive small (PS) and Δe(k) is positive small (PS) then output is positive medium (PM).
7. If input e(k) is zero (Z0) and Δe(k) is positive medium (PM) then output is positive medium (PM).
8. If input e(k) is positive small (PS) and Δe(k) is positive medium (PM) then output is positive big (PB).
9. If input e(k) is positive medium (PM) and Δe(k) is positive medium (PM) then output is positive big (PB).
10. If input e(k) is zero (Z0) and Δe(k) is positive big(PB) then output is positive medium (PM).
11. If input e(k) is positive big (PB) and Δe(k) is positive big (PB) then output is positive big (PB).

C. DEFUZZIFICATION:

The defuzzification process maps the result of the fuzzy logic rule stage to the real number output F[e(k), Δe(k)]. We use the **height**

defuzzification method, which is simple to implement and give relative good results. To describe this method let p(l), l ∈ L be the location of the peak of the membership function , recall that location are given by P(Z0) = 0, P(PS) = 0.33, P(PM) = 0.66, P(PB) = 1.

For each rule $R_i = (l_2^{e}, l_2^{\Delta e}, l_2^{\gamma})$ defines

$$\mu_i = n_e(l_2^{e})\gamma\, n_{\Delta e}(l_2^{\Delta e})$$

$$= \mu\, l_l^{e}\,(c_e e(k))\ \gamma\ \mu\, l_2^{\Delta e}\,(c_{\Delta e}\, \Delta e(k))$$

With γ represent the compensation operator. Then the output of the defuzzification process is given as

$$F\,[e(k), \Delta e(k)] = C_F \frac{\sum_{i=1}^{i=11} p(l_2^{\gamma})\alpha_i}{\sum_{i=1}^{i=11} \alpha_i} \qquad \text{----------------------(a)}$$

Where CF is scaling factor.

Calculation of output:

Assume that at a particular point input error e(k) = 0.55 and change of error Δe(k) = 0.30 we will calculate the output of fuzzy logic controller.

Now input e(k) = 0.55

Δe(k) = 0.30

We have to find $\gamma(k)$ = ?

STEP 1:

Crisp input 1 — Error $e(k) = 0.55$

Fuzzy membership values — POSITIVE SMALL = 0.33

POSITIVE MEDIUM = 0.66

Others = 0

Crisp input 2 — Change in error $\Delta e(k) = 0.30$

ZERO = 0.0011

POSITIVE SMALL = 0.9090

STEP 2 :

(A) If error e(k) = PS and change in error $\Delta e(k)$ = Z0 then output is PS (rule no 2)

$$\mu(2) = \text{Truth value of rule no 5}$$
$$= \mu_{ps\_}(e(k)) \wedge \mu_{Z0}(\Delta e(k))$$
$$= \min(0.33, 0.0011)$$
$$= 0.001$$

(B) If error e(k) = PS and change in error $\Delta e(k)$ = PS then output is PM (rule no 6)

$$\mu(2) = \text{Truth value of rule no 6}$$
$$= \mu_{ps\_}(e(k)) \wedge \mu_{ps}(\Delta e(k))$$
$$= \min(0.33, 0.9090)$$

= 0.33

(C) If error e(k) = PM and change in error $\Delta e(k)$ = Z0 then output is PM (rule no 3)

$\mu(3)$ = Truth value of rule no 3

$= \mu_{ps\_}(e(k)) \wedge \mu_{Z0}(\Delta e(k))$

= min (o.66, 0.001)

= 0.001

Now from equation (a)

$$F[e(k), \Delta e(k)] = C_F \frac{\sum_{i=1}^{i=11} p(l_2^{\gamma})\alpha_i}{\sum_{i=1}^{i=11} \alpha_i}$$

$$= \frac{p(2)\mu_2 + p(3)\mu_3 + p(6)\mu_6}{\mu_2 + \mu_3 + \mu_6}$$

$$= \frac{0.33 * 0.001 + 0.66 * 0.001 + 0.66 * 0.33}{0.001 + 0.33 + 0.001}$$

$$= 0.21879 / 0.332$$

$$= 0.659$$

$$F[e(k), \Delta e(k)] = 0.659$$

CHAPTER-4

CHAPTER-4

Implementation of fuzzy logic based controller in MATLAB

4.1 Introduction:

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include

- Math and computation
- Algorithm development
- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar noninteractive language such as C or FORTRAN.

The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation. MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis. MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

The MATLAB System

The MATLAB system consists of five main parts:

Development Environment. This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, and browsers for viewing help, the workspace, files, and the search path.

The MATLAB Mathematical Function Library. This is a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms. The **MATLAB Language**. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and “programming in the large” to create complete large and complex application programs.

Graphics. MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

The MATLAB Application Program Interface (API). This is a library that allows you to write C and Fortran programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

4.2 Fuzzy tool box (in matlab software)

4.2.1 What can fuzzy logic toolbox do?

The Fuzzy Logic Toolbox for use with MATLAB is a tool for solving problems with fuzzy logic. Fuzzy logic itself is a valuable engineering tool because it does a good job of trading off between significance and precision—something that humans have been doing for a very long time. Fuzzy logic toolbox allows us to do several things, but the most important thing is it lets us to create and edit fuzzy inference. It’s possible to use the Fuzzy Logic Toolbox by working strictly from the command line, in general it’s much easier to build a system graphically.

There are five primary GUI tools for building, editing, and observing fuzzy inference systems in the Fuzzy Logic Toolbox:

1. The Fuzzy Inference System or FIS Editor,

2. **The Membership Function Editor**; the Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. We can display and edit all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system.

