FUZZY BLENDING HYBRID STRUCTURE WITH FUZZY AND CONVENTIONAL PID CONTROLLERS

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ABSTRACT

The aim of this study is to develop a fuzzy blending hybrid controller (FBHC) which mixes the control outputs of a conventional PID and a fuzzy PID controller. The idea behind this design methodology is to combine the beneficial sides of both controllers in its own structure. The fuzzy and the conventional controllers are put into parallel form within this the blending mechanism and generally the advantages of conventional controller in steady-state characteristics and the fuzzy controller in transient characteristics are exploited. In this paper, a new hybrid controller scheme with a blending mechanism that uses simple fuzzy rule base instead of complicated algorithms has been presented. Moreover, the proposed blending mechanism is independent of the type of controllers used in hybridization. Thus, this feature provides the designer an opportunity to use other control strategies within the same mechanism for different processes.

Keywords: fuzzy logic, fuzzy PID + conventional PID, hybrid control, fuzzy blending

1. INTRODUCTION

Despite a lot of research and different effective solutions, conventional PID controllers (proportional-integral-derivative) are the most popular controllers used in industry due to their simplicity and cost affectivity. According to the different sources, the use of conventional PID controllers in industry is in between 90% and 99% (Reznik et. al. 2000). When the system to be controlled is linear the performance of PID controllers is superb, but if the system is a nonlinear or certain uncertainties exist within system, PID controllers cannot achieve a good performance (Er and Sun 2001).

On the other hand, fuzzy controllers are another type of controller and they are widely and increasingly been used by control engineers for too many systems with nonlinearity and uncertainty over the past two decades (Sugeno 1985; Driankov 1996; deSilva 1995). The main advantage of this method is that there is usually no need for a model in designing the fuzzy controller (Passino and Yurkovich 2001). However, defining fuzzy rules and designing the membership functions may unfortunately be time consuming.

These drawbacks and advantages remind a hybrid structure which involves both a linguistic part and a numeric part in its topology. FBHC integrates the advantages of both conventional PID controller and fuzzy controller. This idea naturally interested many engineers. Various hybrid controller designs have been arisen in literature (Xiaoyin and Belmin 1993; Kwok et. al. 1990; Brehm and Rattan 1993).

A self optimal regulating factor is added to the control rule of the fuzzy controller in order to have not only quick dynamic response, but also high steady-state accuracy of a PID (Liang and Qu 1993). An interesting approach with the parallel connection of those two controllers is to use both control outputs in some combination (Li 1998). In that method, a fuzzy P and an ID controller were used in the hybrid controller structure.

In this paper, a new approach toward designing a hybrid controller using a fuzzy blending mechanism has been presented. This is a way to design effective combinations of conventional PID controllers and intelligent methodologies for the industry. The proposed controller FBHC compares the controller outputs within a fuzzy mechanism and that mechanism produces a blending factor. Then, the controller outputs are mixed up appropriately using this factor. Therefore, FBHC can be considered as a mechanism which tries to determine and use the controller output that gives the best system response more effectively. The leading advantage of this blending mechanism is the fact that it is independent from the nature of the controllers used. FBHC structure can easily be applied to both linear and nonlinear systems. In this study, the results of FBHC are compared with the results obtained using both the pure conventional and fuzzy PID controllers and it has been proven that the proposed hybrid controller outperforms the pure forms of both controllers both in transient and steady-state even under disturbances.

Performance comparison between the proposed hybrid controller and the pure of the controllers involved has been carried out by two simulation examples that confirm the superiority of the hybrid controller. The structure of the hybrid controller and the pure of the controllers are presented in section 2, and blending mechanism is described in section 3. The simulation examples are given in section 4. The last part is the conclusion stage.

