A METHOD FOR SELECTION OF PID CONTROL STRATEGY BASED ON FUZZY BEHAVIOUR MODELLING

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Summary

Fuzzy logic is rarely used to implement commercial PID control. It is often seen that operators tune the parameters of a controller according to error versus time curves based on their knowledge and experience, rather than control algorithms. Their tune actions seem to be based on relations between the shape of the response curve and the parameters, rather than on explicit process models. This paper attempts to develop a tool to select a PID controller among different schemes. Due to inaccuracy and uncertainty of the real processes, our proposal implies fuzzy logic. In addition to the PID selector, the contribution of this paper is a new method of conventional PID controller.

Keywords: Fuzzy Logic, Controller, PID, Tuning, Behaviour modelling.

1 Introduction

Fuzzy Logic controllers (FLC) have been reported to be successfully used for a number of complex and nonlinear processes. Much of fuzzy control research is focused on the set-point regulation problem [1]-[5]. Fuzzy control is not much different from conventional PID control, when used in this way. Because it is solving the same set point regulation problem and in essentially the same way, except that fuzzy control provides a non-linear input/output mapping [6].

Conventional PID control is well established in industry and can satisfy the performance requirements of most set-point regulations problems. PID type fuzzy logic controllers rarely appears in commercial applications due to the difficulties associated with the generation of an efficient rule base and the tuning of its large number of parameters. Commercial applications of fuzzy control are largely focused on high-level, task-oriented control rather than the set point regulation.

For set point regulation problems, switching between different control laws is usually a function of the measured plan states. At higher levels of control, switching between different control strategies is based on high level characterisations of the operating environment and they need to be indirectly inferred. In such cases, fuzzy logic is extremely useful for encoding the heuristics to infer the characteristics.

A mathematical model of the plant hardly ever is available and the model can be only inferred through the response to a step input. Due to inaccuracy and uncertainty of the process, it is preferred investigating "heuristic algorithms" instead of "exact algorithms" for the determination of the best PID formula of control. This paper attempts to develop a fuzzy tool to select a PID controller among different schemes and to value their goal achievement.

Our scheme is based on the fact that, a skilled human operator tries to manage the process to get controlled the process irrespective of the nature of the process to control. While controlling a plant, the operator manipulates the process input or controller output with a view to diminish the error within the shortest possible time. It is desirable to incorporate the expert knowledge of design engineers so that the controller can make decisions on the choice of control algorithm and provide diagnostic on the effectiveness of the control.

2 Conventional PID Controllers

The transfer function of a PID controller has the following form:

$$G_c(s) = \frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i s}\right)(1 + T_d s) \qquad (1)$$

Where K_p, T_i and T_d are the proportional controller, the integral and derivative time constant. $U(s)$ is the controller output and $E(s)$ is the error signal.

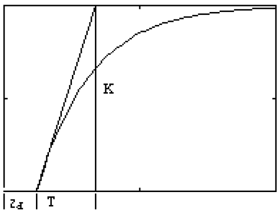

Figure 1: Reaction curve

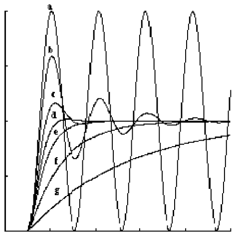

Figure 2: Definition of dynamic behaviour

The tuning formula of Ziegler-Nichols is a well-known scheme for determining good settings of PI and PID controllers for wide range of industrial processes [7]. In the second method of Z-N, *the method of process reaction curve*, the open loop unit step response of the plant usually has the form shown in figure 1. Straight line, with τ_d , T and K approximate the response.

The step response can be approximated by a first-order plus time delay model given in equation:

$$G(s) = \frac{Ke^{-\tau_d s}}{Ts+1} \tag{2}$$

The goal of PID controller design is to determine a set of values of (K_p, T_i, T_d) to meet a given set of closed loop system performance requirements. In practice, it is not possible to achieve all these goals.

Many researchers have tried to overcome the disadvantages of the Ziegler-Nichol method and have suggested some heuristic refinements. There are many useful methods available in literature and it is not possible to cover all of them.The most popular methods are selected in this paper [8]-[14].

They develop a strategy to instantaneously tune (K_p, T_i, T_d) based on the observation of the plant output and the set point, to get a “good” response to set point changes. A good response means that the closed-loop response approximates a given reference response.

