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Design of PID, Fuzzy PD/PID and Single Input Fuzzy Logic Controller for Higher Order System

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Abstract: Fuzzy Logic Controller (FLC) performance is greatly dependent on its inference rules. In most cases, the more rules being applied to a FLC, the accuracy of the control action is enhanced. Nevertheless, a large set of rules requires more computation time. As a result, FLC implementation requires fast and high performance processors. In this paper, it is shown that the inference rule table of a two-input FLCs for Higher Order System can be reduced to form a Single Input Fuzzy Logic Controller (SIFLC), which can be easily implemented using a lookup table. Simulated results are presented to demonstrate the better dynamic performance of higher order system using SIFLC compared to the conventional FLC (CFLC) and classical PID.

Keywords: Fuzzy PD/PID Controller, Ziegler-Nichols Tuning, Signed Distance Method, Single Input Fuzzy Logic Control, PID.

I. INTRODUCTION

Conventional PID controllers have been a wide range of use in industry because of its simple structure and acceptable performance. This controller deals with both time response and frequency response improvements if they are properly tuned. But as the demands increases to control the different systems in industries, performance of conventional controllers are tend to degrade. Now systems are getting complicated day by day introducing higher order plants. There is drastic change in the performance of controllers with the introduction of Fuzzy systems and so the Fuzzy controllers (PD and PID) has been designed and tuned for third order system which is difficult to control by the use of conventional controllers. FLC has been widely used for nonlinear, high order & high dead time plants. This paper has three main considerations. Firstly, a PID controller has been designed for nonlinear unstable third order plant using Zeigler Nichols tuning method[I] & its performance is analyzed. Secondly, for the same system a FLC has been proposed with simple approach and smaller number of rules(four rules) as it gives the same performance by the larger set rule[II]. Even though modern control methods are very promising for non-linear control applications, they require substantial computational power because of complex decision making processes. For example FLC has to deal with fuzzification, rule base storage, inference mechanism and defuzzification operations. Larger set of rules yields more accurate control at the expense of longer computational time. Therefore it may not be practical because there are many implementation aspects that must be addressed, namely real-time response, communication bandwidth, computational capacity and onboard battery. The use of NN is also thought to be impractical due to its unpredictability, particularly when real time self-tuning is considered. Despite these issues, it is known that FLC requires simpler mathematics and offers higher degree of freedom in tuning its control parameters compared to other nonlinear controllers. In this paper, the Single Input Fuzzy Controller

(SIFLC) is proposed. The SIFLC is a simplification of the conventional Fuzzy Controller (CFLC). It is achieved by applying the "signed distance method"[III,IV] where the input to SIFLC is only one variable known as "distance". This is in contrast to the CFLC which requires an error and the derivative (change) of the error as its inputs. The reduction in the number of inputs simplifies the rule table to one dimensional, allowing it to be treated as a single input single output (SISO) controller. Comparatively, the SIFLC reduces the computational burden of the processor because it has less number of rules to compute. Moreover, the rules can be approximated as a piecewise control surface and can be constructed using a simple look-up table[III]. To verify this idea, simulation of a Higher Order System using SIFLC is carried out. The results are compared to the Fuzzy PD/PID controllers and classical PID applied on the same system.

Generalised Form of Conventional Controller

A PID controller is designated by:

$G(s)=P+I+D$

$=K_P+K_I/s+K_Ds$ -------(1)

$=K_P(1+1/T_I+T_Ds)$ ------(2)

Where K_P=proportional gain, K_I=integration coefficient, K_D=derivative coefficient.

T_I=integral action, T_D=derivative action.
For the best performance of the system, there is need of adjusting these three parameters which is more difficult & time consuming.

Design Methodology for PID And Fuzzy PD/PID Controllers

A. PID controller

A PID controller is being designed for a higher order system with transfer function
$G(s)= 10/[s(s^2+6s+8)]$
Fig.1 shows the simulink model of the PID controller and plant with unity feedback.