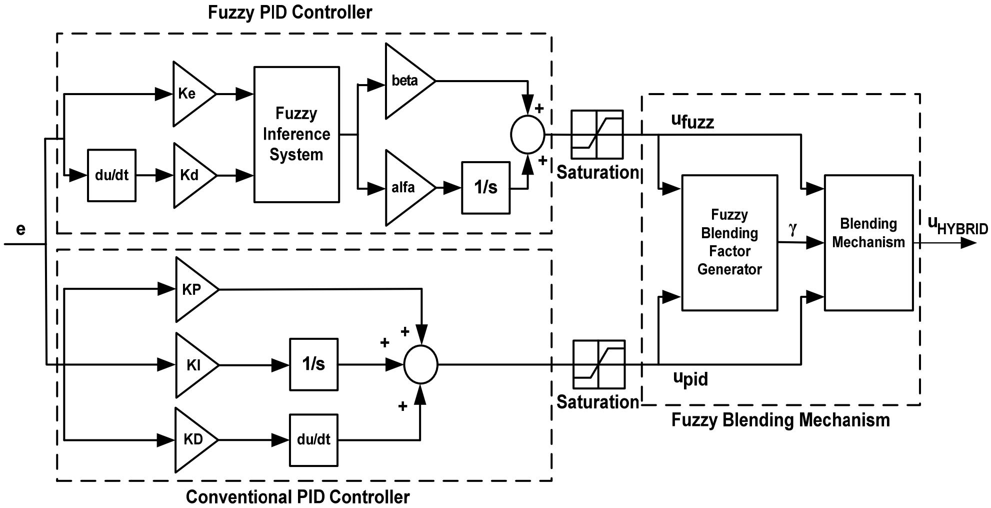

Figure 1: Structure of Fuzzy Blending Mechanism

2. HYBRID FUZZY PID + CONVENTIONAL PID CONTROLLER SCHEME

The proposed structure of the FBHC with a Fuzzy PID and a conventional PID is shown in Figure 1. The first part of this hybrid structure is a Fuzzy PID controller and the inputs of this controller are the system error (e) and the rate of the change of the system error ($\dot{e}$). These inputs are defined as %50 percent overlapped triangular membership functions in the range of [-1, 1], while the output (u) is defined with singleton membership functions as shown in Figure 2. The rule base of the fuzzy controller is composed of 49 rules as given in Table 1.

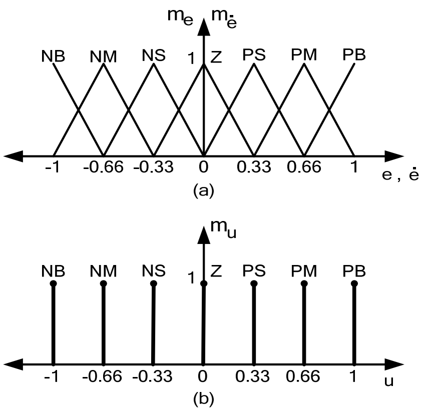

Figure 2: (a) Error, and Derivative of Error, (b) Control Signal Membership Functions of the Fuzzy PID Controller

Table 1: Fuzzy PID Controller Rule Base

$\Delta e / e$	**NL**	**NM**	**NS**	**Z**	**PS**	**PM**	**PL**
PL	Z	PS	PM	PL	PL	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PS	NM	NS	Z	PS	PM	PL	PL
Z	NL	NM	NS	Z	PS	PM	PL
NS	NL	NL	NM	NS	Z	PS	PM
NM	NL	NL	NL	NM	NS	Z	PS
NL	NL	NL	NL	NL	NM	NS	Z

The second part of this hybrid control structure is a conventional PID controller and its transfer function can be given as:

$$G_{PID}(s) = K_p + \frac{K_I}{s} + K_D s \quad (1)$$

where K_P is the proportional gain, K_I the integral gain, K_D the derivative gain.

Either one of the two controllers might have been chosen with aggressive response; that is, small rise time and high overshoot and the other one having a smooth system time response; that is, high settling time and low or no overshoot. Then, this hybrid mechanism will provide a system response exploiting the beneficial sides of both controllers.

