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Fuzzy control of a neutralization process

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Abstract

This paper studies the control of pH neutralization processes using fuzzy controllers. As the process to be controlled is highly nonlinear the usual PI-type fuzzy controller is not able to control these systems adequately. To solve this problem, based on prior knowledge of the process, the pH neutralization process is divided into several fuzzy regions such as high-gain, medium-gain and low-gain, with an auxiliary variable used to detect the process operation region. Then, a fuzzy logic controller can also be designed using this auxiliary variable as input, giving adequate performance in all regions. This controller has been tested in real-time on a laboratory plant. On-line results show that the designed control system operates the plant in a range of pH values, despite perturbations and variations of the plant parameters, obtaining good performance at the desired working points.

Keywords: Process control; Nonlinear dynamics; Fuzzy control; Nonlinear process control; Neutralization process

1. Introduction

Control of the pH neutralization process plays an important role in different chemical plants, such as biological, wastewater treatment, electrochemistry and precipitation plants. However, it is difficult to control a pH process with adequate performance due to its nonlinearities, time-varying properties and sensitivity to small disturbances when working near the equivalence point. Moreover, chemical plants where pH neutralization processes are important usually work with more than one type of product, with frequent product and grade change-overs, resulting in transitions between different regimes. The control system must regulate the plant not only at these varying points, but also in transition regimes, which requires the use of advanced control systems. This topic of pH control is of considerable economic importance due to the strict environmental regulations that limit the amount of allowable off-specification materials.

Several approaches have been proposed in the literature in recent years to solve pH control problems: both nonlinear and linear control techniques have been proposed and proved on neutralization processes.

Most successful linear techniques are based on using multiple linear models evaluated at several working points, for example, the multimodel control approach proposed by Nyström et al. (1998). Using this technique, the controller is designed based on linear quadratic (LQ) technique and then the procedure is combined with two gain scheduling methods, which enables work to be done over a wide range of operating points. A scheduling-gain multimodel LQ controller can be proposed by designing an optimal linear controller for multimodel plant representation (in which models have their stationary gains scaled to the same value). A similar technique has been proposed by Galan et al. (2000), using robust control based on a multilinear model. The proposed methods try to identify the regions and then to decompose the complex system domain, to calculate an optimal controller. It must be pointed out that a multimodel scheme can be classified as robust only in the sense of accommodating a wider range of plant operation. However, it does not require detuning in closed loop performance, as required by regular model based schemes.

Another example is in Toivonen et al. (2003), where velocity-based linearized models are proposed to modify the internal model control applied to designing scheduled

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controllers. The authors applied the proposed method to a strongly nonlinear pH neutralization process, describing the relation between variable changes, without the necessity of a well-defined stationary gain. By modifying the IMC structure, this method can eliminate the steady state offsets.

Although linear controllers are simple to implement, nonlinear controllers give better performance, due to the inherent nonlinear behaviour of the pH process. Nonlinear controllers have been proposed by Narayanan et al. (1998), using three process variables (difference in hydrogen and hydroxyl ion concentrations, hydrogen ion concentration, and pH process) and an internal model control strategy with a nonlinear adaptive model. Nonlinear controllers have also been studied by Yoon et al. (2002), proposing backstepping techniques to handle a wide class of uncertain systems and avoid unwanted cancellations of favourable nonlinearities.

There are also researchers interested in studying pH control using predictive control techniques. For example, Gomm et al. (1996) proposed the use of a neural predictive strategy to study the in-line pH process. They used a nonlinear autoregressive exogenous (NARX) model structure for the proposed approach, which was used on-line to predict future process responses. Norquay et al. (1998) have also studied the use of both static nonlinear elements and linear dynamic elements of the SISO Wiener Model. The authors studied several methods to calculate the predictions: polynomial methods, autoregressive models with exogenous inputs (ARX) and step-response models to represent the linear dynamic element.

Although all these techniques have been proved successfully on real plants, the main difficulty is still the necessity of developing a model that adequately represents the pH process in any operating condition. To solve this problem, this paper discusses a technique based on fuzzy control to design pH controllers without the necessity of any plant model. Different fuzzy controllers have already been developed in the literature: for example, Biasizzo et al. (1997) have proposed predictive control based on a fuzzy model, where the algorithms for linear processes are extended to the nonlinear process.

A similar idea has been proposed by Sing and Postlethwaite (1997), using a fuzzy relational model (FRM) and a predictive controller that consists of three blocks: optimiser, model and objective function. In Edgar and Postlethwaite (2000) a technique to construct a relational model from a fuzzy input space to a crisp output space, evaluating the relation by application of a least-squares identification technique to process past data, has been presented. And Babuska et al. (2002) have proposed a fuzzy self-tuning PI controller for a pH control in a fermentation system, where the essential idea is to tune the controller PI gains on-line by means of a parameter that results from a fuzzy inference mechanism.

Other fuzzy controllers developed in the literature for different systems are Sousa et al. (1997) where a method of designing a nonlinear predictive controller based on a Takagi–Sugeno fuzzy model of the process has been proposed. This fuzzy model, calculated with an identification technique which enables the acquisition of the fuzzy model from process measurements, was incorporated as a predictor in a nonlinear based-model predictive controller using the internal model control scheme to compensate for disturbances and model errors. Finally, in Wu et al. (2003) a common PD-Mandami fuzzy logic controller is designed for all five re-entry flight regions characterized by different actuator configurations. A linear transformation to the controller inputs (the error and its derivative) is applied to tune the controller performance for different flight regions while using the same fuzzy rule base and inference engine.

In this paper, a novel fuzzy controller is used to control a pH neutralization process. As is well known, a typical fuzzy controller is composed of three main components: input signal fuzzification, a fuzzy engine that handles rule inference and defuzzification that generates continuous signals for actuators. The fuzzification block transforms the continuous input signal into linguistic fuzzy variables such as *Small*, *Medium* and *Large*. The fuzzy engine carries out rule inference where human experience can easily be injected through linguistic rules. And the defuzzification block converts the inferred control action back to a continuous signal that interpolates between simultaneous fired rules. The resulting relation is actually a nonlinear relationship, rather than a logic relationship. Thus, two distinct features of fuzzy logic are: human experience can easily be integrated, so it does not need a mathematical model of the system, and fuzzy logic provides a nonlinear relationship induced by membership functions, rules and defuzzification. These features make fuzzy logic promising for process control where conventional control technologies do a poor job and human operator experience exists.

Most fuzzy controllers use control error (e) and change in the control error (Δe) as controller inputs. However, it was experimentally shown in the pH processes that when using only these inputs the fuzzy controller is not able to differentiate the region in which the process operates, which is important information, necessary to control the nonlinear process. Therefore, such fuzzy controllers cannot make a control action based on the knowledge of the process nonlinearity associated with different regions. In this paper a multiregional fuzzy controller is used, following the ideas of Qin and Borders (1994). This controller uses, as an additional input, an auxiliary variable (AV) to indicate in which region the process operates. Such fuzzy controllers can compensate the process nonlinearity, so the control performance is more uniform, and this controller is a general solution for systems with a high and smooth nonlinearity with respect to different regions of operation. Note that, as it is a fuzzy controller, it does not need a mathematical model of the system.

The organization of the paper is as follows: Section 2 presents the proposed pH fuzzy controller; Section 3 describes the laboratory plant, a pH neutralization process,