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A CASE STUDY ON DESIGN AND EVALUATION OF MODIFIED ADAPTIVE FUZZY PID CONTROLLER

Durgesh Nandan*[1], Dr.Pankaj Rai[2]
[1]Electrical Engineering Department,BIT Sindri,Dhanbad,Jharkhand,India- 828123
nandandurgesh2009@gmail.com
[2]HOD, Electrical Engineering Department, BIT Sindri, Dhanbad, Jharkhand,India-828123
Pr_bit2001@yahoo.com

Abstract:Most of process control systems are based on PID controllers, because of their remarkable effectiveness, simplicity and robustness, As PID controller design theory and practical procedures are well developed, it is necessary to pay attention on fuzzy logic controller design and its applications in combinations with PID controllers. There is also necessity to develop adaptive fuzzy PID Controllers, which can automatically retune itself to match the current process characteristics. In particular, focus of the work presented here is mainly on two problems: replacing an operator's control of PID regulators with fuzzy PID controller and to develop a structure for self tuning Fuzzy PID Controller and to develop a structure for self tuning fuzzy PID as modified PID adaptive Fuzzy Controller.

INTRODUCTION

Control Engineering has been an art in which process designers used experiments, their common sense, and their experience to control the process or to set it automatically in the right direction. The main task of a controller is to find a suitable set of commands that can cause the system reach smoothly at the desired state with minimal deviations. The controlled system equations for general case are complex and non-linear; therefore the controller must be able to effectively incorporate nonlinear properties and effects which are not modelled yet, into its basic design.

The most common and popular controller is a PID controller with the simple fixed structure and structural parameters determining the use of proportional action, derivative action and integral action. This controller is so popular that there are many rules of thumb to set the three parameters.

The mathematical representation of the most common formulation of the PID algorithm is:

$$u= kp(e + 1/Ti \int edt + Td\, de/dt) \qquad (1.1)$$

Where u is the controller output, e is the error (usually r- y), r is the desired output or required trajectory, Kp is the proportional gain, Ti is the integral time and Td is the derivative time. The three right-hand side terms are proportional, integral and derivative actions respectively. The proportional term adjusts the speed of response of the system, the integral term adjusts the steady state error of the system and the derivative term adjusts the degree of stability of the system. In designing a linear PID Controller, one must determine the controller gains such that closed –loop feedback system would possess the required dynamic and steady state behaviour. The popular approach is the Ziegler-Nicholas technique.

This approach, based on ultimate gain and period or process reaction curve. Then the desired gains are determined from empirical relations.

Unfortunately, many of the PID loops are in continuous need of monitoring and adjustment, when they are in operation, Most PID controllers are often not properly tuned due to plant parameter variations or due to change in operating condition. There is a significant need to retune if the operating point changes, or retune periodically if process changes with time. This leads to the development of **adaptive Controllers** (PID) which can automatically retune itself to match the current process characteristics. If the controller furthermore adjusts the control strategy without human interventions it is adaptive. The pragmatic definition that Astrom & Wittenmark [2] propose as, anadaptive controller is a controller with adjustable parameters and a mechanism for adjusting the parameters.

