AN INTELLIGENT HYBRID FUZZY PID CONTROLLER

Isin Erenoglu   Ibrahim Eksin   Engin Yesil   Mujde Guzelkaya
Istanbul Technical University, Faculty of Electrical and Electronics Engineering,
Control Engineering Department,
Maslak, TR-34469, Istanbul, Turkey
E-mail:yesil@elk.itu.edu.tr

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ABSTRACT

In this study, a design methodology is introduced that blends the classical PID and the fuzzy controllers in an intelligent way and thus a new intelligent hybrid controller has been achieved. Basically, in this design methodology, the classical PID and fuzzy controller have been combined by a blending mechanism that depends on a certain function of actuating error. Moreover, an intelligent switching scheme is induced on the blending mechanism that makes a decision upon the priority of the two controller parts; namely, the classical PID and the fuzzy constituents. The simulations done on various processes using the new hybrid fuzzy PID controller provides 'better' system responses in terms of transient and steady-state performances when compared to the pure classical PID or the pure fuzzy controller applications. The controller parameters are all tuned by the aid of genetic search algorithm.

INTRODUCTION

As PID is regarded as the standard control structures of the classical control theory, and fuzzy controllers have positioned themselves as a counterpart of classical PID controllers on the same dominant role at the knowledge-rich spectrum (Åström and Hagglund 1995, Oh et al. 2004). PID controllers are designed for linear systems and they provide a preferable cost/benefit ratio. However, the presences of nonlinear effects limit their performances. Fuzzy controllers are successful applied to non-linear system because of their knowledge based nonlinear structural characteristics. Hybridization of these two controller structures comes to ones mind immediately to exploit the beneficial sides of both categories. Naturally various hybrid controller structures have been arisen in literature (Kwok et al. 1990, Brehm and Rattan 1993, Li 1998, Li et al. 1999, Xiaoyin and Belmin 1993, Reznik et al.2000). In some applications, these two control structures are combined by a switch (Ketata et al. 1995, Matsunaga and Kawaji 1991, Otsubo et al. 1998, Parnichkun and Ngaecharoenkul 2001). In (Er and Sun 2001) a fuzzy switching method between fuzzy controller and conventional PID controllers is used to achieve smooth control during switching.

The intent of this study is to design a new hybrid fuzzy PID controller so that a further improved system response performance in both the transient and steady states have been achieved as compared to the system response obtained when either the classical PID or the fuzzy controller has been implemented. Here, the classical PID and fuzzy controller have been combined by a blending mechanism that depends on a certain function of actuating error. An intelligent switching scheme is induced on the blending mechanism that makes a decision upon the priority of the two controller parts. Simulations are performed on MATLAB®/Simulink toolbox to illustrate the efficiency of the proposed method.

INTELLIGENT HYBRID FUZZY PID CONTROLLER STRUCTURE

Fuzzy PID controllers in literature can be classified into three major categories as direct action type, fuzzy gain scheduling type, and hybrid type fuzzy PID controllers (Yesil et al. 2003, Akbiyik et al. 2005). The direct action type can also be classified into three categories according to number of inputs as single input, double input, and triple input direct action fuzzy PID controllers. The classification of fuzzy PID controllers can be seen in Fig. 1.

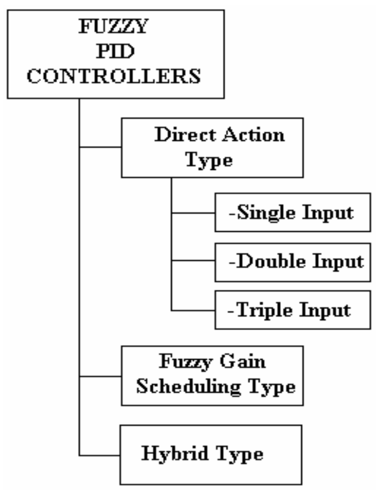

Figure 1: Classification of fuzzy PID controllers

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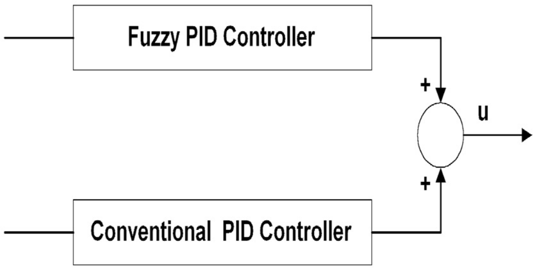

Figure 2: Block diagram of hybrid type fuzzy PID controller.