3 Behaviour Modelling of a PID Controller

Description of controlled plants using dynamic behaviour models is more general than using analytical model [15]. A dynamic behaviour of a system is defined by its dynamic response under a given input signal. A group of systems has a similar dynamic behaviour that can be modelled by choosing a system with simple dynamics.

Any two plants with a similar dynamic behaviour under a given input do not mean that their analytical models are equivalent. If the dynamic equations of two plants are identical they must have a same dynamic response under a given input.

It may be defined very few types of dynamic behaviour to describe all responses to a step input as in figure 2:

a) Oscillation
b) Strong over-damping
c) Slightly over-damping
d) Appropriate
e) Slightly under-damping
f) Under-damping
g) Strong under-damping

4 The PID-selection Mechanism

The goal of the selected PID controllers is to compensate for a minimum overshoot (OS), a minimum setting time (T) and a higher decay ratio (D) of the closed loop response while ensuring that the system remains stable. In this study, the conventional formulas for the PID selector are:

1.- Ziegler-Nichols II
2.- Cohen-Coon
3.- López ITAE
4.- Rovira IAE
5.- Chien-Hornes-Reswick
6.- Rosenberg
7.- Kaya-Scheib
8.- Smith's Predictor
9.- Dahlin

It is shown [16] that the normalised dead time and the normalised process gain can be used to predict the achievable performance of PID controllers tuned by formulas. A previous simulation showed that performance expressed in terms of overshoot, setting time and decay ratio only depends of the dead time in wide range of gain for the selected formulas. Control selection can be established through the previous setting of τ_d and T affected with inaccuracy and uncertainty due to nature of their determination. Usually an exact value of the relation is unknown for the operator.

5 Formulation of the Fuzzy PID Selector

The inference engine provides a set of selection actions according to fuzzified inputs. It contains the knowledge base, which is composed of two components, the database and the fuzzy selector-tuning rule base.

Linguistic variables and fuzzy terms. Three parameters are used as input of the PID selector: overshoot ratio (OR), time deviation ratio (TD) and reduction

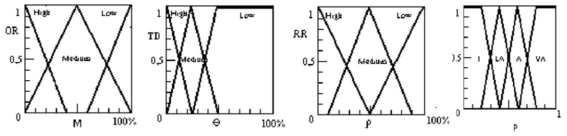

Figure 3: Membership functions

ratio (RR). Each of the three parameters was assigned a linguistic variable and divided intro three fuzzy terms corresponding to meanings of *low (L), medium (M), and high (H).* TD deals with the difference between $T+\tau$ and the actual time and RR deals with the difference between 1st and 2nd peaks of the response

Only an output fuzzy variable is used, corresponding to performance (P) of the control, and assigned a linguistic variable and divided intro four fuzzy terms corresponding to the meanings of *very appropriate (VA), appropriate (A), less appropriate (LA), inadequate (I).*

A relation between fuzzy output and behaviour modelling showed in figure 2 can be established as:

Very appropriate:	d	Less appropriate:	b, f
Appropriate:	c, e	Inadequate:	a, g

Membership functions (L, M, H) assigned with linguistic variables are used to fuzzify physical quantities. Each method provides these values in figure 4. The fuzzified inputs are inferred to a fuzzy rule base, which is used to characterise the relationship between fuzzy inputs and fuzzy output All fuzzy sets are modelled with membership functions.

Knowledge base design. The fuzzy selector-tuning connects the overshoot, the time and to the output In the rule base shown in Table 1, only Zadeh's logical 'and,' which is the min operator, is used. The response of each fuzzy rule is weighted according to the degree of membership of its input conditions.

We define M as the bound percent overshoot, θ as the percent desired time deviation bound, and ρ as the percent reduction bound in next cycle. Once the ratio τ_d/T is fixed, figure 4 provides estimated values of M, θ and ρ. They have been obtained through experimentation with a wide range of plants. Then, these inputs are applied to the fuzzy PID selector. A previous setting of dead time establishes a classification in relation to its control effect. Each formula provides three fuzzy inputs (OR, TD, RR) as shown in figure 3.

Table 1: Fuzzy Rule Base.

