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Real-coded Genetic Algorithm for system identification and tuning of a modified Model Reference Adaptive Controller for a hybrid tank system

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ABSTRACT

Modeling and controlling of level process is one of the most common problems in the process industry. As the level process is nonlinear, Model Reference Adaptive Control (MRAC) strategy is employed in this paper. To design an MRAC with equally good transient and steady state performance is a challenging task. The main objective of this paper is to design an MRAC with very good steady-state and transient performance for a nonlinear process such as the hybrid tank process. A modification to the MRAC scheme is proposed in this study. Real-coded Genetic Algorithm (RGA) is used to tune off-line the controller parameters. Three different versions of MRAC and also a Proportional Integral Derivative (PID) controller are employed, and their performances are compared by using MATLAB. Input–output data of a coupled tank setup of the hybrid tank process are obtained by using Lab VIEW and a system identification procedure is carried out. The accuracy of the resultant model is further improved by parameter tuning using RGA. The simulation results shows that the proposed controller gives better transient performance than the well-designed PID controller or the MRAC does; while giving equally good steady-state performance. It is concluded that the proposed controllers can be used to achieve very good transient and steady state performance during the control of any nonlinear process.

1. Introduction

Regulating liquid level in a tank has been a basic control problem in process industries for a long time. The PID controllers have been used for this purpose traditionally. Cohen–Coon and Ziegler–Nichols methods [1] have been widely used to tune a PID controller [2]. In these methods, the values of proportional gain, integral time constant and derivative time constant are determined for an operating point around which the process can be considered linear. But, when the operating conditions change, PID controller parameters also need to be tuned. Hence, using these methods would result in sub-optimal tuning of the controllers for non-linear and dynamic systems and it needs the intervention of an operator. The urge to design better controllers brings out the need to understand the characteristics of the process as well as possible. This can be achieved by the application of system identification procedure. System identification involves building mathematical models of a dynamic system based on a set of measured input and output data samples. System identification helps in designing a controller for a process in a more effective manner than would be the case without identification.

In conventional identification methods such as least squares [3] and maximum likelihood method [2], a model structure is selected and the parameters of the model are calculated by optimizing an objective function. These methods hold good

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only when the process is operated at about the selected operating point since the process can be considered to be linear around the operating point. But, for the systems with considerable amount of non-linearity, the conventional parameter identification methods fail to provide globally-optimum solution. Further, they require huge amount of input–output data from the system to be identified. There are a few approaches for the identification of non-linear systems like Nonlinear Least Squares, Voltera series, Weiner series, Wavelets [4], and soft computing approaches like Neural Network (NN), Fuzzy Logic (FL) and Genetic Algorithm (GA) [5]. The difficulties with classical approaches can be overcome by the use of the afore-mentioned intelligent techniques and their hybrids for the purpose of identification. NN based approach has been applied for system identification of a pH process by Valarmathi et al. [6]. Kristinsson and Dumont [7] used GA to estimate the location of poles and zeroes of a transfer function and then used this estimate to design a discrete time pole placement adaptive controller. Jiang and Wang [8] used binary-coded GA to estimate the system parameters for a class of nonlinear systems. Boroomand and Menhaj [9] proposed Fractional Dynamic Neural Networks (FDNNs) by means of the Lyapunov-like analysis for nonlinear system approximation. This paper proposes GA for the parameter tuning of the identified model of a hybrid tank system in order to improve the accuracy of the identified model as much as possible.

To have a good performance in spite of environment induced changes in the process set up, the controller must possess the ability to adapt to changes in plant dynamics. Adaptive control methods like Gain Scheduling, Dual Control, Model Reference Adaptive Control (MRAC) and Self Tuning Regulator (STR) can be used to improve the performance of a controller [10]. Gain scheduling suffers from the drawback of being an open loop compensation technique. There is no feedback to make necessary changes in the values of the controller parameters in the event of the schedule being incorrect [11]. The STR estimates the process parameters to adapt the controller to its dynamic changes. The problem with this approach is that small model error can lead to large changes in parameters resulting in possible oscillation of process variables. Dual Control is too complicated to be used for practical problems [11]. Goodwin [12] established global convergence and asymptotic properties of a direct adaptive controller for continuous time stochastic linear systems. Tsai et al. [13] used MRAC to control temperature in a variable frequency oil-cooling machine. Liu and Hsu [14] proposed adaptive back stepping control and MRAC to improve the performance of a sensor-less direct torque control synchronous reluctance motor drive system. Kamalasadan et al. [15] introduced a new concept of Intelligent Supervisory Loop in a Neural Network (NN) based intelligent adaptive controller for the control of dynamic systems and the author used an on-line Radial Basis Function NN in parallel with an MRAC. Miller and Mansouri [16] proposed a scheme in which simultaneous probing, estimation and control is carried out to give better noise performance in MRAC. The scheme used linear predictive control in an MRAC set up. In a basic Model Reference Adaptive System (MRAS), the process output takes a finite amount of time to converge with the output of the reference model. Improving the transient performance of the standard MRAC has been the point of research for quite some time. Datta and Ioannou [17] proposed a modified traditional MRAC that showed improved transient and steady state performance. Mean square tracking error criterion and the L_∞ tracking error bound criterion were used to assess performance in the ideal and non-ideal situations. Miller and Davison [18] proposed a controller comprising an LTI compensator together with a switching mechanism to adjust the compensator parameters so that an arbitrarily good transient and steady-state response is provided for a single-input single-output linear time-invariant plant. The hybrid tank process considered in this paper is a classic example of a highly nonlinear system [19]. In this paper, a modification to the MRAC scheme is proposed to obtain very good transient and steady-state performance during the application of MRAC for the purpose of controlling liquid level in the coupled tank system. The proposed controller is referred to as Modified MRAC throughout the paper.

In order to incorporate intelligence in the controller one could go for soft computing methods like NN, FL, GA, their hybrid structures and other evolutionary algorithms like Particle Swarm Optimization (PSO), Ant Colony, Bacterial Foraging etc. Chang [20] applied Real-coded GA (RGA) for system identification and off-line tuning of PID controller for a system whose structure is assumed to be known previously. Chao and Teng [21] proposed a two-stage tuning method for a PD-like self-tuning fuzzy controller which automatically detects the operating ranges of input variables and then adjusts the scaling factors. Hu and Mann [22] proposed a conservative design strategy for realizing a guaranteed-PID-performance fuzzy controller in which GA is also employed for optimization. Valarmathi et al. [23] made use of PSO for system identification and tuning of Proportional-Integral (PI) controller in a pH process.

In this paper, performance of the Modified MRAC is further improved by using RGA to fine tune some controller parameters off-line. The Modified MRAC which uses RGA is referred to as GA based Modified MRAC in the paper. As the search space is large, application of RGA would more likely give optimal or near-optimal solution.

2. Hybrid tank process

Fig. 1 shows the schematic representation of a hybrid tank system. The hybrid tank system consists of two cylindrical tanks, inter connected by two coupling channels at different heights, both with drain valves to common reservoir situated below. A variable-area valve in these channels is used to vary the interaction between the tanks. Water from a reservoir is pumped by a variable speed pump to tank1 through a control valve. F1 is the flow rate of the influent stream to tank1 and is measured by a turbine flow meter. Water from tank1 flows to tank2 through the coupling channels, and then it finally flows out of tank2. Level of water in tank2 (L2) is measured by a DPT. The flow rate F1 and level L2 are acquired by a Data Acquisition Card NI USB 6008 in Lab VIEW environment. Command signal to open the control valve to vary F1 is given through the