3. **The Rule Editor**; the Rule Editor is for editing the list of rules that defines the behavior of the system.

4. **Rule viewer**; The Rule Viewer can show which rules are active, or how individual membership function shapes are influencing the results.

5. **The surface viewer**. The Surface Viewer is used to display the dependency of one of the outputs on any one or two of the inputs—that is, it generates and plots an output surface map for the system.

The Rule Viewer and the Surface Viewer are used for looking at, as opposed to editing, the FIS. They are strictly read-only tools.

These GUIs are dynamically linked, in that changes we make to the FIS using one of them, can affect what we see on any of the other open GUIs. We can have any or all of them open for any given system. The FIS Editor, the Membership Function Editor, and the Rule Editor can all read and modify the FIS data, but the Rule Viewer and the Surface Viewer do not modify the FIS data in any way.

4.2.2 Importing and Exporting from the GUI Tools

When one saves a fuzzy system to disk, he/she is saving an ASCII text FIS file representation of that system with the file suffix .fis. This text file can be edited and modified and is simple to understand. When one saves his/her fuzzy system to the MATLAB workspace, he/she is creating a variable (whose name he/she choose) that will act as a MATLAB structure for the FIS system. FIS files and FIS structures represent the same system.

Note. If we do not save our FIS to a disk, but only save it to the MATLAB workspace, we will not be able to recover it for use in a new MATLAB session.