The proposed hybrid controller that is given in Fig. 2 possesses two main parts: the classical PID and fuzzy PID controllers. A standard PID controller is also known as the “three-term” controller, whose transfer function is generally written in the “ideal form” as

$$G_{PID}(s) = K\left(1 + \frac{1}{T_I s} + T_D s\right) \tag{1}$$

where K is the proportional gain, K_I the integral gain, K_D the derivative gain, T_I the integral time constant and, T_D the derivative time constant. The “three-term” functionalities are highlighted by the following:

i. The proportional term is providing an overall control action proportional to the error signal through the all-pass gain factor.
ii. The integral term is reducing steady-state errors through low-frequency compensation by an integrator.
iii. The derivative term is improving transient response through high-frequency compensation by a differentiator.

The structure of the fuzzy PID controller, which has two inputs and one rule base, is shown in Fig. 3. The inputs are the classical error (e) and the rate of the change of error $(\dot{e})$.

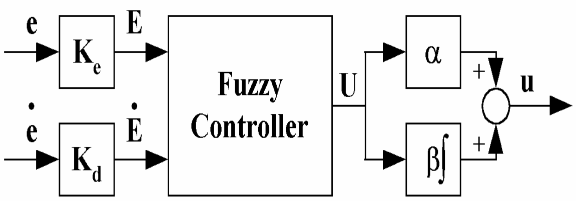

Figure 3: The Fuzzy PID Controller structure

Triangular membership functions are used for input variables as it is shown in Fig. 4. For the output variable u, singleton membership functions are defined as in Fig. 5. The fuzzy PID controller rule base composed of 49 (7x7) rules as shown in Table 1. The control surface of the fuzzy PID controller is also given in Fig. 6.

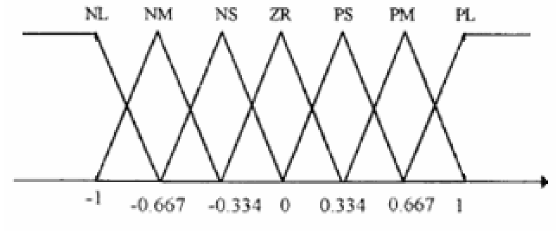

Figure 4: The membership functions of e ,and $\dot{e}$.

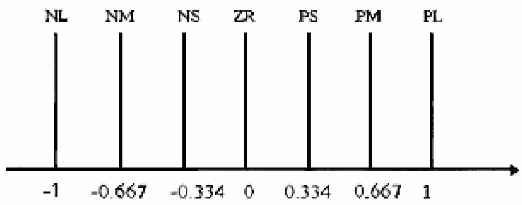

Figure 5: The membership functions of u.

In this paper, the classical PID and fuzzy PID controller are combined by a blending mechanism that depends on a certain function of actuating error. Moreover, an intelligent switching scheme is induced on the blending mechanism that makes a decision on the priority of the two controller parts; namely, the classical PID and the fuzzy constituents. The Matlab/Simulink simulation model of the proposed intelligent hybrid PID controller is shown in Fig. 7. The parameters of the PID controller are denoted by K, T_I, and T_D. As encountered in the literature, these stand for proportional gain, integral and derivative time constants, respectively. The parameters of the fuzzy controller are defined as K_e, K_d, α , and β .