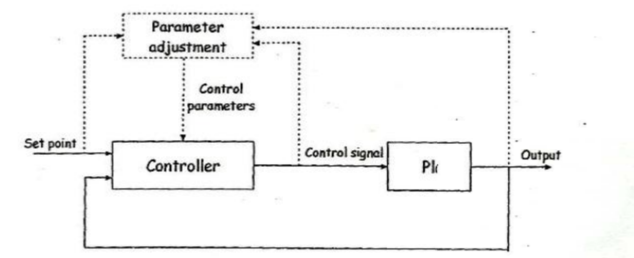

Figure 1.1: Adaptive control systen

adjustments. Gain adjustment is the most common way for tuning fuzzy control because it is easier to tune the gain than the rule base and MF's. The gain structure of fuzzy control is different with its non fuzzy counterparts. Fuzzy control actually has two levels of gain. The scaling gains (i.e.scaling factors) are in the lower level. The fuzzy proportional, integral, and derivative gains, which are formed by coupling scaling gains, are in the higher level. The high level (coarse) tuning can follow the tuning strategy of its nonfuzzy counterparts-try to reach the stable performance by controlling Kp, Ki and Kd. After that, a low level (fine) tuning may be needed to enhance the An adaptive control system can be thought of as having two performance by adjusting the resolution of control variables. The resulting improvements in the system response are loops. One is a normal feedback loop with process (plant) accomplished by making on-line adjustments to the and controller known as inner loop presented by solid line.

The other is the parameter adjustment loop known as the outer loop represented by dash line (Fig.1.1).The parameter adjustment loop is often slower than the normal feedback loop.

The adaptive component of an adaptive controller consists of two parts. First is the process monitor that detects changes in the process characteristics in the form of parameter estimators and performance measure. Second is parameters of the FLC, known as **adaptive fuzzy PID Controller**. In particular, adaptive fuzzy PID controller that modify the fuzzy set definitions or the scaling factors will be called self-tuning controllers.

FUZZY PID CONTROLLER

The basic structure of a PID Controller is the adaptation mechanism which alters the controller parameters on the basis of any detected changes passed to it by process monitor. There are two main approaches for designing adaptive controllers. One is known as Model Reference Adaptive Control (MRAC) method, while the other is called as Self-Tuning method [6].In the presented work, the self-tuning method is considered.

$$u(t) = K_p e(t) + K_I \int e(t)dt + K_d \frac{de(t)}{dt} = K_p\left[e(t) + \frac{1}{T_i}\int e(t)dt + T_d \frac{de(t)}{dt}\right]$$

A fuzzy PID Controller can have many variants .from a theoretical and practical point of view there are the most frequent versions: parallel combinations of fuzzy PI+PD, The Adaptive PID Controllers cannot provide a PD+I, PI+D or P+I+D controllers [5].Fuzzy PI+PD general solution to all control problems. Conventional control approach is unlikely to be efficient, when the processes are non-linear, complex, time variant and delayed. An operator is still needed to have control over the plant. Human control is valuable and very dependent on the knowledge about the process of an experienced operator; as a result many PID controllers are poorly tuned in practice .A quite obvious way to automate the operator task is to employ an artificial intelligence and control engineering, can be considered as an obvious solution, which is confirmed by engineering practice [11].

In a typical PID controller design for system, the controller parameter are initially determined and then tuned manually to achieve desired system response. The manual tuning can be replaced with a fuzzy control supervising a tuning process. Fuzzy control design is involved with two important stages: 1) knowledge base design, and 2) control tuning. In knowledge base design, the control rules are normally extracted from practical experience, which makes the design more difficult. Whereas control tuning is possible with rules, membership functions (MF's), and gain controller settings can't be equivalent to classical PID controller settings due to double proportional gain included in fuzzy controller structure. Fuzzy PD+I controller provides all the benefits of PID control, but disadvantage regarding increasing rise time and settling time of the process. The Fuzzy Controller can be realized with three inputs as error, change of rate of error and the integration of error. However, this method will be hard to implement in practice because of difficulty in constructing three dimensional fuzzy control rule base. Moreover, adding one input variable will greatly increase the number of control rules, the constructing of fuzzy control rules are even more difficult task and it needs more computational efforts. Hence with above difficulties we may want to design a fuzzy controller that possesses the fine characteristics of the conventional PID controller by using the error and the change rate of error as its inputs. The propose Fuzzy PID controller structure that simply connects the PD type and PI type Fuzzy controller together in parallel is shown in Fig3.6.In such a structure reduce the complexity of rule – base design and increase efficiency ,by sharing a common rule base for both fuzzy PI and PD parts.