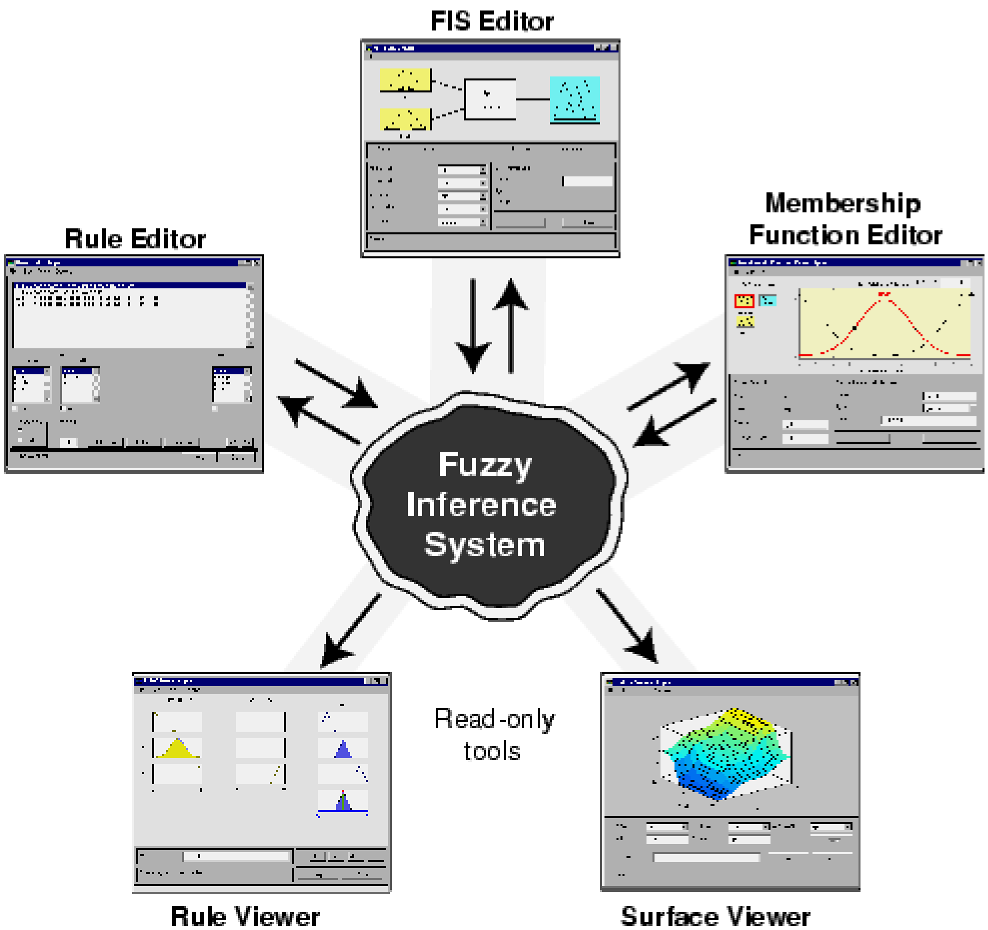

Fig.4.1 overview of fuzzy toolbox inference system

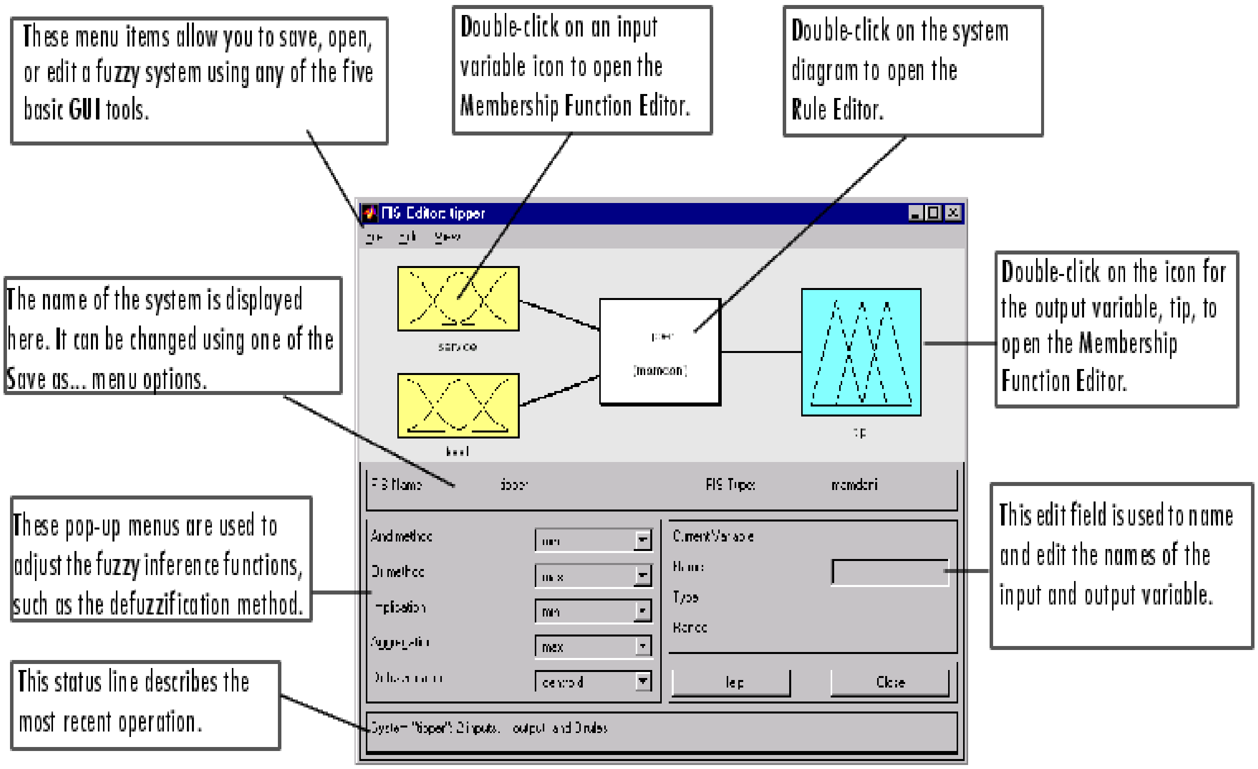

Fig.4.2 the FIS Editor

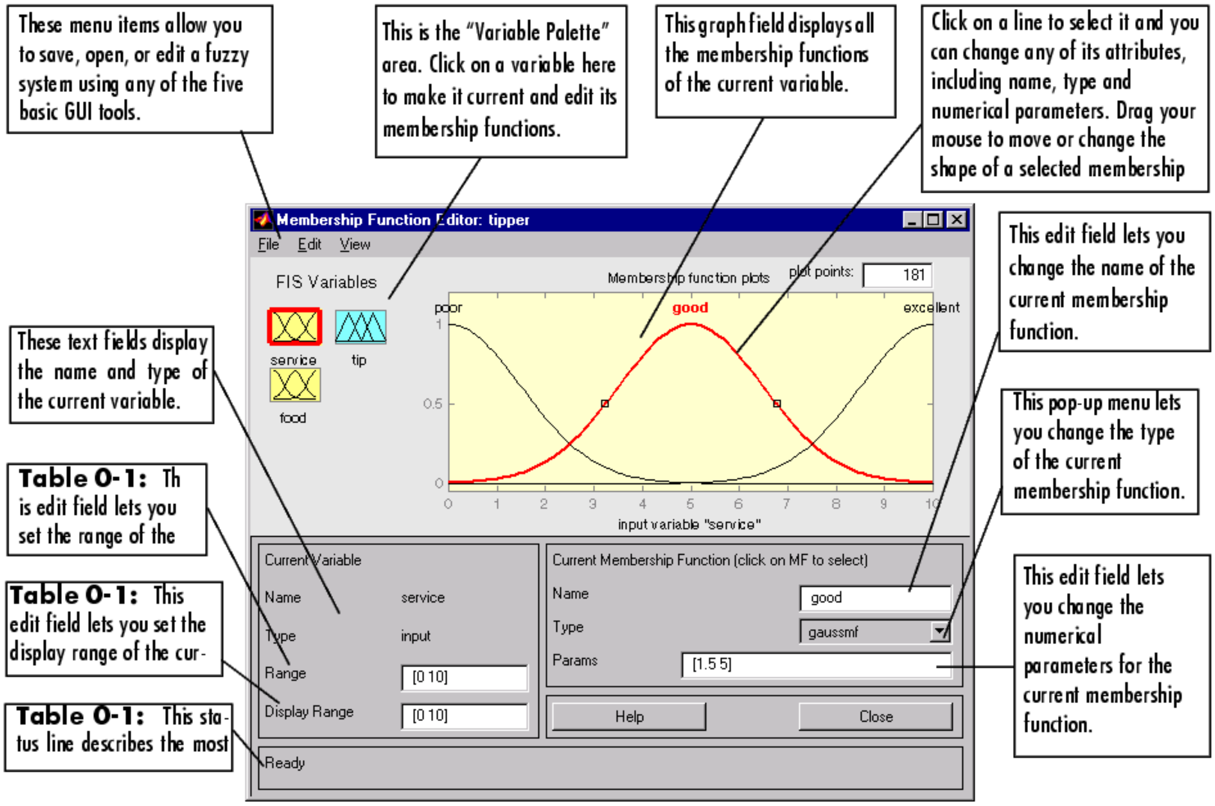

Fig 4.3 Membership Function Editor

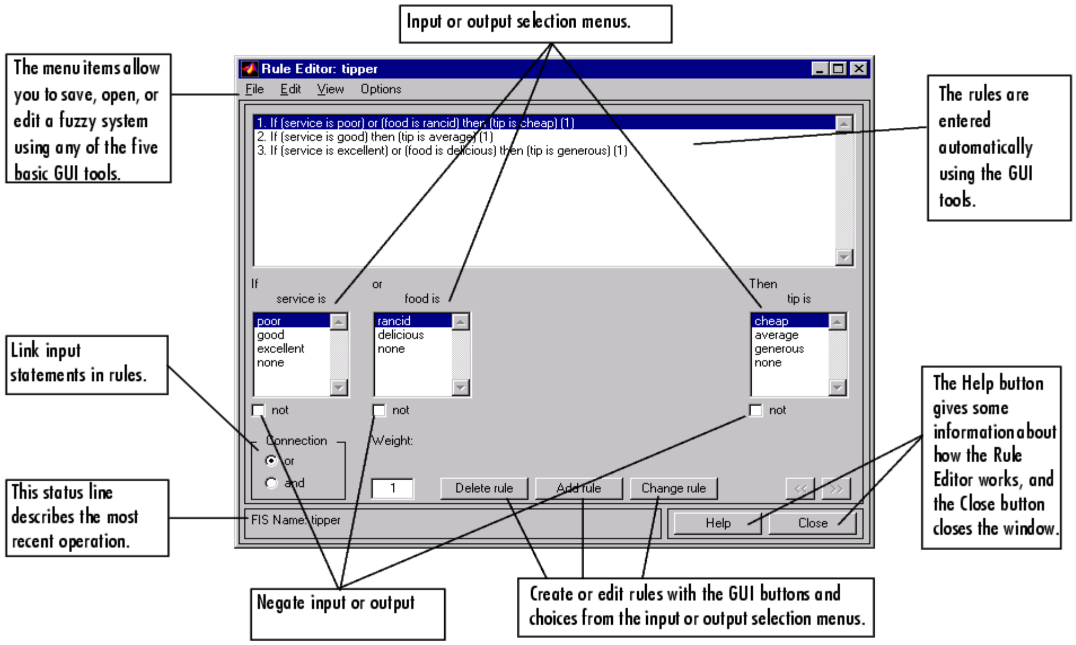

Fig. 4.4 the Rule Editor

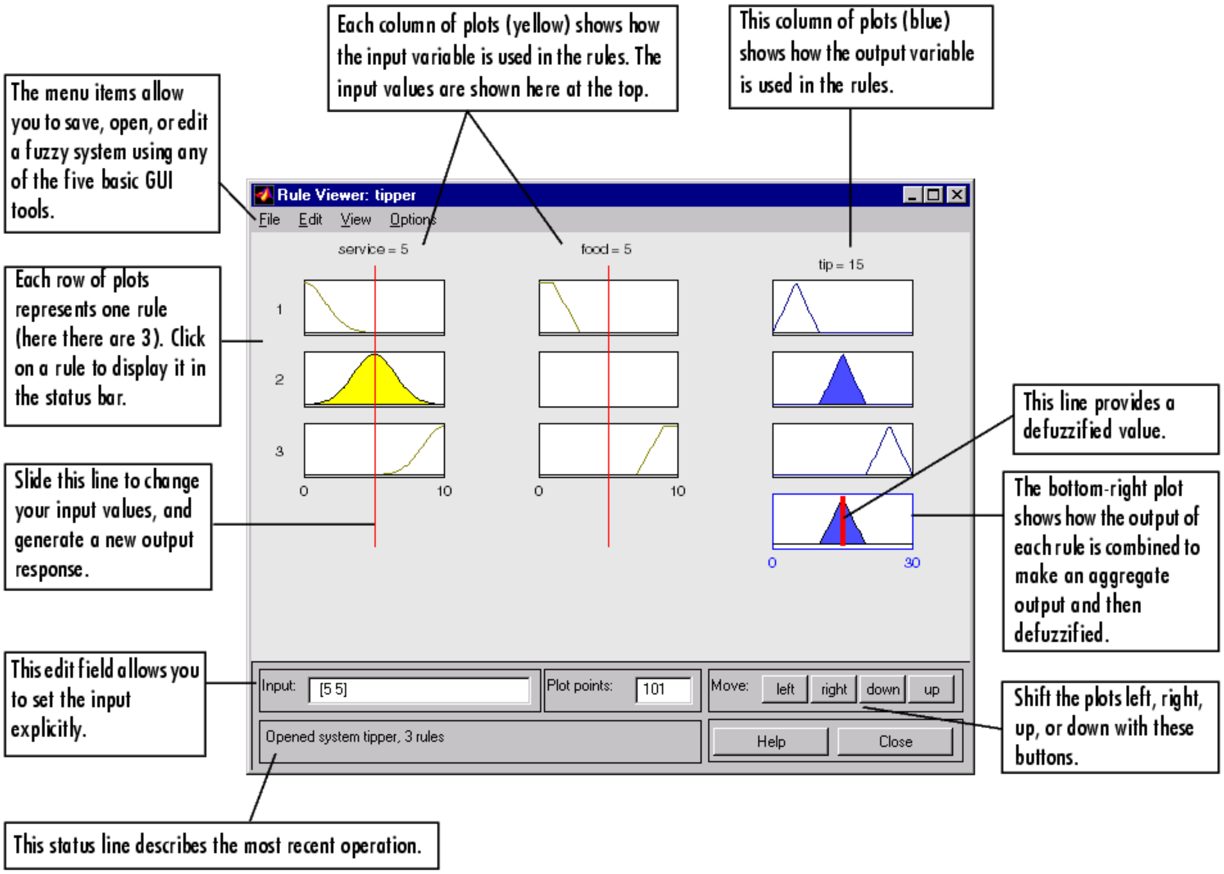

Fig 4.5 the Rule Viewer