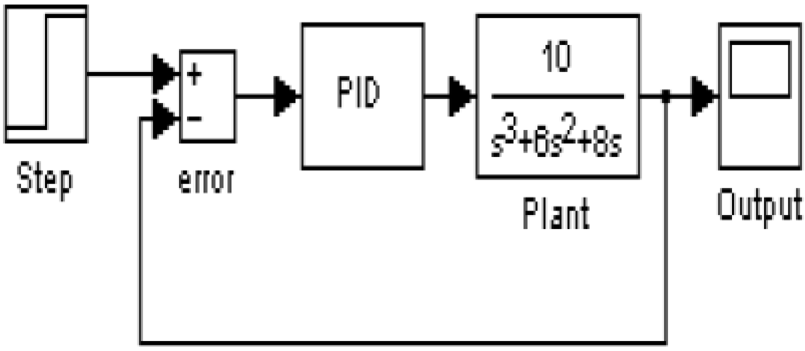


Fig.1. Plant with controller

Tuning of conventional controller has been done by the Ziegler–Nichols Method, which is used in mostly all the Industrial PID Tuning.

Table I: Zeigler-Nichols Method

Controller	**K_p**	**Ki**	**Kd**
P	**0.5*Ku**	**--**	**--**
PI	**0.455*Ku**	**0.545*Ku/Pu**	**--**
PD	**0.71*Ku**	**--**	**0.15*Pu**
PID	**0.588*Ku**	**1.17*Ku/Pu**	**Ku*Pu/13.6**

Ku and Pu are Ziegler-Nichols parameters, can be calculated for plant by inserting the plant in setup with a step input and gain K and tuning the gain K up to which the plant output is sustained oscillations. At that time Gain K will be equal to Ku and Pu will be time difference between two consecutive peaks.

B. Fuzzy logic controller

For the same plant, simulink model of only PID fuzzy controller with unity feedback is shown in Fig2. In this paper for the 2-input FLC, 2 membership functions for each input (error & change in error) & outputs are used. Fuzzy PI+PD Controller have been designed with Fuzzy PI and Fuzzy PD by adding the outputs of the PI and PD controller. It has two inputs Error (E) and change in Error (CE) with Gains GE, GE1 and GCE, GCE1 and an output U with Gain GCU, GU. The controller has been used as feedback controller. To design the fuzzy PID controller first rule base has been created in FIS Editor and the controller has been used as feedback controller. The controller has been tuned by 'Hit and Trial Method' by tuning gains GE, GE1, GCE, GCE1, GU, GCU.

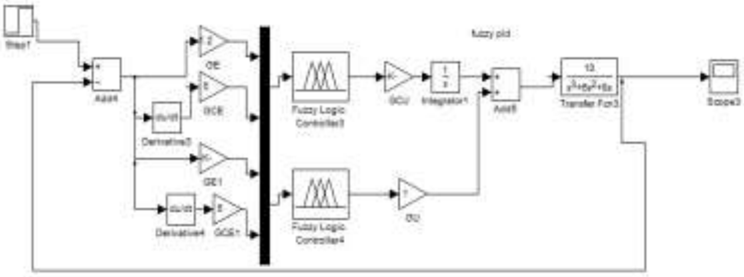


Fig.2. Simulink model of PID fuzzy controller

For a two input fuzzy controller, 3,5,7,9 or 11 membership functions for each input are mostly used [7]. In this paper, only two fuzzy membership functions are used for the two inputs error e and derivative of error(ė) as shown in Fig.3.The fuzzy membership functions for the output parameter are shown in Fig.4, here N means Negative, Z means Zero and P means Positive.

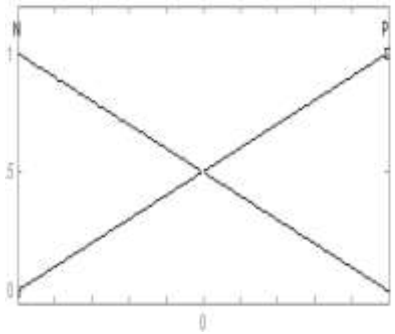


Fig.3. Input membership function(e and ė)

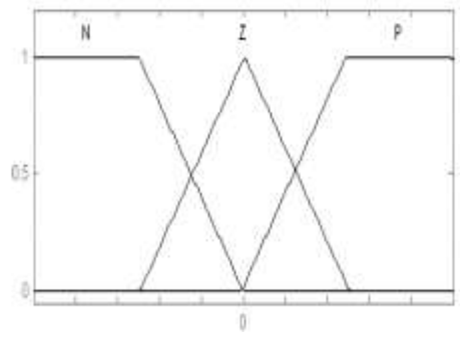


Fig.4. Output membership function

Table II: Fuzzy Rules

e/ □	**N**	**P**
N	**N**	**Z**
P	**Z**	**P**

Design Methodology of SIFLC

A. The signed distance method

Fuzzy Logic controller (FLC) is a linguistic-based controller that tries to emulate the way human thinking in solving a particular problem by means of rule inferences. Typically, a FLC has two controlled inputs, namely error (e) and the change of error (ė). Its rule table can be created on a

two-dimensional space of the phase-plane (e,ė) as shown in Table III. It is common for the rule table to have the same output membership in a diagonal direction. Additionally, each point on the particular diagonal lines has a magnitude that is proportional to the distance from its main diagonal line L_z.

