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A Combined Fuzzy - PID Controller

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Abstract

In this paper, merits of both fuzzy and PID controllers are combined. The combined controller is designed such that the tuning of the PID controller is achieved by the basic fuzzy controller via its rule base. The proposed scheme avoids the tuning of PID parameters which is always a time consuming task, difficult to carry out and often poorly done. Computer simulations are made to demonstrate the satisfactory tracking performance of the combined fuzzy - PID controller.

Key Words : PID control; Fuzzy control

1.0 Introduction

Conventional PID controllers have been extensively used in many Industrial control systems and are still being used. This is due to their structural simplicity, constant disturbance cancellation, error - free tracking of constant set point, and reduced sensitivity to parameter variations. However, tuning of such a controller is usually carried out by trial and error procedures and using some practical rules in some cases. Furthermore, the control performance may deteriorate, even when these parameters are correctly tuned. This is usually as a result of nonlinearity or time varying nature of the process under control. Thus, the tuning is always a time consuming task, difficult to carry out and often poorly done.

Several methods have been developed to address this problem in the sense that the PID parameters are tuned automatically. These methods range from the Ziegler - Nichols methods, pole placement technique to advanced control algorithm.

Currently, the application of fuzzy logic to many technical and Industrial areas is in the increase. This is because fuzzy logic controllers perform better than conventional controllers and are able to control systems not feasible with conventional controllers. Fuzzy logic provides a technique by which qualitative and imprecise linguistic statements are translated into computer algorithms. Thus, providing the implementation of qualitative linguistic statements as regards control procedures and goals for system performance.

Therefore, In this paper, the merits of a PID controller and a basic fuzzy controller are combined to form a new Fuzzy - PID combined controller. The combined controller is designed such that the tuning of the PID controller is achieved by the basic fuzzy controller via its rule base. The error between the set point and the output of the system is divided into three grades corresponding to the PID controller parameters while the control strategy is divided into two modes.

The proposed Fuzzy - PID combined controller is applied to a combustion control design . i.e. control of the system with one input (flow of air) and one output (Oxygen content). Comparison between controls with Fuzzy - PID combined controller and PID pole placement controller is made on the basis of results obtained by computer simulations. The simulation study indicates the superiority of the Fuzzy - PID combined controller over the conventional PID controller, and shows that the Fuzzy - PID combined control scheme seems to have a lot of promise in its application to combustion control design.

2.0 PID Controller

The PID control algorithm consists of proportional, integral and derivative control algorithms. The transfer function of a continuous type PID controller is given as

$$G_c(s) = k_p(1+\frac{1}{T_i s}+T_d s) \qquad (1)$$

where k_p is the proportional gain, T_i is the integral gain and T_d is the derivative gain.

To avoid the differentiating becoming unnecessarily large when the sampling time is very small and consequently result in an unstable control system, we adopted that

$$T_d s = \frac{T_d s}{1+\frac{T_d s}{N}} \qquad (2)$$

where N is the taming factor, usually N $\approx$ (3 - 10) which limits the high frequency gain and thus high frequency noise would not be amplified.

To avoid the differentiating term becoming unstable, we propose to use forward discrete algorithm for the integrator and backward discrete algorithm for the differentiator. Thus,

$$G_c(z) = k_p\left\{1+\frac{T}{T_i(z-1)}+\frac{NT_d}{T_d+NT}\frac{z-1}{z-\beta}\right\} \qquad (3)$$

where $\beta = \frac{T_d}{T_d+NT}$

3.0 The Combined Fuzzy - PID Controller

The proposed architecture of the fuzzy PID Controller is as shown in figure 1 where the error between the desired set point and the output of the control system is divided into three grades and the control strategy is divided into two modes.