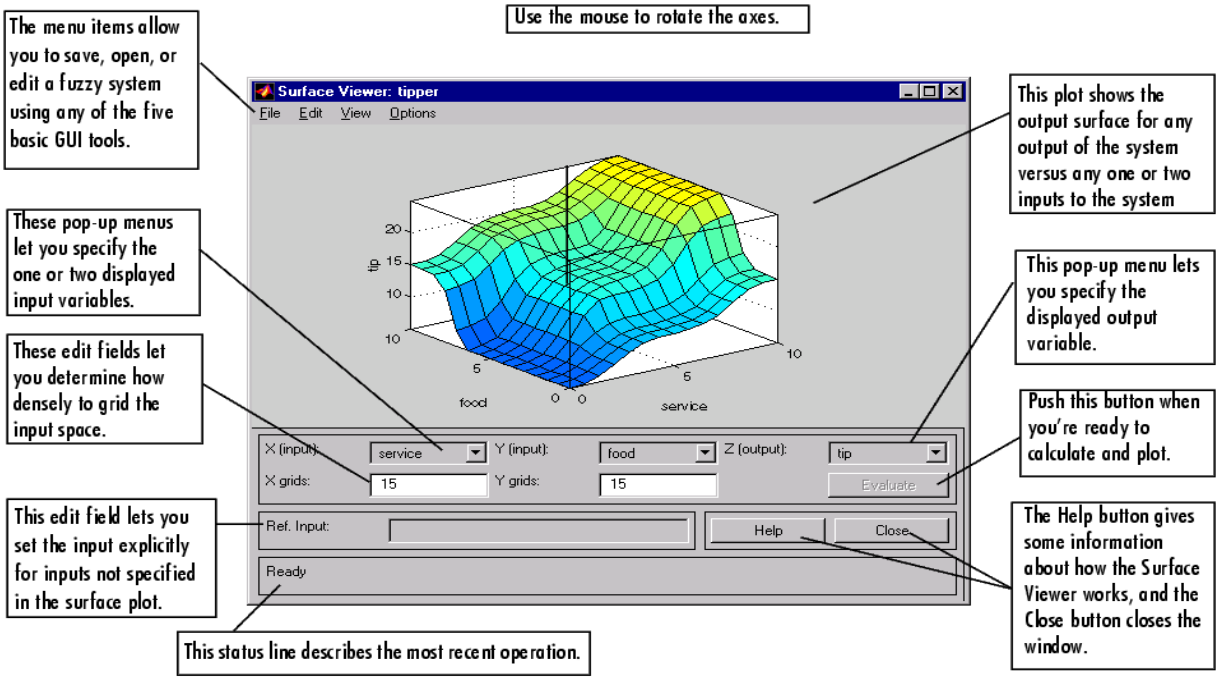

Fig.4.6 Surface Viewer

4.3 Modeling of water heating system

We want to implement fuzzy logic based controller on water heating system. We can consider it as a second order system with transfer function given as

$$T.F = 1/s^2 + s + 1$$

A typical diagram of the system is shown below.

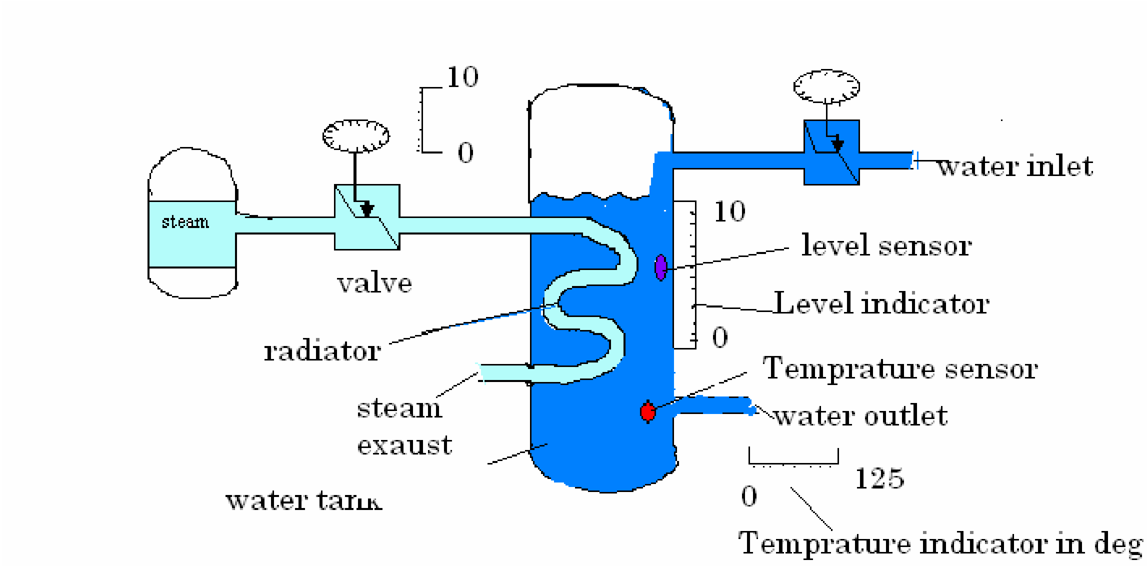

Fig.4.7water heating diagram

Our intension here is to design a fuzzy controller that controls the temperature of water in the tank to set point value in spite of the change in the cold water entering into the tank and hot water flowing out of the tank by regulating the valve, which controls the flow of hot steam.

A fuzzy controller is designed previously and we will generate code in MATLAB for fuzzy controller.

