A Self-tuning Fuzzy PI Controller for Pure Integrating Processes

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Abstract. We propose a self-tuning fuzzy PI controller (STFPIC) for pure integrating process with dead time (IPD) whose output scaling factor (SF) is continuously adjusted in each sampling instant by a non-fuzzy gain modifying factor $\gamma$, which is defined on the normalized error and change of error of the controlled variable and the number of their uniform fuzzy partitions. Performance of the proposed controller is studied for a pure integrating process with dead-time under both set-point change and load disturbance. Performance comparisons with other FLCs are provided in terms of various performance indices along with transient responses. Simulated results justify the effectiveness of the proposed STFPIC.

Keywords: Integrating process, Fuzzy logic controller, Self-tuning fuzzy control, Scaling factor.

1 Introduction

In the process industries, the integrating processes are frequently encountered and many chemical processes [1] can be modeled as a pure integrating plus dead time processes. In many control applications overshoots and/or undershoots are highly undesirable. For this special class of processes effective controller needs to be designed. The Fuzzy Logic Controllers (FLCs) have been successfully used, and proved to be superior to the conventional non-fuzzy controllers for a complex processes [2, 3] and are found to be less sensitive to parametric variations than conventional controllers [4]. Among the various forms, PI-type FLCs is the most common and practical [5, 6] due to their offset eliminating property. For integrating, non-linear and higher order systems, like conventional PI-controllers, the performance of a conventional PI-type FLC is not acceptable due to large overshoot and excessive oscillation [7-9].

The number of fuzzy if-then experts’ rules defined on error ($e$) and change of error ($\Delta e$) of the controlled variable is used in FLC control policy. The membership functions (MFs) of the input and output linguistic variables are usually defined on a common normalized domain. The selection of proper input and output scaling factors (SFs) are very important for FLC design, which in many cases are done through trial and error or based on experimental data [10, 11]. For practical systems including integrating plus dead time processes, the performance of a conventional FLC with a limited number linguistic rules and simple MFs, may not fulfill the requirement.
To overcome such limitations many research works have been reported where either the input-output SFs or the definitions of MFs and sometimes the control rules are tuned to improve the close-loop performance [5-6, 10-15].

The controller in [6] is tuned by dynamically adjusting its output SF in each sampling instant by a gain updating factor ($\alpha$), which is further augmented by a fixed multiplicative factor ($K$) chosen empirically. The value of $\alpha$ is determined by 49 fuzzy rules defined on process error $e$ and change of error $\Delta e$, and derived from the knowledge of process control engineering. Without 49 expert’s defined fuzzy rules, here, we propose a self-tuning scheme for fuzzy PI controller (STFPIC) with non-fuzzy dynamic output scaling factor. The output SF is dynamically modified by a single heuristic rule defined on the normalized error, $e_N$, the normalized change of error, $\Delta e_N$, and the number of their fuzzy partitions or membership functions. As the output SF incorporated the dynamics of the process under control, the proposed controller is expected to improve the performance. It is worthwhile to mention that while developing improved auto-tuning PI/PID controllers [16-18], the authors have embedded such knowledge and information. The performance of the proposed STFPIC is tested by simulation experiments on pure integrating plus dead time process (IPD) with different values of dead time. Also the proposed method is tested with 49 as well as 25 fuzzy rules for controller. Results show a significantly improved performance of the proposed STFPIC compared to its conventional fuzzy (FPIC), RSTFPIC [6], and non-fuzzy ZNPI/ZNPID [20, 21] controllers in transient response and load regulation.

2 Design of the Proposed Controller – STFPIC

Figure 1 shows the simplified block diagram of a non-fuzzy STFPIC. The output SF of the controller is dynamically modified by a non-fuzzy heuristic relation as shown. The various design aspects of the STFPIC are briefly discussed below.

MFs for inputs, (i.e., $e_N$ and $\Delta e_N$) and output, (i.e., $\Delta u_N$) of the controller (shown in Fig. 2) are defined on the common normalized domain [-1, 1]. Except at the two extreme ends, symmetric triangular MFs are used. The relationships between the SFs ($G_e$, $G_{\Delta e}$ and $G_u$), and the input and output variables of the STFPIC are as follows:

$$e_N = G_e \times e$$

(1)

$$\Delta e_N = G_{\Delta e} \times \Delta e$$

(2)

$$\Delta u = (\gamma G_u) \times \Delta u_N$$

(3)

where, $\gamma = K(1 + \frac{1}{m} \times \Delta e_n \times Sign(e_N))$

(4)

In Eqn. 4, $\gamma$ is the on-line gain updating factor for the output SF ($G_u$), $K$ is a constant, which will make required variation in $\gamma$, and $m$ is the number of uniform input ($e$, and $\Delta e$) fuzzy partitions. In this study, we have used $m = 7$ and $m = 5$ as shown in Fig. 2a and Fig.2b. Unlike fuzzy PI controllers (FPIC), which uses only $G_u$ to generate the incremental output (i.e., $\Delta u = G_u \times \Delta u_N$), the incremental output for STFPIC is obtained by using the effective SF, i.e., the product of the gain updating factor $\gamma$ and $G_u$ as shown in Fig. 1. In RSTFPIC [6], the 49 fuzzy Self tuning rules are used to compute the on-line gain.