	OR	TD	RR	P		OR	TD	RR	P
1	L	M	L	I	13	M	H	L	I
2	L	M	M	I	14	M	H	M	LA
3	L	M	H	LA	15	M	H	H	A
4	L	H	L	I	16	H	L	M	I
5	L	H	M	I	17	H	L	H	LA
6	L	H	H	LA	18	H	M	L	LA
7	M	L	L	I	19	H	M	M	LA
8	M	L	M	I	20	H	M	H	A
9	M	L	H	LA	21	H	H	L	LA
10	M	M	L	I	22	H	H	M	A
11	M	M	M	LA	23	H	H	H	VA
12	M	M	H	LA					

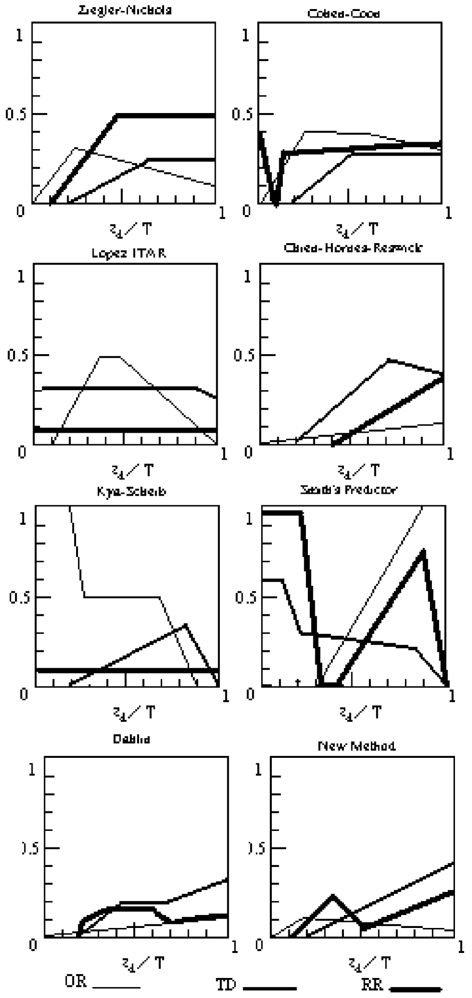

Figure 4: M, θ, ρ values

The selection of a PID controller depends on the order in the classification made by the fuzzy rule base. Once a method is achieved, PID tuning is made with the conventional method.

6 New PID method

In addition to the fuzzy selector, we have designed a new method in order to improve the response of the PID controller. The formulation includes the influence of bounds in the desired response in terms of overshoot, time deviation and reduction ratio.

$$Ti = T + 2\tau_d e^{-\frac{2\rho}{3(\theta+M)}} \tag{3}$$

$$Td = \frac{2\tau_d}{3(1+e^{-\theta})} \tag{4}$$

$$Kp = \frac{2T}{3K\tau_d\left(1+e^{\frac{-TM}{\tau_d}}\right)} \tag{5}$$

7 Numerical simulation

In order to demonstrate the effectiveness of the proposed method and the new formula, we test by numerical simulations time responses of the following plant:

$$G(s) = \frac{20e^{-0.75s}}{(1.5s+1)(0.25s+1)} \tag{6}$$

Settings in the simulation of the proposed method are: $M = 0.01$, $\theta = 0.5$, $\rho = 0.01$. (Figure 5).

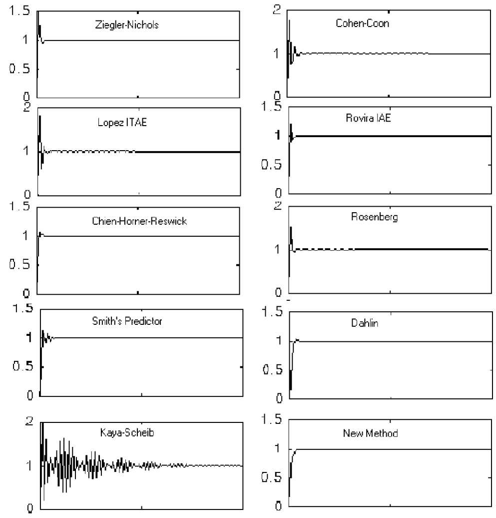

Figure 5: Comparison of time responses

8 Conclusions

The proposed PID selection scheme is human operator oriented. It can select the best appropriate formula for the tuning of a PID controller. A new PID formula is presented that attempt to improve the control with previous setting of bounds in overshoot ratio, time deviation ratio and reduction ratio.

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