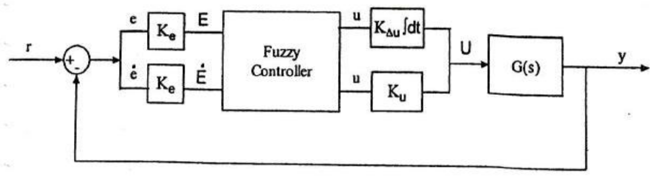

Figure 3.6 Block diagram of fuzzy PID controller

The controller output is the control signal U, a non linear function of error and derivative of error. With the common structure of the dynamics of the fuzzy PID, it is convenient for the further theoretical analysis and evaluation.

ADATIVE FUZZY PID CONTROLLER

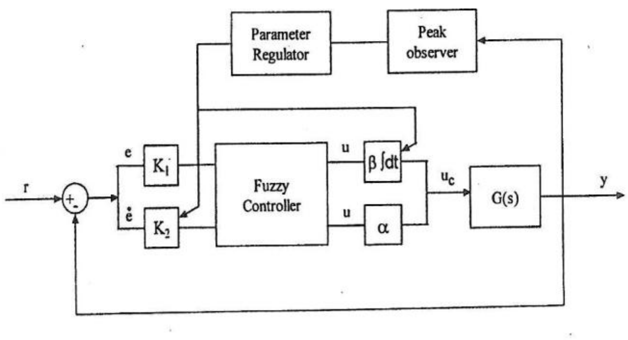

Figure 4.2: Block diagram of the parameter adaptive fuzzy PID controller

rule base the controller output is $\Delta u \equiv u$ for integral control action. The linear approximation to this controller is

$$U = K_u u + K_{\Delta u}\int u dt$$

$$= K_u(K_e e + K_{\dot{e}}\dot{e}) + K_{\Delta u}\int (K_e e + K_{\dot{e}}\dot{e})dt$$

$$= (K_u K_e + K_{\Delta u}K_{\dot{e}})e + K_{\Delta u}K_e \int e dt + K_u K_{\dot{e}}\dot{e}$$

$$= (K_u K_e + K_{\Delta u}K_{\dot{e}})\left[e + \frac{K_{\Delta u}K_e}{(K_u K_e + K_{\Delta u}K_{\dot{e}})}\int e dt + \frac{K_u K_{\dot{e}}}{(K_u K_e + K_{\Delta u}K_{\dot{e}})}\dot{e}\right] \quad (3.18)$$

By comparison the gains in (3.17) and (3.18) are related in the following way,

$$K_p = K_u K_e + K_{\Delta u}K_{\dot{e}} \qquad \frac{1}{T_i} = \frac{K_{\Delta u}K_e}{(K_u K_e + K_{\Delta u}K_{\dot{e}})} \qquad T_d = \frac{K_u K_{\dot{e}}}{(K_u K_e + K_{\Delta u}K_{\dot{e}})} \quad (3.19)$$

The parameter adaptive fuzzy PID controller is composed of a fuzzy PID, a peak observer and a parameter regulator. The peak observer determines the peaks at the control system output and measures the absolute value of the peak. The parameter regulator tunes the controller parameters, scaling factors K2 and β, for each peak according to the peak value at that time. The algorithm for tuning the scaling factors K2 and β of the fuzzy PID Controller is as follows:

K2=K2n/δk, β=δkβs

Where K2s is the initial value of K2 and βs is the initial value of β;δk is the tk(k=1,2,3……….) absolute overshoot at time The Final structure of The Fuzzy PID Control system is