This is known as the Toeplitz structure. The Toeplitz property is true for all FLC types which use the error and its derivative terms, namely e, ė.. and $e^{(n-1)}$ as input variables. The main diagonal line can be represented by

$\dot{e}+\lambda e=0$-----(3)

Where, variable λ is the slope magnitude of the main diagonal line L_z. To derive the distance, d, let $Q(e_0, \dot{e}_0)$ be an intersection point of the main diagonal line and the line perpendicular to it from a known operating point $P(e_1,\dot{e}_1)$, as illustrated in Fig. 5. The distance d can be written as

$d=\dot{e}+\lambda e/\sqrt{1+\lambda^2}$------(4)

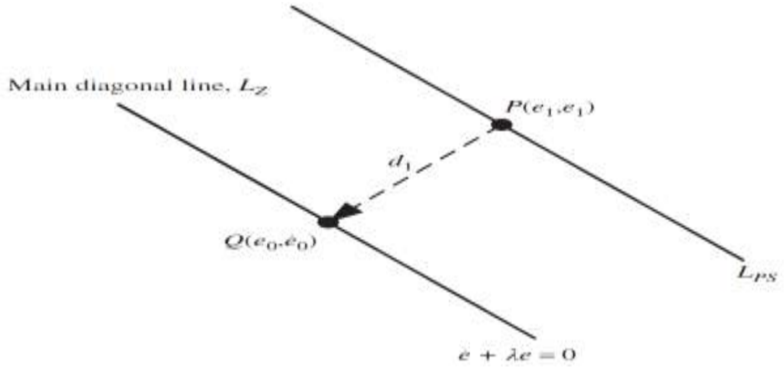


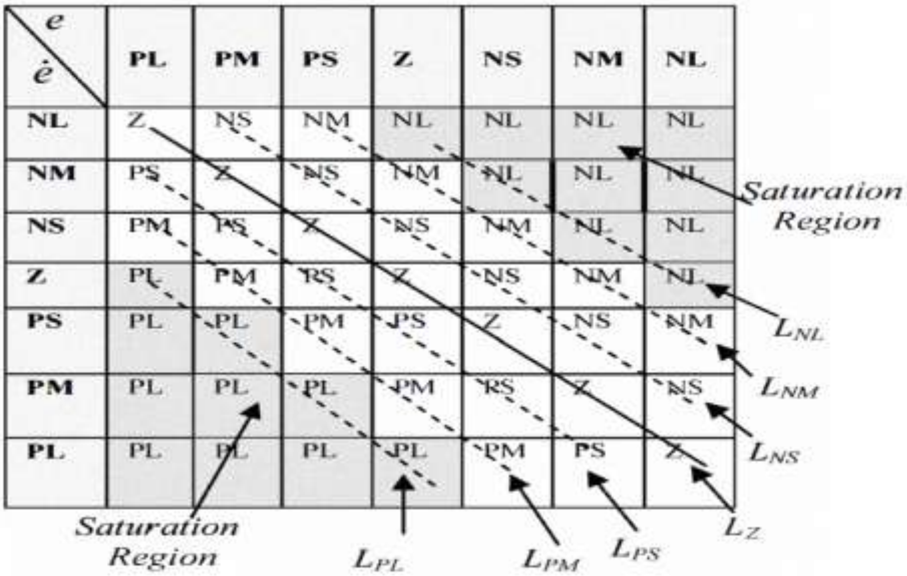
Fig.5. Derivation of distance variable

The overall structure of SIFLC can be depicted as a block diagram in Fig. 6 and the corresponding reduced table is shown in table IV. The output equation can be written as

$$u(k) = u_o(k).r\text{----}(5)$$

The rule base used in the design is given in Table III. The rule base follows closely the rules that were suggested in[V,VI]

