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Research paper

Fuzzy adaptive control system of a non-stationary plant with closed-loop passive identifier

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Abstract

Typically chemical processes have significant nonlinear dynamics, but despite this, industry is conventionally still using PID-based regulatory control systems. Moreover, process units are interconnected, in terms of inlet and outlet material/energy flows, to other neighboring units, thus their dynamic behavior is strongly influenced by these connections and, as a consequence, conventional control systems performance often proves to be poor.

This paper proposes a hybrid fuzzy PID control logic, whose tuning parameters are provided in real time. The fuzzy controller tuning is made on the basis of Mamdani controller, also exploiting the results coming from an identification procedure that is carried on when an unmeasured step disturbance of any shape affects the process behavior.

In addition, this paper compares a fuzzy logic based PID with PID regulators whose tuning is performed by standard and well-known methods. In some cases the proposed tuning methodology ensures a control performance that is comparable to that guaranteed by simpler and more common tuning methods. However, in case of dynamic changes in the parameters of the controlled system, conventionally tuned PID controllers do not show to be robust enough, thus suggesting that fuzzy logic based PIDs are definitively more reliable and effective.

Keywords: PID-controller; Identification; Fuzzy controller; Closed-loop; Unknown disturbances; Auto-tuning control

1. Introduction

Nowadays the conventional proportional-integral-derivative (PID) controllers are the most widely used for process control in most of the industrial plants. The success of PID control logic can be attributed to the achievement of simple structures of automatic control systems (ACS) and its effectiveness for linear systems [1–7]. There is a wide variety of PID controllers tuning rules: the Ziegler-Nichols rule [8–10], the magnitude optimum method [11–16], the direct synthesis methods [17,18], the Internal Model Control methods [9,19–21], the minimum error integral criteria [22–24], the iterative feedback tuning method [25], the virtual reference feedback tuning method [26,27], the approximate *M*-constrained integral gain optimization method [28], AMIGO method [29] and others. The required quality of a PID control system can be achieved by means of a variety of tuning rules once a linear model of the controlled system and a criteria for the assessment of the control performance are chosen.

Usually the conventional PID controller is not effective for complex dynamic systems [30,31]. The complex dynamic systems are those systems with non-linear static characteristics, i.e. those systems that are described by differential equations with time-varying parameters. This feature essentially complicates the design and analysis of PID-based control systems and decreases their control performance.

A number of researchers have conducted studies to combine a conventional PID controller with a fuzzy logic controller (FLC) in order to achieve a better control quality in ACS rather than the one guaranteed by conventional PID controllers. The idea of using fuzzy sets [32] is successfully applied, for the first time, in the control of a dynamic plant developed by Mamdani and Assilian [33]. Currently, there are different types of FLC, but a PID-based FLC is the most common and practical for

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applications to ACS [34–38]. Such FLC is equivalent to a conventional PID controller for the input-output structure [34,39]. PID-based FLC may be constructed by sequentially incorporating FLC and PID controllers or paralleling PID and FLC (PID with an adapter based on FLC). Moreover, the use of FLC logic makes it easy to add nonlinearities and additional input signals to the control law [1], that, in turn, allows to apply PID-based FLC to complex dynamic systems.

A priori information about the dynamics of the controlled plant is required for the synthesis of PID-based FLC. Hammerstein and Wiener models may be used to describe complex dynamics real-life processes [40–43]. Hammerstein and Wiener models are methodologies constituted by the combination of a static nonlinearity (N) and a linear system (L), respectively in the N-L and L-N form. The problem of identifying N and L from input-output data has attracted and attracts a lot of research interests and many methods are available for this problem in literature [40–46]. The nonlinear dynamic system can be approximated by a linear dynamic system near the operating point, which is sufficient for PID tuning. It is not a simple task to define the parameters of the linear dynamic model approximation in the closed-loop system. In [47–49] active methods of identification are proposed; here sine waves in input are used to excite the Wiener continuous-time system and frequency methods are used to determine the unknowns. Unknown additive disturbances create problems for closed-loop identification [50]. Good results can be obtained by using MATLAB system identification toolbox for the identification of the parameters of the process with the use of ARX, ARMAX, BJ state space, polynomial models and others [51].