Table 1: PID type Fuzzy Controller Rule Base

E/E	NL	NM	NS	ZR	PS	PM	PL
PL	ZR	ps	pm	pl	pl	pl	pl
PM	ns	ZR	ps	pm	pl	pl	pl
PS	nm	ns	ZR	ps	pm	pl	pl
ZR	nl	nm	ns	ZR	ps	pm	pl
NS	nl	nl	nm	ns	ZR	ps	pm
NM	nl	nl	nl	nm	ns	ZR	ps
NL	nl	nl	nl	nl	nm	ns	ZR

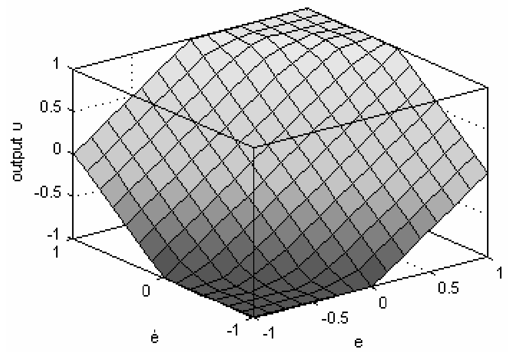

Figure 6: The control surface of the fuzzy PID controller

A switching & blending mechanism firstly decides the dominant one of the two controller structures; namely, classical and fuzzy controllers. The outputs of the fuzzy PID controller and the classical PID controller are then multiplied by either one of the functions 1-f(e) and f(e). 1-f(e) and f(e) are the weighing factors of the blending part of the mechanism. They quantify the level of the activity of the contributing controller and help us to achieve a reasonable tradeoff between the actions generated by the individual controllers. Since the function f(e) has to be positive valued, it has been selected as $f(e)=e^2$. Consequently the hybrid controller's output becomes either

$$U_{HYBRID} = f(e).U_{PID} + (1 - f(e)).U_{FUZZY} \qquad (2)$$

or

$$U_{HYBRID} = (1 - f(e)).U_{PID} + f(e).U_{FUZZY} \qquad (3)$$

It is obvious that when the error is large the controller output multiplied by f(e) is activated more than the other controller part. For this reason, at the early stages of the control action, the controller output which gives the faster response must be multiplied by f(e). The switching part of the mechanism tries to catch the bigger one of the control efforts of the two main controller parts. The idea behind this is that higher control effort should produce faster system response.

SIMULATIONS RESULTS

The following simulations are done in order to see the performance of the proposed hybrid fuzzy PID controller. The controller parameters are all determined using a genetic search algorithm (Goldberg 1989). The Performance Index (PI) or the fitness function used for optimization is

$$PI = \frac{1000}{100.\%P + 6.tp + 3.ts + 100.ess} \qquad (4)$$

where P is the peak, tp is the peak time, ts is the settling time and finally ess is the steady-state error. All genetic searches are done on Genetic Algorithms Toolbox of Matlab 6.5.

Simulation 1

In the first simulation, the following first-order process model with a dead-time is considered:

$$G_1(s) = \frac{1}{s+1} e^{-0.2s} \qquad (5)$$

The corresponding system responses and controller outputs are given in Fig.8 and Fig. 9, respectively. The controller parameters of the classical PID controller are set to K=2, T_I=0.25, T_D=0.025 in order to have a small rise time. On the other hand, the fuzzy PID controller has the following parameters: $\alpha = 0.05$, $\beta = 4.5$, K_e=1, K_d=0.56.

Simulation 2

The second simulation is performed on a second-order process plus dead-time with the transfer function given as follows:

$$G_2(s) = \frac{1}{(s+1)(s+2)} e^{-0.2s} \qquad (6)$$

The controller parameters of the classical PID controller are set to K=0.01, T_I=0.014, T_D=1 to have a smooth response with a small overshoot. On the other hand, the fuzzy PID controller has the following parameters: $\alpha = 0.2$, $\beta = 1.1$, K_e=1.5, K_d=0.2. The corresponding system responses and controller outputs are given in Fig.10 and Fig. 11, respectively.

