A NEW SELF-TUNING BLENDING MECHANISM FOR FUZZY PI AND PD CONTROLLERS

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ABSTRACT

In this study, a new mechanism that blends the "PI-type" and "PD-type" output portions of a fuzzy logic controller (FLC) is presented. The FLC used in this study has a new structure and a newly devised input (s) named as "normalized acceleration". An empirical relation and a rule-base are presented for blending PI and PD portions of the FLC in an on-line and self-tuning fashion. Both the empirical relation and the rule-base use the same inputs of the FLC as intelligent procedures. The robustness and effectiveness of the blending mechanism are illustrated through simulations done on a second-order system with varying parameters.

I. INTRODUCTION

A common FLC derives its decisions from the input error signal (e) and the change of error (de). Thus, it is structurally similar to a classical proportional plus derivative (PD) controller. In fact, the equivalence between this type of FLCs and conventional PD controllers have been established [1, 2]. However, most of the fuzzy logic controllers have been designed as fuzzy PID-type controllers in later studies [3, 4, 5]. PID-type FLCs usually face the following difficulties associated with

- the generation of an effective and reliable rule-base,
- the increase in the size of rule-base with the number of fuzzy sets used for every input variable in a polynomial manner,
- the tuning of large number of parameters.

In study [3], Abdelnour and his friends have achieved a reduction in storage location using the symmetrical properties of 3-D table designed for fuzzy PID controller. As an alternative approach Lee [6] has proposed a method that "gain schedules" a fuzzy PD controller gradually to become a fuzzy PI controller when the response approaches to the steady-state. Similar to this method, Brehm and Rattan [7] have developed a hybrid fuzzy PID controller switching between a fuzzy PD and a PI controller. It is obvious that the "scheduling" or "switching" will not only be difficult to design but also need to vary with system input and/or operating levels.

In this study, a new mechanism is presented for blending the "PD-type" and the "PI-type" output portions of the FLC given in [8]. This FLC consists of two rule-base blocks and a logical switch in between while each one of the rule-base blocks have been designed so that they admit two inputs; namely the "error"(e) and a newly devised input named as "normalized acceleration" (s). The input (s) gives a relative value about the "fastness" or "slowness" of the system response. The blending mechanism is obtained either through an empirical formula or a rule-base both using the same inputs of the FLC in an on-line and self-tuning manner. The robustness and effectiveness of the blending mechanism are illustrated through simulations done on a second-order system with varying parameters.

II. THE NEW INPUT VARIABLE:NORMALIZED ACCELERATION

The normalized acceleration s(k) that provides an important and internal information about the system response is defined in [8] as

$$s(k) = \frac{de(k) - de(k-1)}{de(.)} = \frac{dde(k)}{de(.)} \qquad (1)$$

Here, de(k) is the incremental change in error and it is given by

$$de(k) = e(k) - e(k-1) \qquad (2)$$

and dde(k) is called the acceleration in error and it is given by

$$dde(k) = de(k) - de(k-1) \qquad (3)$$

In (1), de(.) is chosen as follows

$$de(.) = \begin{cases} de(k) & \text{if} \quad |de(k)| \geq |de(k-1)| \\ de(k-1) & \text{if} \quad |de(k)| < |de(k-1)| \end{cases} \qquad (4)$$

The normalized acceleration s(k) given in (1) yields us a relative rate information about the "fastness" or "slowness" of the system response.This rate information remains within a range of [-1,1]. If the system response is very fast, s(k) approaches to 1, and if the system response is very slow, it approaches to –1. When the system response increases or decreases with a constant rate, it is considered as a "medium" rate and s(k) takes the value of zero.

III. PI PLUS PD BLENDING MECHANISM

In process control systems, fuzzy logic PI controllers are most common and practical followed by the fuzzy logic PD controllers. The performance of fuzzy logic PI controllers is known to be quite satisfactory for linear first order systems; however, this performance may degrade for higher order systems, systems with large dead-time and also for nonlinear systems. Fuzzy logic PD controllers are, however, suitable for a limited class of systems. In fact, they should be avoided in presence of measurement noise and sudden load disturbances. Therefore, fuzzy logic PID controllers are used in controlling much larger class of systems. However, fuzzy logic PID controllers are rarely used due to difficulties associated with the generation of an efficient rule-base and tuning of large number of parameters.

Keeping the above facts in mind, we propose a PID-type FLC as shown in Figure 1. The FLC block used in this study is presented in [8]. It consists of two rule-base blocks and a logical switch in between while each one of the rule-base blocks have been designed so that they admit two inputs; namely the "error"(e) and a newly devised input named as "normalized acceleration" (s). When the output of the FLC block in Fig.1 is taken as u(k), this controller acts as a PD-type controller; whereas, the output is taken to be du(k) the controller becomes PI-type controller. The PID-type FLC is obtained paralleling the output of the FLC block as shown in Figure 1.