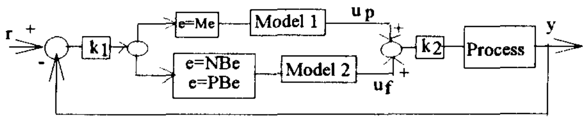

Figure 1: Fuzzy - PID combined Controller

e - error, NBe - Negative Big error, Me - Medium error, PBe - Positive Big error, u_n - output of the combined controller, k_1 and k_2 are scaling factors, model 1 is the conventional PID algorithm and model 2 is the Fuzzy control technique.

The rule base of the combined Fuzzy -PID controller is made up of the following three rules :

Rule 1 : If $e_n = NBe$
then $uf_n = e_n/4$; $up_n = 0$.

Rule 2 : If $e_n = Me$
then $uf_n = 0$;

$$up_n = (\beta+1)up_{n-1} - \beta up_{n-2} + kp(e_n - (\beta+1)e_{n-1} + \beta e_{n-2}) + ki(e_{n-1} - \beta e_{n-2} + kd(e_n - 2e_{n-1} + e_{n-2})$$

Rule 3 : If $e_n = PBe$
then $uf_n = -e_n/4$; up_n

These rules describe how the control output and its change are adjusted.

4.0 Simulation

Simulation studies were carried out to prove the effectiveness of the combined Fuzzy - PID controller. First we consider the combined fuzzy - PID controller for a nonlinear process, and in the second example, the proposed controller is applied to a combustion control design to control a system with one input (flow of air) and one output (Oxygen content). In our simulation studies, we use the discrete simulation method.

Example 1 : A nonlinear process whose dynamic is given as

$$\dot{y}(t) = 0.0001|y(t)| + u(t) \qquad (4)$$

In this case, the fuzzy - PID combined controller parameters are : T = 0.1 ,N = 5, T_i = 0.1, T_d = 0.8, k_p = 0.01, k_1 = 1.0, k_2 = 1.0, and the set - point r = 1. The tracking response of the fuzzy - PID combined controller for this nonlinear process to a step input is shown in figure 2, which depicts a very good tracking result.

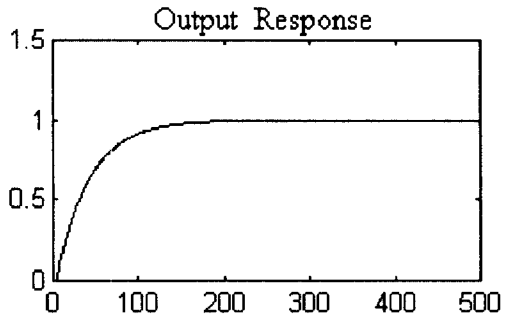

Figure 2 : Result of Example 1

Example 2 : The combustion process model [2]with one input (flow of air) and one output (oxygen content) can be described by

$$\frac{dx}{dt} = \frac{1}{v_k}(-x(\phi_x + \phi_g(v_d - v_0)) + 21\phi_x - 100v_0\phi_g) \qquad (5)$$

where x-volume percentage of Oxygen [vol. %], v_k-combustion chamber volume[m^3], ϕ_g-normalized flow of fuel [kg/s], ϕ_x-normalized flow of air [Nm^3/kg], v_0-theoretical needed air volume for the combustion of fuel unit [Nm^3/kg], v_d-theoretical obtained gas volume from fuel unit[Nm^3/kg].

(5) can be expressed in the form

$$\dot{x}(t) = A_1 u(t)x(t) + A_2 x(t) + Bu(t) + E$$
$$y(t) = x(t - Td) \qquad (6)$$

where

$$u = \phi_x, A_1 = -1/v_k, A_2 = \frac{v_0 - v_d}{v_k}\phi_g, B = \frac{21}{v_k}, E = -$$
$$Td - timedelay$$

According [2], the nonlinear equation (6) is linearized and approximated with a first order system as

$$G(s) = \frac{0.7474}{1 + 4.70s}e^{-Tds} \qquad (7)$$

(7) can be written in time domain with a sampling time of 0.1 second as

$$y(t+1) = 0.9789y(t) + 0.0157u(t - Td) \qquad (8)$$

Th1s linearized Combustion model (8) have been well validated in a real power plant [2].