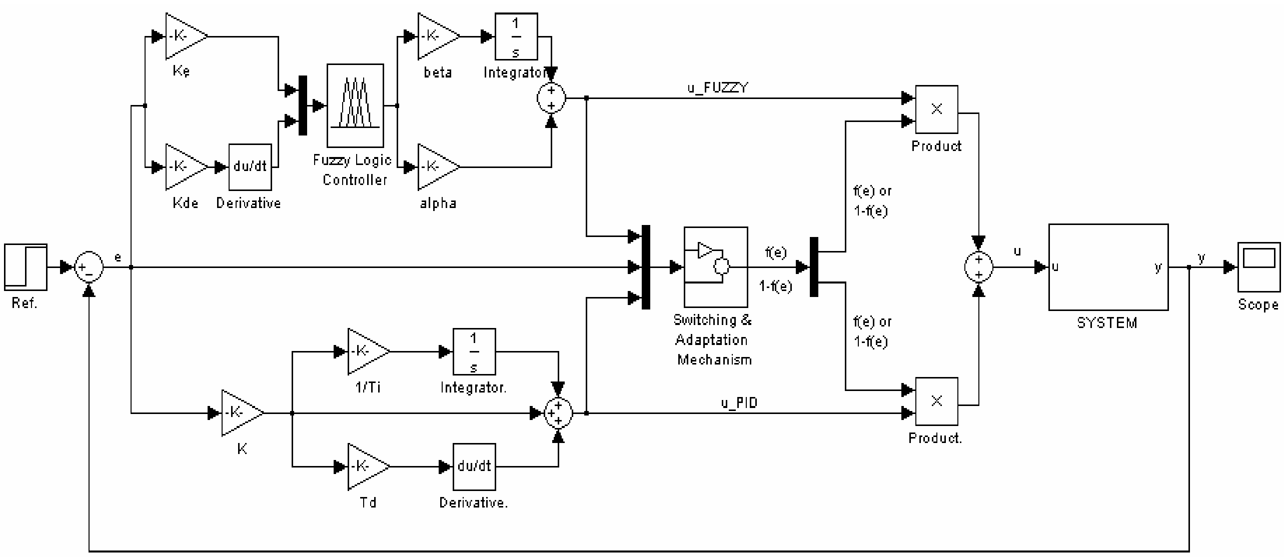

Figure 7: Intelligent Hybrid Fuzzy PID Controller Structure

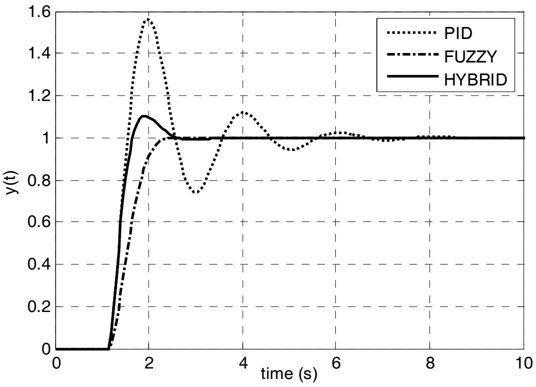

Figure 8: The step responses of all control structure

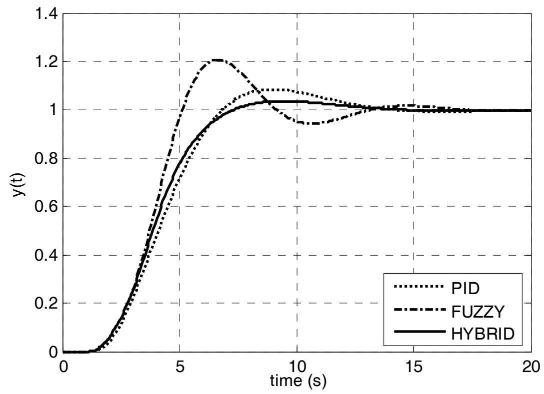

Figure 10: The step responses of all control structures

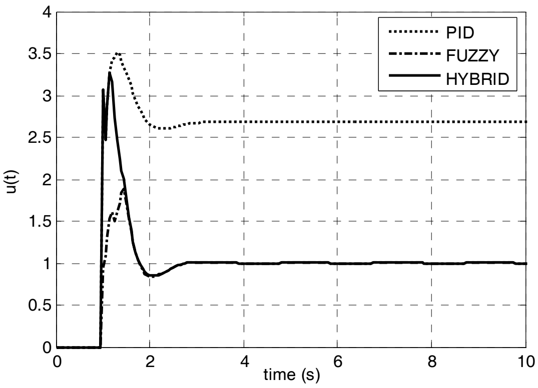

Figure 9: The control output of all control structures

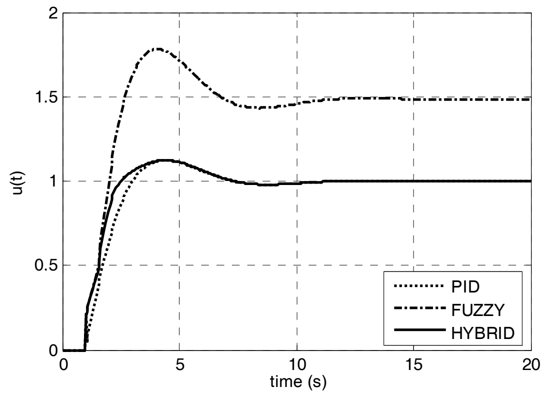

Figure 11: The control output of all control structures

CONCLUSION

A novel design methodology that blends the classical PID and the fuzzy controllers in an intelligent way is introduced in this paper, thus a new intelligent hybrid controller has been achieved. A switching & blending mechanism that depends on a certain function of actuating error is presented. Many simulations done on various processes using the new hybrid fuzzy PID controller have provided 'better' system responses in terms of transient and steady-state performances. Here, only two of these simulations are given and the proposed hybrid fuzzy PID controller is compared to the pure classical PID or the pure fuzzy controller applications. All of the simulation results have shown that the proposed hybrid structure has provided a good and effective performance on system response.

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ISIN ERENOGLU received the B.Sc. degree from the Department of Electrical Engineering of the Faculty of Electrical Engineering of Yıldız Technical University, Istanbul, Turkey, in 2003. She is currently a M.S. student in the Control and Automation Engineering Program of the Institute of Science and Technology of Istanbul Technical University. His research interests are fuzzy control, hybrid control.