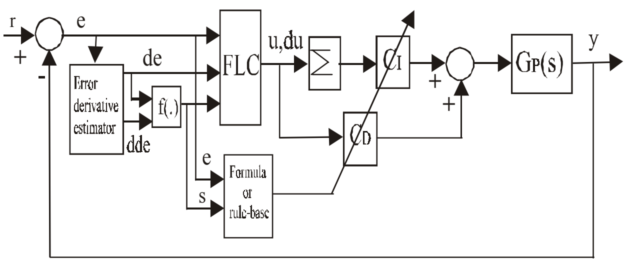

Figure 1.Structure of the PI and PD-type blending mechanism

Since the PID-type FLC is formed blending the PI-type and the PD-type controller outputs, we need two output blending factors that are designated as C_I and C_D for PI-type portion and PD-type portion, respectively. These blending factors can be found by either trial and error or an intelligent evolutionary computational scheme. However, dynamic or adaptive setting of these factors can either be done using an empirical relation or a rule-base in an online manner. In this study, we have proposed an empirical relation and a rule-base that both depend on the input variables of the FLC; namely, the error "e" and the relative acceleration "s". We have set

$$C_D=1-C_I \tag{5}$$

so that an exact blending mechanism is obtained between the two controller types; namely, PI-type and PD- type portions. The blending factor C_I is calculated by either an empirical formula or a rule-base through the metarules that can be summarized as follows:

1) For any specific error value C_I parameter should increase as "s" approaches to –1 and it should decrease as "s" approaches to 1.
2) When the relative speed "s" approaches to –1 and the error is large (that is $|e|$ approaches to 1) then the effect of the PI-type portion or C_I parameter of the fuzzy logic controller should be "highest".

Using the above metarules, an empirical relation for C_I can be proposed as follows:

$$C_I = \exp\left[-\frac{(s+2)}{1+|e|} \right] \tag{6}$$

The above empirical relation is illustrated in Figure 2. Inspecting the figure, it can easily be deduced that the metarules of the blending mechanism are satisfied by the empirical relation.

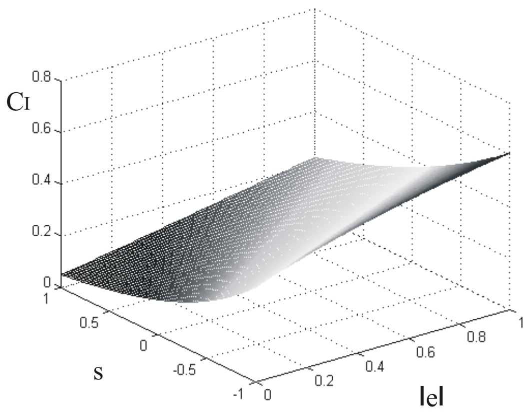

Figure 2. Illustration of the empirical relation of C_I

A FLC block with the tentative rule-base given in Table 1 can be proposed in place of the empirical relation. The inputs of the blending FLC are the absolute value of error "lel" and the normalized acceleration "s". The input variable lel is quantized into fuzzy sets of four levels;

whereas, the input variable s is quantized into three levels, such that,

L= large; M=medium; S= small; Z= zero

Table 1.Rule-base for "C_I"

lel \ s	N	Z	P
L	L	L	M
M	L	M	S
S	M	S	Z
Z	S	Z	Z

The triangular membership functions are assigned for all of the variables. The view of the rule-base is shown in Figure 3. Inspecting this figure, it can easily be seen that the rule-base also satisfies the metarules of the blending mechanism.

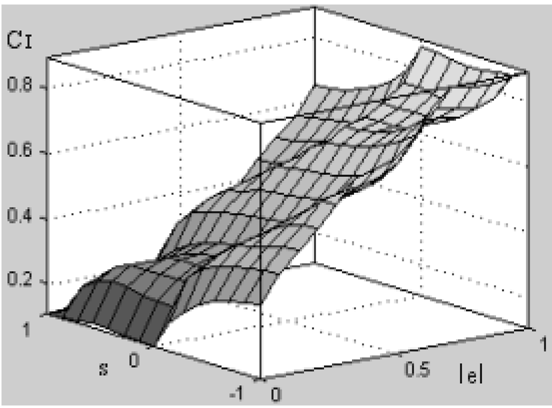

Figure 3.View of the rule-base for C_I

The discrete transfer function of the blending mechanism can be expressed as

$$T_b(z) = C_I \frac{1}{1-z^{-1}} + (1-C_I) = \frac{1-z^{-1}(1-C_I)}{1-z^{-1}} \quad (7)$$

When the parameter C_I is equal to zero the output remains to be PD-type, since the main FLC produces a PD-type output. On the other hand, when C_I is equal to one the output of the blending mechanism becomes PI-type. Then, it is very obvious that, when C_I gets values between 0 and 1, the output can be considered as PID-type.

