Design and Performance Study of Self-Tuning Fuzzy and Neuro-Fuzzy Control Systems

Synopsis of the Thesis Submitted

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Synopsis

Most of the industrial processes under automatic control are nonlinear, complex and higher order systems and most of them have considerable dead-time. The conventional PID controllers are widely used in industry due to their simplicity in arithmetic, ease of use, good robustness, high reliability, stabilization and zero steady state error. Well tuned PI or PID controller performs well around normal working conditions, but its tolerance to process parameter variations are severely affected. In industrial environment these parameters are often varied with time. Among the different parameters in a physical system, dead-time is the most difficult one, as it delays the required control action to a process. Most of the cases, fuzzy logic controller (FLC) tries to incorporate these parameter variations of process, but often it fails to give desired result due to its limited number of *if-then* rules [1, 2]. A FLC consists of various parameters like membership functions, linguistic data-bases, rule-bases, fuzzification and defuzzification strategy, which are not well defined till date. Considering all these parameters, designing an optimal FLC analytically becomes very difficult. These limitations of the conventional FLCs motivated us to design an on-line tuning scheme for fuzzy controller that can control real time systems satisfactorily. We developed different self-tuning schemes for FLCs and same has been tested in different simulated and real time processes.

The first step in designing the controller is to model the plant. System identification is the process of building models of dynamical systems from input-output data. The fuzzy modeling is an integral part of system identification. The main idea of fuzzy modeling is to describe the input-output behavior of a given system by a set of fuzzy *if-then* rules. An unknown system transforms input x_i to output y_i and let the system be denoted by S, thus $y=S(x)$. In the proposed work, we tried to find a suitable computational (linguistic) model for S. However, there are many ill-defined systems; the modeling of such systems is very difficult in absence of experts' knowledge about the data pattern. This fact motivated us to develop an unsupervised mechanism that can pick up required number of *if-then* rules from the input-output data for developing a prototype of the original system.

The brief description and layout of our thesis is presented below.

Chapter-1 gives an overview about the scope and objectives of the thesis. The different background components of our thesis are discussed briefly in this chapter. We review the literature for different approaches of developing self-tuning FLCs. This chapter provides a survey on different techniques used to identify the unknown systems from the available input-output data.

Chapter-2 provides tuning procedure of fuzzy controller and its applications to practical systems. In this chapter, an on-line self-tuning scheme for fuzzy controller is discussed. The proposed self-tuning Fuzzy PI controller (STFPIC) and self-tuning Fuzzy PD controller (STFPDC) adjust their output scaling factors on-line by a fuzzy gain modifier (β) according to the current trend of the controlled process [3, 4]. The performance of the proposed control scheme is investigated in simulated process and also in real time process. A comparative study of investigated processes is made with respect to different performance measures.

Chapter-3 is an extension to the work proposes in ***chapter-2***. Here the fuzzy output gain modifier (β) is further augmented by a multiplicative factor (α), which is directly related to the system dynamics and derived by relay feedback experiment [5 - 7]. STFPIC uses process specific appropriate gain multiplicative factor (α) instead of a fixed numerical value. The modified STFPIC uses only 50 rules in place of 98 rules used earlier [3]. Robustness of the proposed controller is demonstrated by testing on a wide range of processes including nonlinear and marginally stable systems with a considerable variation in dead-time. This chapter provides a brief idea about relay feedback tuning and its application to speed control of DC motor.

Chapter-4 introduces a new auto-tuning scheme for PD-type fuzzy controller. Instead of using large number of fuzzy *if-then* rules for gain adjustment, in this chapter, we proposed a simple non-fuzzy adaptive scheme for design of adaptive fuzzy PD controller (AFPDC). In the proposed AFPDC, output SF of the controller continuously updates by a non-fuzzy multiplicative factor β, which is directly related to the normalized error and normalized change of error of the system under control [8 - 10]. An important point of our proposed scheme is that it significantly reduces the number of rules from the previous cases. The proposed scheme is applied on different second order integrating, nonlinear and non-minimum phase systems with variable dead-time. In this chapter, twin adaptive fuzzy controllers are also proposed to control the position of the trolley crane and swing angle of load more precisely.

Chapter-5 presents the fuzzy modeling scheme for systems, where there is no expert, or expert cannot express his or her knowledge explicitly. In this proposed work, we can find suitable computational (linguistic) model for any unidentified system through structure identification and parameter estimation. For structure identification, Self-Organizing Map (SOM) based clustering technique is proposed [11, 12]. Here, the system identification method is integrated with rule extraction method in such a way that it can pick up essential rules from any processes [13]. The scheme has been successfully tested by identifying the rules required to realize the gain factor of a self-tuning fuzzy PI controller, which is highly nonlinear in nature. Identified gain rules along with initial control rules are used to investigate different linear, nonlinear and marginally stable systems [13]. The proposed scheme has been found to be equally well for function approximation problem. Comparative study with experimental results, control surfaces and MSE values ensured that the proposed rule extraction and fuzzy modeling technique can be used to model any complex system. In this chapter, an attempt has also been made for further MF reduction using similarity measure [14].

Chapter-6 demonstrates the rule extraction technique in two industrial processes. The developed SOM based control scheme in c***hapter-5*** is used here to control the position as well as swing angle of a laboratory based overhead crane [9, 13]. The effectiveness of the proposed approach is also tested in an industrial pressure control loop. The results show that even with significant reduction of rule-base, the controllers' exhibit effective and improved performance in real time systems compared to its conventional fuzzy counterpart.

Chapter-7 concludes by highlighting the contributions of the thesis together with some scope for future work.

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