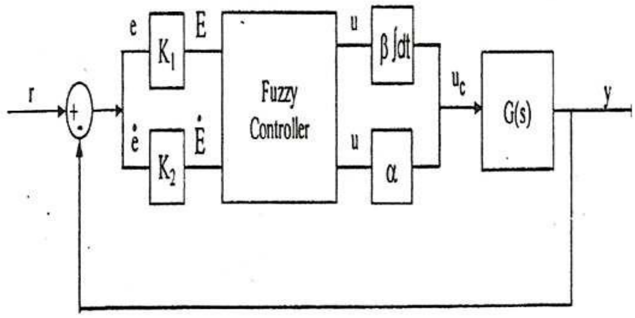

Figure 3.7: The fuzzy PID control system

This algorithm reveals some virtue but also some limitations .This improves the performance of the control system if the value of scaling factors appropriate, but when the peak value becomes very small then value of scaling factor K2 becomes very large and β becomes very small as a result control system can reach instability.

MODIFIED ADAPTIVE FUZZY PID CONTROLLER

Despite of some limitations of parameter adaptive method there is a need to improve the steady–state response of the control system. Fuzzy controller contains a number of sets The Fig.3.7 shows generalized structure of fuzzy PID of parameters that can be altered to improve the Controller. The Considerations behind the selection of this structure are as follows .First, it has the simplest structure having two fuzzy inputs variables and single variable for the fuzzy control output variable. Second, from practical point of view, it seems that the heuristic knowledge is more analogous to that of human operator or expert is easier to be performance of the control system. These are the scaling factors of each variable, the fuzzy IF-THEN rules and the membership function. If we do not change the fuzzy rules and scaling factors, we can adjust the membership function to improve the steady state response of the control system. It is observed that just changing the MF steady state of the acquired. Third, owing to the similarity of the input-output performance is improved but it is hard to improve the relationship between fuzzy and conventional PID transient state. Changes of rule base is self –organizing controllers, It is possible to decide the fuzzy PID controller parameters from conventional PID tuning methods such as, Ziegler-Nicholas tuning formula. Forth, with the simplest FLC, may affect the performance but, it is not so easy to tune the rule base. Finally changes in the scaling factors may affect the performance greatly.

The idea behind the parameter adaptive method is same as changes in the scaling factors but it has some limitation as the variation in the scaling factors K2 and β according to equation(4.3)represented in graph form (dashed line) as shown in Fig.4.3.

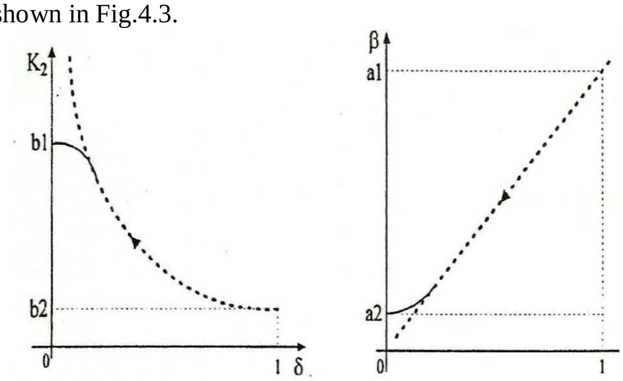

Figure 4.3: Scaling factors K_2 and β variation with δ

(Dashed line-Parameter adaptive method solid line-modified parameter adaptive method)

Here from the start point of the step response of the control system the absolute peak value decreases at each peak as a result K2 increases and β decreases, ideally it reaches infinity and zero respectively. This is the limitation in parameter adaptive method. So in the modified adaptive (b1+b2).so here adjust the β(e(t)) and K2(e(t))roughly with the error of the time. It shows that besides tuning scaling factors, add the a1,a2,b1,b2 parameters expand and modify the tuning region of it. As a result the parameter adaptive fuzzy PID controller structure change as the modification in the parameter β and K2 with the function f(e(t))and g(e(t)) As shown in fig4.4