IV. APPLICATIONS

All of the simulations are done on a second-order linear system described by

$$G_p(s) = \frac{5}{s^2 + \alpha s + \beta} \quad (8)$$

for various values of α, β. It is assumed that the parameters α and β vary in the range of [0, 5]. When the parameters α and β vary within this range, the poles of $G_p(s)$ remain inside the shaded region or stay on the dark and thick line segment as shown in Figure 4. The simulations are carried on the typical four pole configurations as shown in Figure 4 and they are designated as the cases a, b, c and d. The parameter values and the related system types of these cases are given as

Case (a): α =5 and β =0;marginally stable / type-1 system

Case (b): $\alpha = 2\sqrt{5}$ and β =5;criticallydamped/type-0 system

Case (c): α =3 and β =4; over-damped / type-0 system

Case (d): α =0 and β =5; oscillatory / type-0 system

The input and output scaling factors for the proposed FLC are set to the fixed values C_e=C_s=1 and C_u=4. These fixed values are obtained for an "optimal" system response using pure PD-type new FLC. Moreover, no online or offline adjustment or tuning is done on these factors when the system parameters α and β are changed, so that the effectiveness of the blending mechanism has been tried to be demonstrated. In all of the simulations uniformly distributed triangular membership functions are used.

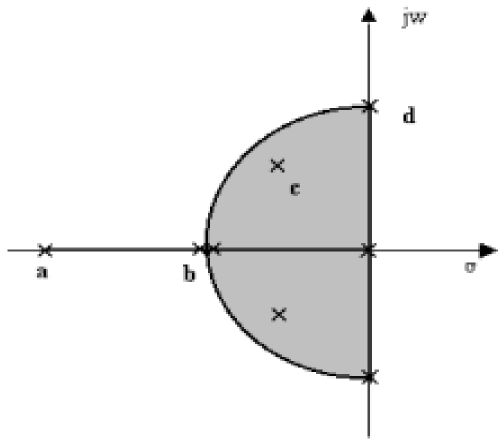

Figure 4. The region for the poles of $G_p(s)$

The basic or primitive type of blending can be achieved by mixing the two portions in equal amounts. In this case, by setting C_I equal to 0.5 (so that C_D also becomes 0.5), even blending of PI and PD portions are obtained. This type of blending does not possess any intelligence and it is named as "direct-even" blending. Simulations with the blending mechanism have been performed using three procedures; namely, "direct-even" blending, the empirical formula (6) and the FLC with the rule-base given in Table 1. The step responses related to the three blending procedures have been presented and compared with each other.

***Case (a)*:** $\alpha = 5$ and $\beta = 0$;marginally stable / type-1 system

The step responses related to case (a) are given in Figure 5. The responses related to the empirical formula and the fuzzy rule-base are almost the same. Although, all three of the responses are satisfactory, the response related to the "direct-even" blending demonstrates a lower quality compared to the other two responses.

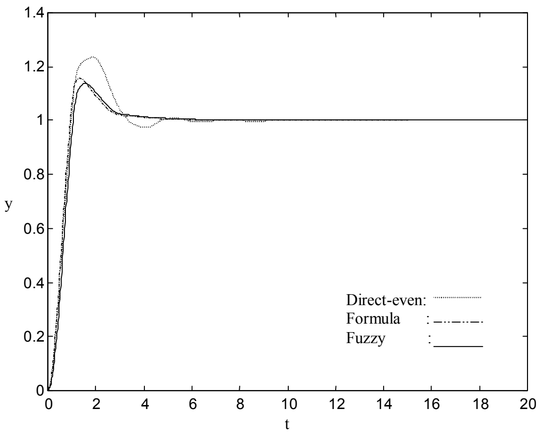

Figure 5. Step responses for case (a)

***Case(b)*:** $\alpha = 2\sqrt{5}$ and $\beta = 5$;criticallydamped/type-0 system

The step responses related to case (b) are given in Figure 6. All three of the responses are again almost the same and satisfactory; however, the response related to the fuzzy blending demonstrates a better quality compared to the other two responses.