IBRAHIM EKSIN received the B.Sc., M.S. and Ph.D. degrees from the Department of Electrical Engineering of Bogazici University, Istanbul, Turkey, in 1976, 1979 and 1983, respectively. He has worked in Honeywell from 1983 to 1985. He then joined Control Systems Division of the Department of Electrical Engineering of Istanbul Technical University and is currently working as a professor in the same division. He is the General Secretariat of NMO of IFAC. His research interests are intelligent control, optimal control and evolutionary computation. His e-mail address is eksin@elk.itu.edu.tr and his Web-page is at www.elk.itu.edu.tr/~eksin.

ENGIN YESIL received B.Sc. degree from the Department of Electrical Engineering of the Faculty of Electrical and Electronics Engineering of Istanbul Technical University, Istanbul, Turkey, in 1998 and M.S. degree from the Institute of Science and Technology of the same university in 2000. He is currently a Ph.D. student and is working as a research assistant in the Control Systems Division of the Department of Electrical Engineering of Istanbul Technical University. His research interests are intelligent control, process control. His e-mail address is: yesil@elk.itu.edu.tr and his Web-page can be found at www.elk.itu.edu.tr/~yesil.

MUJDE GUZELKAYA received the B.Sc. degree from the Department of Electronics and Communication Engineering of the Faculty of Electrical Engineering of Istanbul Technical University, Istanbul, Turkey, in 1982 and M.S. and Ph.D. degrees from the Institute of Science and Technology of the same university in 1984 and 1990, respectively. She is currently a professor in Control Systems Division of the Department of Electrical Engineering of Istanbul Technical University. Her research interests are intelligent control, multivariable control and stochastic optimal control. Her e-mail address is gkaya@elk.itu.edu.tr and his Web-page can be found at www.elk.itu.edu.tr/~gkaya.