3. FUZZY BLENDING MECHANISM (FBM)

FBM is a structure where the control signals of the two control signals are mixed. Different blending algorithms can be suggested but here a method based on fuzzy logic is proposed.

In literature, there also exist other ideas in calculating the blending factor γ; for instance, a simple function depending on the system error e can be used (Erenoglu et. al. 2006). However, the algorithm could have become more complex in order to cover all the system situations. Here, as an alternative, it has shown that a simple fuzzy rule base can be used instead of complicated algorithms. The blending rules used in this study are not complicated ones and they are defined to control the process over a wide range of operating points.

The outputs of the Fuzzy PID controller and the conventional PID controller are multiplied by either the output blending factor γ or (1-γ). The key point of the blending mechanism is to get a reasonable tradeoff between the pure forms of the two controllers. FBM can be given in two main parts; namely, Fuzzy Blending Factor Generator (FBFG) and Blending Mechanism (BM).

3.1. Fuzzy Blending Factor Generator (FBFG)

FBFG is the part of the FBM where the blending factor γ is produced.

3.1.1. Membership Functions

Triangular-shaped functions shown in Figure 3 are chosen as the membership functions due to the resulting simplicity. The fuzzy members for the input are defined as Very Large (VL), Large (L), Medium (M), Small (S) and Very Small (VS).

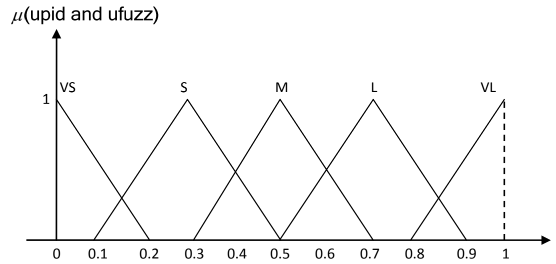

Figure 3: Membership Functions of Control Inputs

The output variable γ is also triangular membership functions are defined as illustrated in Figure 4 the linguistic labels for the memberships are given as Very Very Large (VVL), Very Large (VL), Large (L), Medium (M), Small (S), Very Small (VS) and Very Very Small (VVS).

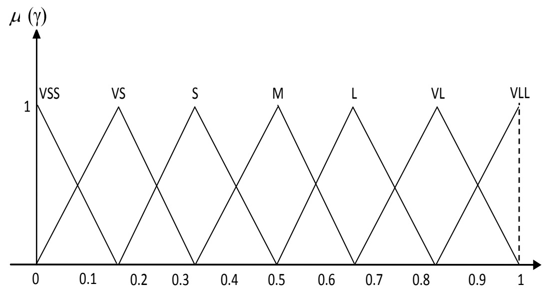

Figure 4: Membership Function of Blending Factor

3.1.2. Rule Base

FBFG rule base is composed of 25 rules as given in Table 2. The number of rules could have been increased; but it has been avoided for simplicity. The rules are between the two controller outputs: Fuzzy PID and Conventional PID and three or more controller outputs might have been used.

It is obvious from the rules that when a controller output is aggressive compared to the other one, the aggressive output multiplied with a higher blending factor and this controller output activates more than the other controller in the hybrid control output. In other words, the controller output which gives the faster response must be multiplied by a greater value of γ in the transient phase of system response. The main idea of this structure is to multiply the dominant control signal with higher fulfillment degree to produce faster system response.

Table 2: FBFG Rule Base

u_{pid} \ u_{fuzz}	**VL**	**L**	**M**	**S**	**VS**
VL	M	L	VL	VLL	VLL
L	S	M	L	VL	VLL
M	VS	S	M	L	VL
S	VSS	VS	S	M	L
VS	VSS	VSS	VS	S	M

The rule base is designed on this basic idea. When Fuzzy PID output (u_{fuzz}) is Very Large (VL) and Conventional PID output (u_{pid}) is Very Small (VS), the bigger blending factor must affect the control output so a Very Very Large (VVL) factor must be multiplied with u_{fuzz}. This means that a Very Very Small factor (1-γ) will be multiplied with u_{pid}.