4.3.1 Matlab m.file for water heating system

```
%tempcontrol
clear all;
close all;
tempcontrol1=newfis(' tempcontrol'); % to creat a new FIS with file name
                                          "tempcontrol.fis"
                                        %definition of Membership function for the
                                        input variable error"
```

```
Tempcontrol1 =addvar(tempcontrol1,'input','error’,[0 1]);      % range of input
                                                                variable "error"
tempcontrol1=addmf(tempcontrol1,'input',1,'Z0','trimf',[0 0 0.33]); % the left,mid,
                                                    right value of membership
                                                    function(triangular ZO )for first input
                                                    "error"
tempcontrol1=addmf(tempcontrol1,'input',1,'PS','trimf',[0 0.33 0.66]);
tempcontrol1=addmf(tempcontrol1,'input',1,'PM','trimf',[.33 .66 1]);
tempcontrol=addmf(tempcontrol1,'input',1,'PB','trimf',[.66 1 1.33]);
%definition of Membership function for the input variable "change in error"
tempcontrol1=addvar(FLCwater1,'input','change in error',[0 1]);    % range of input
                                                variable "change in error"
tempcontrol1=addmf(tempcontrol1,'input',2,'Z0','trimf',[0 0 0.33]);  % the left,mid,
right value of mbership function(trianglular ZO )for second input
 tempcontrol1=addmf(tempcontrol1,'input',2,'PS','trimf',[0 .33 .66]);
 tempcontrol1=addmf(tempcontrol1,'input',2,'PM','trimf',[.33 .66 1]);
 tempcontrol1=addmf(tempcontrol1,'input',2,'PB','trimf',[0.66 1 1.33]);
%definition of Membership function for the output variable
tempcontrol1=addvar(tempcontrol1,'output','output1',[0 1]);
tempcontrol1=addmf(tempcontrol1,'output',1,'Z0','trimf',[0 0 .33]);
tempcontrol1=addmf(tempcontrol1,'output',1,'PS','trimf',[0 0.33 0.66]);
tempcontrol1=addmf(tempcontrol1,'output',1,'PM','trimf',[.33 .66 1.0]);
tempcontrol1=addmf(tempcontrol1,'output',1,'PB','trimf',[.66 1 1.33]);
```

```
% definition of fuzzy rules
rulelist=[1 1 1 1 1;...
          1 2 2 1 1;...
          1 3 3 1 1;...
          1 4 3 1 1;...
          2 1 2 1 1;...
          2 2 3 1 1;...
          2 3 4 1 1;...
          2 4 4 1 1;...
          3 1 3 1 1;...
          3 3 4 1 1;...
          4 1 4 1 1;...

tempcontrol1=addrule(tempcontrol1,rulelist);
```

4.3.2 Results of the program

Writing the following fuzzy matlab code on command prompt gives the following results

```
>> readfis('tempcontrol')

ans =

         name: 'TEMPCONTROL'
         type: 'mamdani'
    andMethod: 'min'
```

```
      orMethod: 'max'
    defuzzMethod: 'centroid'
     impMethod: 'min'
     aggMethod: 'max'
         input: [1x2 struct]
        output: [1x1 struct]
          rule: [1x11 struct]

>> plotfis(ans)
```

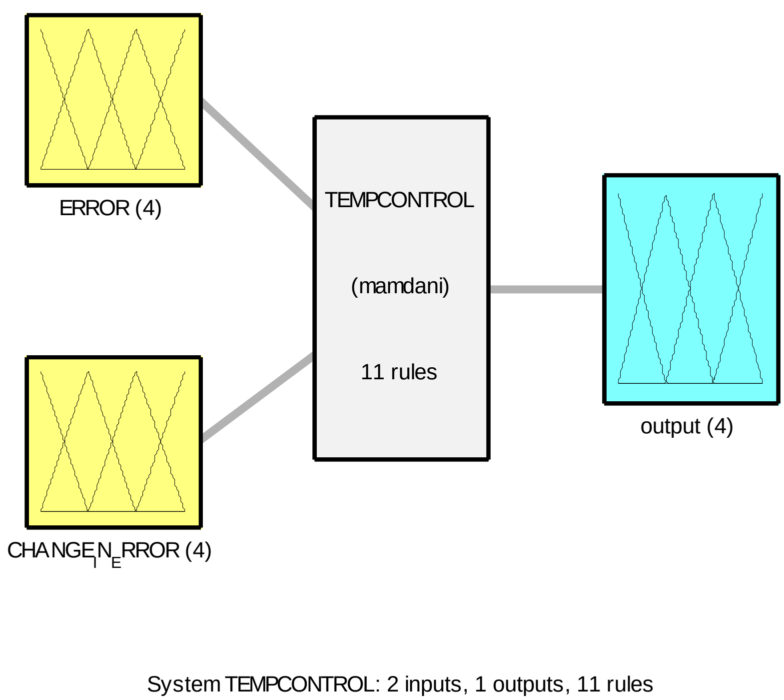

Fig 4.8 FIS diagram

>> plotmf(ans,'input',1)