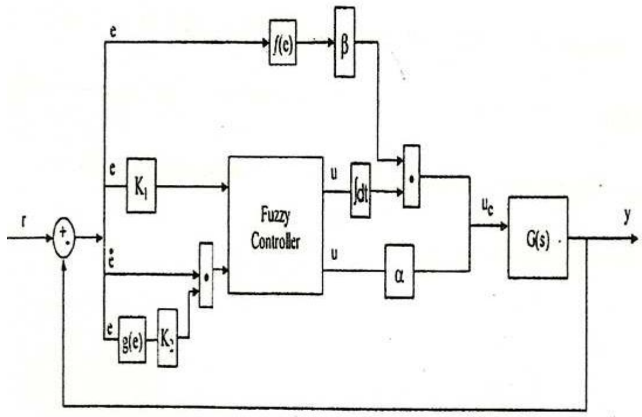

Figure 4.4: Block diagram of modified adaptive fuzzy PID controller

SIMULATION AND RESULTS

Here we have simulated different systems using conventional PID controller (PID), fuzzy PID controller (FPID), adaptive fuzzy PID controller (AFPID) and fuzzy PID controller, the modification over parameter a modified adaptive fuzzy PID Controller (MAFPID). For adaptive method has been suggested. It is observed that simulation first-order system-G1(s)[15],second-order error and absolute peak variations in the system are in system-G2(s)[16] and third-order system-G4(s)[18] are similar way, i.e. when error is maximum, peak value is maximum and when error is zero, peak value is zero.

Let us define the functions f(e(t)) and g(e(t))as, f(e(t))=a1.abs(e(t))+a2 (4.4) g(e(t))=b1.[1-abs(e(t))]+b2 (4.5) considered. For the clear comparison between all the types of controllers stated above several performance measures such as, peak overshoot (%OS), Peak time (tp), rise time (tr), settling time (ts), Integral of Time multiplied Absolute Error (ITAE), and Integral Absolute Error (IAE) are used.

Unit step is the test signal used to examine the transient as well as steady –state behaviour and performance evolution for the different types of controller, with each Where a1,a2, b1 and b2 all are positive constants and e(t) is the error signal with time. Then the self-tuning scaling factors changing with time are described as follows:

β(e(t))=βs.f(e(t)) (4.6) K2(e(t))=K2s.g(e(t)) (4.7) process. In all cases, Mamdani type inference method and centre of gravity (COG) defuzzification method are used. The comparative performance measures of controllers are tabulated for each process, with different values of dead time (L).The simulation work for the different controllers with each process carried out using MATLAB (VersR2008a) Where βs and K2s are the initial values of the scaling

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Factors β and K2 respectively. The objective of the function The process transfer function G1(s) is [15] f(e(t)) is to decrease (e(t))with the change of error. In the other words, the error will be zero and f(e(t)) will eventually G1(s)=2e-.3s/(s+1) (5.1) be equal to a2.However ,the function g(e(t)) is the inverse objective, in the steady state ,the g(e(t)) will be equal to For this process dead time L=0.3. Ziegler-Nicholas tuned PID controller values for(5.1)in [15]are:

Kp=2.0 Ti=0.6 Td=0.15 4

Thus, U(s)=Kp+Ki/s+Kd*s=2+3.34/s+0.3s

Using equation 4.2 the fuzzy PID controller scaling factors are calculated as:

K1=1 K2=0.3 β=3.34 α=0.998

Simulation result with above calculated parameters for PID, FPID and MAFPID shown in Fig.5.6 and various performance indices for unit step response of (5.1) with dead Ziegler-Nicholas tuned PID controller values for (5.2) in [16] are:

Kp=0.4 Ti=0.4 Td=0.125

Thus, U(s)=Kp+Ki/s+Kd*s=0.4+1/s+0.05s

Using equation 4.2 the fuzzy PID controller scaling factors are calculated as: time are tabulated as:

K1=1 K2=0.25β=1 α=0.2 \

Table 5.1: performance analysis for the first-order systemg1(s).