Table III. Rule table with Toeplitz structure



$\dot{e}$ \ e	PL	PM	PS	Z	NS	NM	NL
NL	Z	NS	NM	NL	NL	NL	NL
NM	PS	Z	NS	NM	NL	NL	NL
NS	PM	PS	Z	NS	NM	NL	NL
Z	PL	PM	PS	Z	NS	NM	NL
PS	PL	PL	PM	PS	Z	NS	NM
PM	PL	PL	PL	PM	PS	Z	NS
PL	PL	PL	PL	PL	PM	PS	Z

Signed-distance method

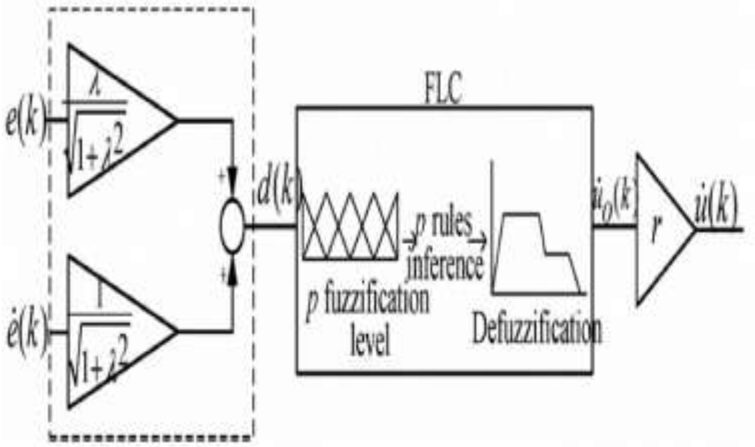


Fig.6. The SIFLC Control structure

Table IV. The reduced rule table using the Signed-distance method

d	**L_{NL}**	**L_{NM}**	**L_{NS}**	**Z**	**L_{PS}**	**L_{PM}**	**L_{PL}**
u_o	**NL**	**NM**	**NS**	**Z**	**PS**	**PM**	**PL**

The main advantage of SIFLC is the significant reduction of the rules that needs to be inferred. In conventional FLC, two inputs are fuzzified and depending on the level of fuzzification p, the number of rules to be inferred is p2 , while the distinguishing features of SIFLC is that, it requires only p rules. The reduction in the number of rules results in faster calculation in SIFLC. Fig. 7 shows the linear control surface used in the design. The proposed SIFLC structure is depicted in Fig. 8. The equation for the mentioned surface can be written as