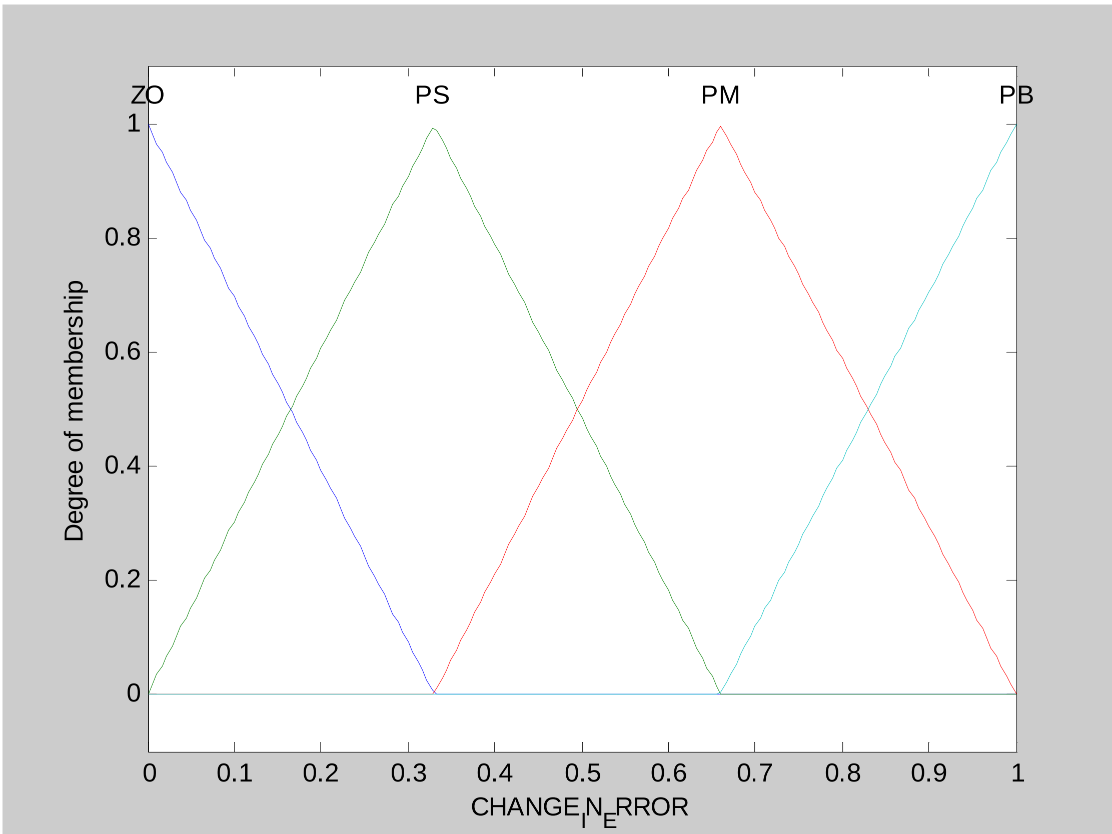

Fig 4.9 membership function of input error

>>plotmf(ans,'input',2)

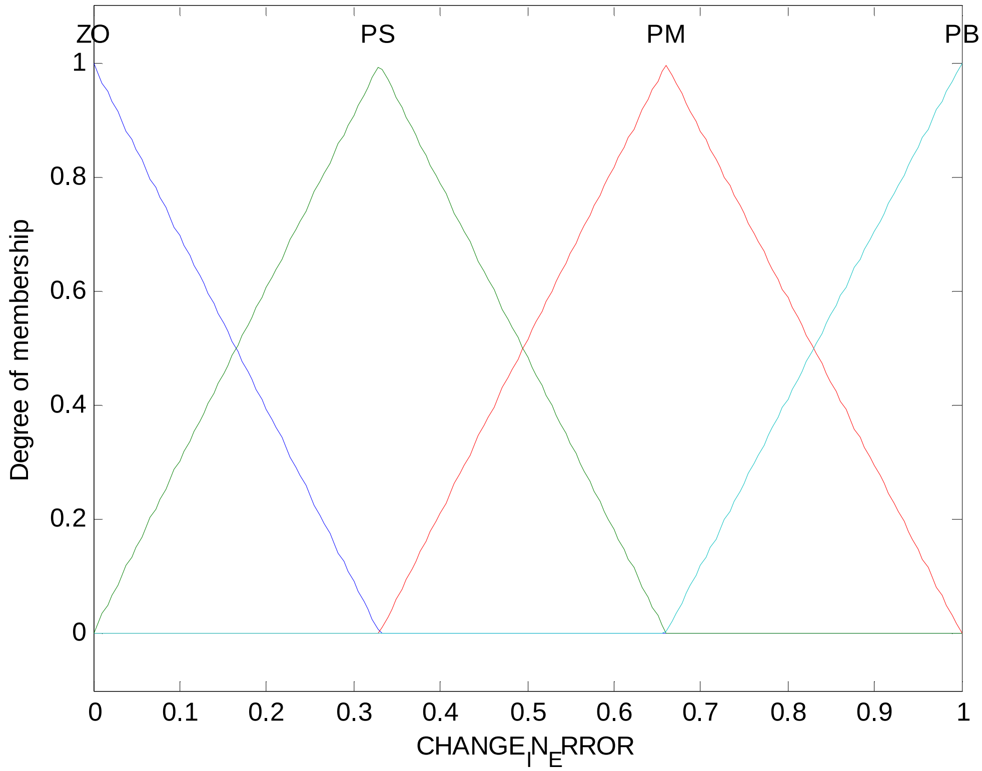

Fig 4.10 membership function of input change in error

>>
plotmf(ans,'output',1)