L	Controller	Peak	%OS	tp (sec.)	tr (sec.)	ts (sec.)	ITAE	IAE
0.3	PID FPID MAFPID	1.14 1.03 1.00	14 3 0	12 1.7 4.8	0.7 1.1 4.8	5 5 5	3.35 3.23 9.10	16.63 18.47 19.81

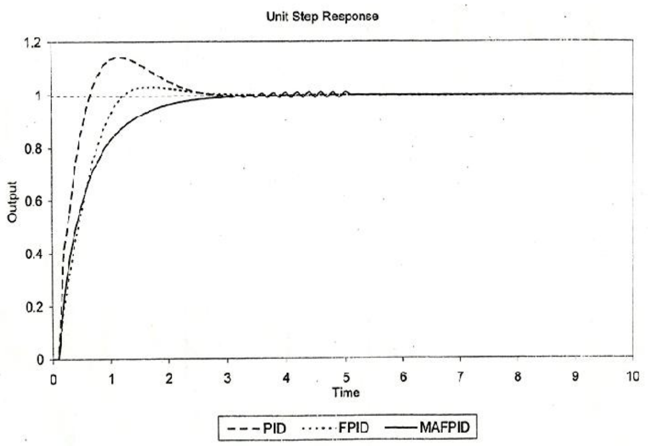

Figure 5.6: Responses of the first-order system $G_1(s)$ with L = 0.3

From the simulation result and performance analysis table a decrease in peak overshoot and an increment in rise time is seen for MAFPID controller. The response of the process with MAFPID controller is over damped and is not necessarily superior to that of FPID.

The Process transfer function G2(s) is [16] G2(s)=2e-ts/(s2+3s+2)

Table 5.2: Performance Analysis For The Second-Order System G2(S)

L	Controller	Peak	%OS	tp (sec.)	tr (sec.)	ts (sec.)	ITAE	IAE
0	PID FPID AFPID MAFPID	1.20 1.126 1.108 1.00	20 12.6 10.8 0	3.8 4.3 5.3 6.0	1.9 2.3 2.9 5.8	17.4 15.3 13.8 13.4	39.53 34.40 46.78 16.27	29.32 30.42 33.60 24.98
0.1	PID FPID AFPID MAFPID	1.245 1.160 1.134 1.00	24.5 16.0 13.4 0	3.8 4.3 5.3 6.3	1.8 2.3 2.9 5.4	17.1 15.3 13.5 12.9	50.09 41.69 53.92 14.91	31.59 32.06 35.10 24.88
0.2	PID FPID AFPID MAFPID	1.295 1.20 1.376 1.030	29.5 20.0 37.6 3.0	3.9 4.3 4.1 3.0	1.7 2.2 1.8 1.8	17.0 15.3 17.2 13.1	65.15 51.48 107.3 16.05	34.42 34.02 40.89 25.41
0.3	PID FPID AFPID MAFPID	1.353 1.245 1.575 1.087	35.3 24.5 57.7 8.7	3.9 4.4 3.9 3.0	1.6 2.1 1.4 1.5	17.0 15.5 15.7 13.7	87.13 65.43 236.11 21.59	37.99 36.47 54.89 27.05

Response of the Second-Order systemG2(s) with L=0

For this process we consider four different values of dead time (L),i.e.L=0,0.1,0.2,0.3.