On the other hand when u_{pid} is VL and u_{fuzz} is VS, the blending factor will be VSS, so the conventional PID ratio will be close to 1 in the hybrid control output. On the other hand, the fuzzy PID fulfillment in the hybrid output will be close to 0.

When u_{fuzz} is Medium (M) and u_{pid} is Medium (M), blending factor is Medium (M) for an equal blending. The surface of the FBFG is illustrated in Figure 5.

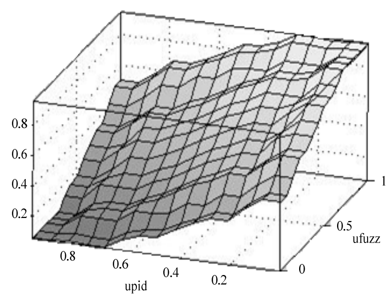

Figure 5: The Surface of FBFG

3.1.3. Scaling Factor

As it can be seen from that Figure 1, after both of the controller outputs, saturation blocks are used. This saturation blocks gives the mechanism the ability to work with the same rule base in different systems and controllers. After the saturation blocks, the controller outputs are mapped in [0,1] region.

By using that kind of saturations and mapping procedure, there is no need to search for the scaling factors. Moreover, saturation is more physical than a searching algorithm.

3.2. Blending Mechanism (BM)

BM has three inputs: Conventional PID controller output u_{pid}, Fuzzy PID controller u_{fuzz} and FBFG output γ. Here the new controller output is calculated as;

$$u_{HYBRID} = u_{fuzz} \cdot \gamma + u_{pid} \cdot (1-\gamma) \tag{2}$$

where u_{HYBRID} is the new control output.

It is so apparent from the rule base that when a controller output is larger from the other that controller output is multiplied a bigger blending factor so it is activated more than the other controller part. FBHC tries to catch the bigger one of the control efforts of the two controllers. Behind this lays the idea of that the higher control effort should produce faster system response.

4. SIMULATION STUDIES

In order to show the benefit of the proposed control structure two simulation examples are presented. For each example, the transient response for the reference changes, the input ($d_1(t)$) and the output disturbance ($d_2(t)$) rejection performance of the proposed hybrid control (FBHC) is compared with a fuzzy PID and conventional PID controllers. The control scheme used for the simulations is presented in Figure 6.
Simulations are performed on MATLAB®/Simulink toolbox to illustrate the efficiency of the FBHC.

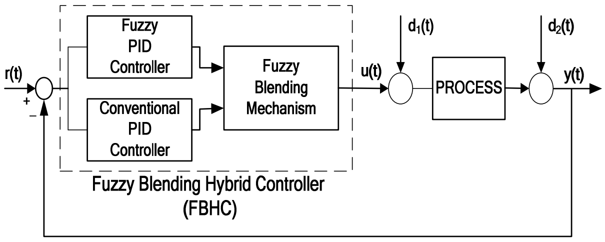

Figure 6: Control Scheme of the Proposed Hybrid Controller

4.1. Linear System

Most of the systems in industry can be modeled as second-order with time-delay systems, therefore the following system has been considered.

$$G(s) = \frac{1}{s^2 + 3s + 1} e^{-0.2s} \tag{3}$$

The controller parameters of the conventional PID controller are designed so as to give a system response with no overshoot and the parameters are as follows: KP=0.92, KI=0.73, KD=0.11. On the other hand, the fuzzy PID parameters have been designed so as to provide a fast rising time as follows: Ke=1.89, Kd=1.35, alfa=1.1, beta=0.1.