$$u_o=(S_1-S_0/X_1-X_0)x+(X_1S_0-X_0S_1/X_1-X_0)\text{-------}(6)$$

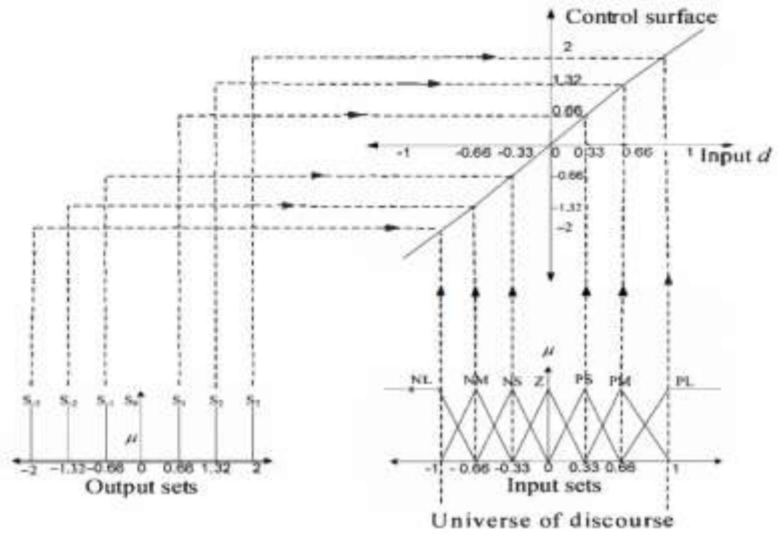


Fig.7. SIFLC control surface with one break point

Signed-distance method

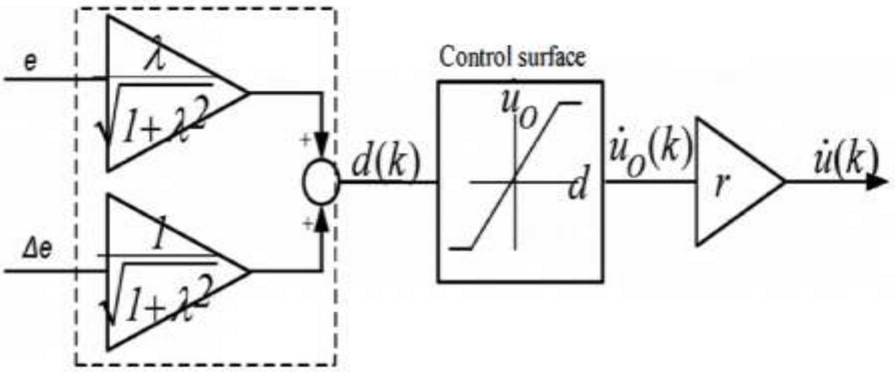


Fig.8. SIFLC structure for the given plant

Fig. 9 shows the error for all the controllers. Fig. 10 illustrates the output response for all three controllers. It can be seen that SIFLC gives better performance in terms of dynamic and steady state response.

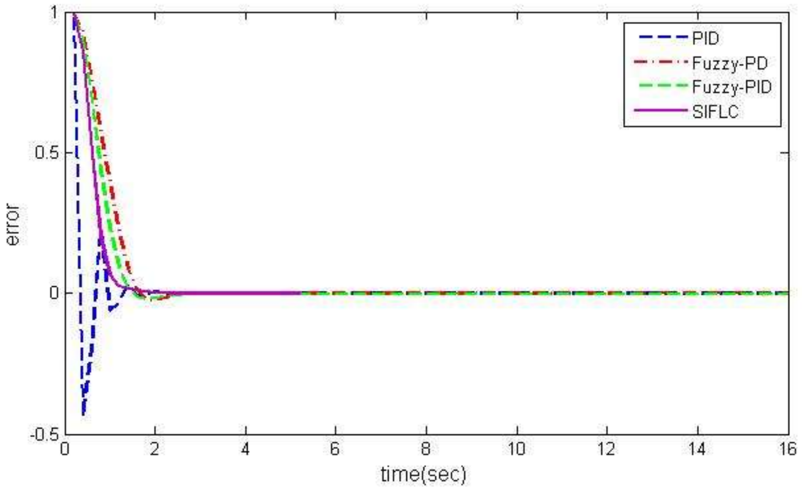


Fig.9. Error response of the controllers

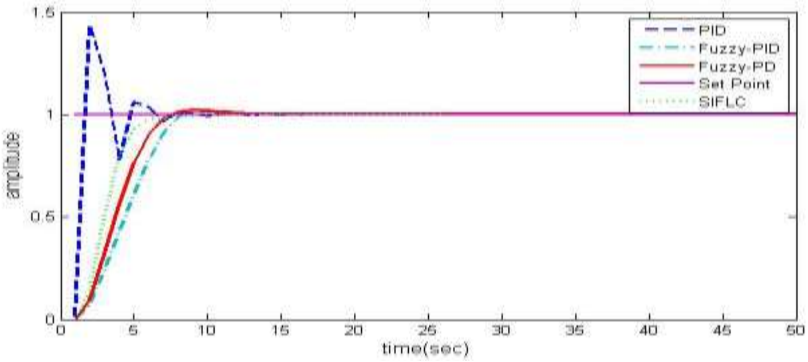


Fig.10. Output response of PID, Fuzzy-PD, Fuzzy-PID and SIFLC

II. SIMULATION RESULTS

Table V. Performance table of the controllers

Controllers	**Mp(%)**	**t_s(sec)**	**t_r(sec)**
PID	**43.88**	**7.35**	**0.55**
Fuzzy-PD	**1.97**	**7.88**	**4.74**
Fuzzy-PID	**1.71**	**7.06**	**3.97**
SIFLC	**0**	**2.78**	**0.88**

From the simulation result shown in figure 11 and from Table V., it can be observe that the SIFLC controller offers better dynamic and steady state response compare to both CFLC and PID. In both SIFLC and CFLC (almost negligible), no overshoots is detected compared to 43% in the classical case. The classical PID controller has a steady state error compare to a zero steady state error in SIFLC and FLC while the settling time of SIFLC is found to be faster than both CFLC and PID systems.

III. CONCLUSION

From the simulation results, it has been shown that the fuzzy controller can stabilize the system efficiently. Also, the performance during the transient period of the fuzzy system is better in the sense that less overshoot was obtained. Moreover, the fuzzy controller provides a zero steady state error.

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