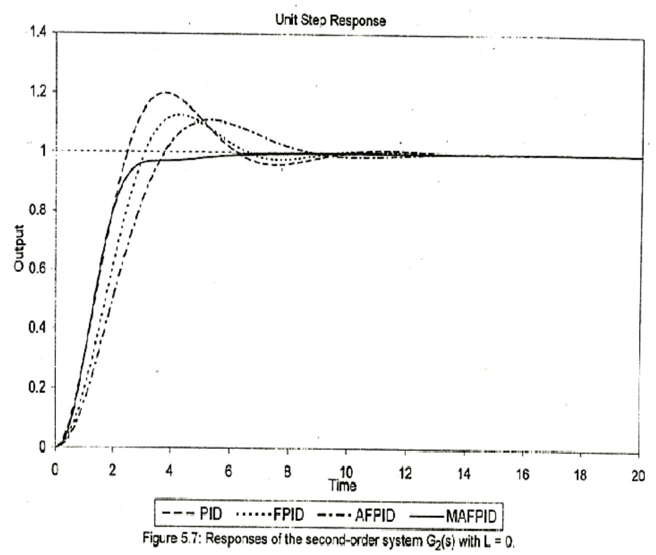

Figure 5.7: Responses of the second-order system $G_2(s)$ with L = 0.