A unit step reference is applied in the beginning, and then at 18th second, the reference is changed from one to 1.5. In addition, an output ($d_2(t)$) and an input ($d_1(t)$) disturbance with amplitude of 0.2 units are applied to the system at 30th second and at 50th, respectively.

The corresponding system responses and controller outputs are given in Figure 7 and Figure 8, respectively. It can be seen from Figure 7 that the proposed controller provides satisfactory performances for different reference signals and disturbances. The system response of the FBHC is always between responses of other controllers as it is expected from the blending mechanism.

The FBHC control signal is between the Fuzzy PID and Conventional PID control signals, since it is blended with different values of γ. When γ is close to 1, FBHC controller performs like Fuzzy PID controller. On the other hand, when the value of γ becomes 0 the output of the proposed controller is equal to the Conventional PID.

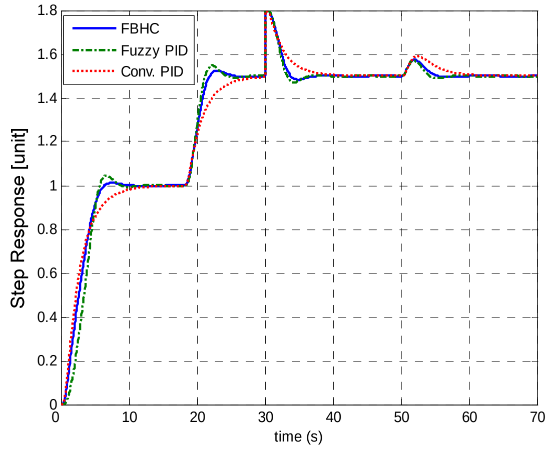

Figure 7: The System Output For Varying Reference Values And Under Disturbances.

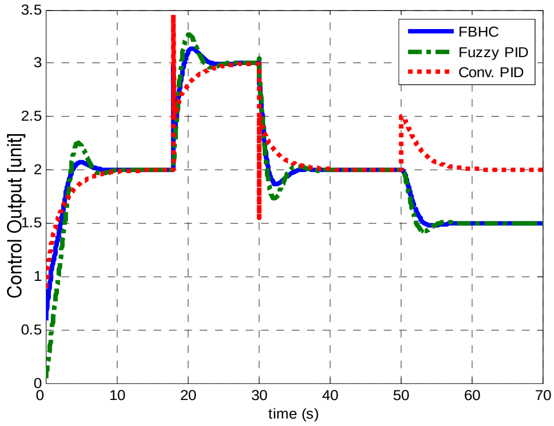

Figure 8: The Control Signal For Varying Reference Values And Under Disturbances.

4.2. Nonlinear System

In the nonlinear simulation study, the proposed controller will be used for a nonlinear spherical tank process as presented in Figure 9. The Simulation results confirm the better performance of the proposed hybrid controller.

A spherical tank system is a nonlinear level control system (Agrawal and Lakshminarayan 2003). The parameters of system are given in Table 3.

The differential equation can be gives as;

$$Q_i(t-d) - Q_o = (\pi - \pi(R-y)^2)\frac{dy}{dt} \tag{4}$$

where R is the radius of tank, Q_i is the inlet flow rate (volumetric), and Q_o is the outlet flow rate (volumetric). d is the delay from input Q_i to the controlled output y. With Bernoulli equation;

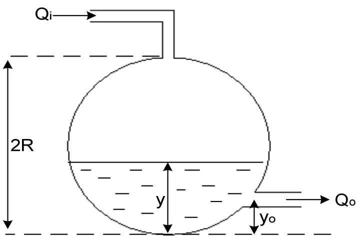

Figure 9: Spherical Tank System

$$Q_o = \sqrt{2g(y - y_o)} \quad (5)$$

where y_o is the height of output pipe and g represents the gravitation constant.