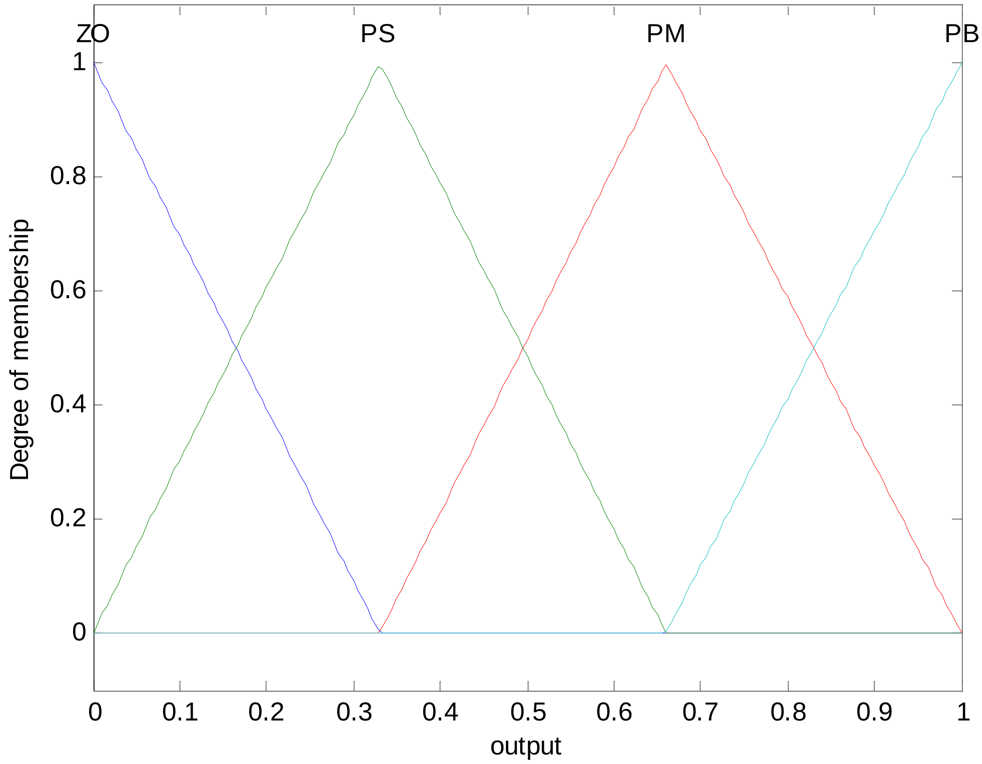

Fig 4.11 membership function of output

>> ruleview(ans)

>> gensurf(ans)

CHAPTER-5

CHAPTER –5

CONCLUSION

5.1 INTRODUCTION:

This report includes the study and design of fuzzy based controller. It involves various designing aspects of fuzzy logic. In this thesis we design a fuzzy based PID controller.

The main thrust of the work presented in this thesis is to suggest a suitable control strategy based on the fuzzy logic based PID controller for control system.

Any scheme can easily implemented in practice simply by using a fuzzy controller with existing PID controller to optimize the performance of the later.

A comprehensive design procedure has been prepared for optimizing the parameter of fuzzy based PID controller.

The dynamic performance of the system with control strategy based on fuzzy logic has been examined.

The aim of this chapter is to highlight the significant contribution of the work carried out in this thesis and making a further scope of work which can study in the area of designing of fuzzy logic based PID controller [17] in process control or in control system.

The main focus of the work presented in this thesis is to suggest a suitable control strategy based on the fuzzy logic based PID controller to a process control systems.

5.2 Significant conclusion of work done

Based on the results reported in previous chapter the following salient conclusions can be made.

1. The dynamic model of the fuzzy based PID controller has been developed.
2. A systematic comprehensive design procedure has been analyzed for fuzzy controller.
3. Our result shows that the conventional proportional integral and derivative (PID) controller while simple to implement and are widely used in industrial application , they exhibit poor performance when applied to a system containing unknown nonlinearities such as dead zone, saturation and hysterisis .

   In this situation fuzzy based controller which optimized the performance of conventional PID controller are the best alternate, which can overcome above said problem, because they have shown superior performance compared to conventional controllers.
4. Our proposed fuzzy based controller is most suitable for time varying, nonlinear, and dynamic and ill understood process. It has found extensive use in control engineering and gives better result than conventional control method.
5. It is very difficult to use conventional control regulator when the dynamic model is infeasible and cannot be express in terms of mathematical model. In this situation fuzzy logic based controller cannot only be applied but also gives the fruitiest result.

6. in this thesis the scheme is based on trying to compensate for overshoot and undershoot in transient response for a control process and our fuzzy controller is designed specifically for PID controller, which are widely used in practice and is easy to implement in practice since exiting PID controller can be used in conjunction with the fuzzy controller without modification.

5.3 SIMULATED RESULTS AND DISCUSSION

Following results has obtained for fuzzy precompensated PID controller and conventional PID controller and these are compared.

Parameters used for PID controller

$K_p = .24$

$K_d = .12$

Ki = .03

The fuzzy controller uses the command input y_m and the plant output y_p to generate a precompensated command signal y'_m describe by the following equations.

State equation for fuzzy controller

$e(k) = y_m(k) – y_p(k)$--(1)

$\Delta e(k) = e(k) – e(k-1)$ --(2)

$y(k) = F[e(k), \Delta e(k)]$---(3)

$y'_m(k) = y_m(k) + y(k)$ ---(4)

$U(k) = u(k-1) + kp\ \Delta e(k) + ki\ e(k) + kd[\Delta e(k) – \Delta e'(k-1)]$ ------------(5)

5.4 Further scope of work:

As a result of extensive investigation in the area of fuzzy based controller ,following guidelines for work seen to be work pursuing.

1. the problem of analyzing the stability of the control scheme in this thesis is the important problem and a topic of ongoing research.
2. Exploring the possibility of use of fuzzy logic controller to perform high level control function that fall outside the domain of conventional control method. Fuzzy logic based PID controller are also most suitable for time varying nonlinear, dynamic and ill understood process.
3. Development of artificial neural network and comparing its performance with fuzzy logic based controller.

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