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A new adaptive configuration of PID type fuzzy logic controller

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ABSTRACT

In this paper, an adaptive configuration for PID type fuzzy logic controller (FLC) is proposed to improve the performances of both conventional PID (C-PID) controller and conventional PID type FLC (C-PID-FLC). The proposed configuration is called adaptive because its output scaling factors (SFs) are dynamically tuned while the controller is functioning. The initial values of SFs are calculated based on its well-tuned counterpart while the proceeding values are generated using a proposed stochastic hybrid bacterial foraging particle swarm optimization (h-BF-PSO) algorithm. The performance of the proposed configuration is evaluated through extensive simulations for different operating conditions (changes in reference, load disturbance and noise signals). The results reveal that the proposed scheme performs significantly better over the C-PID controller and the C-PID-FLC in terms of several performance indices (integral absolute error (IAE), integral-of-time-multiplied absolute error (ITAE) and integral-of-time-multiplied squared error (ITSE)), overshoot and settling time for plants with and without dead time.

1. Introduction

The fuzzy set theory was firstly introduced by Zadeh to control plants which are difficult to model [1]. Since Mamdani performed the first fuzzy control application [2], fuzzy logic controllers (FLCs) have been widely accepted as one of the most promising solutions for many nonlinear problems. Over the last few years, it has been revealed that FLCs might sometimes be a good technique of designing controllers for different systems over the traditional approaches such as conventional linear PID (C-PID) controllers as they have proven to be more robust and less sensitive to parametric variations [3–13].

The selected type of the controller highly depends on the application [14]. The most popular linear controllers are proportional-derivative (PD), proportional-integral (PI), and proportional-integral-derivative (PID) configurations while the most utilized fuzzy controllers are PD (PD-FLC), PI (PI-FLC), and PID (PID-FLC) types [14].

Among different types of FLCs, just like the extensively utilized conventional PI controllers in various systems [15], PI-FLCs are the most common and practical ones followed by PD-FLCs since they contain the inherent stability of proportional (P) and the offset elimination ability of integral (I) controllers. The performances of PI-FLCs are recognized to be quite satisfactory for linear first-order systems. However, their performances for higher order systems with integrating elements or large dead time, as well as nonlinear systems might be very bad in terms of large overshoot and excessive oscillation. Such systems may be eventually uncontrollable [16]. PD-FLCs are appropriate for a limited class of systems and not recommended in the presence of measurement noise and sudden load disturbances [17].

An FLC has a fixed set of control rules, usually derived from experts' knowledge. The membership functions (MFs) of the associated input and output linguistic variables are generally predefined on a common universe of discourse. For the proper designs of FLCs, successful selection of input and output scaling factors (SFs) and/or tuning of the other controller parameters are/is crucial jobs, which in many cases are carried out through trial and error or based on some training data. Among the tunable parameters, SFs have the highest priority due to their global effect on the control operation. However, relative importance of the input and output SFs to the performance of an FLC system is yet to be fully investigated.

Most of the practical processes under automatic control are nonlinear higher order systems and may have considerable dead time. In addition, some parameters may be time variant or randomly changed due to variations in the ambient conditions. For these reasons, dead time is recognized as one of the most difficult dynamic elements naturally occurring in physical systems [15]. The FLC tries to incorporate this nonlinearity by a limited number of IF-THEN rules, which may not always be sufficient to produce a good approximation to the controller output required for the optimum performance. In such a situation, only static or fixed valued SFs and predefined MFs may not be sufficient to eliminate this drawback. To overcome this, many research works on tuning of FLCs have been reported where on-line or

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off-line approaches are used to tune the input/output SFs or change the definitions of fuzzy sets in order to match the plant characteristics [16–30].

Authors of [16–30] have tried to enhance the tuning methods of FLCs to make their design faster and more practical for real life applications. However, unlike conventional controllers a standard and systematic method for the tuning of FLCs (PI-FLC, PD-FLC or PID-FLC) is yet to be established. There are also many fuzzy controllers that are tuned using fuzzy inference mechanisms [5–49]. Moreover, most of the reported works on FLC tuning is limited only to the first-order linear systems with dead time while it is very hard to apply these relatively models to practical processes that are generally nonlinear and higher order systems with large dead time. Accordingly, there is a need for a robust tuning scheme of FLCs. Unfortunately, unlike the conventional PI, PD, and PID controllers, FLCs have no fixed structures because there is still no well-defined criteria for deciding on 1) the shape of MFs; 2) the number of linguistic values; 3) the standard rule-base; and 4) the most appropriate inference mechanism and defuzzification strategy. These limitations and difficulties associated with the design an optimal FLC have inspired the authors to look into means of tuning SFs and propose a new configuration to improve the existing structures.

Based on the above points, the aim of this paper is to develop a new configuration for PID type FLC to improve the performance of both C-PID controller and C-PID-FLC.