Practically, in chemical and nuclear industries (i.e. integrated separations, extractions [52,53], crystallization processes to purify U and Pu from other fusion side-components) any processing step has a high level of automation but, in the contrary an insufficient automation in process control occurs. Moreover field operators need to work within the control loops of complex physicochemical processes. On the one hand, all processes are high responsibility technology (HRT), i.e. high performance technology with respect of safety level. On the other hand, they are also complex dynamic systems.

The purpose of the research is to develop a method of synthesis for low-level ACS (relative to HRT), which will provide the required control performance also in the presence of a significant change in the process parameters and several step disturbances with unknown amplitudes and durations. A Low-level ACS must fulfill the following limitations: control in the tight real-time mode should be performed with hot standby of the controllers; applied controllers have limited computation abilities which do not allow an extension of the mathematical support functions; for the purpose of control, conventional PID controllers should be employed.

2. Material and methods for the fuzzy adaptive control of a generic plant

The proposed method employs algorisms for the plant identification coupled with fuzzy systems such as Mamdami controllers [54,55]. The layout of a generic ACS plant is presented in Fig. 1 while a scheme of an adaptive fuzzy controller is shown in Fig. 2.

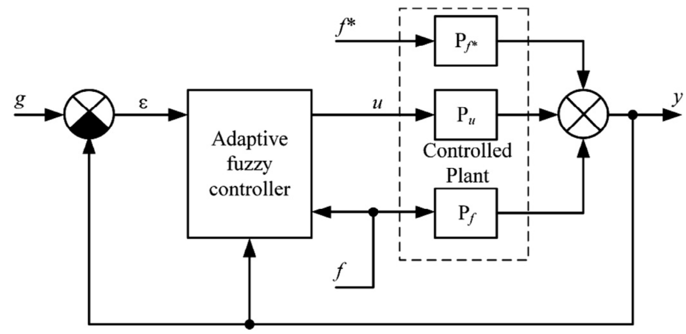

Fig. 1. Fuzzy adaptive control system. g : reference signal; f^* : non-measurable disturbance; f : measurable disturbance; P_u : plant control channel; P_f : plant disturbance channel; P_f^* : plant non-measurable disturbance channel; y: controlled variable; ε : control error is defined as $\varepsilon = g - y$.

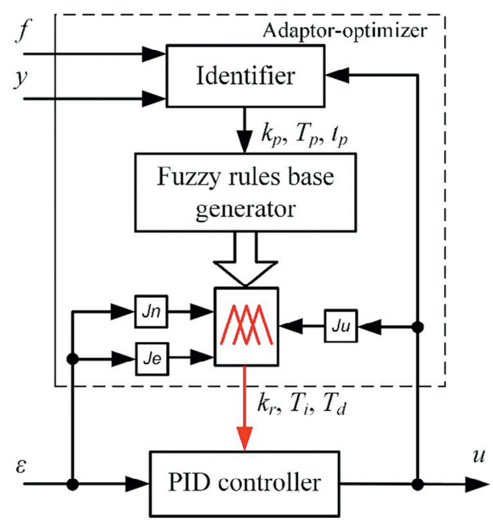

Fig. 2. Adaptive fuzzy controller for an ACS.

The optimization problem consists of maximizing or minimizing a functional which plays the key role from the viewpoint of the design of adaptive and optimal control systems. It is addressed here in the following form:

$$\min\left(Je_k + Ju_k + Jn_k\right) \tag{1}$$

where

$$Je_k = \sqrt{\frac{\sum_{j=k}^{k+he}\left(\varepsilon_j\right)^2}{he-1}} \tag{2}$$

$$Ju_k = \sqrt{\frac{\sum_{j=k}^{k+hu}\left(u_j - u_k\right)^2}{hu-1}} \tag{3}$$

Jn_k – the number of control error oscillations in the interval he, (2)