Table 3: Spherical tank parameters

Radius of tank [m]	R = 1m
Delay from Q_i to y	d = 0 s
Gravity acceleration [m/s^2]	g = 9.81
Height of the output pipe [m]	y_o=0.1m
Inlet volumetric flow rate [m^3/s]	$Q_i(t)$
Outlet volumetric flow rate [m^3/s]	$Q_o(t)$
Height of liquid level [m]	y

The controller parameters of the conventional PID controller are designed so as to give a system response with no overshoot and the parameters are as follows: K_P=0.72, KI=2.51, KD=0.051. On the other hand, the Fuzzy PID controller parameters have been designed so as to provide a fast rising time as follows: Ke=4.62, Kd=1.61, alfa=6.021, beta=1.523.

It is assumed that the initial value of the tank height is 0.1m. Since the nonlinearity is directly related to the level of the water, the controller has been tested for different reference values as 0.4 m and 1 m. After the process output is converged to the set point, at 25th second an input disturbance with a value of 0.1 m, and an output disturbance with a value of 0.1 m at 35th second are applied in order to examine the disturbance rejection of the control structure.

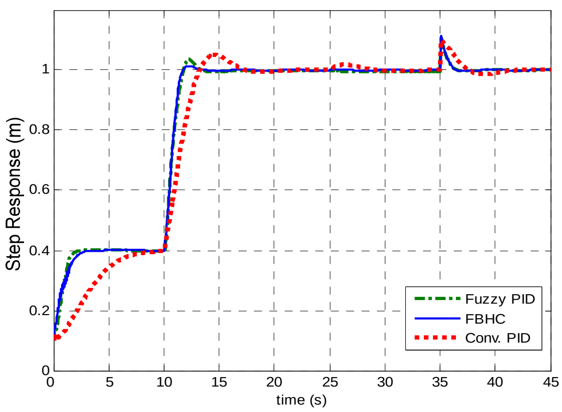

Figure 10: The System Output For Varying Reference Values and Under Disturbances.

The corresponding system responses and controller outputs are given in Figure 10 and Figure 11, respectively. It can be seen from Figure 10 that the proposed controller provides satisfactory performances for different reference signals and disturbances.

The FBHC control signal is between the Fuzzy PID and Conventional PID control signal, since it is blended with different values of γ. When γ is close to 1, FBHC control output is like Fuzzy PID output.

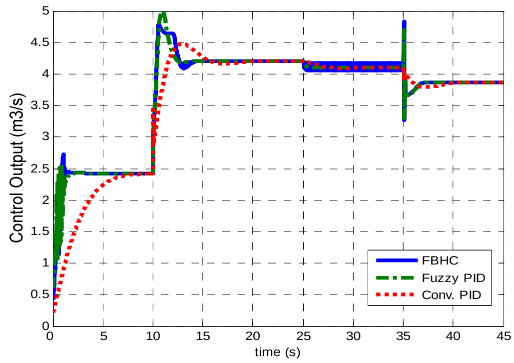

Figure 11: The Control Signal For Varying Reference Values And Under Disturbances.

5. CONCLUSIONS

A new method toward designing a Fuzzy PID and Conventional PID type hybrid controller using a fuzzy blending mechanism has been presented in this paper. Conventional PID controllers are very popular controllers in industry due to their simplicity and cost affectivity. With this hybridization methodology, intelligent technology can be inserted more easily into the real-life industrial projects. Here, a fuzzy blending mechanism, which hybridized two well known controllers, is designed so that it produces a remedy for most of the system situations such as reference changes, different types of disturbances. The main idea of this design is to use the dominant control signal with higher fulfillment degree to produce faster system response for rising time and then blending with the other control output in order not to have a major overshoot.

The proposed controller has been applied to both linear and nonlinear systems. Performance comparison between the presented controller and the controllers involved has been carried out by a system simulation results all confirm the advantage of the presented controller.

The fuzzy blending mechanism is independent of the controllers that have been hybridized; so for the future work, other control methods can be used to have a different type of hybrid controllers for different processes.

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