First, a new non-adaptive PID type FLC (NA-PID-FLC) is proposed. The statement “non-adaptive” indicates that SFs are not adjusted while the controller is functioning. Then, an adaptive PID type FLC (A-PID-FLC) is proposed by continuously adapting the output SFs of NA-PID-FLC using a gain updating factor. Two design approaches are introduced to tune the initial values of SFs; a simple method based on its well-tuned counterpart (C-PID controller) and a stochastic method called hybrid-bacterial foraging-particle swarm optimization (h-BF-PSO) algorithm. To verify the

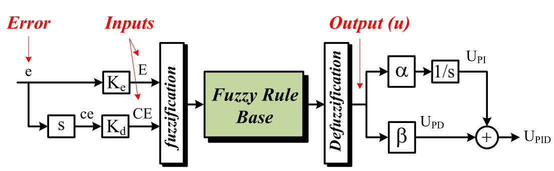

Fig. 1. Structure of C-PID-FLC [32].

Table 1
Linear rule base for C-PID-FLC [32].

CE	*E*						
	NL	**NM**	**NS**	***Z***	**PS**	**NM**	**NS**
NB	NB	NB	NB	NB	NM	NS	*Z*
NM	NB	NB	NB	NM	NS	*Z*	PS
NS	NB	NB	NM	NS	*Z*	PS	PM
Z	NB	NM	NS	*Z*	PS	PM	PB
PS	NM	NS	*Z*	PS	PM	PB	PB
PM	NS	*Z*	PS	PM	PB	PB	PB
PB	*Z*	PS	PM	PB	PB	PB	PB

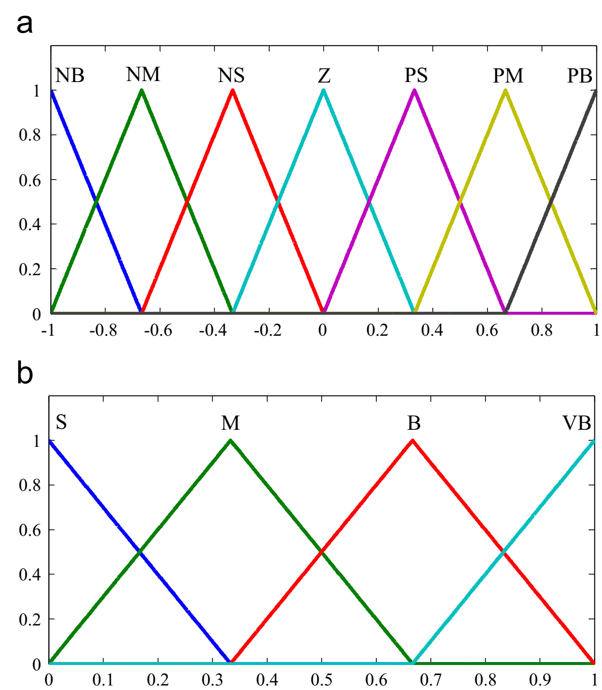

Fig. 3. Membership functions for (a) *E* and CE, and (b) k_{p_FZ} and k_{i_FZ}.

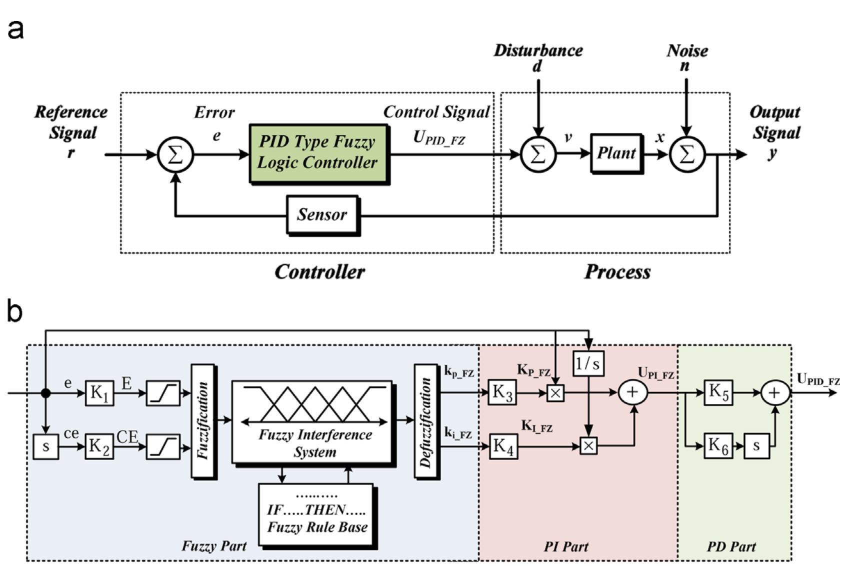

Fig. 2. Structure of (a) control system and (b) proposed NA-PID-FLC.