Response of the Second-Order system G2(s) with L=0.1 5

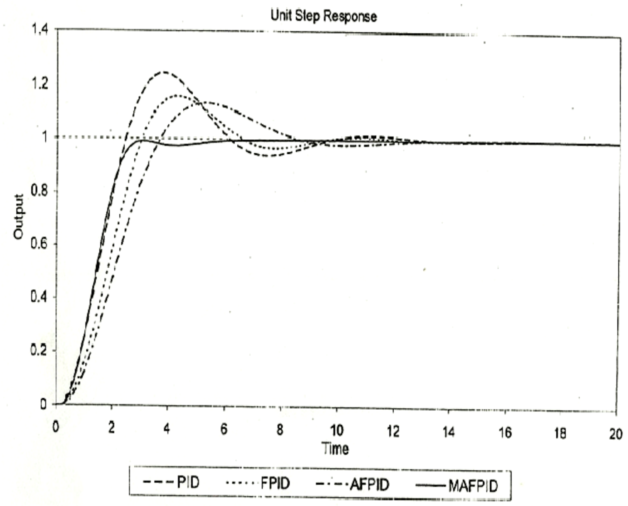

Figure 5.8: Responses of the second-order system $G_2(s)$ with L = 0.1

Response of the Second-Order system G2(s) with L=0.2

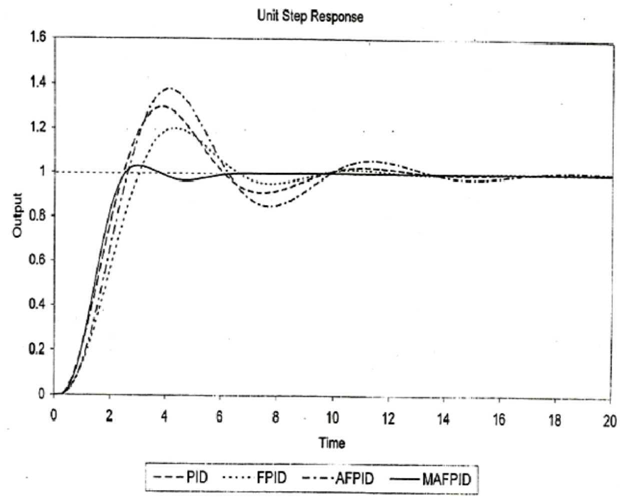

Figure 5.9: Responses of the second-order system $G_2(s)$ with L = 0.2

Response of the Second-Order system G2(s) with L=0.3

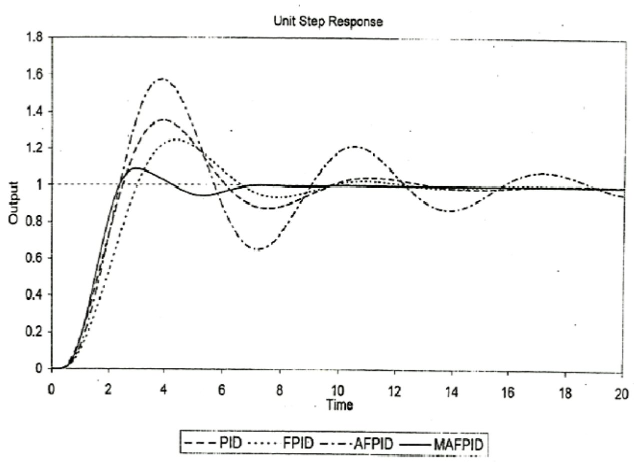

Figure 5.10: Responses of the second-order system $G_2(s)$ with L = 0.3

From the simulation result, Fig.5.7 to 5.10 and performance analysis table 5.2, we see that, peak overshoot decreases with small variation in rise time using MAFPID controller. Using equation 4.2 the fuzzy PID controller scaling factors are calculated as:

K1=1 K2=0.284 β=38.014 α=30

Table 5.4 : Performance Analysis For The Third-Order System G4(S)

Controller	Peak	%OS	tp(sec.)	tr(sec.)	ts(sec.)	ITAE	IAE
PID	1.557	55.7	1.4	0.6	10	15.40	30.78
FPID	1.294	29.4	1.4	0.6	9.7	12.28	28.95
MAFPID	1.181	18.1	1.2	0.6	8.8	6.37	26.71

Response of the Third Order systemG4(s)

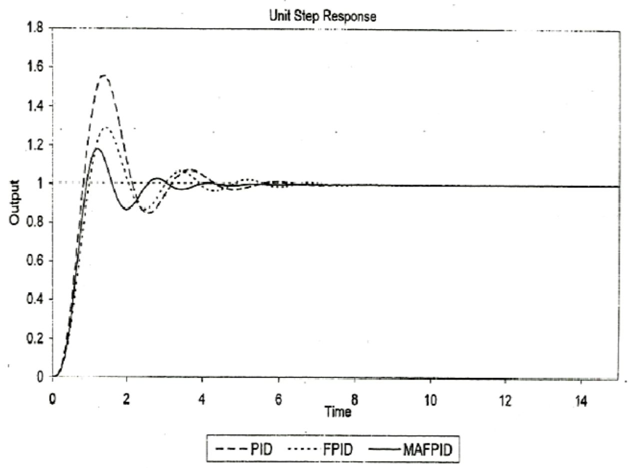

Figure 5.15: Responses of the third-order system $G_4(s)$

From the simulation result, Fig 5.15 and performance analysis table 5.4 for the (5.4), we see that, improvement in steady state response with peak overshoot decreases using MAFPID. Rise time remain unchanged with the different System settles down faster with the MAFPID controller. MAFPID shows definite improvement in performance for all values of time delay controller. The response controller is oscillatory of the process with AFPID

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The process transfer function G4(s) is [18]

G4(s)=1/(s+1)(s+2)(s+3)=1/s3+6s2+11s+6 (5.4)

Ziegler-Nicholas tuned PID controller values for (5.4) in[18] are:

Kp=36 Ti=0.947 Td=0.2367

Thus,U(s)=Kp+Ki/s+Kd*s=36+38.014/s+8.521s

To summarize, the result shows modified adaptive fuzzy PID controller improve the performance over the other types of controller for a wide variety of systems. in general a greater damping is produced leading to a general improvement in performance, except for first order type-0 systems.

CONCLUSION

Modified parameter adaptive method improves the performance of Fuzzy PID controller. Using this method decreases the equivalent integral component of fuzzy PID controller gradually with the system response process time. As a result damping of the system increase when system is about to settle down with keeping the proportional component nearly unchanged, guaranteed in quick reaction against the error.

With The MAFPID controller, the oscillation of the system is strongly restrained and the settling time is shortened greatly. Simulation results present the better performance of the MAFPID controller as Peak overshoot and settling time decreases for a wide variety of system.

Due to the self-tuning mechanism the performance of MAFPID remains within the acceptable limit when the process is associated with dead time. The most important feature of the MAFPID structure is that it does not depend on the process being controlled (i.e. process independent).

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