The fuzzy - PID combined controller parameters are : T = 0.1 ,N = 5, T_i = 0.5, T_d = 0.8, k_p = 1.6, k_1 = 7.11, k_2 = 1.0, and the set - point r = 1. The tracking response of the fuzzy - PID combined controller for a step input is shown in figure 3 together with the control input response. while that of a PID controller using the pole assignment method with kp = 0.2179, ki = 0.0296, kd = 0.3945 and time delay td = 18 seconds is shown in figure 4. Comparing these results, it is evident that the result of figure 3 is remarkable. There is great improvement in the control performance with the fuzzy - PID combined scheme. These simulation results revealed that the fuzzy - PID combined controller has better transient and steady state tracking responses.

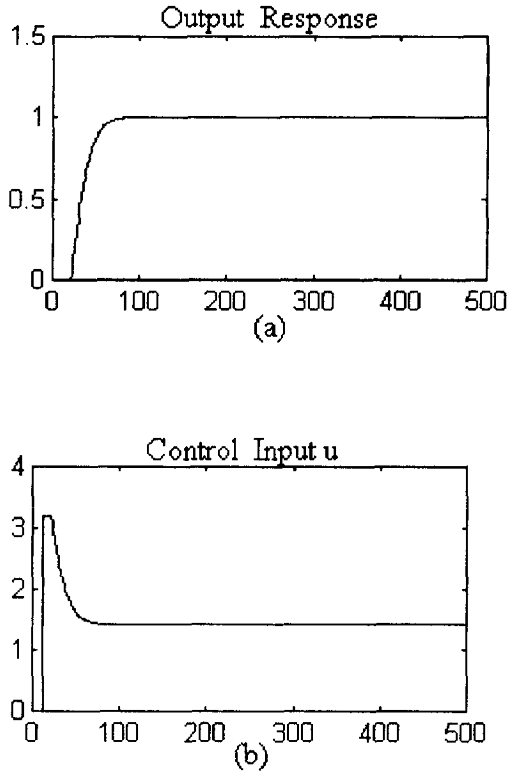

Figure 3 : Result of Fuzzy - PID Control Scheme for Example 2

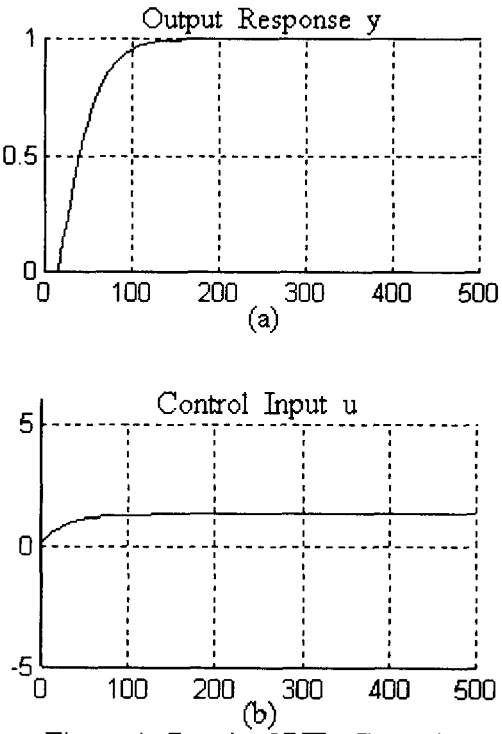

Figure 4 : Result of PID Control Scheme

5.0 Conclusion

In this paper, the merits of Fuzzy and PID controllers are combined such that the difficult in tuning of the PID controller parameters is avoided. In the combined Fuzzy - PID controller, tuning is achieved by the fuzzy control scheme through its rule base. This scheme is very easy when compared with the tuning of the parameters of the conventional PID controller.

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