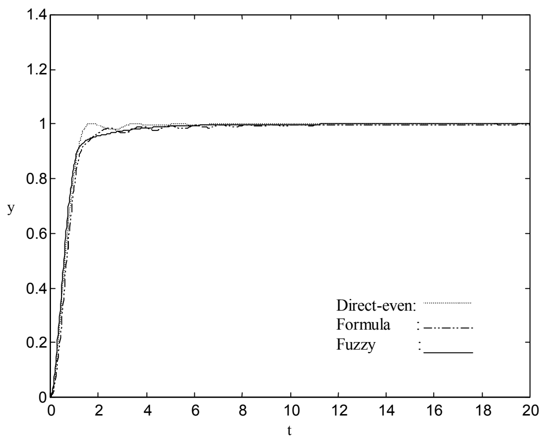

Figure 6.Step responses for case (b)

***Case (c)*:** $\alpha = 3$ and $\beta = 4$; over-damped / type-0 system

The step responses related to case (c) are given in Figure 7. Although, all three of the responses are similar to each other and oscillatory, the response related to the fuzzy blending demonstrates a slightly better quality compared to the other two responses. It is quite possible that much better responses could be obtained if the input and output scaling factors of the FLC were tuned.

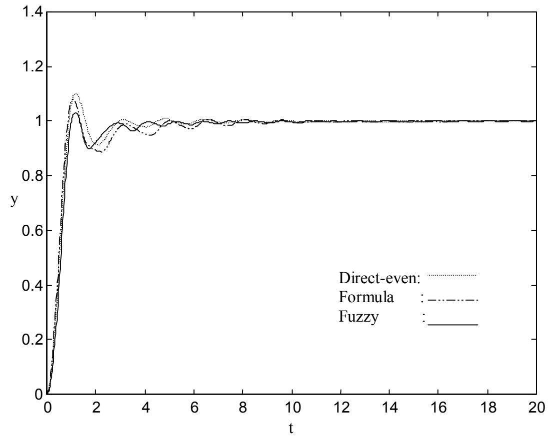

Figure 7.Step responses for case (c)

***Case (d)*:** $\alpha = 0$ and $\beta = 5$; oscillatory / type-0 system

The step responses related to case (d) are given in Figure 8. Since the system to be controlled is of oscillatory type and no tuning on the input and output scaling factors are done, the output response becomes unstable for "direct-even" blending procedure. However, when an intelligent blending mechanism such as a fuzzy rule-base or a empirical formula is used, the system response remains to be stable with an acceptable oscillatory behavior under the same operating conditions; that is, pre-assigned input and output scaling factors are not changed. This case is the most remarkable one since it shows the effectiveness and use of the intelligent blending mechanisms developed in this study.

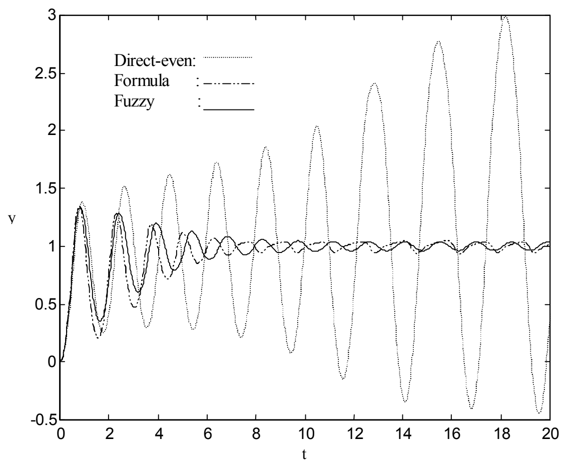

Figure 8.Step responses for case (d)

V. CONCLUSION

In order to design a PID-type of controller from a PD-type FLC a new blending mechanism with intelligent procedures are developed in this study. The output of the blending mechanism is obtained either using an empirical relation or a rule-base in an online and intelligent manner or a fixed setting of blending factors. The empirical relation and the rule-base use the same the input variables of the proposed FLC. The robustness and effectiveness of the new FLC and the blending mechanism are illustrated through simulations done on a second-order system with varying parameters.

When pure PD-type FLC configuration is implemented for a second order and type-1 system, a quite good performance can be achieved. When pure PI-type configuration is used for type-0 systems with an order higher than two, the performance degrades quite a bit. In these cases, a PID-type configuration is inevitable and this can be achieved by blending PD and PI portions of the controller. The step responses related to the blending mechanism with three different procedures have been presented and compared with each other. In these simulations, it has been observed that the blending with an intelligent procedure (rule-base or empirical formula) produces better results compared to both "direct- even" procedure (fixed blending factors) and pure PI-type or PD-type configurations.

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